แบบจำลองความคิดรวบยอดเพื่อประกอบการตัดสินใจเปลี่ยนอุปกรณ์ไฟฟ้าในอาคาร จากการคำนึงถึงผลวิเคราะห์วัฏจักรชีวิตของเสียอันตราย

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CONCEPTUAL DECISION SUPPORT MODEL FOR RETROFITING ENERGY CONSUMING EQUIPMENT IN EXISTING BUILDINGS BY CONSIDERING LCA OF WASTE HAZARDOUS SUBSTANCES

Mr. Kua-anan Techato

A Dissertation Submitted in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy Program in Environmental Management
(Interdisciplinary Program)
Graduate School
Chulalongkorn University
Academic Year 2007

Thesis Title	CONCEPTUAL DECISION SUPPORT MODEL FOR RETROFITING ENERGY CONSUMING EQUIPMENT IN EXISTING BUILDINGS BY CONSIDERING LCA OF WASTE HAZARDOUS SUBSTANCES
By	Mr. Kua-anan Techato
Field of study	Environmental Management
Thesis Advisor	Professor Daniel J. Watts, Ph.D.
Thesis Co-advisor	Assistant Professor Sumate Chaiprapat, Ph. D.

Accepted by the Graduate School, Chulalongkorn University in Partial Fulfillment of the Requirements for the Doctoral Degree

....Dean of the Graduate School
(Assistant Professor M.R. Kalaya Tingsabadh, Ph.D.)

THESIS COMMITTEE

....Chairman
(Chantra Tongcumpou, Ph.D.)

....Thesis Advisor
(Professor Daniel J. Watts, Ph.D.)

....Thesis Co-advisor
(Assistant ProfessorSumate Chaiprapat, Ph.D.)

....Member
(Punjaporn Weschayanwiwat, Ph.D.)

....Member
(Tawan Limpiyakorn, Ph.D.)

....External Committee
(Renu Cheokul, Ph.D.)

เกื้ออนันต์ เตชะโต: แบบจำลองความคิดรวบยอดเพื่อประกอบการตัดสินใจเปลี่ยนอุปกรณ์ไฟฟ้า ในอาคาร โดยคำนึงถึงผลวิเคราะห์วัฏจักรชีวิตของเสียอันตราย (CONCEPTUAL DECISION SUPPORT MODEL FOR RETROFITING ENERGY CONSUMING QUIPMENT IN EXISTING BUILDINGS BY CONSIDERING LCA OF WASTE HAZARDOUS SUBSTANCES)
อ. ที่ปรึกษา ศ. ดร. แดเนียล เจ วัตตส์, อ.ที่ปรึกษาร่วม ผศ.ดร.สุเมธ ไชยประพัทธ์. 136 หน้า.

วิธีปกติในการตัดสินใจใช้งบประมาณเพื่อการเปลี่ยนอุปกรณ์ประสิทธิภาพพลังงานต่ำในอาคาร คือการพิจารณาผลตอบแทนทางด้านการเงินและระยะเวลาคืนทุนอย่างง่าย ซึ่งทำโดยแรงผลักดันจากการบังคับใช้กฎหมายและการส่งเสริมการใช้อุปกรณ์ที่มีประสิทธิภาพพลังงานสูง แต่วิธีปฏิบัติเดิมนั้นปราศจากการพิจารณาปัจจัยด้านสิ่งแวดล้อม โดยเฉพาะการคิดต้นทุนด้านการจัดการของเสียอันตรายที่เกิดจากอุปกรณ์ประสิทธิภาพพลังงานต่ำที่ถอดออกมาจากอาคาร การวิเคราะห์วัฏจักรชีวิตของผลิตภัณฑ์นั้น ๆ เป็นวิธีที่คำนึงถึงวัสดุและพลังงานที่ใช้รวมถึงเงินลงทุนและผลกระทบด้านสิ่งแวดล้อมที่เกิดขึ้นตลอดวัฏจักรชีวิต โดยในการศึกษาครั้งนี้จะพิจารณาปรอทในหลอดไฟฟ้าแสงสว่างและสารคลอโรฟลูออโรคาร์บอนในเครื่องปรับอากาศ เพื่อเป็นตัวแทนของเสียอันตรายในอาคาร เพราะเป็นวัตถุอันตรายที่สร้างผลกระทบจากขั้นตอนการถอดอุปกรณ์ประสิทธิภาพพลังงานต่ำออกและติดตั้งแทนที่ด้วยอุปกรณ์ประสิทธิภาพพลังงานสูง ผลที่ได้จากการวิเคราะห์ตามแนวคิดการประเมินวัฏจักรชีวิตของเสียอันตรายจะใช้เป็นส่วนประกอบในการสร้างแบบจำลองหลักการตัดสินใจ ซึ่งเรียกว่า ENVIROGY โดยแสดงองค์ประกอบที่ต้องคำนึงถึงก่อนการลงทุนในมาตรการเปลี่ยนอุปกรณ์เดิม มาเป็นอุปกรณ์ที่มีประสิทธิภาพพลังงานสูง ซึ่งประกอบด้วยพลังงานที่ประหยัดได้ (E) ค่าใช้จ่ายในการรีไซเคิลของเสียจากการเปลี่ยนอุปกรณ์ (N) ผลเสียจากของเสียอันตรายที่เกิดขึ้น (V) เงินลงทุนเพื่อการอนุรักษ์พลังงาน (I) ความเสี่ยงจากการขนส่งของเสียอันตราย (R) ผลกระทบจากการใช้อุปกรณ์ประสิทธิภาพสูง (O) มาตรการแทรกแซงจากภาครัฐ (G) และผลที่ได้รับจากกลไกสะอาดภายใต้กรอบการทำงานขององค์การสหประชาชาติ (Y) ค่า ENVIROGY ที่คำนวณได้ในการเปลี่ยนหลอดฟลูออเรสเซนต์จาก 40 วัตต์ เป็น 36 วัตต์ ชี้ว่าต้นทุนภายในและภายนอกคือ -1,483 บาทต่อ 10 ปี ต่างจากกรณีที่คิดเพียงต้นทุนในการเปลี่ยนอุปกรณ์และค่าไฟฟ้าที่ประหยัดได้ (ต้นทุนภายใน) ภายในซึ่งให้ค่า ENVIROGY เท่ากับ -1,272 บาทต่อ 10 ปี สำหรับเครื่องปรับอากาศขนาด 12000 บีทียูต่อชั่วโมง ค่า ENVIROGY ที่คิดทั้งต้นทุนภายในและภายนอกมีค่าเป็น -56,572 บาทต่อ 10 ปี ต่างจากกรณีที่คิดเพียงต้นทุนภายในซึ่งให้ค่า ENVIROGY เท่ากับ -46,962 บาทต่อ 10 ปี ส่วนต่างของค่า ENVIROGY ของกรณีที่คิดและไม่คิดต้นทุนภายนอกคือมูลค่าที่เกิดจากผลกระทบต่อสิ่งแวดล้อมซึ่งควรได้รับการบริหารจัดการอย่างเหมาะสมจากภาครัฐ หลักในการประเมินค่า ENVIROGY สามารถนำไปประยุกต์ใช้ได้กับอุปกรณ์อนุรักษ์พลังงาน และอุปกรณ์ที่ใช้หรือผลิตพลังงานชนิดอื่น ๆ ได้เช่นกัน

สาขาวิชา การจัดการสิ่งแวดล้อม
ปีการศึกษา 2550

ลายมือชื่อนิสิต..........
ลายมือชื่ออาจารย์ที่ปรึกษา.......... (แทน)
ลายมือชื่ออาจารย์ที่ปรึกษาร่วม..........

4689704620 : MAJOR ENVIRONMENTAL MANAGEMENT
KEY WORD: DECISION MODEL / RETROFITTING / HAZARDOUS WASTE

KUAANAN TECHATO: CONCEPTUAL DECISION SUPPORT MODEL FOR RETROFITING ENERGY CONSUMING Q UIPMENT IN EXISTING BUILDINGS BY CONSIDERING LCA OF WASTE HAZARDOUS SUBSTANCES. THESIS ADVISOR: PROF. DANIEL J. WATTS, Ph.D., THESIS COADVISOR: ASST. PROF. SUMATE CHAIPRAPAT, Ph.D., 136 pp.

The budget spent for retrofitting low energy efficiency equipment in buildings is normally planned after financial consideration of an internal rate of return and a simple payback period. The retrofitting has typically been done under forces from both mandatory and voluntary schemes in which an environmental review usually has not been considered. One of the overlooked aspects within the energy conservation measures is the cost of hazardous waste management from the removed. To facilitate consideration of all inventories and impacts, LCA (Life Cycle Analysis) is a good approach covering an environmental aspect, particularly hazardous waste, throughout the life cycle from raw material preparation, removal of existing equipment, installation, to appropriate waste disposal. This study takes into account only Hg in fluorescent tubes and CFC in air conditioners as representative of the wastes due to their potential emission during retrofitting. The LCA result is used to construct a conceptual decision making model, named ENVIROGY that clearly shows the components and structures of investment in retrofitting. In the model developed ENVIROGY is composed of energy, net waste recycling, violence impact from hazardous waste, investment for retrofitting, risk in terms of money, operating impact, government intervention, and yield from CDM (Clean Development Mechanism) by the UNFCCC (United Nation Framework Convention on Climate Change). The calculated ENVIROGY shows that for the whole lifetime of a retrofitting of 36 Watt fluorescent lamp, an investor has to pay for a net internal and external cost of -1,483 Baht/10 years. The value of ENVIROGY is -1,272 Baht/10 years for the base case which accounted only for energy consumption and investment for retrofitting. Likewise, a 12,000 Btu air-conditioner, ENVIROGY value is -56,572 Baht/10 years whereas the value of ENVIROGY is -46,962 Baht/10 years for the base case. The cost difference of ENVIROGY compared to base case should be managed by government at the phase of initial application for retrofitting. The ENVIROGY approach can be applied to other energy consuming and conserving equipment.

Field of Study Environmental Management
Academic year 2007

Student's signature ....
Advisor's signature ....

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List of Abbreviations

ABEC	Adjustments to the Building Energy Code
AC	Air-conditioner
BERC	Bureau of Energy Regulation and Conservation
B.E.	Buddhist Era
Btu	British thermal unit
CDM	Clean Development Mechanism
CdTe	Cadmium Telluride
CER	Credit Emission Reduction
CFC	Chlorofluorocarbon
C_2H_4	Ethene
CIS	Copper Indium Diselenide
CML	Centrum voor Milieukunde, Leiden University
CO	Carbon Dioxide
DANIDA	Danish International Development Assistance
DBs	Designated Buildings
DC	Direct current
DEDE	Department of Alternative Energy and Efficiency
DEDP	Department of Energy Development and Promotion
DEHP	Di-Ethyl Hexyl Phthalate
DIW	Department of Industrial Work
DTEC	Department of Technical and Economic Cooperation of Thailand
EMS	Energy Management System
EGAT	Electricity Generating Authority of Thailand
GaAs	Gallium Arsenide
GDP	Gross Domestic Product
MJ	Mega Joule
MWh	Mega Watt-hour
PMU	Project Management Unit
PRET	Promotion of Renewable Energy Technology
EC	Energy Conservation
ECP	Energy Conservation Promotion
EDIP	Environmental Design of Industrial Product
EEI	Electrical and Electronics Institute Thailand
EI	Eco-indicator
EOL	End of Life
EPA	Environmental Protection Agency
EPPO	Energy Planning and Policy Office
FL	Fluorescent
GHGs	Green House Gas
GWh	Giga Watt-hour
HCFC	Hydro-Chlorofluorocarbon
HIDs	Hi Intensity Discharge Lamps
HFC	Hydro-Fluorocarbon
Hg	Mercury
H_2N_2O	Nitrosamine
HF	Hydrofluoric acid
HNO_3	Nitric acid
IRR	Internal Rate of Return
IPCC	Intergovernmental Panel on Climate Change

ISO	International Standard Organization
JI	Joint Implementation
kVA	kilo Volt-Ampere
kW	kilo Watt
kWh	kilo Watt-hour
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MW	Mega Watt
NaOH	Sodium Hydroxide
NEPC	National Energy Policy Council
NREL	National Renewable Energy Laboratory
Pb	Lead
ODS	Ozone Depletion Substances
O_3/kg	Ozone per kilogram
OTTV	Overall Thermal Transfer Value
PCD	Pollution Control Department
PCBs	Polychlorinated Biphenyls
PFD	Process Flow Diagram
PO_4	Phosphate
PV	Photovoltaic
REACH	Restriction of the Use of Certain Hazardous Substances
RoH	Restriction of Hazardous Substance
RTTV	Roof Thermal Transfer Value
SLCA	Streamline LCA
SPOLD	Society for the Promotion of Life Cycle Development
SPB	Simple Payback Period
SO_2	Sulfur Dioxide
TCLP	Toxicity Characteristic Leaching Procedure
TIS	Thai Industry Standard
TJ	Terra Joule
TR	Ton of Refrigeration
USD	United State Dollar
UV	Ultraviolet
W	Watt
WEEE	Waste Electrical and Electronic Equipment
W/m^2	Watt per Square Meter
WTP	Willingness to pay

CHAPTER I

INTRODUCTION

1.1 Background

The environmental approvals of buildings typically are separated from energy performance assessment and implementation in the design and construction phase. During the operation of the designated building, it is in fact necessary to address the environmental effects particularly due to their cost issues. Because the scheme for energy performance assessment in designated buildings has been worked out thoroughly, it is apparently clear, however the issue of environmental concerns remains to be integrated into the scheme of energy use reduction. Consideration of the financial assessment for energy conservation of retrofitting measures by using IRR (Internal Rate of Return) or SPB (Simple Payback Period) without including the environmental disposal costs of wastes is one of the most obvious shortfall where the integration concept is needed. In the case of existing building, there currently is no significant integration of environment dimension into the retrofitting energy conservation measures. The streamlined concept of adding homogeneously the environmental aspect into consideration of energy conservation will be defined as “ENVIROGY” in this study.

1.2 Objectives

The objective of this study is to create a preliminary conceptual model based on life cycle analysis idea that explains the dimensions of hazardous waste in the energy conservation measures used in existing buildings in view of the need to balance energy savings with implementation cost and implicit cost.

1.3 Hypotheses

There are certain sources of hazardous waste resulted from the energy conservation measures applied in existing buildings and all of the factors involved should be used to create a preliminary conceptual model to itemize each component in the cost structure of a retrofitting process.

1.4 Theoretical Background

The environmental impact of energy utilization and hazardous waste from the initial stage of raw materials acquisition or research and development to the final disposition of a product and package as waste has a composite effect on the environmental quality. One of the systematic approaches for identifying and evaluating opportunities to improve the environmental performance of industrial activity is termed Life Cycle Analysis (LCA). There are three phases of LCA programs, i.e. inventory phase, impact or interpretation phase, and improvement phase (See Appendix A for more detail of LCA). Life Cycle Inventory (LCI) is the identification of the material and energy balance achieved by mapping the process within a boundary (Lagrega, 2001).

The steps of the Inventory Phase are as follows:

- Organize team
- Target the product or process
- Diagram the life cycle
- Identify inputs and outputs

Following the Inventory are the steps of Life Cycle Impact Assessment (LCIA) that deals with the ecological effects, human health effects, and related issues such as habitat modification and noise. Assessments are as follows:

- Regulatory strategy
- Non-regulated targets

The final steps are those of the Life Cycle Improvement Assessment, which is used to find opportunities to reduce the environmental impact of releases, energy use, and raw material consumption by assessing designs, materials, processes, consumer uses, and waste managements strategies. The steps are as follows:

- The identification of improvement options
- A comparative evaluation of a set of options

The concept of waste minimization requires that the raw materials, technologies, products, workers, and processes behave cooperatively as modeled in Fig. 1 (Sristit, T. 2004).

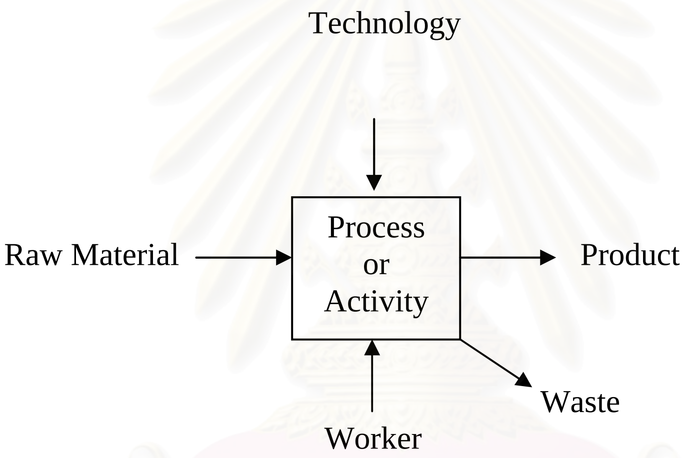

Fig. 1.1 Preliminary Model of Waste Minimization

1.5 Scope of Study:

The area of overlap between energy and environment in LCA investigated in this study will include only on the energy conservation measures planned or used in existing buildings and the resulting aspects of environmental hazardous waste. The preliminary energy conservation measures considered in this study include fluorescent lamp replacement and air-conditioner upgrades.

Hazardous waste here means a solid waste or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may cause or significantly contribute to an increase in mortality or an increase in serious irreversible. The contribution could be incapacitating reversible, illness or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

The created preliminary conceptual model is composed of all important factors of concern based on the relationships and data from life cycle analysis; including the energy saved, implementation cost, operational and maintenance cost, disposal cost, and implicit costs generated indirectly from the hazardous waste.

The primary sources of data for this study will be acquired from Thailand. In case there is not enough data from primary sources, applicable international data will be used.

1.6 Methodology

1.6.1 Identify the energy conservation measures that could be used in existing buildings that involve hazardous materials.

- Review all energy conservation measures in existing buildings from various sources of building retrofitting manuals or guidelines from the database of the Department of Alternative Development and Efficiency or the Energy Conservation Project funded by the Energy Planning and Policy Office (EPPO) or other sources.
- Select the measures that particularly relate to hazardous materials; e.g. heavy metals and radioactive materials in fluorescent lamps, CFCs in air-conditioners, and PCBs (Polychlorinated Biphenyls) or DEHP (Di-Ethyl Hexyl Phthalate) in ballasts or HIDs (Hi Intensity Discharge Lamps).

1.6.2 Consider the hazardous materials that tend to be hazardous waste in air-conditioner and lighting tube and identify two major substances of hazardous wastes for the study

- Classify the energy conservation measures that are used in existing building by considering the flow of material through such measures.
- Consider only the measures that emit or generate hazardous waste and select two hazardous wastes for this study. (One from air conditioning measures and another from lighting measures)

1.6.3 Identify the goal and definition of the Life Cycle Analysis and conduct the Life Cycle Inventory.

- Identify goal and scope of LCA, operational unit, main function, sub-function, functional unit, and reference flow.
- Conduct Life Cycle Inventory by combining inputs and outputs (material, energy, and emissions) to the process trees or process flow diagram (PFD).
- Define the quality of data input, i.e. duration of study, source of data, and assumption of data

1.6.4 Investigate the energy saved, implementation cost, operational cost, maintenance cost, and disposal cost through the Life Cycle.

- View the value chain of equipment recycling or disposal by using the data from the secondary sources or companies announced as recycle or waste disposal factories by the Department of Industrial Work (Section 1 Item 1.1 hazardous and non-hazardous waste disposal in cement kiln, Section 1 Item 1.3 hazardous and non-hazardous waste landfills, and Section 2 Separation and Recycle).
- Investigate the energy saving, implementation cost, operational cost, maintenance cost, and disposal cost for life cycle cost.

1.6.5 Conduct the Life Cycle Impact Assessment of hazardous waste from the energy conservation measures in order to find the impact from the hazardous waste.

- Select the relevant impact for the Life Cycle Impact Assessment e.g. global warming, ozone depletion, resource depletion, energy depletion, photochemical oxidation, acidification, human toxicity, aquatic eco-toxicity, and eutrophication.
- Identify indicator to be used in each category, e.g.;
  Global warming potential (Infrared radiation W/m^2): kg CO_2
  Ozone depletion (Stratospheric ozone breakdown: kg CFC11
  Acidification (Deposition/Acidification Critical Load): kg SO_2
  Heavy metals: kg Pb
  Summer smog: kg C_2H_4
  Energy resource depletion: MJ
  Eutrophication (Deposition/ N/P equivalents in biomes): kg PO_4
  Carcinogen substance: kg Benzo Alpha Pyrene
  Photochemical oxidation (Troposphere O_3 formation): kg O_3/kg emission
  Human toxicity (Predicted Environmental Concentration): kg1,4 dichlorobenzene
- Identify characterization model that serves to convert impact from one source to others in the same category e.g. IPCC Model (Intergovernmental Panel on Climate Change) is one of the acceptable models for climate change (The model normally exists in the software of LCA).
- Classify inputs and outputs into the category of impact and consider the optional method in LCIA, e.g. to normalize (to relate impact indicator to the bigger picture, e.g. country, continent, or world), grouping (group impact into fatalities, ecosystem, and health), or weighting (factor applied to the impact to emphasize the sensitivity).
- Analyze the quality of data by gravity analysis, uncertainty analysis (Monte Carlo Analysis), and sensitivity analysis.
- Consider the impact from the perspective of the mandatory approach (regulatory from building energy code, environmental code, relevant policy, law, regulation, and notification from the Department of Alternative Energy Development and Efficiency, the Department of Public Works and City Town Planning, the Pollution Control Department, the Department of Industrial Work).
- Consider the impact from the perspective of the voluntary approach by the International Standardization Organization that is ISO 14001:1996 or TIS 14001-2539 Environmental Management Systems (EMS): Specification with Guidance for Use and ISO 14004:1996 or TIS 14004-2539 Environmental Management Systems: General Guidelines on Principles, Systems and Supporting Techniques.

1.6.6 Interpret the result from LCI and LCIA

- List the results from LCI
- Present impact indicator from LCIA in each step of cycle
- Evaluate the completeness and sensitivity analysis
- Conclusion and recommendation

1.6.7 Conduct a Life Cycle Improvement Assessment and create a conceptual model

- List the barriers and incentives for the reduction of hazardous waste.
- Investigate the relationship among all costs and then integrate them into the conceptual model called ENVIROGY which blends between energy and environment aspects.
- Balance the opportunities for saving in the economic analysis with costs from the impact of the hazardous waste.

- Explain the possible predictions resulting from the relationship of all costs involved in the model.

1.7 Conclusion

The next chapters will provide the details of each step following this methodology. The approach and review of the hazardous waste from energy conservation measures in existing buildings will be explained. Subsequently investigation on their life cycles and effects will be undertaken based on the existing criteria for a decision making model. During this stage, the literature review will be conducted to identify the components of a new decision support model named ENVIROGY. The life cycle analysis of highly - energy efficient air-conditioners and fluorescent lamp replacement in existing buildings will be conducted. Lastly application of the developed model to other equipments will be evaluated, leading to the conclusion of the work.

CHAPTER II

HAZARDOUS WASTE AND ENERGY CONSERVATION

2.1 Introduction

Environmental and energy issues around the world are getting more and more attention. It is necessary for the government in each country to increase its role in stimulating awareness on these issues. If we consider sustainable development definition proposed by the United Nations Commission is “to meet the needs of the present without compromising the ability of future generations to meet their own needs” energy in high demand world society and environment cannot be separated. They should be integrated by the merging of energy conservation, renewable energy approaches, and pollution prevention. One important area of the integration is the issue of hazardous waste that results from the energy conservation measures employed in existing buildings. There are certain sources of hazardous waste in the energy conservation measures that are typically applied in existing buildings. It is very important to consider the implicit cost of hazardous waste management in the balance between energy savings and implementation cost. The LCA approach on energy conservation measures can be used to identify the phases or materials that create the major environmental impacts. To reduce the hazardous waste at source, a preliminary conceptual model, created from the factors relating to the environmental impacts, should be brought into consideration before the implementation of the energy conservation measures takes place (Vitooraporn, 2001).

2.2 Energy Conservation in Existing Buildings in Thailand

The Energy Conservation Commission in Thailand was started officially by the Energy Conservation Promotion Act (ECP Act) of 1992 and the establishment of the ECP Fund provided for relevant activities in the energy conservation area. Article 24 of the ECP Act stipulates that the capital and assets of the ECP Fund must come from two main sources. The first is money transferred from the Petroleum Fund at an amount determined by the Prime Minister’s Office. The second part comes from levies imposed on petroleum product producers and importers at a rate determined by the NEPC (National Energy Policy Council). Additional sources are surcharges on power consumption, government subsidies at times, remittances from the private sector in the country and abroad, and the interest incurred from the ECP Fund. The EC (Energy Conservation) Program that incorporates a Compulsory, Voluntary, and Complementary Plans is used as the key instrument in implementing energy conservation projects (ECG, 2000).

The compulsory program enacted under the Royal Decree of Designated Building 1995 defines designated buildings (DBs) as buildings under the same house number where the total capacity of the transformer installed is higher than 1,000 kW / 1,175 kVA or the total annual energy consumption is higher than 20 TJ. The DBs shall conform to the Ministerial Regulation 1995, Numbers 1, 2, and 3 issued under the ECP Act that specify the Energy Regulation, Energy Audit, and Target and Plan respectively. The Energy Regulation forces the designated buildings to comply with the Building Energy Code covering the requirement for three systems i.e. the Overall and Roof Thermal Transfer Value (OTTV and RTTV), the Lighting Power Density (LPD), and the efficiency of Air-conditioning systems (DEDP, 2000).

Energy conservation inside the buildings is one of the following measures.

- The reduction of heat from sunlight that enters the building.
- The use of efficient air-conditioning, which includes maintaining the room temperature at an appropriate level.
- The use of energy–efficient construction materials and the demonstration of the qualities of such materials.
- The efficient use of light in the building.
- The use and installation of machinery, equipment and materials that contribute to energy conservation in the building.
- The use of operation control systems for machinery and equipment.
- Other measures for energy conservation as prescribed in the Ministerial Regulations (BERC, 2000).

At the end of the year 2003, there were 1,646 designated buildings in Thailand and approximately 40% were in compliance with the OTTV and RTTV requirements. About 83% had complied with the lighting power density regulations and around 50% had complied with the air-conditioning standard. It was found that the existing Building Energy Code creates the following problems (AIT, 2003). The building that does not comply the building energy code has to invest into certain energy conservation measures.

Energy conservation measures in existing buildings play an important role in the compulsory plan within the energy conservation plan of Thailand and will be supported as a strategy of Thai Energy Development (EPPO, 2003).

The DANIDA (Danish International Development Assistance) had signed an agreement with DTEC (Department of Technical and Economic Cooperation of Thailand) to support technical assistance for the Adjustments to the Building Energy Code Project (ABEC) implemented by the Department of Alternative Energy Development and Efficiency (DEDE). The overall objective of this project is to reduce the energy consumption in designated buildings and the immediate objectives are to improve the codes, to increase the awareness and knowledge of the stakeholders, and to enhance the capacity of DEDE by training during the project (Building Energy Code, 2001).

The revised building energy code was prepared for a target group, namely the buildings that are going to be constructed (newly proposed) instead of existing buildings. This is the concept of “right at first”, which is designed to control the energy efficiency or consumption before the final stage of energy consumption. After the revised building energy codes are applied to the buildings to be constructed, the existing building energy code will be canceled. The existing buildings will be lead to a voluntary incentive scheme (DEDE, 2004).

The history of energy conservation in the designated building sector leads to the conclusion that the building owners have to more or less apply the energy conservation measures within the buildings. At the design phase or construction phase up to the operating period, the energy aspect is usually a key factor in performance assessment (Hui, 2003).

The designated buildings that are going to be constructed require approval or compliance with the Building Control Ministerial Regulations, where most of the environmental issues are related to the treatment of wastewater and garbage, air, noise, and other non-hazardous waste (Theptaranon, 2003).

New buildings, however, can apply the concept of both energy and environment conservation during the design phase; whereas, energy conservation measures can be applied to the existing buildings only for retrofitting. Almost all of the currently available measures are focusing on the energy efficiency issues and do not pay attention to other dimension of the environmental issues. From the investment perspective, a lot of money is spent in the field of energy conservation measures in existing buildings. From the years 2002 to 2006, the estimated subsidy and non-subsidy investment in energy conservation measures in designated buildings were estimated at approximately 3,165.51 million baht. Many energy conservation projects in existing building have claimed that the environmental issue has been addressed by converting the energy saving into carbon dioxide reduction (an avoided cost of 1 MW of electricity is 45 mil baht, 1 GWh electricity generated produces 660 ton of carbon dioxide, and a carbon dioxide reduction of 1 ton worth 8,000 baht) (DEDE, 2000).

2.3 Hazardous Wastes from Energy Conservation Measures

Hazardous wastes by the definition of the Resource Conservation Recovery Act of the US regulation means a solid waste or combination of solid wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness or pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed. The meaning is not different from the Act of Hazardous Material 1992 by the Department of Industrial Works, Thailand which defines hazardous wastes as those wastes that are flammable, oxidizers and peroxides, toxic, disease-causing, radioactive, mutagenic, corrosive, irritating, hazardous to plant, property, or environment (DIW, 1992).

The preliminary equipment categories discussed in the energy conservation measures in the Specification of Energy Efficient Product 2000, by the Department of Energy Development and Promotion, are fluorescent lighting fixtures, lighting reflectors, compact fluorescent lamps, tubular fluorescent lamps, electronic ballasts, low loss ballasts, small air conditioners, electronic thermostats, heating or cooling surface insulation, heating reflective insulation, and voltage regulators. These classes of equipment were used in the implementation of the energy conservation measures in existing buildings. From review of the database of the Department of Alternative Energy Development and Efficiency, about 366 types of the energy efficient measures can be classified into 4 groups, i.e. Energy Management, Energy Efficiency Improvement, Retrofitting (Remove the existing equipment and replace with a new item), and New Installation. The energy conservation equipment in existing buildings associated with hazardous materials are (1) fluorescent lamps that contain mercury, lead, cadmium, sodium, and radioactive materials, (2) air-conditioner containing CFC's, (3) closed cell insulation for piping H_2N_2O (Nitrosamine), (4) luminary reflectors containing Zn, and (5) ballasts of HIDs (Hi Intensity Discharge Lamps) containing PCBs (Polychlorinated Biphenyls) or DEHP (Di-Ethyl Hexyl Phthalate), which are classified by the U.S. EPA as a probable human carcinogen (DEDP, 2000).

Retrofitting includes measures that produce hazardous waste particularly as a result of the disposal of the removed units. Mercury in fluorescent lamps and CFC's from air-conditioners are the high in quantity and can create potential serious problem among other components (See Appendix B for more detail of toxicology of Mercury and CFC refrigerant). From the Guideline for the Used Fluorescent Lamp Management by the Bureau of Hazardous Waste Management, the Pollution Control Department, the quantity of used fluorescent lamps in Thailand was at 41 million lamps in 2004, of which 70% are the straight tube variety. From the perspective of sources, 66.4 % are from the residential sector, 32.2 % are from big buildings, and 1.4 % from transportation services. The cost (based upon Japanese experience) of a straight tube recycling plant is about 50 million baht with a processing capacity of 6 million tubes per year and an operating cost of 1 Baht/lamp. With regard to the collection system, there is no official collection system for the fluorescent lamp or even any direct regulation for it (PCD, 2004).

2.4 LCA as a Tool in Impact Assessment of Hazardous Waste

The environmental impact of energy utilization and hazardous waste generated over the span from raw materials acquisition and research and development to the final disposition of a product and package has an effect on the quality of the environment. One of the systematic approaches for identifying and evaluating opportunities to improve the environmental performance of industrial activity is Life Cycle Analysis (LCA). There are three phases of LCA programs, i.e. inventory phase, impact or interpretation phase, and improvement phase. Life Cycle Inventory (LCI; ISO 14041) is the study of material and energy balance carried out by mapping the process within a boundary. Next are the steps of Life Cycle Impact Assessment (LCIA; ISO 14042) deal with the categories and indicators.

The final steps are those of the Life Cycle Improvement Assessment (ISO 14043), which is used to find opportunities to reduce the environmental impact of releases, energy use, and raw material depletion by assessing designs, materials, processes, consumer uses, and waste management (Lagrega, 2001).

About 1,646 existing designated buildings in Thailand are compulsorily regulated under the Energy Conservation and Promotion (ECP) Act 1992. The master plan of the Department of Alternative Energy Development and Efficiency (DEDE) expected to save about 1,442 mil kWh within the period of 2002-2011 with a budget of 3,166 mil Baht. It can be assumed that a budget of 2.2 Baht is invested to save 1 kWh whereas 1.80 Baht/kWh is the generation cost from natural gas. Such reductions can be cost effective if the awareness is also increased. The budget however does not include the cost of hazardous waste management. The result of LCA that includes waste management costs may affect the decision making model for the energy conservation investment. The retrofitting approach may be moved to the last priority or the energy efficient product designer may have to redesign the energy consuming equipment. In addition, the information from using CFC and Hg as representative of hazardous wastes generated from retrofitting for energy reduction in buildings in this study could also be applied to other hazardous wastes not only from the sector of energy efficiency but also the renewable energy sector, e.g. Pb in batteries for PV cells (DEDP, 2000).

The scope of LCA for the hazardous waste resulting from the energy conservation measures in existing buildings here is defined by the following terms.

- Functional unit; A kWh of saving from energy conservation
- Parameter; Air conditioner and fluorescent lamp
- Process; A retrofit by replacing old unit with high energy efficient equipment
- Duration; 2002-2011 (the period of Thai master plan of energy conservation)
- Operational unit; A retrofit in existing building
- Main function; Save energy & prevent environmental pollution
- Sub-function; promote energy conservation awareness
- Reference flow; A 12000 Btu air-conditioner and 36 W fluorescent lamp
- Targeted hazardous waste; CFC & Hg in energy conservation measures
- Initial System Boundary; Retrofitting, Recycling, and Disposal

2.5 Existing Criteria Applied to the Evaluation of the Energy Conservation

The data from the retrofitting of fluorescent lamps and the air-conditioners in Park Lane Mansion, Khet Huai Kwang (HK), and Bangkok Business College (BBC) are shown in Table 2.1

When only IRR (Internal Rate of Return) or SPB (Simple Payback Period) without incorporating environmental disposal costs during the financial assessment of energy conservation retrofitting measures are considered, benefits for retrofitting are so overwhelm. However, this is an obvious example where the concept of integration energy-saving costs of benefits together with environmental costs is needed. In the category of existing buildings, there is no significant integration of environment into the retrofitting energy conservation measures. The concept of adding the environmental aspect homogeneously into the streamlined consideration of energy conservation will be called “ENVIROGY”

Table 2.1 SPB and IRR of example buildings

Building	Measures	Saving (kWh/yr)	Saving (Baht/yr)	Investment (Baht)	SPB (Yr)	IRR (%)
Park Lane	FL AC	447 204,560	1,269 782,440	1,634 1,830,000	1.29 2.34	77.21 44.05
HK	FL AC	- 56,248	- 143,173	- 935,822	6.54	- 24.99
BBC	FL AC	- 175,701	- 458,935	- 4,030,200	- 8.80	- 8.56

Note:

FL the retrofitting of the fluorescent lamps,

AC the retrofitting of the air-conditioners,

SPB simple payback period,

IRR is internal rate of return

(Source: One Stop Service, DEDE, 2005)

2.6 Conclusion of the Existing Conceptual Decision Support Model

The concept of waste minimization requires the materials, technologies, products, workers, and processes to behave cooperatively as modeled in Fig. 2.1 (Sristit, 2003). The model is composed of the important factors of concern based on the relationships and data from life cycle analysis; that is the energy saved, implementation cost, operational cost, maintenance cost, disposal cost, and implicit cost resulted from the hazardous waste. Next chapter will present the effect from using IRR and SPB before proposing the new model

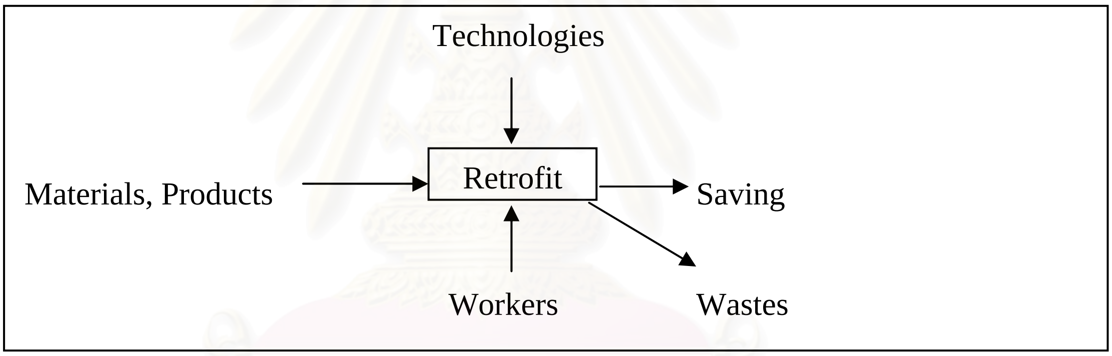

Fig. 2.1 Preliminary model for retrofitting

CHAPTER III

LIFE CYCLE COST OF HAZARDOUS WASTE

3.1 Introduction

Thailand ratified its participation in the Kyoto Protocol on August 28, 2002. Because Thailand is a developing country, it is grouped in Non-Annex I of the United Nations Framework Convention on Climate Change. Therefore Thailand has no commitment to reduce greenhouse gases (GHGs) in any duration and quantity. The Kyoto Protocol challenges future climate policy cooperation to reduce 5% of the 1990 baseline emission by industrialized countries (Annex I Countries) of greenhouse gases (CO_2, CH_4, N_2O, HFC, PFC, and SF_6) during 2008-2012. The mechanisms for reducing emissions are Domestic Action, Emission Trading (ET), Joint Implementation (JI), and the Clean Development Mechanism (CDM) (See Appendix C for more detail of CDM). The criteria necessary for projects to be claimed under CDM are that they be voluntary projects, sustainable development projects and provide Additionality to the environmental, societal, and financial impacts. “Additionality” in this context means that the value, particularly in terms of GHG reduction would not have happened in the normal course of events—it is driven, or obtained, only because of this project. Energy efficiency improvement, energy generation from renewable sources, fuel switching to lower carbon content and forest plantation are examples of approaches possible under CDM to reduce the emission of GHG. These types of activities are planned to increase the financial feasibility of the project by the trading of tons of CO_2 equivalent issued in the form of Certified Emission Reduction (CER) certificates. This can be called a scenario of monetization for CO_2 reduction which involves changing non-financial value into financial value (United Nation, 2004). In Thailand, the main sources of CO_2 emission are the energy sector (62%), land use and land use change and forestry (30%), and the industrial sector (8%) (DIW, 2005).

The use of energy causes damage to human health, natural ecosystems, and the built environment either directly or indirectly. Such damages are defined as external costs or externalities because they are not explicitly reflected in the market price of energy. These externalities traditionally are ignored. Nowadays, the internalization of externalities to assist policy and decision making is being realized. Externality is one of the scenarios for bringing indirect costs into the direct costs of activities through monetizing external costs and adding them into internal costs (Appendix D) (Meyerhofer, 1997).

CER and externality are good examples of monetization and internalization. The goal of reduction of the quantity of hazardous waste from every source including energy conservation measures should be applied by adapting either the scheme of CER or externality and thereby creating a system where waste reduction can provide tangible economic benefit.

3.2 Energy Conservation in Existing Building in Thailand

The Thai Royal Decree of Designated Building 1995 defines designated buildings (DBs) as buildings under the same house number where the total capacity of the transformer installed is more than 1,000 kW / 1,175 kVA or the annual energy consumption is more than 20 TJ. These buildings are the existing buildings which consume the majority of energy in the building sector. The status of designated buildings in Thailand is shown in Table 3.1 (DEDE 2005). The number in the table shows that only 964 buildings from 1,859 buildings have set the target and plan for the implementation of the energy conservation measures.

Table 3.1 Status of Designated Buildings in Thailand 2004

Activities of Designated Buildings	Accumulated Designated Buildings until the end of 2003	Designated Building 2004	Total
Registered (Buildings)	1,646	213	1,859
Personnel Responsible for Energy (people)	1,237	247	1484
Target and Plan (Buildings)	603	361	964
Energy Conservation Potential (million Baht)	581	320	901

(Source: The Department of Alternative Energy Development and Efficiency, 2004)

Two typical energy conservation measures used in existing designated buildings are the retrofit of air-conditioners and fluorescent lamps, which contain certain amounts of CFC and Hg, respectively. After the implementation of the retrofitting measures, CFC and Hg in the removed air conditioner and fluorescent tubes need strict, good management practice to avoid the emission of CFC and the contamination by Hg in the environment.

3.3 CFC

In 1985, the Vienna Convention on Protection of the Ozone Layer was first set up to recognize the dangers of ozone layer depletion. Two years later, in 1987 the Montreal Protocol on Substances that deplete the ozone layer took effect and was followed by amendments to the Protocol in London (1990), Copenhagen (1992) and Vienna (1995). At present more than 155 countries, including Thailand, have ratified the Montreal Protocol. The Protocol sets out the time schedule for stopping and reducing the manufacture of Ozone Depleting Substances (ODS) which are listed as "controlled substances". It requires all Parties to ban exports and imports of controlled substances from and to non-parties. Developed countries eliminated CFC consumption as of January 1, 1996. Developing countries have a grace period and must complete their phase out by January 1, 2010, though several countries will complete their phase out much before this date (Chirdpun 2001).

Data from the Project Management Unit (PMU) of the Department of Industrial Work about CFCs and their substituted substances now used in Thailand are shown in Table 3.2 Refrigerants used in air-conditioners are CFC-11 or CFC-12, will be replaced by HCFC-123 or HFC – 134a (PMU, 2005).

Regarding the situation of CFC’s in Thai industry, under the Act of Factory B.E. 2535, there is the Notification of the Ministry of Industry No.2 B.E. 2540 that bans of CFC in household refrigerators and the subsequent Notification of the Ministry of Industry No.3 B.E. 2540 also bans new factories to produce spray containing CFC. The total CFC 11 and CFC 12 used in Thailand was 3,462 metric ton in the year 2001; whose distribution in refrigerant sector was as follows (Chirdpun, 2001).

- Chiller CFC-11 130 ton
- Chiller CFC-12 15 ton
- Household refrigerator CFC-12 20.5 ton
- Commercial refrigerator CFC-12 66 ton
- Cold room & container CFC-12 39 ton
- Mobile air conditioning CFC-12 1,780 ton

Total 2,050.5 ton

CFC-11 and CFC-12 in the refrigerant sector represent 59.2% of the total CFC-11 and CFC-12 in every sector in Thailand.

Table 3.2 CFCs and substitution in Thailand

CFCs		**Existing CFCs**	**CFCs Substitution**
Application	**Application**		
Refrigerant	Car	CFC-12	HFC-134a
	Refrigerator	CFC-12	HFC-134a
	Chiller/Air conditioner	CFC-11 / CFC-12	HCFC-123 / HFC-134a / absorption chiller
	Cold storage	CFC-12	HFC-134a
Aerosols (Spray)	Consumer	CFC-11 / CFC-12	Hydrocarbon (Propane and Butane)
	Medical product	CFC-11 / CFC-12	HFC-134a
Foam	Soft foam	CFC-11	H2O, Methylene Chloride
	Hard foam	CFC-11	HCFC-141b, H2O, Cyclopentane
	Semi hard foam	CFC-11	HCFC-141b
	Polystyrene	CFC-12	Hydrocarbon (Propane and Butane)
Cleaning Agent	Precision cleaning	CFC-113	Aqueous System e.g. Alkaline Base
	Textile	1,1,1-Trichloroethane	1,1,2-Trichloroethylene and other solvent
	Electronics	CFC-113	Aqueous System / No-Clean Technology

Source: PMU, DIW, Thailand 2005

3.4 Mercury

EU Directive 2002/95/EC (Legal requirement in EU countries): announced on February 13, 2003 with an implementation deadline on July 1, 2006 on the Restriction of the use of certain hazardous substances in Electrical and Electronic Equipment (EEE) called RoHs. The directive bans the use of heavy metal (Pb, Hg, Cd, and Cr-6) and brominated flame retardants (PBB, and PBDE) in EEE except; Hg in compact fluorescent lamp which allows not exceeding 5 mg/lamp, Hg in straight fluorescent lamps for special purposes, and Hg in other lamps not specifically mentioned in this Annex of RoHs. In addition to the EU Directive mentioned, the EU Directive 2002/96/EC (EU Directive 2003/108/EC amended) requires manufacturer or importer to collect or encourage the return of waste electrical and electronic equipment (WEEE) for recycle, reuse, or recovery in order to reduce the impact on the environment. This must be carried out without payment from the consumer except for historical waste (produced before WEEE) for which some fee may be charged to the consumer. This Directive directly affects Thai exporters because the list of products in WEEE covers both fluorescent lamps and air conditioners (See Appendix E for more detail of the situation of Roh and WEEE) (The Department of Foreign Trading, 2003).

At the 7th International Conference on Mercury as a Global Pollutant at Ljubljana, Slovenia 27 June-2 July 2004, used fluorescent lamps were officially defined as hazardous waste contaminated with mercury. It is reported that mercury in Thailand is imported from Spain and the Netherlands at the rate of 14 tons per year. Manufacturers of fluorescent lamps are a part of the group of mercury consumers (ICMGP, 2004)

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In Thailand, there are many legislative limits and frameworks for mercury control, i.e. effluent standard 5 μg/l, emission standard 3 mg/Nm^3, coastal water areas 0.1 μg/l, and surface water 2 μg/l, appropriate measures in accordance with good petroleum industry practice to prevent mercury pollution, food standard of 0.5 μg/g for seafood, and 0.02 μg/g for other food, and 0.5 μg/g for fishery products. Mercury, categorized as a hazardous waste, is under legislation which is fragmented with regard to jurisdiction and authority i.e. Enhancement and Conservation of National Environment Quality Act B.E. 2535, Factory Act B.E. 2535, Hazardous Act B.E. 2535, Public Health Act B.E. 2535, and Petroleum Act B.E. 2514 and 2532. The authority directly concerned with industrial hazardous waste is the Hazardous Waste Disposal Subdivision of the Office of Industrial Service and Waste Management in the Ministry of Industry. The Ministry of Industry has also issued several ministerial regulations i.e. The Ministry Announcement No.25 (1998), which decrees that all factories have to carry out proper treatment of polluting and discarded materials, The Ministry of Industry Announcement No.57 (1990), which stipulates that all waste materials specified in the Basel Convention are toxic wastes and have to be under the control of the law, and the Ministry of Industry Regulation No. 2 (1992), which stipulates the control of all waste pollutants or any other materials that are hazards to the environment (PCD, 2001).

Fluorescence production uses mercury as an electrode and the processes are carried out in closed systems. Therefore, the mercury will not be discharged during the manufacturing process but the removal and improper management of fluorescent lamps can cause the contamination of Hg into the environment (PCD, 2001).

From the Guideline for Used Fluorescent Lamp Management 2004 by the Bureau of Industrial Waste and Hazardous Waste, The Pollution Control Department, Ministry of Natural Resource and Environment, the volume of waste fluorescent lamps in Thailand in 2004 was about 41 million tubes. The straight tube share is 70% of the total amount. From the perspective of sources of the used tubes 66.4 % is from the residential sector, 32.2 % is from large buildings, and 1.4 % is from transportation services. The cost (based upon Japanese experience) of a straight tube recycle plant is about 50 million Baht for a processing capacity of 6 million tubes per year, at an operating cost of 1 Baht/lamp (PCD, 2004).

3.5 Calculation of SPB and IRR

The retrofitting of an existing fluorescent lamp lighting system to an energy efficient fluorescent lamp twice within 10 years (5-year life time is doubled in this study to be the same as air-conditioner that has a 10-year lifetime.) normally gives energy and money saving as calculated by equation (3.1)-(3.6). For fluorescent lamps the labor cost for installation is 0 Baht/lamp while the operating factor of the fluorescent lamp, the recycling cost for a fluorescent lamp, the collection cost of a wasted fluorescent lamp, the scrap value for fluorescent lamp (neglected in this calculation), the externality studied by the Promotion of Renewable Energy Technology Project (PRET, 2005) in 2005 for Thailand, the amount of CO_2 emission (including the amount of other emission converted to CO_2 with the equivalent factor) per kWh of energy consumption, and the price of a ton of CO_2 reduction for trading (called carbon credit) total for 0.32 Baht/kg. The calculation method of the energy and money saving follows the energy audit report as the equation (3.1)-(3.6) shown below (DEDE, 2005).

$$E_s = (C_1 - C_2) \times H \times D \times O_f \qquad \text{.......(3.1)}$$

$$Ec = C_2 \times H \times D \times O_f \qquad \text{.... ...(3.2)}$$

$$M_s = E_s \times C_p \qquad \text{......... (3.3)}$$

$$SPB = (I_n + L) / M_s \qquad \text{..........(3.4)}$$

$$SPB_w = (I_n + R + C + S) / M_s \qquad \text{........(3.5)}$$

$$SPB_e = (I_n + R + C + S + E_t \times L_t \times E_c) / (M_s + C_c \times E_s \times E_m + E_s \times E_t) \qquad \text{..........(3.6)}$$

E_s Energy saving (kWh)
E_c Energy consumption (kWh)
M_s Money saving from retrofitting energy consuming equipment (Baht/year)
C_1 Capacity of existing fluorescent lamp (kW)
C_2 Capacity of new fluorescent lamp (kW)
H Hour per day (hr/day)
D Day per year (day/year)
O_f On-Off factor (%)
C_p Cost of power (Baht/kWh)
SPB Simple payback period (year)
SPB_w Simple payback period with waste management cost (year)
SPB_e Simple payback period with waste management cost and external cost (year)
In Investment for energy consuming equipment (Baht)
L Labor cost (Baht)
R Recycling cost (Baht)
C Collecting cost (Baht)
S Scrap value (Baht)
E_t Externality[1] from monetized impact from CO_2 emission (Baht/kWh)
C_c Price of a ton CO_2 reduction for trading (Baht/kg)
Em CO_2 equivalent emission per kWh energy consumption (kg/kWh)
Lt Lifetime of energy consuming equipment (year)

[1] Externality is composed of abatement cost and damage cost

The retrofitting of an existing air-conditioner to the high energy efficiency air-conditioner (corresponding to new air conditioner which is labeled as number 5 according to the classification of the Electricity Generating Authority of Thailand (EGAT) laboratory with the same capacity of 1 TR within 10 years normally gives energy and money saving as calculated by equations (7)-(12). The cost of an air-conditioner, the labor cost for installation (for both removal of the existing and the installation of new air-conditioner), the operating day factor, on-off factor, and operating factor of air-conditioner's compressor, the collecting cost of used air-conditioner, the scrap value for an air-conditioner for refrigerant recovery, the revenue from returned refrigerant, the revenue from material, and revenue from cast iron, the externality studied by the Promotion of Renewable Energy Technology Project (PRET, 2005) in 2005 for Thailand, the amount of CO_2 emission (including the amount of other emission converted to CO_2 with the equivalent factor) per kWh of energy consumption, and the price of a ton CO_2 reduction for trading (called carbon credit) totals for 0.32 Baht/kg. Calculation method of the energy and money saving follows to the energy audit report as the equation (7)-(12) hereinafter (DEDE, 2005).

$$E_s = (C_1 - C_2) \times T_r \times H \times D \times O_d \times O_f \times O_c \quad \text{..........(3.7)}$$

$$E_c = C_2 \times H \times D \times O_d \times O_f \times O_c \quad \text{..........(3.8)}$$

$$M_s = E_s \times C_p \quad \text{..........(3.9)}$$

$$SPB = (I_n + L) / M_s \quad \text{........(3.10)}$$

$$SPB_w = (I_n + R + C + S) / M_s \quad \text{........(3.11)}$$

$$SPB_e = (I_n + R + C + S + E_t \times L_t \times Ec) / (M_s + C_c \times E_s \times E_m + E_s \times E_t) \quad \text{........(3.12)}$$

E_s Energy saving (kWh)
E_c Energy consumption (kWh)
M_s Money saving from retrofitting energy consuming equipment (Baht/year)
C_1 Capacity of existing air-conditioner (kW/ton)
C_2 Capacity of new air-conditioner (kW)
H Hour per day (hr/day)
D Day per year (day/year)
O_d Operating day (%)
O_f On-off factor (%)
O_c Operating factor of compressor (%)
T_r Refrigerating ton (ton)
C_p Cost of power (Baht/kWh)
SPB Simple payback period (year)
SPB_w Simple payback period with waste management cost (year)
SPB_e Simple payback period with waste management cost and external cost (year)
I_n Investment for energy consuming equipment (Baht)
L Labor cost (Baht)
R Recycling cost (Baht)
C Collecting cost (Baht)
S Scrap value (Baht)
E_t Externality from monetized impact from CO_2 emission (Baht/kWh)
C_c Price of a ton CO_2 reduction for trading (Baht/kg)
E_m CO_2 equivalent emission per kWh energy consumption (kg/kWh)
L_t Life time of energy consuming equipment (year)

The calculation of the internal rate of return can be done by using spread sheet of cash flow in order to find out the net present value. The internal rate of return is the discount rate that makes the net present value equal to zero.

It is easily seen that the aspect of hazardous waste management need to be considered at the beginning of the decision making process. One possible option to facilitate such consideration is to monetize the external costs from retrofitting, recycling, and disposal. After that the decision maker can add the monetized impact into the existing decision making tools. The external cost could be:

- Monetized environmental impact from operating
- Monetized environmental impact from retrofitting, recycling, and disposal
- Monetized risk during transportation
- Revenue from Clean Development Mechanisms

The monetized environmental impact from operating had been done previously using the externality of energy consumption because it has been proven by many LCA studies of energy consuming equipment that energy consumption plays much more important role than other phases in the life cycle of the equipment and its use. The externality for Thailand is estimated by PRET which has brought the externality (damage cost and abatement cost) from European Countries and converted with the GDP to the Thai level at 0.36 Baht/kWh (See more detail in appendix D).

The LCA of retrofitting, recycling, and disposal using the categories of Eco-Indicator 95 (3 groups of fatalities, health, and ecosystem), allow the used of weighting factors that can convert all indicators into the equivalent amount of CO_2 emission. The CO_2 emission total was subsequently again converted via conversion factors 0.26 kg CO_2/kWh and 0.36Baht/kWh (PRET, 2005) into its monetized impact (Table 3.3).

Table 3.3 Monetized impact from retrofitting, recycling, and disposal (for FL and AC)

Single Score	Category	Indicator	Relative Weighting Indicator (RWI)	kg equivalent of indicator (kg eq)	RWI x kg eq (FL)
EI95	Ozone depletion	R11	40	0.0002	0.0080
	Heavy metal	Pb	2	0.0259	0.0518
	Carcinogen	PAH	4	0.0006	0.0024
	Summer smog	C2H4	1	0.0017	0.0017
	Winter smog	SO2	2	0.0027	0.0054
	Pesticide	Ingr	10	0.0000	0.0000
	Greenhouse effect	CO2	1	0.0034	0.0034
	Acidification	SO2	4	0.0056	0.0224
	Eutrophication	PO4	2	0.0007	0.0014
Total (kg of CO2 eq)					0.1

Single Score	Category	Indicator	Relative Weighting Indicator (RWI)	kg equivalent of indicator (kg eq)	RWI x kg eq (AC)
EI95	Ozone depletion	R11	40	3.0E-07	1.2E-05
	Heavy metal	Pb	2	2.0E-06	4.0E-06
	Carcinogen	PAH	4	9.0E-07	3.6E-06
	Summer smog	C2H4	1	1.6E-05	1.6E-05
	Winter smog	SO2	2	1.9E-05	3.8E-05
	Pesticide	Ingr	10	0.0E+00	0.0E+00
	Greenhouse effect	CO2	1	8.1E-06	8.1E-06
	Acidification	SO2	4	4.6E-05	1.8E-04
	Eutrophication	PO4	2	4.8E-06	9.6E-06
Total (kg of CO2 eq)					0.0003

Note: FL is fluorescent lamp and AC is air-conditioner

Monetized Impact = Externality / COeq emission per kWh x kg CO2eq

= (Baht/kWh) / (kg CO2equ/kWh) x (kg CO2eq)

Monetized Impact FL = 0.36 / 0.26 x 0.01

= 0.14 Baht

Monetized Impact AC= 0.36 / 0.26 x 0.003

= 0.001 Baht

Risk in terms of money in this study pays attention to the transportation of waste. Payment cost for insurance is used as perceived risk and the statistic of accident from transportation of hazardous waste is used to calculate the probability per year. The Ministry of Industry, Thailand issued a notification enforcing 10 million Baht insurance/accident in transportation of hazardous waste (MOI, 2006). Normally the accident insurance will receive the real payment of 0.1% of the budgeted maximum payout per incident. In the year 2004, there were 6 accidents from hazardous waste transportation (ONEP, 2004).

Probability = accidents / days in year x insurance payment

= 6 / 365 x 100,000

= 1,644 Baht/10 years.

ERM Company Limited had studied in 2005 that for Thailand that the price of a ton CO_2 reduction is 320 Baht. So, the yield from Clean Development Mechanisms is the result from the multiplication of the reduction of CO_2 from energy saving and the conversion factor 320 Baht/ton of CO_2 reduction (ERM, 2005).

Table 3.4 concludes all the parameter used in the calculation of life cycle cost of the retrofitting a 36 W fluorescent lamp and 12000 Btu air-conditioner.

Table 3.4 Parameters used in the life cycle analysis

Parameter	Unit	Input	Composition (%)	Total Weight (kg)	% Recovery	Source
Investment FL & maintenance	Baht/FL	70				DEDE 2003
Aluminum in FL	kg/FL	0.01	5	0.20001	75%	PCD, 2004
Glass in FL	kg/FL	0.18	90		75%	PCD, 2004
Hg 10e-5 + phosphor 10 e-2 kg	kg/FL	0.01001	5			PCD, 2004
Labor cost	Baht/kg	0				DEDE, 2003
New Capacity	Watt/FL	36				DEDE, 2003
Compared capacity	Watt/FL	40				DEDE, 2003
Operating factor	%	40				DEDE, 2003
Hg recovery cost	Baht/FL	0				KKU, 2007
revenue from glass	Baht/kg	0.50				KKU, 2007
revenue from aluminum	Baht/kg	35				KKU, 2007
revenue from other scrap	Baht/kg	0				KKU, 2007
Collecting 200 km 3 ton truck	Baht/kg	1.5				GENCO, 2005
Investment AC & maintenance	Baht/AC	20000				DEDE, 2003
Aluminum in AC	kg/AC	1.7	5	31.6	75%	Bitwise 2004
Copper in AC	kg/AC	3.23	10		75%	Bitwise 2004
HCFCR22 in AC	kg/AC	1	3			Bitwise 2004
Plastic in AC	kg/AC	1.63	5		75%	Bitwise 2004
Steel in AC	kg/AC	24	76		75%	Bitwise 2004
Labor cost:remove & install	Baht/AC	4,000				DEDE, 2003
Compared kW/ton	kW/ton	1.25				DEDE, 2003
kW/ton of AC (12,000 Btu)	kW/ton	2.00				DEDE, 2003
Operating day	%	80				DEDE, 2003
On-off factor	%	80				DEDE, 2003
Operating factor-compressor	%	80				DEDE, 2003
Refrigerant recovery cost	Baht/AC	176				Recycler 2004
revenue from refrigerant	Baht/kg	0				Recycler 2004
revenue from compressor	Baht/kg	500				Recycler 2004
revenue from scrap	Baht/kg	160				Recycler 2004
Collecting 200 km 3 ton truck	Baht/kg	1.5				GENCO, 2005
External cost CO2 equivalent	Baht/kWh	0.36				PRET. 2005
CO2 equivalent emission	kg/kWh	0.26				PRET, 2005
Price of a ton CO2 reduction	Baht/kg	0.32				ERM, 2005
Disposal Cost for FL	Baht/kg	9.0				GENCO, 2005
Disposal Cost for AC	Baht/kg	5.8				GENCO, 2005
Average price of electricity	Baht/kWh	2.5				DEDE , 2003
Monetized risk - 10 yrs (R)	Baht/kg	1,644				MOI, 2006

3.6 Change of SPB and IRR by Adding External Costs

Using IRR (Internal Rate of Return) and SPB (Simple Payback Period) as criteria for energy conservation project approval in existing buildings without consideration of environmental disposal costs or recycling cost is an area where the concept of integration between energy and environment is needed. The retrofitting of 40 Watt to 36 W fluorescent lamps normally gives energy and money saving as calculated in Table 3.5 (base case).

The adding of external costs will extend the simple payback period of a project from 4.8 to 4.9 years. With the same information the IRR before adding the recycling cost is 19.8% and will drop down to 18.4% after adding the recycling cost. The significant change happened when impact and external cost were added. SPB would be 17.2 years and IRR fell below zero. It is noted that the calculation was based on the following assumptions: (1) the price of lamp is from the specification book of DEDE 2003, (2) calculation method of saving is the methodology from the energy audit report of the designated buildings by DEDE, (3) recycling cost of 36 W lamp is the average from American Technology US EPA and Japanese Technology PCD Thailand, and (4) the electricity tariff is the average from the power annual report of DEDE in year 2005.

The retrofitting of 12,000 Btu (1 Ton of Refrigeration: TR) air conditioner with an existing Energy Efficiency Ratio (EER) of about 2.00 kW/TR (whereas the EER average from 106 units of 1 TR in 1,646 designated buildings in the DEDE database is 1.57 kW/TR) to new air conditioner label number 5 of the same capacity of 1 TR while having an EER of 1.25 kW/TR according to the classification of EGAT's laboratory (The Electricity Generating Authority of Thailand). The retrofitting normally incurs energy and money saving as calculated in Table 3.5.

This adding of external costs will change the simple payback period of a project from 3.4 to 2.9 years. It is shorter as the revenue from scrap value of the removed air-conditioner. With the same information the IRR before adding the recycling cost is 10.8% and will drop down very slightly to 10.77% after adding the recycling cost. The significant change occurred when external costs had been added. SPB reached 5.4 years and IRR were only 1.9%. It is noted that the calculation was based on the following assumptions: (1) price of air conditioner is from the specification book of DEDE 2003, (2) calculation method of saving is the methodology from the energy audit report of the designated buildings by DEDE, (3) recycling cost of a 1 TR air conditioner is based on Japanese Technology, and electricity tariff is the average from the power annual report of DEDE in 2005.

The model needs more mechanisms to be opened for other parameters to be added in the future to provide more realistic information for the decision maker. The additional cost that may incur in the future in the evaluation of the financial feasibility of projects, e.g. the full analysis of life cycle cost is a tool used in financial impact analysis.

From the calculation, the cost of recycling and disposal are quite low and supposed to be attractive, which could be added at the beginning of decision making but it was normally ignored. This is clearly because of the low awareness of decision makers or unavailability of decision support model that incorporates the importance of hazardous waste management.

Table 3.5 SPB and IRR of retrofitting: Fluorescent Lamp

Cash flow (CF) of retrofitting	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	IRR (%)	SPB (year)
Investment and consumption	-70	0	0	0	0	0	-70	0	0	0	0		
Labor cost	0	0	0	0	0	0	0	0	0	0	0		
Saving	0	35	35	35	35	35	35	35	35	35	35		
Net CF (Base Case)	-70	29	24	20	17	14	-12	10	8	7	6	19.8%	4.8
Investment	-70	0	0	0	0	0	-70	0	0	0	0		
Labor cost	0	0	0	0	0	0	0	0	0	0	0		
Hg recovery	0	0	0	0	0	0	0	0	0	0	0		
Revenue from glass	0.13	0	0	0	0	0.13	0	0	0	0	0		
Revenue from Aluminum	0.49	0	0	0	0	0.49	0	0	0	0	0		
Revenue from scrap	0	0	0	0	0	0	0	0	0	0	0		
Recycling	-1	0	0	0	0	-1	0	0	0	0	0		
Collecting	-1.5	0	0	0	0	-1.5	0	0	0	0	0		
Disposal cost of hazardous waste	-0.13	0	0	0	0	-0.13	0	0	0	0	0		
Saving	0	35	35	35	35	35	35	35	35	35	35		
Net CF (recycle-disposal)	-72	29	24	20	17	13	-12	10	8	7	6	18.4%	4.9
Investment	-70	0	0	0	0	0	-70	0	0	0	0		
Labor cost	0	0	0	0	0	0	0	0	0	0	0		
Hg recovery	0	0	0	0	0	0	0	0	0	0	0		
Revenue from glass	0.13	0	0	0	0	0.13	0	0	0	0	0		
Revenue from Aluminum	0.49	0	0	0	0	0.49	0	0	0	0	0		
Revenue from scrap	0	0	0	0	0	0	0	0	0	0	0		
Recycling	-1	0	0	0	0	-1	0	0	0	0	0		
Collecting	-1.5	0	0	0	0	-1.5	0	0	0	0	0		
Disposal cost of hazardous waste	-0.13	0	0	0	0	-0.13	0	0	0	0	0		
Saving	0	35	35	35	35	35	35	35	35	35	35		
Operating impact	0	-46	-46	-46	-46	-46	-46	-46	-46	-46	-46		
Retrofitting-recycling impact	0	0	0	0	0	0	0	0	0	0	0		
CO2 Trading	0	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15		
Net CF (recycle-disposal-impact)	-72	-8	-7	-6	-5	-5	-27	-3	-2	-2	-2	<0	16.6
Investment	-70	0	0	0	0	0	-70	0	0	0	0		
Labor cost	0	0	0	0	0	0	0	0	0	0	0		
Hg recovery	0	0	0	0	0	0	0	0	0	0	0		
Revenue from glass	0.13	0	0	0	0	0.13	0	0	0	0	0		
Revenue from Aluminum	0.49	0	0	0	0	0.49	0	0	0	0	0		
Revenue from scrap	0	0	0	0	0	0	0	0	0	0	0		
Recycling	-1	0	0	0	0	-1	0	0	0	0	0		
Collecting	-1.5	0	0	0	0	-1.5	0	0	0	0	0		
Saving	0	35	35	35	35	35	35	35	35	35	35		
Operating impact	0	-46	-46	-46	-46	-46	-46	-46	-46	-46	-46		
Retrofitting-recycling impact	0	0	0	0	0	0	0	0	0	0	0		
CO2 Trading	0	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15		
Disposal cost of hazardous waste	-0.13	0	0	0	0	-0.13	0	0	0	0	0		
Monetized risk	-23.3	0	0	0	0	-23.3	0	0	0	0	0		
Net Cash Flow with all external costs	-95	-8	-7	-6	-5	-14	-27	-3	-2	-2	-2	<0	17.2

Table 3.6 SPB and IRR of retrofitting: Air-conditioner

Cash flow (CF) of retrofitting	year 0	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 9	year 10	IRR (%)	SPB (year)
Investment	-20000	0	0	0	0	0	0	0	0	0	0		
Labor cost	-4000	0	0	0	0	0	0	0	0	0	0		
Saving	0	8410	8410	8410	8410	8410	8410	8410	8410	8410	8410		
Net CF (Base Case)	-24000	7008	5840	4867	4056	3380	2816	2347	1956	1630	1358	10.8%	3.4
Investment	-20000	0	0	0	0	0	0	0	0	0	0		
Labor cost	-4000	0	0	0	0	0	0	0	0	0	0		
Refrigernat recovery	0	0	0	0	0	0	0	0	0	0	-176		
revenue from refrigerant	0	0	0	0	0	0	0	0	0	0	0		
revenue from compresser	0	0	0	0	0	0	0	0	0	0	500		
revenue from scrap	0	0	0	0	0	0	0	0	0	0	160		
Recycling	0	0	0	0	0	0	0	0	0	0	-1236		
Collecting	0	0	0	0	0	0	0	0	0	0	-2		
Disposal cost of hazardous waste	-10	0	0	0	0	-10	0	0	0	0	0		
Saving	0	8410	8410	8410	8410	8410	8410	8410	8410	8410	8410		
Net CF (recycle-disposal)	-24010	7008	5840	4867	4056	3376	2816	2347	1956	1630	1237	10.8%	2.9
Investment	-20000	0	0	0	0	0	0	0	0	0	0		
Labor cost	-4000	0	0	0	0	0	0	0	0	0	0		
Refrigernat recovery	0	0	0	0	0	0	0	0	0	0	-176		
revenue from refrigerant	0	0	0	0	0	0	0	0	0	0	0		
revenue from compresser	0	0	0	0	0	0	0	0	0	0	500		
revenue from scrap	0	0	0	0	0	0	0	0	0	0	160		
Recycling	0	0	0	0	0	0	0	0	0	0	-1236		
Collecting	0	0	0	0	0	0	0	0	0	0	-2		
Disposal cost of hazardous waste	-10	0	0	0	0	-10	0	0	0	0	0		
Saving	0	8410	8410	8410	8410	8410	8410	8410	8410	8410	8410		
Operating impact	0	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030		
Retrofitting-recycling impact	0	0	0	0	0	0	0	0	0	0	0		
CO2 Trading	0	276	276	276	276	276	276	276	276	276	276		
Net CF (recycle-disposal-impact)	-24010	5546	4622	3852	3210	2671	2229	1857	1548	1290	953	3.8%	5.19
Investment	-20000	0	0	0	0	0	0	0	0	0	0		
Labor cost	-4000	0	0	0	0	0	0	0	0	0	0		
Refrigernat recovery	0	0	0	0	0	0	0	0	0	0	-176		
revenue from refrigerant	0	0	0	0	0	0	0	0	0	0	0		
revenue from compresser	0	0	0	0	0	0	0	0	0	0	500		
revenue from scrap	0	0	0	0	0	0	0	0	0	0	160		
Recycling	0	0	0	0	0	0	0	0	0	0	-1236		
Collecting	0	0	0	0	0	0	0	0	0	0	-2		
Saving	0	8410	8410	8410	8410	8410	8410	8410	8410	8410	8410		
Operating impact	0	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030	-2030		
Retrofitting-recycling impact	0	0	0	0	0	0	0	0	0	0	0		
CO2 Trading	0	276	276	276	276	276	276	276	276	276	276		
Disposal cost of hazardous waste	-10	0	0	0	0	-10	0	0	0	0	0		
Monetized risk	-1809	0	0	0	0	0	0	0	0	0	0		
Net Cash Flow with all external costs	-25819	5546	4622	3852	3210	2671	2229	1857	1548	1290	953	1.9%	5.40

3.7 Conclusion

If the recycling and disposal costs are added into the calculation of IRR and SPB in the retrofitting process, the values of both parameters would not change much from the base case (retrofitting without recycling and disposal cost). If the external cost from retrofitting, recycling and disposal cost (monetized environmental impact from operations, monetized environmental impact from retrofitting – recycling – disposal, monetized risk during transportation, and revenue from Clean Development Mechanisms) were added into the calculation of IRR and SPB would changed dramatically from the base case. It can be concluded that external cost is an important factor that should lead to change in the decision making process. The resulted of IRR and SPB which includes the external cost cannot be interpreted in view of finance or project approval because it becomes lower than the traditional criterion for retrofitting (IRR higher than 9%). used criteria (To do retrofitting, IRR should be higher than 9%). Next chapter will present the proposed model and the background named ENVIROGY accounting the external cost into the model.

Chapter IV

COMPONENTS OF ENVIROGY

4.1 Introduction

Energy policy, one of the most important current issues, is difficult to separate from environmental policy. Therefore, policy formulating has to by necessity consider in both aspects together (Christiansen, 1990). The integration of energy and environment is not a new concept. Since 1983, energy conservation effort had been advised and encouraged to include the allocation of responsibility for waste generated (Mclelland and Cook, 1993: Vera and Langlois, 2007). The integration of energy and environment will be more complex if the external costs are internalized into the investment cost. Substantial costs, impacts of hazardous wastes, and risk have been considered in the potential application of many technologies (Bezdek, 1993) and externalities are internalized in policy making process (Curlee, 1993: Lutz and Munasinghe, 1994) but most of the integration uses linguistic variables (Doukas et al., 2007) or scoring method in making final decision. The joint impact of environment and energy were homogeneously combined using the best judgment of experts or researchers. There are some uncertainties and potential biases in the judgment of people whereas some more specific and straight forward method such as Life Cycle Analysis (LCA) is an excellent approach but need comprehensive information or database. The objective of this study is to propose a practical and homogeneous approach called ENVIROGY that provides combination of energy and environment and also internalization of external costs to investment cost.

4.2 Approach of Integration and Internalization

The term “ENVIROGY” is proposed here in order to provide a single indication in terms of money used for justification of the investment in energy conservation of retrofitting measures. There are two case studies in this study, one is the replacement of existing low efficiency air-conditioner rated at 12000 Btu (1.79 kW/ton) with the higher efficiency – Label 5 (1.25 kW/ton) and another is the replacement of 40 Watt fluorescent lamps with 36 W fluorescent lamps. Input data used are acquired in the Thai context e.g. cost of fluorescent lamp from Thai suppliers, labor cost from real installation of projects in Thailand, and recycling cost from Thai recycling companies.

ENVIROGY is the summation of expense or income occurring from retrofitting of both internal and external views for investors (Fig. 4.1). To calculate ENVIROGY by summing up components - E, N, V, I, R, O, G, and Y, it is necessary to know the details of each component.

E is energy consumption or saving
N is net waste recycling cost
V is the violence impact from hazardous waste or disposal cost
I is investment cost for retrofitting
R is risk in terms of money
O is operating impact in terms of money
G is government intervention for promotion or fee
Y is yield from the Clean Development Mechanism

The components of ENVIROGY are tentatively proposed and used for energy consuming equipment and related hazardous substances. If it is used in other contexts, additional components might be considered and added.

Each component of ENVIROGY had been considered along the life cycle of the retrofitting process. Manufacturing, retrofitting, operation, transportation, recycling, and disposal are considered with supportive idea from various studies. It is found that some part can be neglected (Table 4.1) as is typically done for LCA studies.

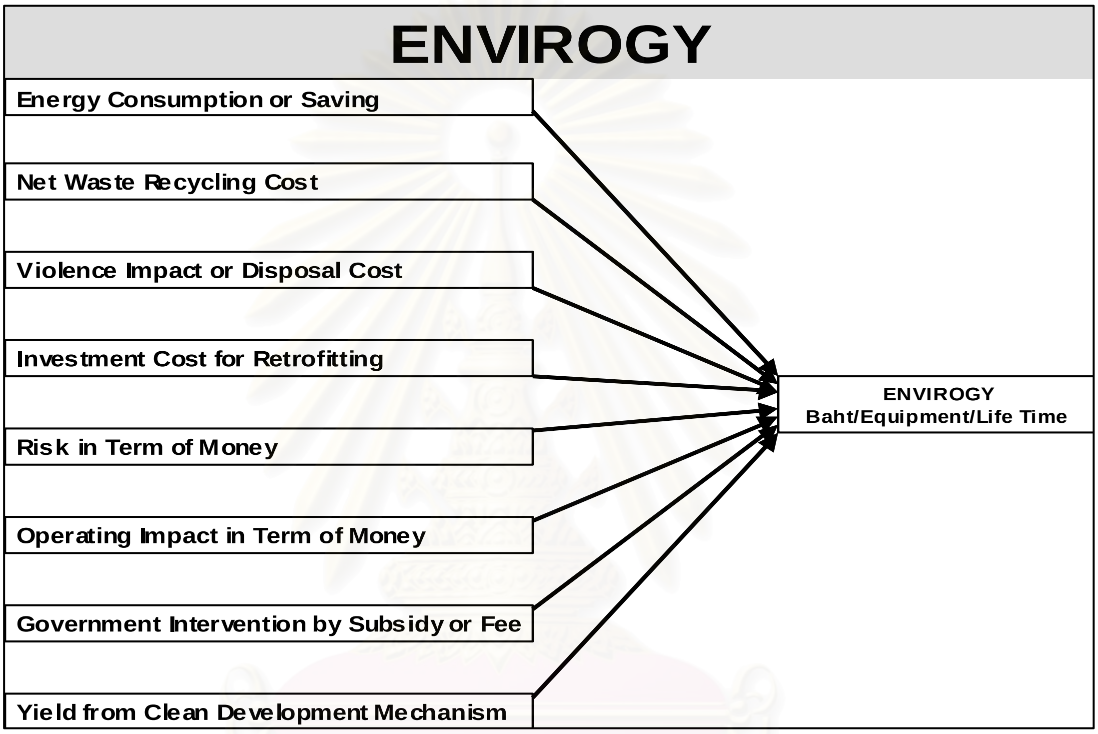


Fig. 4.1 Conceptual model of ENVIROGY

- Net waste recycling cost incurs only from the transportation, recycling cost, and revenue from scrap value.
- Violence impact from hazardous waste will occur in cases where there will be some leakage. If the disposal had been done correctly, the investor has to pay only for the original disposal cost (In this chapter, the violence impact is calculated from the disposal cost of whole lamp or air-conditioner in order to simplify the calculation whereas next chapter will calculated this part from using LCA approach).
- Risk in terms of money, this study pays attention to the transportation of waste. Payment for insurance is used as perceived risk and the statistic of accidents resulting from transportation of hazardous waste is used to calculate the probability per year.
- Operating impact had been determined from the LCA of the air-conditioner and LCA of fluorescent lamp. Both show the same conclusion that the major impact in all categories comes from the operating phase. The emission of CO_2 from energy consumption is the major contributing causes during the operation. Externality in

currency unit Baht/kg CO_2 emission is therefore used as the conversion factor to convert operating impact to money value.

- Government intervention could be a subsidy, penalty, fee, tax, or loan. This study uses the real current of 30% subsidy of the equipment price for retrofitting of fluorescent lamps and air conditioner under the Standard Measure project of the Department of Alternative Energy Development and Efficiency, Ministry of Energy (Thailand).
- Yield from the Clean Development Mechanism (CDM) is selected as the price of CO_2 reduction as studied by ERM Siam i.e. 0.32 Baht/kg CO_2 reduction. The reduction of CO_2 here is simplified from the saving of energy and emission.

The result of ENVIROGY could be either a plus or minus value. If the result is minus, it means there is some recurring or continuous expense in the life time of the energy consuming equipment of study. On the other hand, the plus value shows net income from the life time of such equipment.

4.3 Result and Discussion

The calculation of ENVIROGY had been done step by step Table 4.2 and 4.3. During retrofitting phase, E from energy saving, I from investment of retrofitting, and Y from accounting the yield from the Clean Development Mechanism are calculated. In the phase of operating, E from energy consumption, I from operating cost, O from operating impact, and the subsidy from government are calculated. Collection and transportation phase includes both direct cost and the indirect cost from insurance. The last phase creates the cost of recycling and disposal. The ENVIROGY for a 36 W fluorescent lamp is 5,849 Baht/lamp/10 years and the ENVIROGY for a 12000 Btu air-conditioner is -70,509 Baht/air-conditioner/10 years. The assumption for each component at this stage has not been defined exactly or standardized. The demonstration of the ENVIROGY value is thus important to consider together with the Fig. 4.1. The value of ENVIROGY here is only the indicator of the cost from the whole lifetime because equipment in various contexts could give different values of ENVIROGY depending on specific individual design or operational characteristics e.g. ENVIROGY of energy generating equipment will produce energy instead of consuming energy.

The combination of components in ENVIROGY had been done in terms of monetary value. Actually the monetary value in each year along the lifetime must be discounted as the time series from the reduction by inflation combined with increasing effects from the interest rate. The summing up into monetary value makes ENVIROGY easy to understand instead of the typical scores or points used in many other single indicator approaches. Monetizing each component into monetary value is based on the philosophy that every thing can be either directly or indirectly measured. The measurement or estimation in monetary value should be practically related to a simple, available, and acceptable database e.g. the case of risk estimation in transportation of hazardous waste which is based on its insurance cost and the probability derived from accident statistics (See Appendix F – column “collect and transport to recycle plant” and row “risk”). This simplification will avoid the need for a huge database in software or knowledge of some exact and complex method. This approach provides not only the benefit from the understanding the combined energy-environment effect for a given change, but it also provides opportunities to compare impacts from alternative equipment if the data is based on the same sets of assumptions.

4.4 Conclusion

This work shows that the preliminary conceptual model named ENVIROGY can work using a standard set of assumptions. ENVIROGY is a single indicator expressed in terms of monetary value used to explain net expense or income along the lifetime of energy consuming equipment, taking into consideration the environmental implications.

From the approach and result it is easily seen that many issues such as energy consumption or savings, net waste recycling cost, violence impact from hazardous waste or disposal cost, investment cost for retrofitting, risk in terms of money, operating impact in terms of money, government intervention for promotion or fee, and yield from the Clean Development Mechanism can be combined into a single monetary indicator named ENVIROGY as shown in Table 4.2 and 4.3.

Lessons learned can be applied to the promotion of renewable energy e.g. batteries of PV cells. As it is common idea that PV cells is good but for the whole lifetime it could be some aspects to concern in monetary value. The changing of conceptual-decision support model will change the purchasing procedure by adding into the qualification of bidder in taking and returning of waste. The retrofitting of some equipment may be the last priority if the ENVIROGY shows some high negative cost. The designers have to redesign their products to optimize the net monetary value that is determined using a broader base of factors. Next chapter will present the LCA process in order to find the hazardous waste amount and its monetized impact in order to plug into the proposed model called ENVIROGY.

Table 4.1 Scope of ENVIROGY utilized at all phases in life cycle of the products of study based on 10-year lifetime (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Energy consumption or saving	*Fluorescent Lamp* 34 MJ *Air-conditioner* 122 MJ	*Fluorescent Lamp* 378 MJ (105 kWh) *Air-conditioner* *44,701MJ* (12,417 kWh)	*Fluorescent Lamp* 3,405 MJ (946 kWh) *Air-conditioner* 103,478 MJ (28,744 kWh)	*Fluorescent Lamp* 0.07 MJ *Air-conditioner* 11.6 MJ	*Fluorescent Lamp* 0.15 MJ *Air-conditioner* 6.9 MJ
Net waste recycling cost	No recycle	No recycle	No recycle	Collecting to the recycling factory 200 km or 1.5 Baht/kg	Recycling cost for is 2.5 Baht/lamp and 1,225 Baht/air-conditioner. Scrap value is 2.6 Baht/lamp and 750 Baht/air-conditioner
Violence impact or disposal cost of hazardous waste	Before retrofit	No leakage	No leakage	No leakage	9,000 Baht/ton of lamp and 5,800 Baht/ton of air-conditioner
Investment cost for retrofitting	Before retrofit	Equipment and Labor cost of retrofitting can save 20-40%	Maintenance cost has been added at the beginning of retrofitting	Normally not in the investment cost	Option to account investment of recycling plant per lamp

Table 4.1 (Continued) Scope of ENVIROGY utilized at all phases in life cycle of the products of study based on 10-year lifetime (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Risk costing	Before retrofit	Risk assessment becomes fundamental to all phases of the development of waste management facilities	It is assumed that there is no risk during operation	1,644 Baht per accident paid for insurance	Risk needs to be reduced from the beginning of product design to reduce the risk from used product
Operating impact	3.5% CO_2 emission during manufacturing	CO_2 is selected as one of the multi-criteria approach of the evaluation of office building retrofit	The Externality is 0.362 Baht/kWh of electricity consumption	0.2% CO_2 emission during transportation in the LCA	2.8% of CO_2 emission during recycling of air-conditioner (EEI, 2005)
Government intervention	Before retrofit	Investment subsidy is often used.	It is the major task of governmental policy to induce the energy conservation before it is economically acceptable	Tax exempt in transportation could be used	Tax on waste generators or disposers can raise revenue for cleanup
Yield from CDM (CO_2 reduction)	Before retrofit	8 USD/ton CO_2 reduction	Accounted in retrofitting	No CO_2 reduction	CO_2 can be used as considered output in the economic analyses of waste disposal options

(More detail of table 4.1 is in Appendix E)

Table 4.2 Parameters of ENVIROGY for fluorescent lamp (Total ENVIROGY is -5,849 Baht/36 W fluorescent lamp/10 years)

	Retrofit (Saving)	Operate (Consumption)	Collect and Transport	Recycle and Disposal
E	105 kWh x 2.5 Baht/kWh = +263 Baht	946 kWh x 2.5 Baht/kWh = -2,365 Baht		
N			1.5 Baht/kg x 0.2 kg = -0.3 Baht	2.86 Baht x 2 times (10 years) = -5.72 Baht for recycling +2.6 Baht from scrap value
V				9 Baht/kg x 0.2 kg x 2 times = -3.6 Baht
I	70 Baht x 2 lamps (10 years) = -140 Baht	0 Baht		
R			1,644 Baht x 2 times (10 years) = -3,288 Baht	
O		0.362 Baht/kWh x 946 kWh = -342 Baht		
G		30% of 70 Baht = +21 Baht		
Y	0.32 Baht/kg CO_2 reduction x 105 kWh saving x 0.256 kg CO_2 equivalent emission/kWh = +8.6 Baht			

Table 4.3 Parameters of ENVIROGY for air-conditioner (Total ENVIROGY is -70,509 Baht/12000 Btu air-conditioner/ 10 years

	Retrofit (Saving)	Operate (Consumption)	Collect and Transport	Recycle and Disposal
E	12,417 kWh x 2.5 Baht/kWh = +31,042 Baht	28,744 kWh x 2.5 Baht/kWh =-71,860 Baht		
N			1.5 Baht/kg x 31.6 kg = -47 Baht	-1,236 Baht for recycling +750 Baht from scrap value
V				5.8 Baht/kg x 31.6 kg =-183 Baht
I	-20,000 Baht/air-conditioner	-4,000 Baht/air-conditioner		
R			-1,644 Baht	
O		0.362 Baht/kWh x 28,744 kWh = -10,348 Baht		
G		30% of 20,000 Baht = +6,000 Baht		
Y	0.32 Baht/kg CO_2 reduction x 12,417 kWh saving x 0.256 kg CO_2 equivalent emission/kWh = +1,017 Baht			

Chapter V

LCA OF RETROFITTING

5.1 Introduction

This work will present a life cycle analysis and determines the environmental impact from the energy conservation measures that produce hazardous waste. The hazardous waste considered for this study is mercury in low energy efficiency fluorescent lamp and HCFC in air-conditioner that are removed in retrofitting. A 36 - W fluorescent lamp and a 12000 Btu air-conditioner are the reference flows for this study.

"Designated building" in Thailand is a building that consumes energy at a rate higher than 20 TJ/year or the one that has installed transformers rated at more than 1,000 kW or 1,175 kVA (DEDP, 2000). Energy conservation in designated buildings is an important task because its result in terms of energy saving can directly reduce the expense to the building owners. An estimated budget of 154 million USD was spent during 1995 to 2003 to save 56.3 million USD in 1,234 designated buildings in Thailand (WEC, 2005). Retrofitting the buildings by replacing low energy efficiency air-conditioners and fluorescent lamps are two typical measures from the 366 measures recorded by the Department of Alternative Energy Development and Efficiency (DEDE, 2005). The saving from evaluation of 139 state owned buildings shows that the average saving ranges around 20-45% (Table 5.1).

Table 5.1 Average saving from 139 retrofitted state owned buildings in Thailand Year 2001

Building type	Saving from air-conditioning system (%)	Saving from lighting system (%)	Total saving (%)	Internal Rate of Return: IRR (%)	Simple Payback Period: SPB (year)
Academics	18	21	39	9.2	4.0
Office of department	10	11	21	17.3	7.0
Administration government office	19	14	33	18.0	7.9
Hospital	11	11	22	13.2	5.8
State Enterprise	13	15	28	16.4	7.2
Municipal	28	15	43	12.5	5.5

(TU Energy Conservation and Management Center, 2001)

The Bureau of Energy Regulation and Conservation (BERC), in 2002 had followed up the management of waste removed during the retrofitting activities. It was found that from 139 selected buildings, 59% of the removed air-conditioner was destroyed according to the rules of treasury division, 21% was donated to other organizations, 18% was reused, and 4% was unclassified. From the same study, only 35% of the lighting fixture was destroyed according to the rules of the treasury division, while 18%was donated to other organizations, and as high as 47% was unclassified (TU, 2001). The reused of the removed air-conditioners or fluorescent lamps will increase the energy load from the perspective of the country's overall electricity consumption. From these data, we can conclude that there was improper waste management at the end of retrofitting. The problem will become worse as the number of retrofitting activity for air-conditioners and fluorescent lamps grows larger due to increasing promotion of energy conservation in buildings. And the situation will be more severe if the hazardous waste e.g. mercury from fluorescent lamps or refrigerant from air-conditioners leaks and contaminates the environment. Proper recycling and disposal of the removed air-conditioners and fluorescent lamps must be promoted and strictly implemented to avoid the negative environmental impacts.

5.2 Recycle of Air-conditioners and Recovery of Refrigerant

The split type air-conditioner is comprised of two separate parts; the fan coil unit and the condensing unit. In recycling, the first stage, for the fan coil unit, is the disassembling process. The screws are manually removed and the external casing, fan and internal components are taken apart. The coil or heat exchanger contains a high proportion of copper and aluminum. This component is placed on a conveyor belt so that it does not mix with other components and is then sent to a crushing machine. For the condensing unit, the first stage is also manual dismantled. The heat exchanger and the compressor are separated. The refrigerant and oil used in the refrigeration cycle is recovered. The recovered refrigerant is sealed and sent to a treatment facility that specializes in the appropriate reprocessing of these types of gases. In some instances, the refrigerant has already escaped from very old air-conditioners before it comes to the recycling facility. In such case, used-oil cannot be easily extracted from the appliance. The coils from both the fan coil unit and the condensing unit are crushed into pieces of mixed metals. Next, the pieces travel under a magnet to separate the steel. Afterwards, the remaining pieces pass through bi-brating screen as they are separated into aluminum and copper by the differences in the specific densities of the materials.

The compressor is crushed and recovered by using magnetic force for steel separation. Next, the remaining parts of the compressor are put into a device called an "Eddy Current Separator." Inside, the pieces of copper repel the electrical current and fly out of the machine. This is how copper is recovered. Here, the pile is again placed under a magnet to recover the small metal pieces. By making the effort to utilize such processes, the amount of material recovered is maximized. The crushing and separating room is sealed so that noise pollution from the recycling facility is minimized. The materials recovered from the compressor come out in separated piles from the line outlet. There are two types of steel material, recovered; large pieces and small pieces. Unfortunately the small pieces by themselves are not suitable for cast metal so they are packed into press molds before being sent to a foundry. Moreover, the recovered aluminum is also pressed to allow efficient transportation to a non-steel smelting plant. It is sent along with the recovered copper (Panasonic, 2005).

Professional technicians closely following the specifications and guidelines under the code should do the recovery of the refrigerant. There are two methods for recovering refrigerant from domestic appliances: In the first method called active recovery, the equipment consists of a compressor with a filter-drier and a condenser that extracts the refrigerant from domestic appliances and stores it in a recovery cylinder. After connecting the hose to the air-conditioner, the gaseous refrigerant is transferred to the recovery unit by the compressor. It is then sent to the condenser, which transforms it into a liquid. The refrigerant is sent from the recovery unit to a pressurized recovery cylinder, where it is stored. The quality of the refrigerant is improved by the filters, which remove suspended particles, moisture and oils for reuse (must be treated and kept with industry standards). In the first method, the recovery efficiency is about 88%. The equipment cost is about 10,000 USD for average capacity but the operating cost is low (cost of transportation to the site and man-hour of the technician). As for the second method named adsorption recovery, the equipment consists of a cylinder filled with a zeolite matrix capable of adsorbing the refrigerant from the domestic appliances. The gaseous refrigerant is transferred by diffusion to the recovery unit, where the refrigerant is absorbed to the zeolite. A pump is used to create a suction to remove the remaining refrigerant. Once the cylinder is saturated with the refrigerant, it must be returned to the manufacturer, where the refrigerant will be desorbed. The recovery efficiency of this method is around 93%. The equipment cost is about 300 USD for average capacity but the operating cost is high compared to the active recovery method due to the additional cost for desorption (Green Lane, 2004).

5.3 Recycle of Fluorescent Lamps and Recovery of Mercury

Mercury-containing fluorescent lamps, which cannot pass the Toxicity Characteristic Leaching Procedure (TCLP), must be handled as a hazardous waste with full requirements for final recycling, treatment, or disposal, according to the policies of New York State in the U.S. This approach helps remove these wastes from municipal landfills and incinerators, providing stronger safeguards for public health and the environment (NYSDEC, 2005).

In the recycling of fluorescent lamps, the lamp must maintain its structural integrity and the end caps must be in place. Next step, the fluorescent lamps will be transported to the recycling facility. After temporary storage, the lamps will be processed in the crusher, separator, particle and vapor filtration systems, and material handling systems. The resulting materials generated from this activity are end caps, glass, and phosphor powder. End caps are collected, sampled, analyzed for mercury content, and shipped to an off-site metals recycling facility for their aluminum content. Glass is sampled and analyzed for mercury and sent for recycling or disposal, depending on the current market. The phosphor powder is separated and collected in containers whereas the ferrous filaments of the lamps are removed by a magnetic separator. Both are shipped off-site for reprocessing.

The mercury recovered from the recycling is triple distilled (heat up to the boiling point triple times) and sold on the domestic market as technically pure mercury. An industrial blower maintains negative pressure across the entire lamp processing system, drawing air through the system to clean off residual dust and powder with a series of nine bag house cartridge filters. These filters are automatically flushed to prevent particle build-up inside, and air passes through a carbon filtration system prior to discharge. The powder is fed into the retort unit where, through the application of heat, the mercury vaporizes, and then condenses into liquid form. This commodity-grade mercury is collected for the triple distillation process. Retorted mercury is distilled three times to remove impurities. When the triple distillation process is complete, an independent metallurgical laboratory who analyzes the mercury for appearance and purity must certify that it is at least 99.99 % pure. Upon verification of purity, the technically pure mercury product is packaged and sold to companies that manufacture mercury salts, mercury-containing devices, or utilize mercury in electronics and various research and development applications (AERC, 2006).

5.4 Life Cycle Assessment

LCA is an objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment to assess the impact of those energy and material uses and releases to the environment and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use, re-use, maintenance, recycling, and final disposal (SETAC, 1999).

There are three phases of LCA process, i.e. inventory phase, impact or interpretation phase, and improvement phase. Life Cycle Inventory (LCI) is the study of the material and energy balance in the process defined within a specified boundary (Lagrega, 2001). Next is the step of Life Cycle Impact Assessment (LCIA) that deals with the ecological effects, human health effects, and others, such as habitat modification and noise. Final step is the Life Cycle Improvement phase that will find opportunities to reduce the environmental impact of releases, energy, and raw material by assessing designs, materials, processes, consumer uses, and waste managements.

Owing to the comprehensive steps of LCA, there are many software and database developers e.g. SimaPro of the Netherlands, Gabi of Germany, and others in Table 5.2 (TEI, 2004).

Table 5.2 LCA Softwares and countries of developers

Software	Country
SimaPro, EcoScan life, CEDA, CMLCA	Netherlands
GaBi, Umberto, LEGEP, GEMIS, GaBi, OGIP	Germany
TEAM, EIME, WISARD	France
LCAiT, WWWLCAW, EPS 2000	Sweden
KCL-Eco	Finland
Umberto	Germany
EcoPro, EMIS, SIMBOX, REGIS	Switzerland
Boustead	UK
NIRE-LCA (Japanese) (13% market share) JEMAI-LCA	Japan
AUDIT/APCC	Austria
EIO-LCA, TRACI	USA

To do LCA, if the area of interest is a subset of the whole life cycle, the approach named Streamlining or Simplifying LCA (SLCA) is used for a more feasible and relevant consideration without losing the key features of the LCA approach.

SLCA is more suitable than the LCA in this context because of the saving of time and cost for data collection, easy to focus and find the opportunity for change in design, less routine work in conducting and variably application. SLCA however is inferior to LCA in the aspects that there is no capability to track overall material, there is less ability to consider much different products, and there is only minimal capability to track improvement over time (Graedel, 1998).

Life cycle thinking provides the basis for optimizing the requirements of both the producer and the end-user. Both the environmental and user-friendly features are taken into account in the product or process design from its very inception. This enables the control of environmental aspects occurring at the beginning step. Such early intervention could minimize the degree of environmental impact (Junnila, 2004). For assessing a product, process or service regarding its environmental impact during its entire life cycle from “cradle to grave” in the environmental and economic dimension, limitations and methodological problems of life cycle analysis must be kept in mind. LCA does not conventionally incorporate socio-economic impacts. Moreover, it is time consuming for data collection and the data have to be rigorously manipulated. It is also difficult to interpret and it is not always transparent (TEI, 2004). LCA is applied in various sectors e.g. comparison of energy policy, design for environment, recycling design, and information disclosure. LCA can identify environmentally preferred products in government procurement or eco-labeling programs (for benchmarking). LCA can also determine the ecological footprint on the environment (Lee and Koh, 2002).

In 1960s and 70s, energy analyses were broadened to develop the Resource and Environmental Profile Analysis (REPA) - a quantitative methodology that formed the beginnings of life cycle assessment (Pomthong and Thumrongrut, 2006). The history of LCA formally began in the 1970s from the investigations of SETAC on the energy requirements in the U.S. Emission and raw materials were added later. SETAC in North America and the U.S. EPA developed methodology for Inventory Analysis and Impact Assessment. Similar efforts were undertaken by SETAC-Europe. After that ISO 14040-14043 became the LCA standard and there is the Society for the Promotion of Life Cycle Development (SPOLD in Europe). In Asia, there are also developers and practitioners. AIST (National Institute of Advanced Industrial Science and Technology, Japan), MGB (Mines and Geosciences Bureau, the Philippines), and IMSAT (Institute of Mining Sciences and Technology, Vietnam) have tried to form a network in Asian countries since 1998. APEC (Asia-Pacific Economic Cooperation) at IST W/G (Industrial Science and Technology Working Group) with Australian counterparts has developed the LCA network in the APEC region. JEMAI (Japan Environmental Management Association for Industry is entrusted to develop LCI and LCIA methods from the NEDO (New Energy and Industrial Development Organization). In Thailand, TISI, TEI, and DIW have disseminated LCA as a part of ISO 14000 via TBCSD (Thailand Business Council for Sustainable Development) since 1997. In1997, the Thai LCA Forum/Network was set up and in the year 2000, the first LCA study (LCA for Thailand Electricity Grid Mixes by TEI) was conducted. Subsequently, organizations such as Thai Research Fund (TRF), National Science Technology Development Agency (NSTDA), National Metal and Materials Technology Center Thailand (MTEC), and universities have become more practitioners. In the year 2005, there were many projects about LCA e.g. study tour named Green Camp Program for 15 persons in Japan, project of LCI database for Thailand, and the preparation of the Thai LCA Software and Manual.

In order to enable sustainable product development and to guide industry in adopting eco-efficiency and lifecycle thinking into commerce, there is a need for readily understandable system assessment tools. One method that has been specially designed to meet the needs of product developers is the EPS-system (Environmental Priority Strategies in product design), which is based on the life cycle assessment methodology. In its first version the EPS system was developed during 1990 and it has been further improved. ISO has recently forwarded an international standard on the LCA procedure. The EPS systems perspective follows this ISO standard. The EPS system has been used in a number of industrial evaluations of, for example cables, refrigerators, printed electric circuits, gasoline, packaging materials and auto parts. In this version of EPS the environmental load unit, ELU, is designed as a measure for societal environmental priorities, by means of willingness to pay (WTP) assessments. The basic method evaluates emissions by means of WTP for changes caused by the emissions to the environment. Raw material resources are evaluated by WTP for alternative renewable methods (concerning emissions to environment) to produce comparable utility (Steen, 1995).

In Hong Kong, LCA of building construction had been done and included the calculation for the retrofitting stage, energy, wastes, and costs due to replacement of worn out materials and components in the building within the operating stage. Only materials used to replace worn out elements, plus the associated wastes and auxiliary materials are accounted for in the calculation. The result showed impacts including those incurred due to landfilling of the replaced materials and the wastes. Such impacts are not related figuratively directly to the decision making of the retrofitting phase (SAR, 2005).

In our study, Gabi-lite, software developed by IKP Stuttgart University and PE-Europe GmbH, Germany, was used. Because of the role of life cycle assessment in product development becomes more and more substantial and the increasing sensitivity for environmental questions and economic efficiency which is setting high demands. Behind GaBi-lite is the expertise of 15 years of software development. It is user-friendly and powerful despite the reduced extent of its functions in this version. A high degree of clarity can be achieved from the step of working. Whether a life cycle assessment is generated on a process or a production cycle level, the extensive database content gives the results a well-founded basis. Numerous evaluation methods and indicators can ensure the reliability of calculation (PE, 2006).

5.5 Objective and Scope of Life Cycle Analysis

This study is based on Thai conditions but the issue is not restricted to Thailand since retrofitting by replacing low energy efficiency equipment with high-energy efficiency equipment can be found in many countries. Moreover the problem of hazardous waste from the low energy efficiency equipment that is removed is going to be more serious if the management of hazardous waste from energy conservation measures is not done properly.

The objective of this study is to evaluate the environmental impact from the energy conservation measures that generate hazardous waste. The hazardous waste considered for this study is mercury in low energy efficiency fluorescent lamps that is removed and HCFC in the removed air-conditioners in retrofitting of the building.

The functional unit for the study is a retrofit process defined by replacing 40 W with 36 W fluorescent lamps and replacing a 1.79 kW/ton air-conditioner with a 1.25 kW/ton unit through their disposal phases. The duration of the study is 2002 - 2011 (the period of the master plan of energy conservation in Thailand). The reference flow of LCA is a 36 W fluorescent lamp and a 12000 Btu air-conditioner. The hazardous wastes considered are mercury in fluorescent lamps and HCFC in air-conditioners. The location of the study is preliminarily in the context of Thailand. (See Fig. 5.1 for boundary of LCA in dotted line).

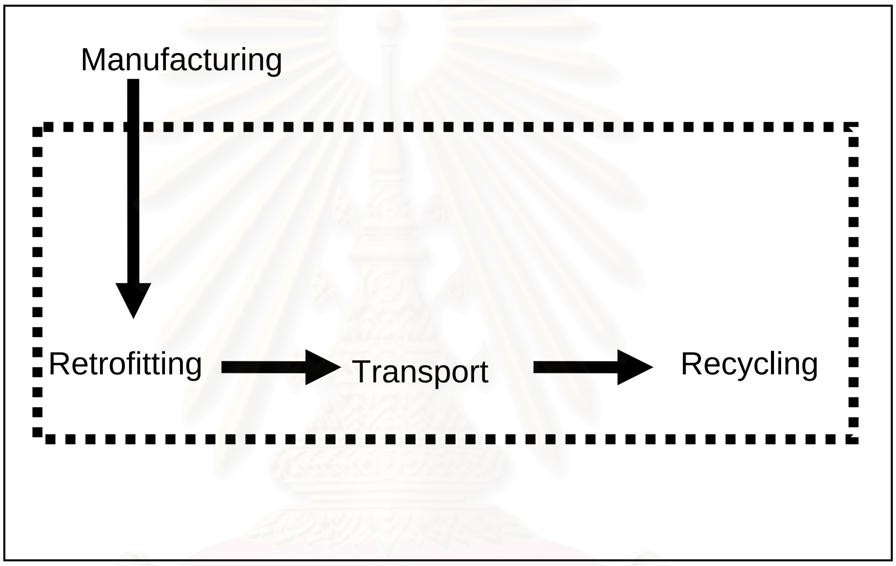


Fig 5.1 Scope of LCA for energy conservation by retrofitting
(Dotted line is the boundary of this study)

5.6 Life Cycle Inventory (Model and Input)

Removing the existing equipment, which has low energy efficiency, will fulfill the retrofitting for either fluorescent lamps or air-conditioners. After that, the new equipment, which has high-energy efficiency, will be installed to replace the removed units. During the retrofitting, it is assumed that there is no leakage of mercury from the fluorescent lamps or no breaking of the tubes during this process. Similarly, for air-conditioners, it is assumed that there is no leakage of the refrigerant from the compressor. The technician who removes the existing air-conditioner has to squeeze and fold or cap the copper tubes running from the compressor in order to avoid any leakage.

The transportation model in this study is the carrying of removed low energy efficiency equipment on the 3.5-ton truck. The starting point is the retrofitted building and the destination is the recycling plant. The assumed distance travel is 200 km, which is used for estimation of the transportation cost for fluorescent lamps and air-conditioners at 4,500 Baht per 3 tons (GENCO, 2007).

The model for recycling and its input are derived from the recommendation by the Pollution Control Department (PCD, 2004 and PCD 2007). The recycle of one fluorescent lamp will start from collecting, proceeding to crushing and screening (granulator and separator), and recycling of aluminum and glass but mercury will be distilled to purify. For air-conditioners, HCFC will be vacuumed and taken for Teflon manufacturing whereas the rest will be disassembled for recycling i.e. cast steel, standard steel, copper, aluminum, plastics, and other parts as shown in Fig. 5.2 and 5.3, respectively. The last in this particular study is to bring all the models into the LCA software tool, Gabi.

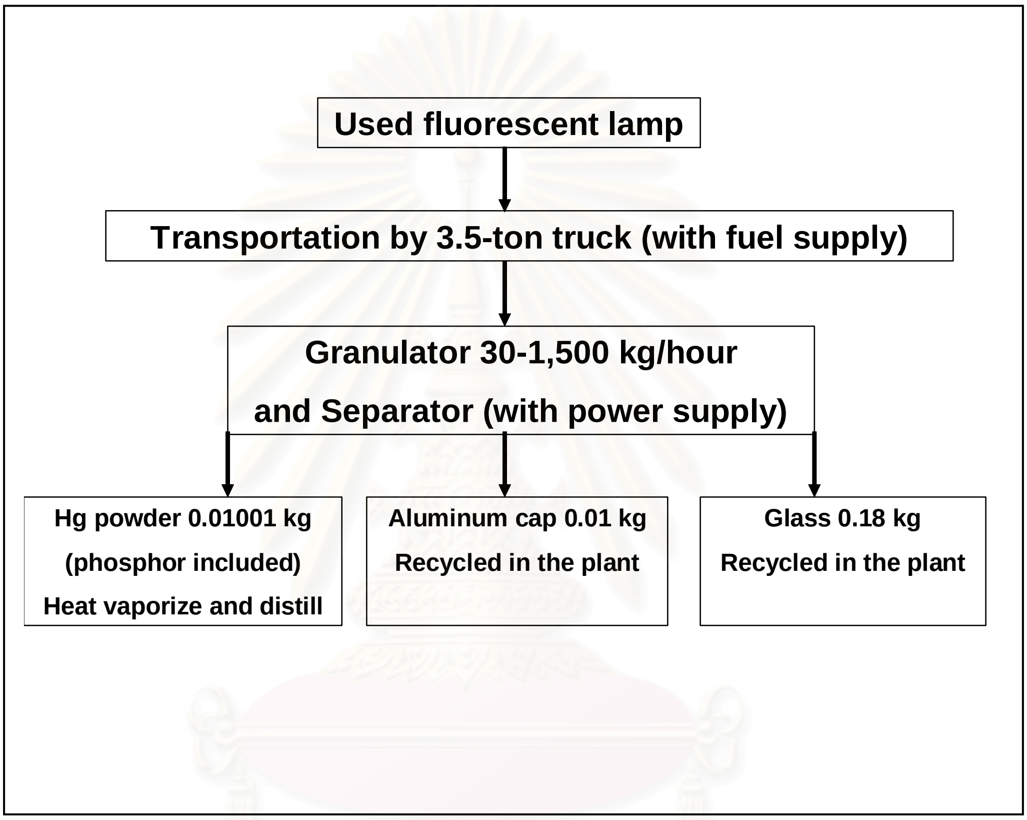


Fig. 5.2 LCI of fluorescent lamp

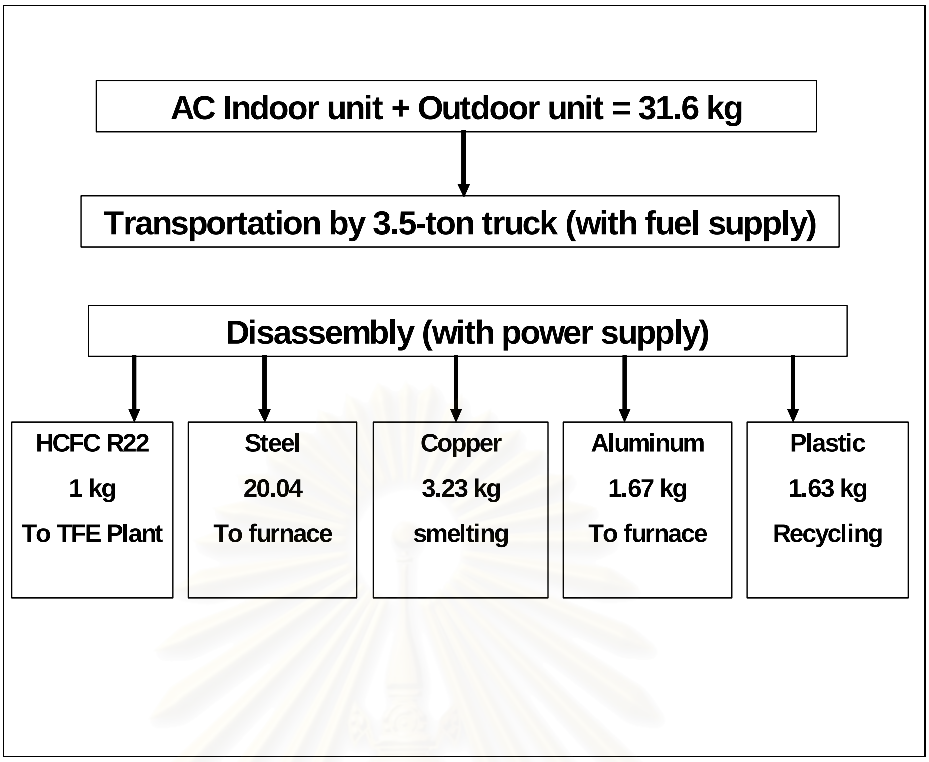


Fig. 5.3 LCI of air conditioner

5.7 Impact Assessment Method and Scenario

The general procedure for conducting a life-cycle impact assessment begins with selecting and defining impact categories. From reviewing the available acceptable impact categories e.g. CML (Centrum voor Milieukunde, Leiden University), EI (Eco-indicator), and EDIP (Environmental Design of Industrial Product), EDIP 1997 version Waste Evaluation is the category selected for this study because of its wide acceptance especially the consideration of hazardous waste. The impact categories and indicators are bulk waste, hazardous waste, nuclear waste, and slag – ashes (Table 5.3)

Bulk waste is construction waste and similar waste, which is deposited at, controlled waste deposits. This waste is characterized by the fact that it does not contain environmentally hazardous substances. Hazardous waste is waste, which must be brought to special processing plants or to a special deposit for hazardous waste. This waste is characterized by the fact that it contains environmentally hazardous substances, which may be released during the stay at the deposit. Radioactive waste is waste of low radiation intensity from nuclear power plant. One of the major problems associated with radioactive waste is the fact that much of it will be radioactive for hundreds of thousands, if not millions, of years, and thus will require isolation from the human environment. Slag and ashes are the by-products of incineration processes. Slag and ashes are usually disposed of at special waste disposal sites (Vestas, 2006).

5.8 Results

There are many studies indicating the significance of the waste in the impact category of CML. The result will be classified into the categories using the following items and impact indicators.

Abiotic depletion	kg Sb equivalent
Global warming	kg CO_2 equivalent
Ozone layer depletion	kg CFC11 equivalent
Human toxicity	kg 1,4 Dichlorobenzene equivalent
Fresh water aquatic ecotoxicity	kg 1,4 Dichlorobenzene equivalent
Marine aquatic ecotoxicity	kg 1,4 Dichlorobenzene equivalent
Terrestrial ecotoxicity	kg 1,4 Dichlorobenzene equivalent
Photochemical oxidation	kg C_2H_2 equivalent
Acidification	kg SO_2 equivalent
Eutrophication	kg PO_4 equivalent

Using the impact indicators above, the results cannot be related readily to the hazardous waste, therefore EDIP 1997 with the category of hazardous waste modeled inside is thus relevant to the study of the importance of contributions from hazardous waste. For a 36 W fluorescent lamp, the bulk waste 1.64E-5 kg, hazardous waste 1.11E-4 kg, radioactive waste 1.09E-9 kg, and slag-ashes 6.02E-7 kg were generated at the end of life of the retrofitting cycle (See Fig. 5.4). For a 12000 Btu air-conditioner, the bulk waste 0.58 kg, hazardous waste 0.11 kg, radioactive waste 0.0002 kg, and slag-ashes 0.01 kg also come out at the end of life of the retrofitting cycle (Fig. 5.5).

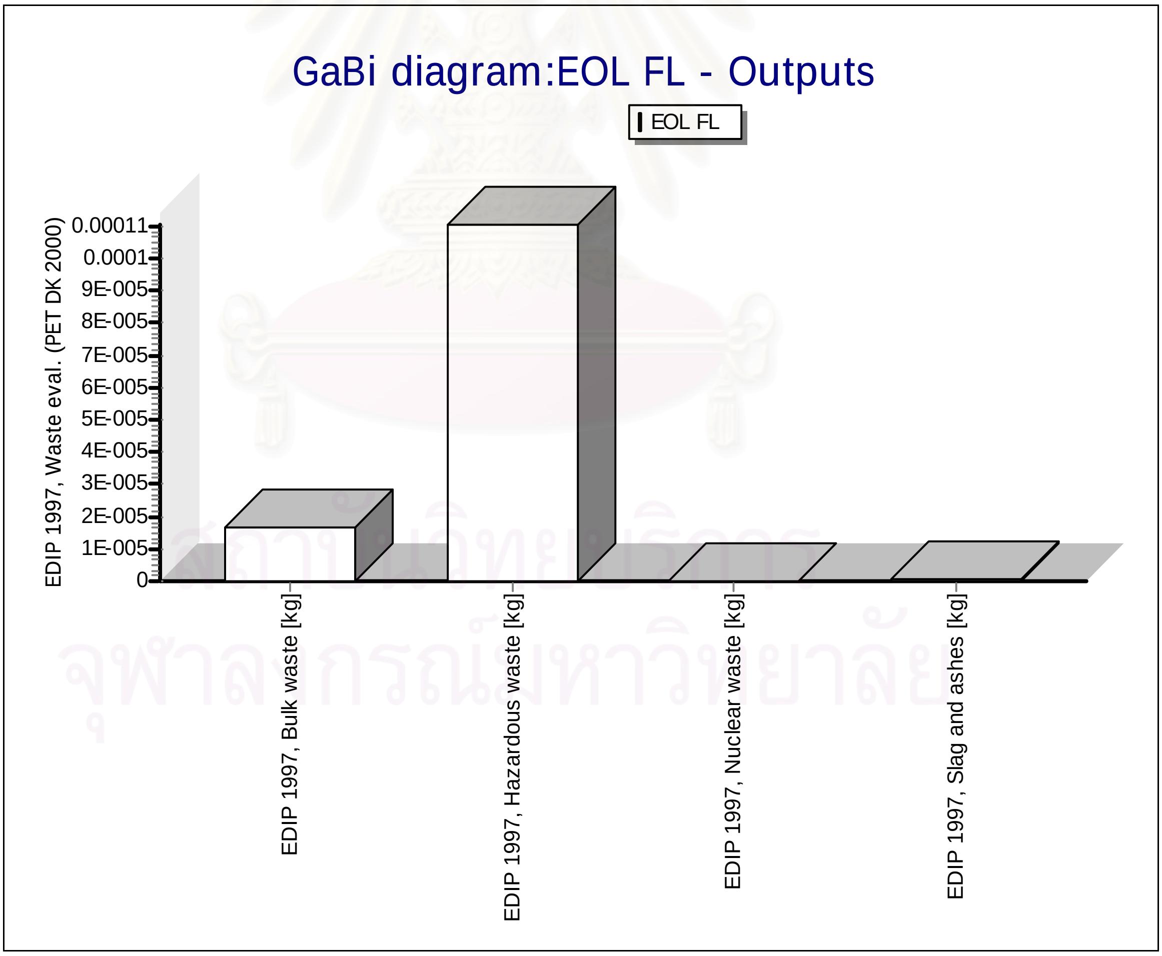


Fig.5.4 Amount of hazardous waste - 36 W fluorescent lamp at the end of life cycle (EOL) of a retrofitting

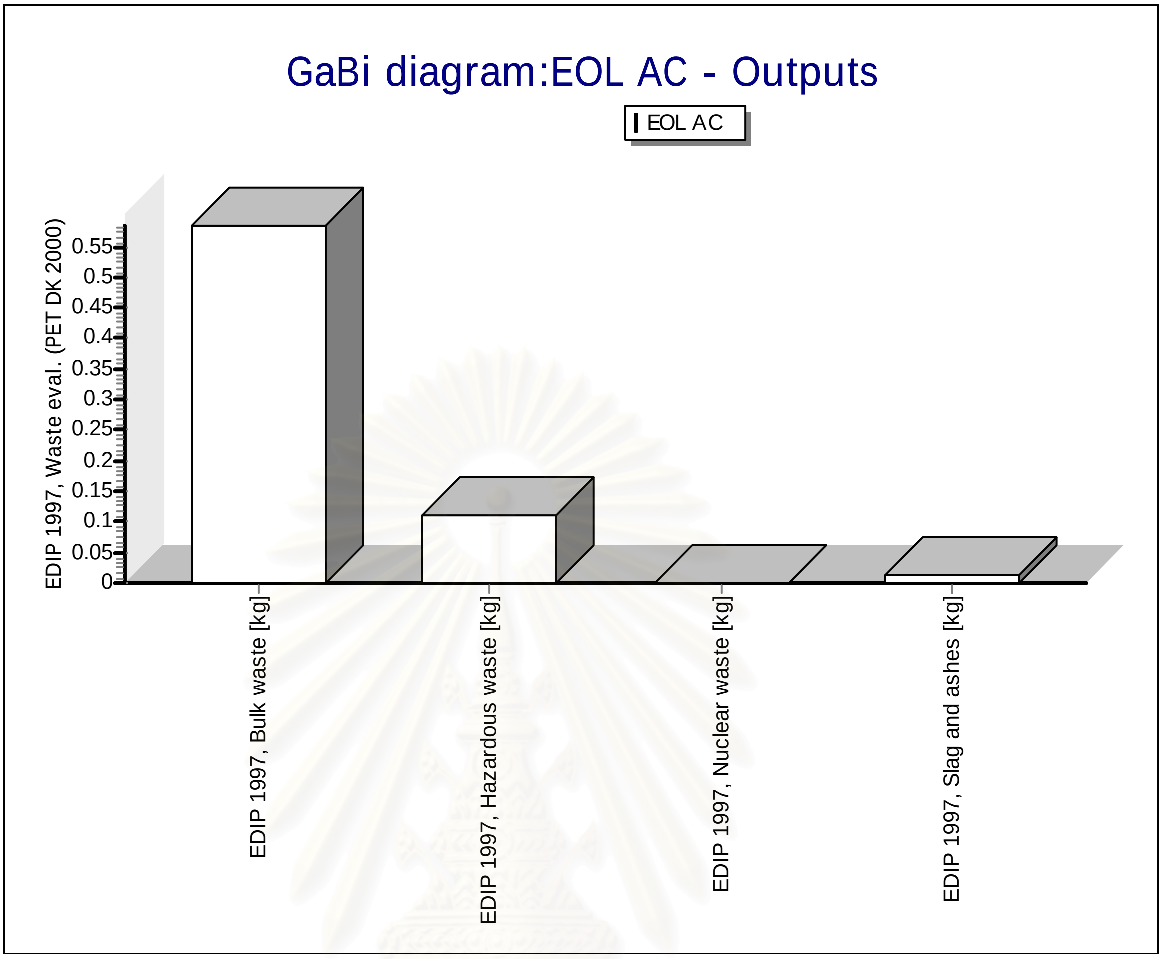


Fig. 5.5 Amount of hazardous waste of - 12000 Btu air-conditioner at the end of life cycle (EOL) of a retrofitting

5.9 Discussion and Conclusion

One of the systematic approaches for identifying and evaluating environmental impact for a product or process is Life Cycle Analysis - LCA. There are many LCA studies for energy consuming equipments. All studies gave the same result that is that the operation or period of use creates the highest impact from consumed energy. For example, the National Research Center for Environental and Hazardous Management Research had grant for the research on the life cycle analysis for fluorescent lamps in Khon Kaen municipality. The result show that the life cycle assessment of an 18-Watt fluorescent lamp by using the category of Environmental Design of Industrial Products (EDIP), indicated that the largest environmental impact was the usage stage, which causes global warming accounting for 2.6E+01 kg-CO_2 or 74.34% of the life cycle impact, ozone depletion 1.6E-04 kg-CFC11 or 81.23% of the life cycle impact and acidification 4.4E-01 kg-SO_2 or 68.60% of the life cycle impact, in these particular categories. The major global warming impact during the usage stage occurred from the consumption of electricity because part of the power is generated from natural gas and lignite (Tantempsapya and Yossapol, 2005).

Another example is the LCA of a 12000 Btu air-conditioner. The environmental impact assessment by the Electrical and Electronics Institute (EEI Thailand) using the single score impact category named Eco-indicator 95 (Green house gas emission, ozone depletion, acidification, eutrophication, heavy metal, carcinogen, photochemical oxidant formation, energy resources consumption, and solid waste), also indicated that the largest environmental impact occurred during the operation followed by assembly and disposal, respectively. The score during operation is 157 points, which is mainly from heavy metals associated with the fuel mix used in energy consumption during the lifetime of 10 years. The score is 1.46 points during manufacturing and -0.11 point during recycling of the materials (EEI, 2005). The result from EEI corresponds to Environmental Report 2001 of Daikin Industries Ltd that the major impact comes from the operation phase.

This study will not repeat the scope of LCA as presented in the two studies mentioned in the previous paragraph because the energy consuming equipment described in those studies are manufactured for new installations. The life cycle of new installation equipment starts from manufacturing to recycling and disposal whereas the life cycle of retrofitting equipment starts from acquiring or purchasing of the new equipment. In addition, there will not be the scenario of with and without recovering of the hazardous materials for new installations. The amount of hazardous waste for the case of without recovering hazardous materials can be estimated by directly adding the amount of mercury from fluorescent lamp or refrigerant from the air-conditioner into the amount of hazardous waste from retrofitting.

This study aims at finding out the hazardous waste amount (called impact in the category of EDIP 1997 Waste Evaluation) from the retrofitting of the energy consuming equipment (36 W fluorescent lamp and 12000 Btu air-conditioner are used for this study). The hazardous waste from the retrofitting of a 36 W fluorescent lamp is 1.11E-4 kg which is not small compared to the amount of bulk waste because of the low total weight of the lamp. On the other hand, the amount of hazardous waste from a 12000 Btu air-conditioner is 0.11 kg which is very small compared to the amount of bulk waste because of the heavy total weight of the air-conditioner. Nuclear waste (from power mix – mixed of energy resources to get a unit of electricity) and slag-ashes are neglected compared to the bulk waste and the hazardous waste.

The amount of hazardous waste from fluorescent lamps and air-conditioners does not relate directly to the total weight of the equipment. This small amount from this retrofitting will be much more important when magnified by the number of units in a countrywide retrofitting scheme compared to the current country level of hazardous waste generation. Because of their intrinsic hazard even at the small amount, the policy makers who deal with hazardous waste should be aware of this characteristic before issuing any relevant policy. From this perspective, policy makers in the field of energy conservation should realize that the waste from the retrofitting process may contain components of hazardous waste. Consideration of this characteristic and subsequent planning for the appropriate waste management method at first can reduce any future problem of contamination by the hazardous waste. Design of the product may be changed if there is some effect from selection of the energy consuming equipment. The priorities of energy conservation measures could be changed if the policy maker had added this aspect of hazardous waste into the decision making step. If the small amount had contaminated a broad sector of the environment, the cost of treatment will normally be more expensive than paying attention to the recycling and disposal in the first place.

Chapter VI

CONCEPTUAL DECISION SUPPORTING MODEL: ENVIROGY

6.1 Introduction

The Environmental Fund in Thailand was established under the Enhancement and Conservation of National Environmental Quality Act 1992. The objective is to promote solutions for environmental problems with participation of all sectors, through provision of the air pollution controls, wastewater treatment systems, and a waste disposal system (Wattana, 2003). Waste disposal, especially the Waste Electrical and Electronic Equipment (WEEE or E-waste) is one important problem in Thailand. In 2003, E-waste was estimated at 58,000 tons and the recyclable content was 80% of this amount. Recycling of E-waste, particularly fluorescent lamps and air-conditioners, has to be concerned about Mercury and Hydro-Chlorofluorocarbons (HCFC) contained in these E-wastes. The Cleaner Technology and Eco-product Development group assigned by the Pollution Control Department, Ministry of Natural Resource and Environment has issued at manual for the proper recycling of fluorescent lamps and air-conditioners. The Department of Alternative Energy Development and Efficiency under the Ministry of Energy has also expressed concern about recyclable waste and the use of low impact - refrigerant in air-conditioners by adding it into the criteria for buildings a requirement for benchmarking in the aspect of energy and environment (DEDE, 2007).

To promote retrofitting, the ECP Fund (Thailand) has subsidized the proposed measures by considering the Simple Payback Period (SPB) and the Economical Internal Rate of Return (EIRR) for retrofitting energy consuming equipment in existing buildings. The Bureau of Energy Regulation and Conservation (BERC), the Department of Alternative Energy Development and Efficiency in collaboration with Thailand Development and Research Institute (TDRI) have developed the spreadsheet software named CAFÉ: Calculation of Financial Internal Rate of Return (FIRR) and Economical Internal Rate of Return (EIRR). The definition used for EIRR in CAFÉ is the rate of return excluding tax, excise (tax on alcohol or cigarette), and import tax and vice versa for FIRR with the accounting of administrative cost and cost escalation. This software is used for evaluating the measures in the Target and Plan of each designated building in Thailand in order to get a subsidy from the government for the implementation of the retrofitting of energy consuming equipment in existing buildings. If EIRR is higher than 9% and FIRR is higher than an average three months of Minimum Retail Rate of Krung Thai Bank plus 2%, the subsidy will be approved at 15-60% depending on the total budget of each project. In sum, the existing conceptual-decision support models used nowadays are the Simple Payback Period and the Internal Rate of Return (TDRI, 2000).

6.2 Selection of Energy Consuming Equipment

The preliminary energy consuming equipment discussed in the energy conservation measures in the Specification of Energy Efficient Product 2000 by the Department of Energy Development and Promotion or DEDP (DEDP, 2000) are fluorescent lighting fixtures, lighting reflectors, compact fluorescent lamps, tubular fluorescent lamps, electronic ballasts, low loss ballasts, small air conditioners, electronic thermostats, heating or cooling surface insulation, heating reflective insulation, and voltage regulators. These kinds of energy consuming equipments were used in the implementation of the energy conservation measures in existing buildings. From the review of the Department of Alternative Energy Development and Efficiency's database, there are 366 types of the energy efficient measures. The process of retrofitting energy consuming equipments in existing buildings is related to hazardous materials including mercury, lead, cadmium, sodium, and radioactive materials in fluorescent lamps, HCFC's in air-conditioners, H_2N_2O (nitrosamine) in closed cell insulations for piping, Zn in luminary reflectors, and PCBs (polychlorinated biphenyls) or DEHP (di-Ethyl hexyls phthalate) classified by the U.S. EPA as a probable human carcinogen in ballasts or HIDs (Hi-Intensity Discharge Lamps).

6.3 Investigation of Hazardous Material

Energy conservation measures can be classified into 4 groups, i.e. energy management, energy efficiency, retrofitting, and installation (ECP, 2000). Among these 4 groups, retrofitting (removal of the existing installation and replacing with a new one) has the highest potential to produce hazardous waste to the environment.

Two typical energy conservation measures used in existing buildings are to replace air conditioners and fluorescent lamps with higher efficiency energy consuming equipment, which contain certain amounts of HCFC and Hg both in the existing one and the new one. After the implementation of the retrofitting measures, HCFC and Hg in the removed air conditioner and fluorescent tubes require strict and good management practice to avoid the emission of HCFC and contamination by Hg in the environment. These two measures have been selected for this study because Hg and HCFC are technologically and commercially used without other substitute substances.

6.4 Proposed New Conceptual Decision Support Model

Energy policy, one of today's most important issues, is difficult to separate from environmental policy. Decision making in formulating policy therefore has to be concerned with both aspects (Christiansen, 1990). The integration of energy and environment is not a new concept. Since 1983, energy conservation efforts have been recommended to include the allocation of responsibility for waste (Mclelland and Cook, 1993: Vera and Langlois, 2007). The integration of energy and environment will be more complex if the external cost must be internalized into the investment cost. Substantial costs, hazardous wastes, and risk have been considered in the application of many technologies (Bezdek, 1993) and externalities are internalized in fulfillment of policy (Curlee, 1993: Lutz and Munasinghe, 1994) but most of the integration uses descriptive variables (Doukas et al., 2007) or scoring method in making final decisions. The disparate parameters were homogeneously combined based upon the judgment of experts or the researcher. There are some uncertainties and potential biases in judgment of people whereas some more specific method such as Life Cycle Analysis (LCA) is an excellent approach but needs comprehensive information from databases. A more practical supporting model proposed, called ENVIROGY is designed to provide a combination of energy and environment implications and also internalization of external cost to investment cost.

Energy conservation and environmental management can be integrated in various approaches. External costs from environmental impact can be internalized into the investment of retrofitting energy consuming equipment throughout its life cycle in existing buildings. The scope of integration must be wide, practical, and homogeneous incorporating energy consumption or saving, net waste recycling cost, violence impact from hazardous waste or disposal cost, investment cost for retrofitting, risk in terms of money, operating impact in terms of money, government intervention for promotion or fee, and yield from the Clean Development Mechanism. The combination termed ENVIROGY can predict the net cost and benefit for the particular choice of application covering the whole lifetime of a fluorescent lamp and air-conditioner in retrofitting.

After the amount of hazardous waste had been calculated, it is necessary to transform that quantity into units of Bahts in order to plug into the EVIROGY procedure. The draft of the Thailand country report prepared by Greenpeace Southeast Asia (Thailand) in 2001 shows that the master plan for the elimination of hazardous waste is to establish industrial waste management centers in several provinces. The Ministry of Industry emphasized incineration of hazardous waste as its approach. The construction of a proposed industrial waste incinerator is supposed to be in Bang Pu Industrial Estate costing 220 Million Baht and is designed to support incineration of approximately 10,000-50,000 tons of waste per year. In this study, the disposal cost for fluorescent lamps is 9.0 Baht/kg and for air-conditioners are 5.8 Baht/kg which is the disposal cost from the hazardous waste-disposing company (Genco, 2007).

6.5 Result of ENVIROGY Calculation

ENVIROGY can be calculated by plugging in each component as mentioned previously. The calculated ENVIROGY value covers the whole lifetime of a retrofitting of a 36 W fluorescent lamp, an investor has to pay for both internal and external cost -1,483 Baht/10 years. The real life time of a fluorescent lamp is about 5 years but the cash flow duration was doubled to 10 years with one time reinvestment. This was done in order to adjust the period of study for fluorescent lamp to an air-conditioner’s comparison. The value of ENVIROGY is -1,272 Baht/10 years for the base case, which accounts only energy consumption and the investment for retrofitting.

Likewise, a 12,000 Btu air-conditioner, the ENVIROGY value is -56,572 Baht/10 years whereas the value of ENVIROGY is -46,962 Baht/10 years for the base case which accounts for energy consumption and the investment for retrofitting. In this calculation, it had already taken into account the discount rate of money: inflation 3.5% and long term investment in the bank or government bond 3%, so the discounted rate is 0.2% (see equation 6.1 for discount rate)

Discount rate = (1-i)/(1-r) – 1 ……………………………….…….(6.1)

i is long term interest rate
r is inflation rate

The list of each component (Table 6.1) shows that energy consumption is the major part of the ENVIROGY value. If energy consumption and investment on equipment and labor cost are ignored, the operating impact occurring from energy consumption will become the dominant part. If the operating impact is ignored, the monetized risk will become the dominant part.

Table 6.1 ENVIROGY Calculation (Fluorescent Lamp and Air-Conditioner)

	ENVIROGY Fluorescent Lamp	Baht/ 10yrs	Total (Baht)	Total 1 (%)	Total 2 (%)	Total 3 (%)
E	Energy saving from recycling	1.1				
	Energy saving from retrofitting	147				
	Energy consumption	-1322	-1175	**79**		
N	Revenue from material saving	1				
	Revenue from glass scrap	0.13				
	Revenue from Aluminum scrap	0.49				
	Revenue from other scrap	0				
	Recycling cost	-1.4				
	Collecting cost	-0.4	0	0	0	1
V	Disposal Cost of Hazardous Waste	-0.13	-0.13	0	0	0
I	Equipment	-98				
	Labor cost	0	-98	7		
R	Risk Assessment	-23	-23	2	11	**82**
O	Retrofitting-recycling impact	-0.001				
	Operating impact (CO2 eq.)	-191	-191	13	**87**	
G	Government (Subsidy)	0	0	0	0	
Y	Yield from CO2 reduction	5	5	0	2	17
	Envirogy (all)	**-1,483**		100	100	100
	ENVIROGY Air-conditioner	Baht/ 10yrs	Total (Baht)	Total 1 (%)	Total 2 (%)	Total 3 (%)
E	Energy saving from recycling	543				
	Energy saving from retrofitting	35257				
	Energy consumption	-58762	-22962	**39**		
N	Refrigerant recovery cost	-176				
	Revenue from material saving	362				
	Revenue from compressor scrap	500				
	Revenue from other scrap	160				
	Recycling cost	-1,236				
	Collecting cost	-47	-437	1	4	13
V	Disposal Cost of Hazardous Waste	-10	-10	0	0	0
I	Equipment	-20,000				
	Labor cost	-4,000	-24000	41		
R	Risk Assessment	-1,809	-1809	3	15	**53**
O	Retrofitting-recycling impact	-0.14				
	Operating impact (CO2 eq.)	-8,509	-8509	14	**71**	
G	Government (Subsidy)	0	0	0	0	
Y	Yield from CO2 reduction	1,155	1155	2	10	34
	Envirogy (all)	**-56,572**		100	100	100
	Cost of Recycling	**Baht**	**Discount**	**rate**		
	Recycling cost: Baht/FL	1	Inflation	(f)		3.5
	Recycling cost: Baht/AC	1,236	Interest	(r)		3.0
			discount	(d)		-0.2

6.6 Sensitivity Analysis and Monte Carlo Analysis

From changing -10%, -5%, 5%, and 10% of the input for ENVIROGY, the variation of ENVIROGY take place with high sensitivity for the parameters related to energy consumption and energy saving, i.e. capacity of equipment, operating factors, electricity cost, and external cost (See Table 6.2).

To know the uncertainty of ENVIROGY by Monte Carlo Analysis, all parameters were varied within a reasonable range in calculating the ENVIROGY value. It was found that the expected ENVIROGY value for a retrofitting of a 36 W fluorescent lamp is -1,498 Baht/10 years with the standard deviation of 90 Baht/10 years. The expected ENVIROGY value for a retrofitting of a 12,000 Btu air-conditioner is -54,007 Baht/10 years with standard deviation 2,233 Baht/10 years. The result gives the idea that what should be the mean value of ENVIROGY in the randomized parameter.

Table 6.2 Sensitivity analysis of ENVIROGY

	Parameter	Unit	Variation of Input for Sensivity Analysis					%Change of ENVIROGY			
			-10%	-5%	0%	5%	10%	-10%	-5%	5%	10%
Fluorescent lamp	Investment FL & maintenance	Baht/FL	63	67	70	74	77	-1	-0.3	0	1
	Aluminum in FL	kg/FL	0.0090	0.0095	0.0100	0.0105	0.0110	0	0	0	0
	Glass in FL	kg/FL	0.16	0.17	0.18	0.19	0.20	0	0	0	0
	Hg 10e-5 + phosphor 10 e-2 kg	kg/FL	0.009	0.010	0.010	0.011	0.011	0	0	0	0
	Labor cost	Baht/kg	0	0	0	0	0	0	0	0	0
	New Capacity (high efficiency)	Watt/FL	32	34	36	38	40	-19	-10	10	19
	Compared capacity (low efficiency)	Watt/FL	36	38	40	42	44	10	5	-5	-10
	Operating factor	%	36	38	40	42	44	-9	-5	5	9
	Hg recovery cost	Baht/FL	0	0	0	0	0	0	0	0	0
	revenue from glass	Baht/kg	0.45	0.48	0.50	0.53	0.55	0	0	0	0
	revenue from aluminum	Baht/kg	32	33	35	37	39	0	0	0	0
	revenue from other scrap	Baht/kg	0	0	0	0	0	0	0	0	0
	Collecting 200 km 3 ton truck	Baht/kg	1.4	1.4	1.5	1.6	1.7	0	0	0	0
Air-conditioner	Investment AC & maintenance	Baht/AC	18,000	19,000	20,000	21,000	22,000	-4	-2	2	4
	Aluminum in AC	kg/AC	1.5	1.6	1.7	1.8	1.9	0	0	0	0
	Copper in AC	kg/AC	2.9	3.1	3.2	3.4	3.6	0	0	0	0
	HCFCR22 in AC	kg/AC	0.9	1.0	1.0	1.1	1.1	0	0	0	0
	Plastic in AC	kg/AC	1.5	1.5	1.6	1.7	1.8	0	0	0	0
	Steel in AC	kg/AC	22	23	24	25	26	0	0	0	0
	Labor cost:remove & install	Baht/AC	3,600	3,800	4,000	4,200	4,400	-1	0	0	1
	New Capacity (high efficiency)	kW/ton	1.13	1.19	1.25	1.31	1.38	-23	-11	11	22
	Compated capacity (low efficiency)	kW/ton	1.80	1.90	2.00	2.10	2.20	17	8	-8	-17
	Operating day	%	72	76	80	84	88	-5	-3	3	5
	On-off factor	%	72	76	80	84	88	-5	-3	3	5
	Operating factor-compressor	%	72	76	80	84	88	-5	-3	3	5
	Refrigerant recovery cost	Baht/AC	158	167	176	185	194	0	0	0	0
	revenue from refrigerant	Baht/kg	0	0	0	0	0	0	0	0	0
	revenue from compressor	Baht/kg	450	475	500	525	550	0	0	0	0
	revenue from scrap	Baht/set	144	152	160	168	176	0	0	0	0
	Collecting 200 km 3 ton truck	Baht/kg	1.35	1.43	1.50	1.58	1.65	0	0	0	0
External Cost	Externality cost CO2 equivalent	Baht/kWh	0.33	0.34	0.36	0.38	0.40	-2	-1	1	2
	CO2 equivalent emission	kg/kWh	0.23	0.24	0.26	0.27	0.28	0	0	0	0
	Price of a ton CO2 reduction	Baht/kg	0.29	0.30	0.32	0.34	0.35	0	0	0	0
	Disposal Cost for FL	Baht/kg	8.1	8.6	9.0	9.5	9.9	0	0	0	0
	Disposal Cost for AC	Baht/kg	5.2	5.5	5.8	6.1	6.4	0	0	0	0
	Average price of electricity	Baht/kWh	2.250	2.375	2.500	2.625	2.750	-4	-2	2	4
	Monetized risk - 10 yrs (R)	Baht/kg	1,480	1,562	1,644	1,726	1,808	0	0	0	0

6.7 Scenario Analysis of ENVIROGY Calculation

As the calculation of ENVIROGYvalues can be ignored or taken only for some part, this approach can lead to the scenario analysis (See Fig. 6.1 and 6.2) for both a 36 W fluorescent lamp and a 12,000 Btu air-conditioner.

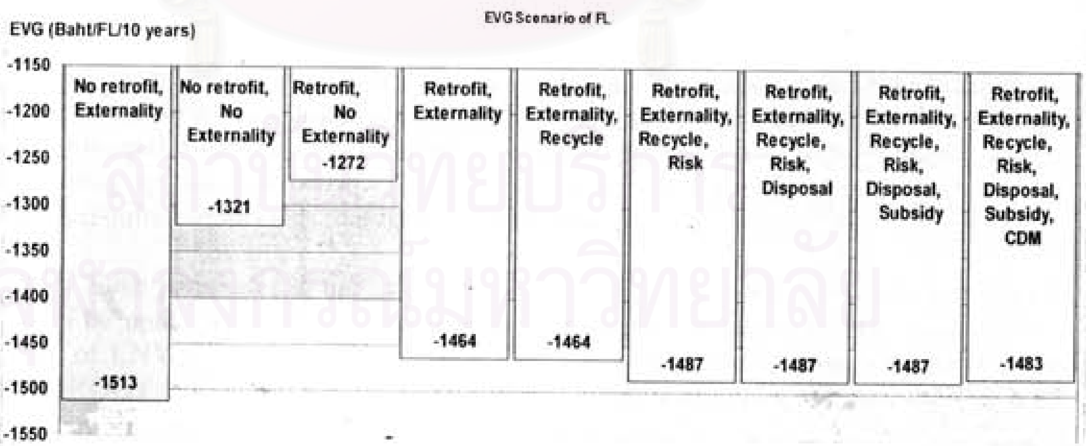


Fig. 6.1 Scenario analysis of a 36 W fluorescent lamp

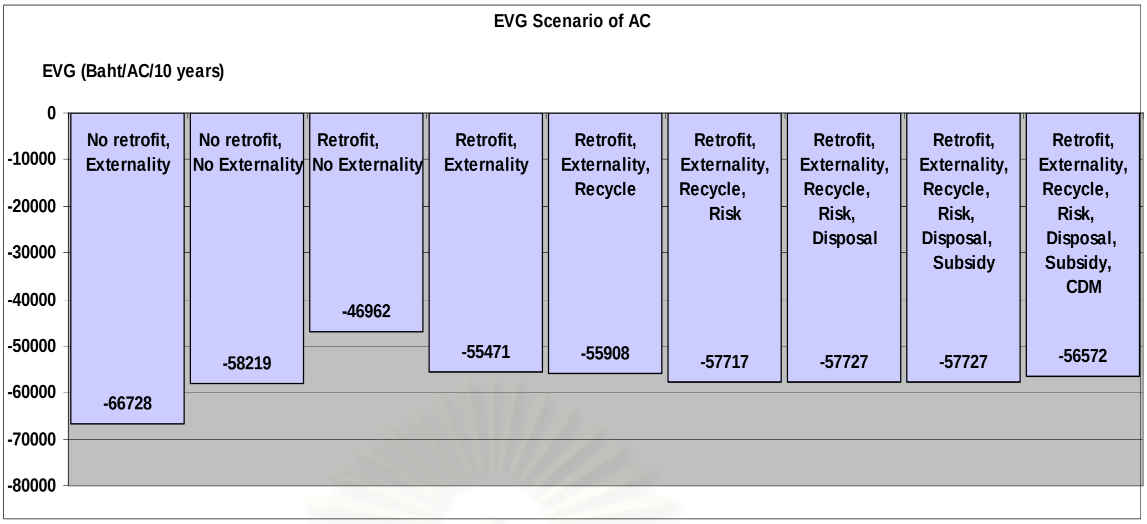


Fig. 6.2 Scenario analysis of a 12,000 Btu air-conditioner

Scenario analysis of ENVIROGY for both fluorescent lamps and air-conditioners gives the same trend of results. The ENVIROGY is worst for the case where there is no retrofitting and the externalities are added into it. The ENVIROGY value is absolutely better for investors if no externality is accounted and the retrofit added more benefit to the ENVIROGY of about (66,728-46,962)/(66,728) = 29%. The recycling cost, monetized risk during transportation, disposal cost of hazardous waste, and revenue from CDM do not change the ENVIROGY more than (66,728-57,727)/(66,728) = 13%. sceneario very much.

6.8 Life Cycle Interpretation and Improvement

Life cycle improvement in these retrofit situations must correspond to the policy of the government to control hazardous waste. From the equation of ENVIROGY, it is clear that the impact from hazardous waste is very little compared to the energy consumption which is dominated by the operating factor, or compared to the price of carbon credits and externality (high sensitivity parameter). To increase the importance of the impact from hazardous waste, there are some possible solutions derivable from the equation of ENVIROGY.

First is to increase the factors used to monetize weight of hazardous waste to monetary values. This way increases the weighting of the importance of the hazardous waste in the form of external cost. Second is to add the penalty defined by the relevant governmental organizations. This option is based on the polluter pays principle. Third is to bring up risk assessment. There is possible risk in dealing with hazardous waste, which requires some costs that have not frequently been accounted for.

Each parameter in the calculation of ENVIROGY, when used for other cases, has to be updated, revised or changed to fit the specific situation. The result of the value of ENVIROGY thus has some uncertainty depending on time and place. The ENVIROGY value with this approach could be a good guideline for decision makers, showing the trend of net expense along the life cycle but should not be referred to as the exact number.

6.9 Result and Discussion

The ENVIROGY's components has been quantified and summed in terms of monetary value. The value in each year along the life cycle must be discounted according to the inflation along with the increasing effect from the interest rate. The summing up into money values makes ENVIROGY easy to understand instead of an abstract score or point value as used in other single indicator LCA-based approaches. Monetizing each component into money value is based on the philosophy that everything can be either directly or indirectly measured. The measurement or estimation in monetary value should be related to a simple, available, and acceptable database. Such simplification will avoid the need for a huge database in software or knowledge of some exact and complex calculations.

Recycling costs and disposal costs for hazardous waste are normally proportional to the weight of the materials. This by-weight charge could lead us to concrete foundation of pollution prevention to reduce the waste amount and also the recycle and reuse of these waste materials as resources instead. Thus, deposit refund system if legislated will be a leaping step to complete the loop of recycle.

One more issue that has not been mentioned in this work is the value added from circulation of money occurred in the downstream industry of equipment. This kind of benefit is normally considered by governments to contribute to macroeconomic of the country. This theme could be the next possible topic of study for further expansion of the approach.

The ENVIROGY approach can point out the importance of recycling and disposal of hazardous waste in the illustration of the scenario of no recycling and disposal causing monetized contamination. Hg from one fluorescent lamp can pollute 20,000 L of drinking water over the drinking water quality standard (Phillips, 2005). Such contamination costs about 200,000 Baht. The 200,000 Baht is about 200 times the ENVIROGY value. This 200 times can be used in increasing awareness by all stakeholders in order to acknowledge the worst case of retrofitting without recycling and disposal of hazardous waste.

Energy consumption seems to be the majority of the ENVIROGY value and has high sensitivity to ENVIROGY whereas the disposal cost of hazardous waste, cost of recycling, operating impact, and the yield from the Clean Development Mechanism are much less. From the user's perspective of energy consuming equipment, environmental awareness is necessary to the decision making process because external cost changes ENVIROGY very little (1%-14% from Table 6.1). From the policy maker's perspective, consideration of energy and environment in ENVIROGY should not be ignored. The monetized impact from the worst scenario e.g. no recycling and no disposal of hazardous waste will be of benefit in communicating and increasing awareness on the part of all stakeholders.

6.10 Conclusion

From the approach and result it is clearly seen that many issues such as energy consumption or saving, net waste recycling cost, violence impact from hazardous waste or disposal cost, investment cost for retrofitting, risk in terms of money, operating impact in terms of money, government intervention for promotion or fee, and yield from the Clean Development Mechanism can be combined into a single practical value.

Lessons learned can be applied to the promotion of renewable energy e.g. investment in solar photovoltaic or wind turbines. The conceptual-decision support model proposed could change the purchasing procedure by adding into the qualification of the bidder in bringing back and returning of waste to responsible party. In such scenario product designer may have to redesign in order to avoid some economic liability at the end of their products life.

Chapter VII

ENVIROGY OF A 3 KW CdTe SOLAR PHOTOVOLTAIC (PV)

7.1 Introduction

Conventional energy is criticized as an unsustainable source of energy leading to a belief that it should be replaced with renewable energy i.e. wind, hydro, solar, biomass, biogas, and also solid waste incineration. Solar energy is a kind of renewable energy, which is mentioned in many aspects, e.g. energy production, CO_2 emission reduction, investment cost, lifetime, recycling, and hazardous substances. This paper will present all major aspects in terms of monetary value regarding PV especially Cadmium Telluride – thin film type in order to inform all stakeholders about its cost and benefit along the entire product lifetime.

A photovoltaic cell (PV cell) is a semiconductor that converts visible light (or infrared IR or ultraviolet UV) into direct current (DC). PV cells can be connected together to form solar modules, arrays, or panels. PV cells are made of silicon combined, or doped, with other elements to regulate the behavior of electron and hole from the absence of an atom. Copper Indium Di-Selenide (CIS), Cadmium Telluride (CdTe), and Gallium Arsenide (GaAs) are other possibilities for producing PV cells. The flat pieces of positive (P) type and negative (N) type are placed together in PV cell, and the physical boundary between them is called the P-N junction. When appropriate radiation strikes the P-N junction, a voltage difference is produced between the P type and N type materials. Electrodes connected to the semiconductor layers allow current to be drawn from the device. One of the major advantages of photovoltaic is the fact that they are non-polluting and, unlimited, requiring only real estate, sunny radiation, and low maintenance (Sangarasri, 2005).

Decision making in using PV has to concern with both aspects of energy and environment (Christiansen, 1990). The integration of energy and environment is not a new concept. Since 1983, the energy conservation effort has been recommended to include responsibility for waste (McClelland and Cook, 1993: Vera and Lang Lois, 2007). The integration of energy and environment will be more complex if the external cost must be internalized into the investment cost. Substantial costs, hazardous wastes, and risk have been considered in the application of many technologies selection (Bezdek, 1993) and externalities are internalized in fulfillment of policy objectives (Curlee, 1993: Lutz and Munasinghe, 1994) but most of the integration uses descriptive variables (Doukas et al., 2007) or a scoring method in making the final decision. This approach leads to homogeneous combination based upon the judgment of expert or researcher. There are some uncertainties and possible biases in judgment of people whereas some more specific strategy such as Life Cycle Analysis (LCA) is an excellent approach but needs comprehensive information or databases. The practical and homogeneous approach called ENVIROGY combines energy and environment and also provides for internalization of external cost to investment cost. It will be used to quantify cost and benefit for both internal and external cost along the lifetime of 3 kW CdTe PV (thin film) systems.

7.2 ENVIROGY Approach of Integration and Internalization

From the concept of life cycle cost covering a product from the phase of raw material to the phase of waste disposal, all phases of the life cycle are rarely applied at the beginning of decision making in choosing the product because of the complexity of the complete LCA approach. The concept ENVIROGY here proposes to cover all costs in all phases of a product incorporating the aspects of economics, energy, and environment. In the appendix H, the aforementioned concept has been explained in more detail including an example of calculation.

The concept "ENVIROGY" has been proposed here to provide a single indication expressed in terms of money that can be used for justification of the investment in energy consuming or generating equipment. ENVIROGY is the summation of expenses or incomes occurring from retrofitting in both internal and external views for investors. To calculate ENVIROGY by summing up the components: E, N, V, I, R, O, G, and Y (Equation 7.1), it is necessary to know details of each component.

$$ENVIROGY = E + N + V + I + R + O + G + Y \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7.1)$$

Each component of ENVIROGY had been considered along the life cycle of the retrofitting process. Manufacturing, retrofitting, operating, transporting, recycling, and disposal are considered with supportive data from various studies. It is found that some parts can be neglected (Likewise table 4.1).

- E Energy consumption, generation, or saving along the lifetime.
- N Net waste recycling cost happened only from the transportation to the recycling site, recycling cost, and revenue from scrap value.
- V Violence impact from hazardous waste will occur in cases where there will be some leakage of the waste to the environment. If the disposal had been done correctly, investor would have to pay only for the disposal cost.
- I Investment cost
- R Risk in terms of money, this could be any risk along the life cycle of the product but normally the dominant part is picked to be considered.
- O perating or manufacturing impact in terms of money had been concluded from LCA. Most of studies show the same conclusion that the major impact in all categories of energy consuming equipment comes from the operating phase whereas for PV, it is opposite to the case of energy consuming equipment. The energy consumption mainly occurs during the manufacturing of the PV cell. The emission of CO_2 from energy consumption is therefore the major cause during the manufacturing. Externality in currency unit Thai Baht/kg CO_2 emission is used as conversion factor to convert impact to money value.
- G Government intervention could be actually subsidy, penalty, fee, tax, or loan. This study uses the case of 80% subsidy of the equipment price for investment.
- Y Yield from the Clean Development Mechanism (CDM), the price of CO_2 reduction studied by ERM Siam i.e. 0.32 Baht/kg CO_2 reduction. The reduction of CO_2 here is simplified from the saving of energy and emission.

7.3 Energy Consumption, Generation, or Saving from PV Cells

Type of PV cell could be single crystalline (mono-crystalline), polycrystalline, amorphous (0.0005 micron thin film), or tandem cell (multilayer). Each type has advantages and disadvantages as shown in Table 7.1 (PV Tech, 2005). Energy consumption for PV manufacturing and recycling is shown in Table 7.2

Energy Payback Period is the ratio of energy consumption for PV cell production to the annual energy generated from PV cell. (Progress in PV, 1987). Energy generation of 40,523 MJ/year is estimated from the energy payback period and the energy consumption for production. For the lifetime of 30 years, total energy production, with reduction of 1% every year from deterioration, is 1,054,812 MJ (Tesco Lotus Rama 1, 2004). From Table 7.2, the energy consumption is 85,099 MJ from manufacturing and 64,759 MJ from recycling. Thus, net energy is +905,134 MJ or 251,426 kWh or 628,565 Baht (2.5 Baht/kWh).

Table 7.1 Advantage and disadvantage of PV cells

Type	Efficiency	Price	Energy Payback Period (year)
Single crystalline silicon	20-24%	High	4.17
Multi crystalline silicon	13-18%	Low	3.66
Gallium arsenide (crystalline)	20-29%	Very high	Not available
Amorphous silicon (Thin-film)	8-13%	Very low	2.1
CdTe (Thin-film)	10-17%	Low	2.1 (assumed from Amorphous silicon)
CIS (Thin-film)	10-19%	Low	2.1 (assumed from Amorphous silicon)

Table 7.2 Energy consumption during 3 kW PV manufacturing and recycling (Photon International, 2003)

PV Components	PV Manufacturing Energy (MJ)	Glass, Al & Cell Recycling (MJ)
Cell	69,545	55,636
Glass	3,277	2,622
Aluminum	7,223	6,501
Total	85,099	64,759

7.4 Net Waste Recycling Cost of PV Cells

In Germany, according to PVSEC (2004), there is the first prototype company for PV cell recycle of solar cells in the world named Deutsche Solar. The main process is to burn solar panels (1.5 m x 2.2 m) with a natural gas burner. The investment for this factory was 700,000 USD. The capacity for burning PV cells is 150 ton/year (equivalent to the capacity of the installed PV generation 1 MW). Cost of burning is 92 USD/ton. The process of recycle starts from disassembly of the solar panel from the aluminum frame, diode, wiring, and control box. Then the burning of solar panel will be done at 500-600°C in order to melt the EVA (Ethyl Vinyl Acetate) plate. After increasing the temperature to 800°C EVA will become acetic acid and CO_2. At the same temperature, Tedlar as the back sheet will emit CO_2 (g) and HF (g). The burnt PV cells removed from panel can be reused at a rate of about 80%. The ribbon and anti-reflection layer will be separated with a chemical agent. The solar cell can be quickly reusable or extracted out and melted into new wafer. Glass and aluminum frames are sent to the recycling process.

PV Cells Inc. (SSI) developed the operation for recycling CdTe modules, which starts with disassembly of a module and recovery of lead wires. Then, the module is crushed in a hammer mill. The coated glass and most of the EVA are crushed and mechanically separated including chemical dissolution. EVA is completely recovered. The recovery of tellurium is 80% and it is sold as commercial grade. The remaining metal containing in Cd-rich sludge is currently sent to a Cd recovery process. The recovered cadmium can be used for NiCd battery production. The total cost for this operation is approximately 4-5 cent/W. For 3 kW solar PV, the waste recycling cost is 6,000 Baht (Sasala, 2000: Fthenakis, 1996).

7.5 Violence Impact from Hazardous Substance or Disposal Cost of PV Panels

There are many kinds of PV cells and various materials in the life cycle inventory for the production of a solar cells, e.g. SiH_4 (Silane), $HSiCl_3$ (Trichlorosilane), B_2H_6 (Diborane), H_2, CH_4, and N_2, Zn, ZnO, and Ag are used for coating the electrode. EVA is used to wrap up the PV cell. Tedlar, glass sheet, aluminum frame, silicone, by pass diode, sticker, junction box, screw, glass tape, and glass cleansing liquid are used during the panel assembly. From the list of materials, the hazardous substances used during the life cycle of solar PV production are SiH_4 (Silane) and Trichlorosilane for purification of silicon. Care must be taken in storage, transportation, and utilization of these materials by periodically measuring the leakage with gas detector. Waste gas with SiH_4 has to be passed through a gas scrubber before released emission to the atmosphere. (Faculty of Engineering, CU, 2005) The inventory of main input flows to the CdTe module manufacturing process are glass 24,960 g/m^2, water 1,250 g/m^2, EVA 630 g/m^2, CdTe + CdS + $CdCl_2$ + Sn + Ni/V + ITO + Sb_2Te_3 230 g/m^2, and electricity 236 kWh/m^2 (Raugei, 2007). The manufacturing of PV cells uses some toxic chemicals and generates hazardous wastes that should be disposed of by local facilities (US DOE, 2006).

Environmental regulations can determine the cost and complexity in dealing with end of life PV modules. If they were characterized as hazardous, special requirements for material handling, disposal, record keeping, and reporting would escalate the market price due to the cost of module decommissioning. Recycling PV systems at the end of their useful life adds to the environmental benefits and can further enhance market support. Also recycling answers public concerns about hazardous materials in PV modules that can create barriers to market penetration (Fthenakis, 2000).

Solar modules could be used for 30 years (Fthenakis, 2000). The quantity of PV cells considered as waste by the end of life is very small. During operation of PV cells, it is claimed that the waste is zero as a result of operation. It is however estimated that by the year 2020, the growing PV industry will produce a PV waste stream. Used solar cells are generally safe for landfills because materials are usually encased in glass or plastic which does not allow the hazardous materials to leach out in the landfill. This allows it to pass the tests such as the US-EPA Toxicity Characterization Leachate Procedure (TCLP). Some modules, however, could be classified as hazardous waste. The leachability of metals in landfills currently is characterized by elution tests such as the US-EPA Toxicity Characterization Leachate Procedure (TCLP) - a worst-case scenario tests. The small pieces (<1 cm^2) of broken modules are suspended and rotated in an eluent for 24 hours. The presence of metals in the eluent are then measured and compared with limits prescribed by each testing protocol. If the metals' concentration exceeds the limits, the modules are demonstrating the metals' leachability and may need to be recycled or disposed of in a hazardous-waste landfill. If the metals are not leaching above the limits, the modules can be disposed of in a commercial landfill.

After recycling by physically separating module frames, junction boxes and wires; then, the modules are fragmented, and the metals are stripped in successive steps of chemical dissolution, mechanical separation, and precipitation or electro-deposition. At the end, the mounts, glass, EVA, and a large fraction of metals are recovered (e.g. 80–96% of Te, Se, Pb). The remaining metals (e.g. Cd, Te, Sn, Ni, Al, and Cu) are contained in a sludge, which must be disposed of, or further recycled.

The cost of secure landfill disposal is 9 Baht/kg and 1.5 Baht/kg for transportation cost within the distance of 200 km (Genco, 2007). For 3 kW, the area of solar module is 25 m^2 and the weight is 30 kg. The part that cannot be recycled is around 20% or 6 kg, so the disposal cost and transportation is -63 Baht.

7.6 Investment of PV Installation

Power production from a PV system needs the charge controller to be a center linking from PV arrays (a group of cells called module and a group of modules called array) to batteries. From the battery, DC loads can be connected directly whereas the AC loads need inverter with AC loads. (Pollap, 2005)

Data and Investment for PV Cell Unit (Pollap, 2005):	
Solar Roof-Top Output, Power	3 kW
Solar Module (3 kW)	362,000 THB
Inverter & Grid Protection (3kW)	75,400 THB
Control Equipment (3 kW)	41,400 THB
Materials (3 kW)	32,700 THB
Labor (3 kW)	27,500 THB
Transport (3 kW)	15,000 THB
VAT (7%)	38,780 THB
Turnkey cost/ kW capacity	197,593 THB/kW
Total Investment	592,780 THB
Economical Conditions:	
Portion of Loan Financing	70 %
Portion of Equity Capital	30 %
Principal, Bank Loan	414,946 THB
Equity Capital	177,834 THB
Pay-back Period, Loan	10 Year
Interest/Repayment(s)	57,721 THB/year
Operational Conditions and Income:	
Plant Factor	0.137

Operational Hours	1,200 hours/y
Power Production	3.6 MWh/year
Own Consumption - Power (0%)	0 MWh/year
Power Production, Net	3.6 MWh/year

7.7 Risk Assessment from Transportation

Various chemicals such as hydrofluoric acid (HF), nitric acid (HNO_3) and NaOH are used to clean the silicon wafers and to remove any oxidized residue. The extremely hazardous material should be avoided with regard to contact and prevented from release into the water system. The safety measures must be well established if it is used frequently.

For a CdTe cell, there are a number of significant problems regarding their safe disposal and manufacturing. Cadmium is a poisonous element produced as a by-product of zinc extraction, where it is frequently disposed in un-environmentally friendly ways by pumping the sludge containing cadmium to the pond without treatment in the mining industry. It is toxic at low levels and can lead to symptoms such as fragile bones, hypertension, and eventually death. It is also assumed to be carcinogenic in chronic cases. Presently 98% of cadmium is used in paints, pesticides, stabilizers and batteries. In the US for example only 1.5-3% of total cadmium is used in the solar industry. Due to its toxicity, regular monitoring of staff at CdTe plants is needed to ensure that chronic exposure does not occur. While the use of cadmium is banned or limited in many instances, particularly where it is hard to recycle or take care of, European Union regulations do not currently prohibit its use in photovoltaic cells, since it is in a stable non-metallic form (typically CdTe), and is not soluble in water.

One of the principle concerns regarding this type of PV cell has been the potential effects of very high temperature on the cells – such as in an accidental fire. Temperatures of residential heating or fire would not be high enough to cause the release of the chemicals because the melting point of CdTe is around 1050 °C. However in industrial heating where other fuels are used, temperatures could potentially be high enough to melt the cadmium, causing it to run to the edge of the units. In the laboratory, tests have shown that this can indeed happen, raising the concern that significant amounts of CdTe as opposed to pure cadmium could be released into the environment. However, in additional tests in which whole CdTe modules were exposed to a temperature of 1100 °C, it was found that the liquid cadmium-telluride was captured in the molten glass of the module, rendering it effectively harmless. This means that while there is some potential for the release of CdTe, the vast majority should be captured in inert glass droplets. In any case, the presence of any cadmium is likely to be far less of a danger than the fire itself. Furthermore, the amount of cadmium involved is very small (Fthenakis, 2000).

The correct and responsible disposal of CdTe PV cells, once they reach the end of their useful lives, must be carried out. Landfilling may be inappropriate as there is potential for leaching. The solar cell industry should take back and recycle the modules to recover cadmium and other valuable components.

The cadmium used for PV cells is not produced specifically, but is present as a byproduct of the mining industry (typically zinc manufacture). In any case, the amounts of cadmium, which could be released into the environment by PV cells in a worst-case scenario, are actually low, with current estimates at 0.02 g/GWh. The cadmium used in PV cells is very stable because of the binding up with tellurium. This is the reason why cadmium emission from PV cells is less than the cadmium emission from coal fired power plants. Under normal circumstances coal fired power stations emit 360 times more cadmium into the air per kWh than is needed in PV cells per kWh generated (Cameron, 2007).

A number of substances are considered as a potential to pose acute and/or chronic hazards on the work force in the PV industry, e.g. acids, solvents etc. The hazards of these substances are controllable by the safety measures usually employed in chemical or semiconductor industries (Phylipsen, 2000).

The occupational risks of thin film module manufacturing generally seem quite acceptable provided that normal industrial health and safety practices are implemented. External safety risks from module manufacturing are mainly due to the storage and handling of explosive and toxic gases. The storage of large quantities of silane for a Si production and of hydrogen selenide for CIS production may be serious safety risks for workers and public. Health risks resulting from the use of CdTe modules have been evaluated from a number of different exposure means, e.g. emissions during a fire and emissions from broken modules. In all cases, the risk was found to be negligible or small. In conclusion, there are no serious health, safety, and environmental aspects in transportation of PV cell (Alsema, 2000). ItTherefore, it is assumed that the monetized risk from using PV cell is 0 Baht.

7.8 Operating Impact

Cadmium compounds cannot be emitted from modules during normal operation or during accidents. Emission to the environment could occur only in the municipal waste incinerator. Large scale implementation of CdTe PV modules does not present any risks to health and the environment, and recycling the modules at the end of their useful life completely resolves an environmental problem. During a useful life of 30 years, these modules do not produce any pollutants or noise (Fthenakis, 1996). Impact during operation is therefore negligible. If the scope of consideration is expanded to manufacturing phase, there will be impact from energy consumption during manufacturing of 85,099 MJ per 3 kW. Here the operating impact which is a component of ENVIROGY will involve only the phase after manufacturing until recycling. It is noted that energy consuming equipment always has high and dominant impact during the operation and much higher than the manufacturing phase. The impact from energy consumption during manufacturing is therefore neglected. The energy saving, consumption, and use for recycling could be accounted for as well if the data are available. The main energy consumption therefore occurs during recycling that is 64,759 MJ or 17,989 kWh multiplied with the externality 0.362 Baht/kWh (Appendix D) of electricity consumption (PRET, 2005). The operating impact therefore costs 6,512 Baht (multiplication of 0.362 Baht/kWh and 17,989 kWh).

7.9 Government Intervention and Yield from CDM

It is calculated that IRR will be 10% if the produced electricity can be sold at the production subsidy of 14.32 Baht/kWh or 51,831 Baht/year whereas the normal tariff is 3.46 Baht/kWh when cost of electricity is 2.98 Baht/kWh. Another possible option to reach 10 % IRR is to give the investment subsidy of 82.27% or 487,680 Baht (EGAT, 2002). There is no subsidy at this level in the real situation as the government budget is limited.

The U.S. National Renewable Energy Laboratory (NREL) has found that relative to burning coal, every gigawatt-hour of electricity generated by PV would prevent the emission up to 10 ton of SO_2, 4 tons of NO, 0.7 tons of particulates (including 1 kg of Cd and 120 kg of As), and up to 1,000 tons of CO_2. The emission of CO_2 from the solar cell itself is zero during use because PV systems require little or no maintenance or oversight. Considering a 3 kW PV power plant, the output 40,523 MJ/year or 11,256 kWh/year, the CO_2 reduction is 0.011 ton (Interpolation from 1,000 ton CO_2 reduction: 1 GWh electricity production from PV power plant) ERM Company Limited had determined in 2005 that for Thailand the price of a ton CO_2 reduction is 320 Baht. So, the yield from CDM for PV cell 3 kW is 3.52 Baht/year or 101 Baht/30 years

7.10 Result and Discussion

From equation (7.1), ENVIROGY can be calculated by plugging in each component as aforementioned in each previous topic.

E: Energy generation +628,565 Baht
N: Net waste recycling cost -6,000 Baht
V: Violence impact from hazardous waste or disposal cost -63 Baht
I: Investment cost -592,780 Baht
R: Risk in terms of money 0 Baht
O: Operating or manufacturing impact in terms of money -6,512 Baht
G: Government intervention +487,680 Baht
Y: Yield from Clean Development Mechanism +101 Baht

ENVIROGY = E+N+V+I+R+O+G+Y
ENVIROGY = +628,565 - 6,000 - 63 - 592,780 + 0 - 6,512 + 487,680 + 101
= +510,991 Baht

Table 7.3 Distribution of monetary value of ENVIROGY's components

ENVIROGY 's components	E	N	V	I	R	O	G	Y
Distribution (%)	36.51	0.35	0	34.43	0	0.38	28.33	0.01

The calculated ENVIROGY interprets that for the whole lifetime of a CdTe PV cell 3 kW, the investment and external cost is +510,991 Baht and its distribution in Table 7.3.

Energy generation, investment cost, and the government intervention in this case seems to be the majority of the ENVIROGY value whereas the disposal cost of hazardous waste, cost of recycling, operating impact, and the yield from the Clean Development Mechanism are much less than the major part. From the perspective of the user, awareness is really important to improve the decision making in installation of PV cell because external cost changes ENVIROGY very little. There is no monetary value force the user to be careful about the recycling and disposal whereas the benefit from energy generation is very worth. From the perspective of the policy maker, consideration of majority and minority components in ENVIROGY should be emphasized. If some minor part needs to be focused on, the monetization of that part may be improved e.g. if the yield from CDM is raised, it could become a major part. Another example is the adding up of the penalty from the government for the improper management of hazardous waste can increase the weight of the environmental aspect compared to the major part from energy generation.

7.11 Conclusion

From the result of this study, it is clearly seen that many issues such as energy consumption or saving, net waste recycling cost, violence impact from hazardous waste or disposal cost, investment cost for retrofitting, risk in terms of money, monetized operating impact, government intervention for promotion subsidy or fee, and yield from the Clean Development Mechanism can be combined in one term as ENVIROGY.

The components in ENVIROGY can be converted in monetized values and added together to yield a single monetized value. The money value in each year along the life cycle must be discounted in time series as a result of inflation and interest rates. The summing up into money makes ENVIROGY easy to understand instead of abstract scores or points as used in many other single indicator systems based on LCA. Conversion of each component into monetary value is based on the philosophy that everything can be either directly or indirectly measured by available databases.

CHAPTER VIII

SOLUTION FOR HAZARDOUS WASTE FROM ENERGY CONSERVATION

8.1 Introduction

Energy is an important factor for buildings in both aspects of quality of life for occupants and cost for buildings owner. The cost burden for the building owner is getting and will be larger overtime and this is the reason energy conservation measures are implemented almost universally, especially in large buildings. Economic internal rate of return and simple pay back period are used as criteria for decision making in retrofitting of the buildings. The other aspects such as environmental aspect are, if ever, considered separately to those aforementioned criteria. This work will synthesize the results from previous studies of retrofitting energy conservation measures in existing buildings, life cycle cost of hazardous waste from energy conservation measures, internalization of external cost into the investment of retrofitting energy consuming equipment, life cycle analysis of hazardous waste from energy conservation measures, ENVIROGY conceptual decision support model, and application of ENVIROGY to PV cell. The review of the result from these studies would lead to the solutions for the management of hazardous waste from energy conservation measures in existing buildings.

8.2 Value Chain of Retrofitting Energy Consuming Equipment in Buildings

From Fig. 8.1, the retrofitting of energy consuming equipment in buildings starts from the preparation of material as input for the assembly of the energy consuming equipment. If the efficiency of equipment is low or the lifetime is low, it will soon need new and high efficiency equipment to replace the old one. The objective of retrofitting is energy saving whereas there are recyclable and hazardous wastes from retrofitting that need to be handled.

From the stand point of value chain, the decision making at the beginning of equipment selection is very important. Life cycle thinking is the appropriate concept in this situation. Wrong decision or short-term thinking from buying cheap equipment at initial phase causes the loss from low energy efficiency in operation phase and high environmental expense at the disposal phase. The selection of buying equipment is very important because it is always play dominant roles and considered as a part in the retrofitting of energy consuming equipment in buildings.

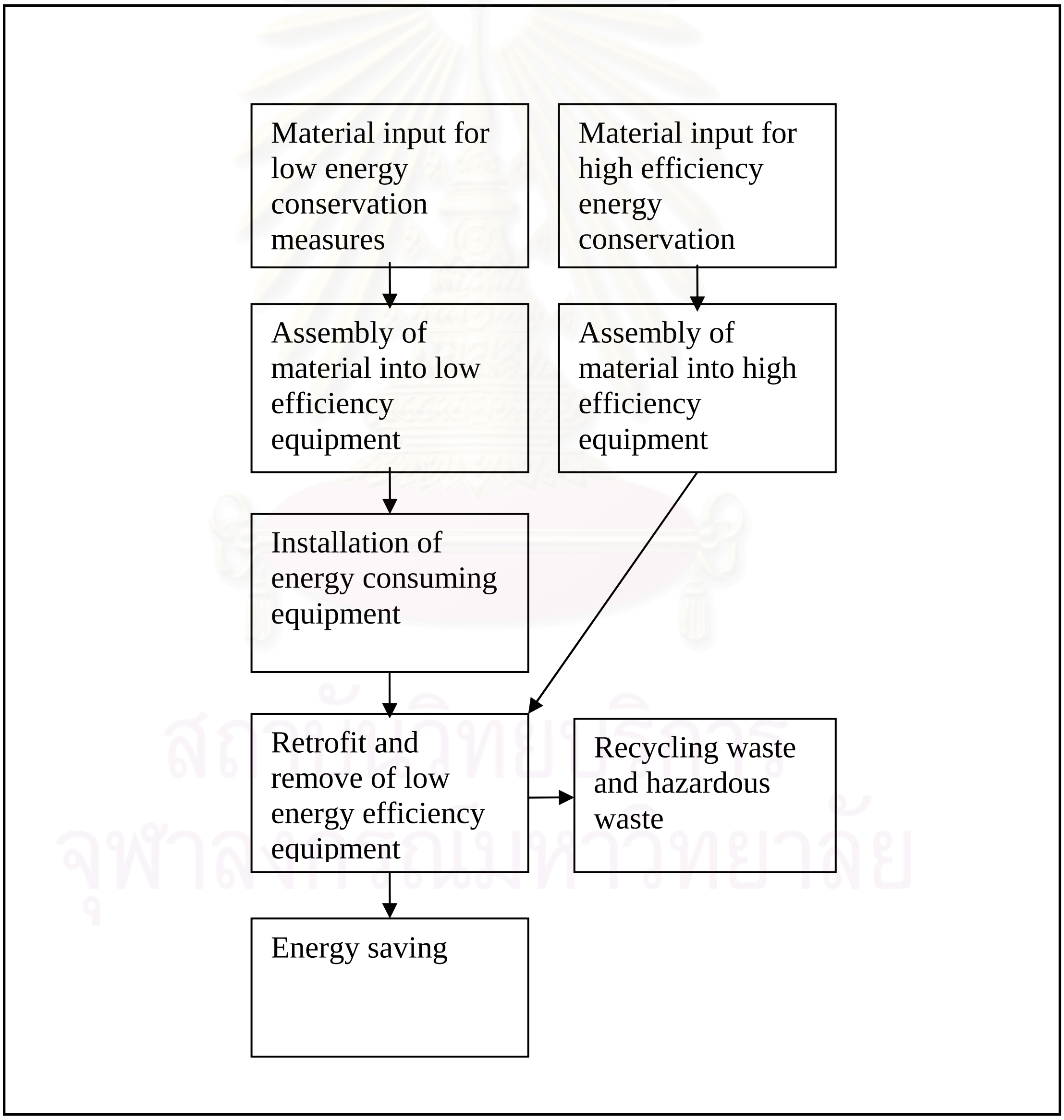
8.3 Mandatory and Voluntary Approach of Retrofitting

In view of mandatory approach to the retrofitting of energy consuming equipment in existing building, Thailand has started implementing the enforcement of the new building energy code in 2007. The new code, building performance, allows each building to comply either each system (air-conditioning, lighting, and building envelope) or whole building performance. This code, a pushing approach, is one of the most advanced compared to the building code of many countries. It is also more flexible than other prescriptive requirements in some countries like Australia, Hong Kong, and Malaysia. In view of voluntary approach, standard labeling, guideline, best practice, pilot project, technology transfer, and awareness promotion are often used in many countries including Thailand.

For voluntary approach, there are many schemes used in pulling energy conservation and environmental management e.g. standard labeling, international standard, demand side management, and awareness increasing.

The pushing and pulling are the great driving force in increasing retrofitting in buildings for higher energy efficiency. However, with the larger number of retrofitting expected in the near future, the waste from implementing of retrofitting need to be considered seriously..

Fig 8.1 Value chain of retrofitting energy consuming equipment in buildings



8.4 Barriers for Retrofitting with Proper Hazardous Waste Management

The barriers to the recycling energy consuming equipment which contain hazardous substance are listed correspondingly to the value chain

- Hazardous substance cannot be technically replaced or reduced
- Collecting of waste from retrofitting is difficult due to leakage or improper method
- Benefit from recycling is not return directly within a short time.
- Regulation of retrofitting with proper hazardous waste management is unavailable
- Lack of awareness in retrofitting stakeholders

The solutions to five main barriers above are listed respectively as follows.

- Research and development
- Management
- Subsidy
- Enforcement of law, fee, and tax
- Education

8.5 Existing Decision Support Model for Retrofitting

The conceptual model for retrofitting is composed of all the important factors based on the relation and data from life cycle analysis; that is the energy saving, implementation cost, operational cost, maintenance cost, disposal cost, and implicit cost generated from the hazardous waste (Fig 8.2)

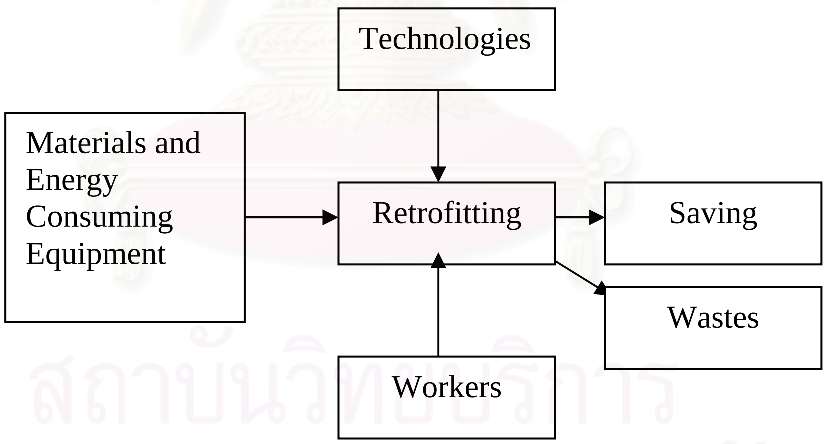


Fig. 8.2 Model of existing retrofitting

It is known that there are some wastes from retrofitting but it does not take in the consideration before the implementation of retrofitting. The model therefore needs to be revised and improved for better expected concrete action of waste management after the retrofitting.

8.6 Life Cycle Cost of Retrofitting

If the recycling and disposal are added into the calculation of IRR and SPB of the retrofitting, results will change slightly (4-6 months and 1-1.5% more) from base case (without recycling and disposal cost). If the external cost from retrofitting, recycling and disposal cost (monetized environmental impact from operating, monetized environmental impact from retrofitting – recycling – disposal, monetized risk during transportation, and revenue from Clean Development Mechanisms) are added into the calculation of IRR and SPB of the retrofitting, results for both IRR and SPB will change significantly (2-10 years and 10-20% more) from base case. It could be concluded that external cost is an important factor to change the decision making for retrofitting.

8.7 Decision Support Model - ENVIROGY

From the approach and result it is obviously seen that many issues like energy consumption or saving, net waste recycling cost, violence impact from hazardous waste or disposal cost, investment cost for retrofitting, risk in terms of money, operating impact in terms of money, government intervention for promotion or fee, and yield from Clean Development Mechanism can be combined into a single indicator named ENVIROGY – monetary value. The ENVIROGY reflects the distribution of important aspects, especially in environment dimension. For example, the purchasing procedure can be changed by adding into the qualifications of bidders the ability and credential to manage hazardous wastes from retrofitting properly.

8.8 LCA of Hazardous Waste

Many studies give the same result that the operation or usage period creates the highest impact from the consumed energy. The major global warming impact during the usage stage occurred from the consumption of electricity because parts of power were generated from fossil fuels such as natural gas, and lignite (Tantempsapya and Yossapol, 2005).

The small amount of hazardous waste from fluorescent lamp and air-conditioner will be much more important in the view of country level because of the large number of retrofitted buildings nowadays. Policy makers who deals with energy conservation should be aware of this fact in generation of any relevant policies because o the hazardous nature of the wastes. Considering this characteristic and planning for the appropriate method at the early stage can reduce future problems of environmental contamination of such hazardous wastes. Design of the products may be changed if there is some liability of the producers or manufactures of the energy consuming equipments for the waste. The priorities of energy conservation measures could be changed if the policy maker had added this aspect of hazardous waste into the decision making step because of the additional cost. The adding of some cost to stakeholders therefore must be deliberated and planned to avoid using this reason to stop implementing the energy conservation. In view of environment, if the small amount had contaminated to the environment, the cost of clean-up will normally be more expensive than paying attention to the recycling and proper disposal in the first hand.

8.9 ENVIROGY of Fluorescent Lamp and Air-conditioner

For the retrofitting a 36 W fluorescent lamp, ENVIROGY is -1,483 Baht/10 years. For the retrofitting of 12000 Btu air-conditioner, ENVIROGY is -56,572 Baht/10 years. As ENVIROGY showed the result in monetary value, it is therefore easy for not only policy maker but also understandable for general level of persons who related to the energy and environment sector.

8.10 ENVIROGY of PV cell

To monetize each component into money value is based on philosophy that everything can be either directly or indirectly measured. The calculated ENVIROGY interprets that for the whole lifetime of CdTe PV cell 3 kW, the investment and external cost is +510,991 Baht. ENVIROGY is applicable to solar photovoltaic system.

8.11 Conclusion of Preliminary Conceptual Decision Support Model

ENVIROGY is the summation of expenses and incomes occurring from retrofitting both internally and externally for investors. ENVIROGY is a preliminary conceptual decision support model explaining in the aspects that include hazardous waste from energy conservation measures deployed to existing buildings. ENVIROGY has been developed with the concept of life cycle thinking where all components occurring along the life cycle are added together. The component of energy saving could be pushed or pulled as the driving force from the energy code or standard of equipment efficiency in the market.

Using of ENVIROGY can solve the problem of using IRR and SPB which has problem when accounted external cost especially the result interpreting the unviable retrofitting even there is saving. The meaning of ENVIROGY does not reflect the conflict to the financial view because it is not benchmarked to the interest rate or attractive time that the money will be returned.

8.12 Discussion on Promising Implementation of ENVIROGY

The implementation of ENVIROGY will increase the cost of initiating energy conservation measures because of the externality, recycling cost, monetized risk and disposal cost. These costs however will reflect to the proper activities along the lifetime of retrofitting cycle. The decision maker should add these costs and update the approval of these costs in the implementation.

For existing low efficiency equipment, the additional cost from normal retrofitting, paid by building owners, should be subsidized by the government (Fig. 8.3). For existing high efficiency equipment in the building at the end of lifetime, the additional cost, from normal retrofitting, during recycling and disposal should be paid by manufacturers (Fig. 8.4). This concept is fair to the building owners who would like to do the retrofitting as they will get the saving from investment in buying and installing the high efficiency equipment. Manufacturers should take back their end of life product to recycle or dispose properly as they get the profit from producing and selling the product to building owners. The part of operating impact should be promoted with some subsidy from government to change their business as usual.

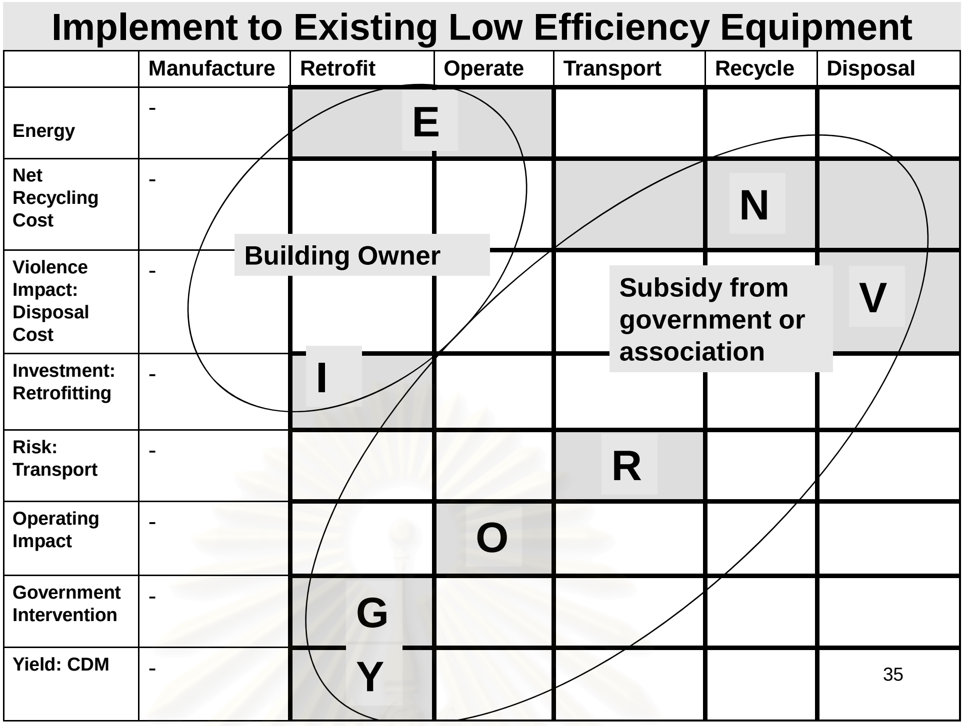


Fig. 8.3 Implementation of ENVIROGY at the end of lifetime of low efficiency equipment

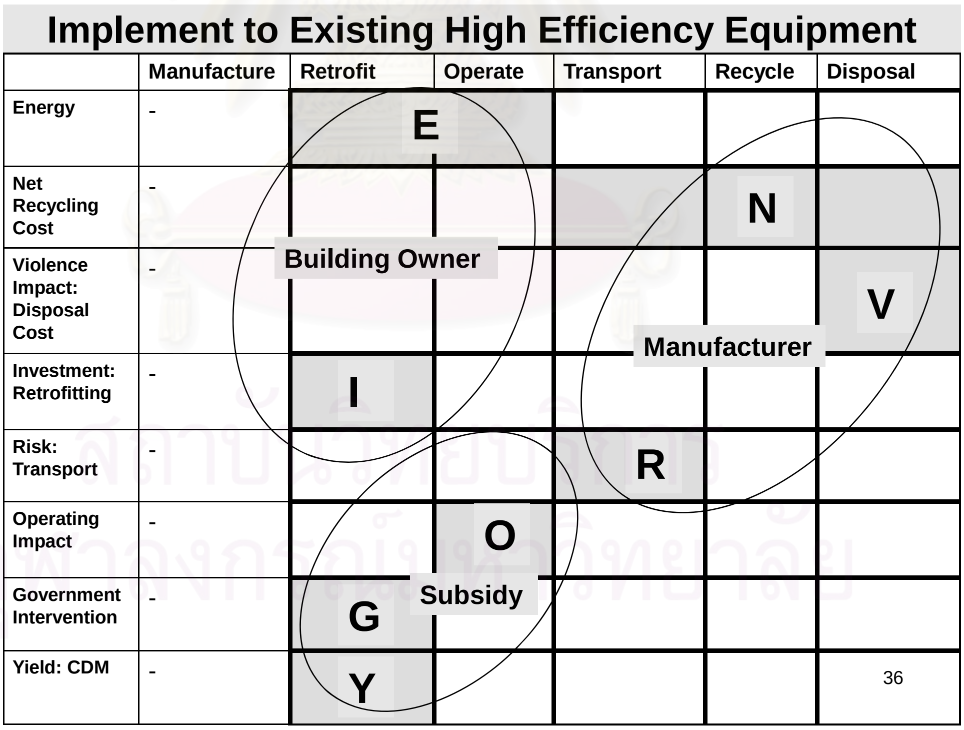


Fig. 8.4 Implementation of ENVIROGY at the end of lifetime of high efficiency equipment

Additional costs paid by manufacturer may affect small enterprises and eventually will be passed on to consumers by adding into the selling price of energy consuming equipment. The starting phase of using ENVIROGY should be managed properly by government and passed to the association later to avoid the burden load of government and to be efficient managed. It is expected that ENVIROGY may add the awareness to stakeholders, which synchronize well with the concept of green purchasing.

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Appendix

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APPENDIX A

BASIC KNOWLEDGE OF LCA

Mats-Olov Hedblom

People and industries the world over are acknowledging that we can no longer take the environment for granted. The resolutions that were passed at the Rio Conference in 1992 charge every world society with the task of attaining a proper balance between their social, economic and environmental responsibilities. Partly in response to that conference, world industries have agreed to develop a suite of tools for environmental management – the ISO 14000 series of standards.

Corporations who have identified the environmental dimension as the most important aspect of good global citizenship are currently seeking tools that will help them to condense this dimension into strategic scenarios of the future. One such tool is the life-cycle assessment.

The author describes how Ericsson, as a member of the IT industry, is in the process of establishing a sound environmental platform on which to base their operations, now and in the future.

Part 1 of this three-part series of articles deals with various international perspectives of the environmental issue. Part 2 describes the life-cycle assessment in depth. Part 3 demonstrates how Ericsson can apply the findings from the life-cycle assessment, designing for the environment and labeling products according to the emerging ISO 14025.

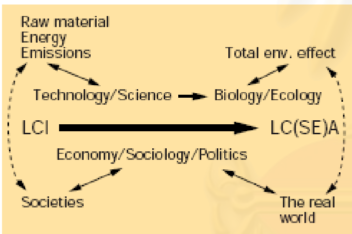
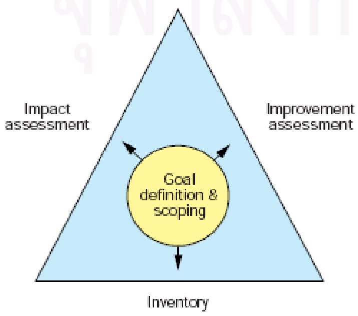


Figure 1
Cooperation between the engineering and ecological sciences can bridge the gap in knowledge of the cause and effect of environmental threats.

Figure 2
SETAC technical framework for the life-cycle assessment.



Life-cycle assessment – industry's strategic tool for survival

The purpose of this article is to give insight into emerging methods that compose the life-cycle assessment (LCA), which will be used for describing interactions between industrial and societal activities and the immensely complex environment that forms the basis of sustained wealth and human prosperity.

An article recently published in Nature[1] on the general role of research and science stated that:

- "The scientific enterprise is full of experts on specialist areas but woefully short of people with a unified world view."
- "Scientists are trapped in their own specialisms, leaving others, often poorly qualified, to represent to the public the larger architecture and interconnections of modern scientific theories."
- "Scientific education has become so specialized that scientific literacy is little more advanced among scientists than it is among non-scientists."
- "Undergraduates who have completed courses on cell biology and evolution are unable to discuss broad issues in evolutionary theory, let alone Earth history or cosmogony, in any greater depth than can their non-scientist peers. Physics students don't know how a protein differs from a nucleic acid; chemistry students don't know the age of Earth; geology students cannot give a simple account of metabolism or say why the sky is blue."

With tools developed for the LCA, we are finally able to obtain scientifically defensible descriptions of good and bad interrelationships between industrial product systems, the human society, and the external environment. The most important part of this development is the link between mass- and energy-engineering sciences and sciences (biology, ecology) that deal with the environmental indicators that most often reflect the negative impact of industry or society's activities (Figure 1).

The absence of a life-cycle assessment has enabled anyone to speak out on subjective grounds as "environmental specialists." While stakeholders in branches of industry that heavily burden the environment (automobile manufacturers, forestry, oil companies) fear, express concern over, or even fight ISO 14000 standardization, the information technology (IT) industry, with its inherently low-impact profile, only stands to gain from it.

This article presents the dynamics of LCA-related developments within the International Organization for Standardization (ISO). It also introduces elements of the most advanced form of the LCA, called the life-cycle stressor-effects assessment (LCSEA), which is certain to be practiced by environmentally progressive companies throughout the world. Ericsson is the first telecommunications corporation to apply the LCSEA.

Overview of the life-cycle assessment – historic development

The life-cycle assessment was first developed as a system-oriented tool for tracking material and energy flows in industrial systems during the energy shortage of the early 1970s. Having emerged from the science of throughput analysis, the life-cycle assessment was essentially an inventory exercise that involved calculating material and energy input and output in a defined industrial system or subsystem.

The system or subsystem was divided into discrete unit operations for which input and output data were collected. The data was then gathered and aggregated to generate a sum total of resources used, energy consumed and of environmental releases by species. Next, the data was normalized to a specified functional unit of measure. Aggregation, allocation and normalization were typically based on standard assumptions about mass and energy balance. Procedures and data were reported in mass and energy units.

Several computer models were developed in Europe and in the US to perform the iterative calculations needed to conduct life-cycle inventories (LCI). In time, these models were expanded, integrating data on a broad range of discharges into the air, water and ground, and accommodating the growing volume of data for basic upstream processes. By the late 1980s, a variety of life-cycle models were in use around the world.

Life-cycle methods expanded as government agencies, industry, institutions and non-governmental organizations began to use them for more than simply tracking inventories. For instance, the life-cycle assessment was thought capable of facilitating comparisons of the environmental impact associated with alternative production technologies and competing materials, as well as of communicating the environmental performance profile of products sold on the market.

The SETAC LCA framework

In an effort to harmonize methods and the resulting databases of various models, the Society for Environmental Toxicology and Chemistry (SETAC) set out in the late 1980s to spearhead the development of a common conceptual technical framework for the life-cycle assessment. The framework was to be hammered out in a series of technical workshops based on the contributions of developers, practitioners, industry users, and stakeholders of the LCA model.

In 1990, SETAC published the proceedings of their first workshop, which was a proposal for a technical framework. Under this framework, the LCA was described as having three separate components: inventory, impact assessment, and improvement assessment (Figure 2). In later workshops, a fourth component – which consisted of goal-setting and scoping – was added to the framework.

The inclusion within the technical framework of a distinct impact-assessment stage reflected the need for clarifying the environmental significance of data collected at the inventory stage and recognized the in-

Box A
Terminology

BOD Biological oxygen demand.

Category endpoint Representation of the natural environment, human health, or resources used to designate an impact category.

Category indicator Modeled inventory results that represent a given life-cycle impact within an impact category.

CD Committee draft.

Characterization factor A factor that converts a life-cycle inventory result into a common numerical scale within an impact category for aggregation into indicator results.

Completeness check Process of verifying that sufficient information exists from each phase (inventory analysis, life-cycle impact assessment) to reach a conclusion from interpretation.

Consistency check Process of verifying that interpretation complies with the defined goal and scope before conclusions are reached.

DfE Design for the environment.

DIS Draft international standard.

Environmental issue Input, output (results from the LCI) and environmental indicators (results from the LCIA), that are important to the definition of the goal and scope.

EOL End of life.

EPA Environmental Protection Agency.

EPS Environmental priority strategy – A Swedish LCA tool for designers and engineers.

Evaluation The second step of the life-cycle interpretation, including completeness check, sensitivity check, consistency check, etc.

GIS Geographic information system.

GWP Global warming potential.

HC Hydrocarbon.

Impact category Group of life-cycle impacts that illustrate the connection between certain inventory results and a specific indicator and endpoint.

Indicator A simplification and distillation of complex information intended as a summary description of conditions or trends.

ISO International Organization for Standardization.

IT Information technology.

LCA Life-cycle assessment.

LCI Life-cycle inventory.

LCIA Life-cycle impact assessment.

LCSEA Life-cycle stressor-effects assessment.

Life-cycle impact Representation of environmental change caused by a product system. Note: The life-cycle impact does not indicate actual environmental effects.

Life-cycle interpretation Phase of the life-cycle assessment in which findings of the inventory analysis, of the impact assessment, or of both, are combined in a manner that complies with the defined goal and scope, in order to reach conclusions and recommendations.

Life-cycle inventory result Outcome of a life-cycle inventory analysis which, in crossing the system boundary, represents interaction of the system with the environment.

Measurement endpoints A change in flora, fauna, human health or resources that represents a significant measurable deviation from a defined baseline.

NO_X Nitrous oxide.

POCP Photochemical ozone creation potential.

SAGE Strategic Advisory Group on the Environment.

Sensitivity analysis Systematic procedure for estimating the effects on the outcome of a study of the chosen methods and data.

SETAC Society for Environmental Toxicology and Chemistry.

SO_X Sulfur oxide.

Stressor A specific system input, output or activity that is linked to an observed effect or related group of effects.

Stressor-effects network The interlocking physical, biological and chemical events that connect a specific system input, output or activity (that is, the stressor) to an observed effect or related group of effects.

Uncertainty analysis A systematic procedure for ascertaining and quantifying the uncertainty introduced into the results of a life-cycle inventory, due to the cumulative effects of input uncertainty and data variability. Uncertainty analysis uses either ranges or probability distributions to determine uncertainty in the results.

VOC Volatile organic compound.

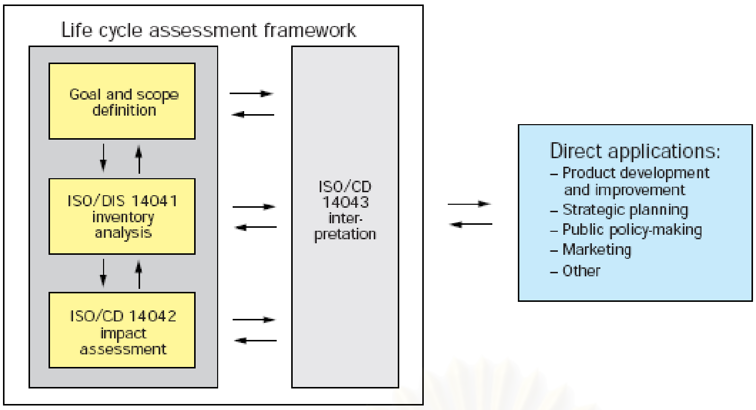


Figure 3
ISO/DIS 14040 – phases of the life-cycle assessment

herent difficulties in deriving environmental significance from input and output data that had been aggregated, allocated, and normalized.

Besides SETAC's achievements, several national and regional efforts were launched to describe the techniques, application and limitations of the life-cycle assessment. These include the Nordic Guidelines, which were developed by a consortium of Nordic research institutions, and draft guidelines by the Environmental Protection Agency (EPA) in the US. These initiatives lent further support to the basic SETAC framework, including clear recognition of the need for an impact-assessment phase.

ISO standardization of the 14040 series on life-cycle assessment

Following the United Nations conference on environment and development in 1992, and the subsequent formation of the Strategic Advisory Group on the Environment (SAGE), pressure grew to make the life-cycle assessment the standard tool for environmental management. After the ISO 14000 standardization effort was formally initialized in 1994, the SETAC technical framework was adopted as the starting point for standardizing the life-cycle assessment (Table 1).

Based on existing practice, the work of formulating general life-cycle assessment principles (14040) and of writing the mass and energy inventory standards (14041) proceeded rapidly to draft international standard (DIS). However, efforts to standardize the life-cycle impact assessment (LCIA, 14042), which is based on 14041, ran into severe roadblocks because the life-cycle inventory was never designed to link input and output data to actual environmental effects.

ISO 14040 – principles and framework of the LCA

The framework standard ISO 14040, which defines the content of any investigation that claims to be a life-cycle assessment, clearly states its limitations as being one of several environmental management techniques (risk assessment, environmental performance evaluation, environmental auditing). Moreover, it does not address the economic or social aspects of a product or product system. A life-cycle assessment must define its goal and scope, inventory analysis, impact assessment and interpretation of results (Figure 3).

It is no secret that by fudging with the scope and system boundaries of an investigation it has been possible to manipulate results. Therefore, to be credible, investigations must have well-defined goals and scope.

Table 1
Documents in the ISO series of standards

Document	Title	Status (Fall, 1997)
14040	LCA Principles and Framework	Draft international standard
14041	LCA Life-Cycle Inventory Analysis (mass and energy)	Draft international standard
14042	LCA Life-Cycle Impact Assessment	Committee draft
14043	LCA Interpretation	Committee draft

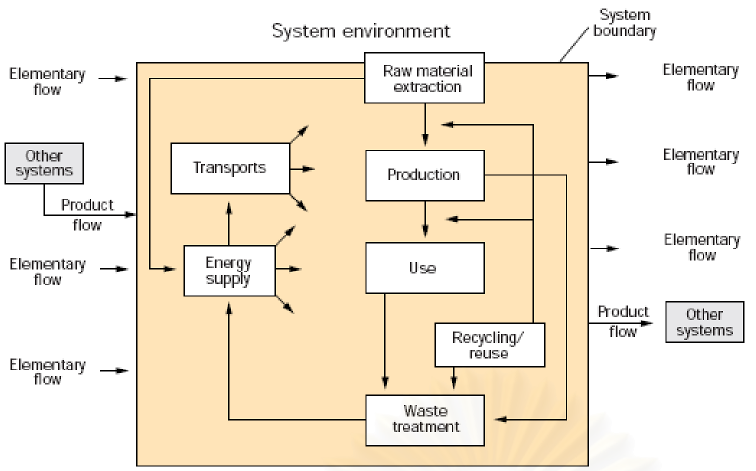


Figure 4
Example of a product system, including unit processes, elementary flows, and product flows that cross the system boundary (either into or out of the system), and intermediate product flows within the system.

In the past, the life-cycle assessment could knowingly be used to give false marketing messages. It was also self-deceptive; that is, if not scientifically well founded, it could give false guidance.

The scope of an investigation must clearly define and describe the following items:

- Function – the scope of the life-cycle assessment must specify the function of the system being studied.
- Functional unit – a functional unit is a measure of the performance of the product system's functional output. A system may comprise several functions. The function being studied must be directly dependent on the goal and scope of the assessment; moreover, its related functional unit must be measurable.

A system's boundaries determine which unit processes are to be included in the life-cycle assessment. Several factors affect system boundaries, including the intended application of the study, assumptions, cut-off criteria, data and cost constraints, and the intended audience.

Data-quality requirements specify in general terms the characteristics of the data needed for the study. The data-quality requirements of an investigation which supports a comparative assertion that is to be disclosed to the public must stand up to scrutiny. The same goes for rules that stipulate how the critical review process may be performed.

ISO 14040 defines the requirements that must be fulfilled by the life-cycle inventory analysis, the life-cycle impact analysis, the life-cycle interpretation, and the final reports.

ISO/DIS 14041 – life-cycle inventory analysis

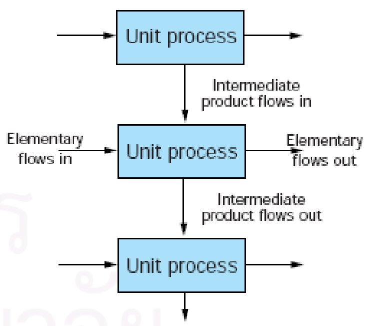
The most important part of the life-cycle inventory analysis (ISO/DIS 14041) deals with how data is collected and handled in order to give results of high integrity.

A product system is a collection of operations whose flow of intermediate products performs one or more defined functions (Figure 4). The essential property of a product system is characterized by its function; thus, a product system is not defined solely in terms of its final products.

Product systems are subdivided into unit processes, where each process encompasses the activities of a single operation or group of operations (Figure 5). Because the system is a physical system, each unit process obeys the laws of conservation of mass and energy. Therefore, mass and energy balances provide a useful check on the validity of any unit process description.

One problem with any life-cycle assessment method lies in the allocation or partitioning of the input and output flows of a unit process to the product system being studied. Life-cycle inventory analyses consist of linking unit processes within an overall system by simple material and energy flows. In practice, however, few industrial

Figure 5
Example of a unit process within a product system.



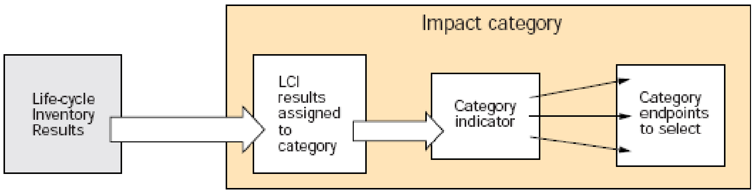


Figure 6
Schematic of concepts for defining impact categories.

processes yield a single output or are based on a linearity of raw-material input and output. In fact, most industrial processes yield more than one product and they recycle intermediate or discarded products as raw materials. ISO 14041 provides guidance on the principles and procedures of allocation.

Companies and institutions that gather mass and energy unit process data into huge data banks for subsequent sale to third parties have driven the development of life-cycle inventory methods. Their intention is to create easy-to-use database tools for designers and construction engineers whose work influences the ultimate environmental profile of a product system (design for the environment, DfE). The life-cycle inventory will also play a major role in coping with upcoming legislation in much of Northern Europe on producer responsibility – which directly addresses the cradle-to-grave flow of mass in product systems.

ISO/CD 14042 – life-cycle impact assessment

The life-cycle impact assessment assists in interpreting and identifying the significance of life-cycle inventory results, thereby making them more understandable and manageable relative to the natural environment, human health, and resources. It also helps direct the focus of other environmental techniques for assessing in greater detail a particular environmental impact and for better ascertaining the significance of the impact.

The general procedure for conducting a life-cycle impact assessment begins with selecting and defining impact categories (Figure 6). An impact category illustrates the relationship between certain inventory results and a specific indicator and its endpoint. Typical impact categories are global warming, eutrophication, and the formation of photochemical oxidants (smog). In this context, an endpoint might be a change in the climate, dead fish or hospitalized people.

Life-cycle inventory results are classified by impact category. Inventory results that solely belong to one category are assigned to that category; for example, phosphate is exclusively assigned to eutrophication. Other results relate to several categories; for example, nitrogen oxides contribute to acidification and eutrophication.

By means of modeling categories (often referred to as characterization), each contribution assigned to an indicator is normalized – through equivalency factors – to the overall category effect. The scientific relevance of using characterization and normalization factors has been the subject of much debate. Several supporting techniques have been suggested for evaluating the significance of end results. The most important application of the life-cycle inventory assessment directly compares competing product systems whose major environmental impact categories are well recognized.

ISO/CD 14043 – life-cycle interpretation

Life-cycle interpretation, which is the last phase of a complete life-cycle assessment, condenses useful results for use by clients in their decision-making processes. Some parties advocate that it is possible to bypass the life-cycle impact assessment, jumping directly from life-cycle inventory (14041) to the interpretation phase.

At the same time, the need for assessing environmental impact has given rise to several impact-evaluation models. Owing to numerous shortcomings, however, these models have not been accepted as the basis of the impact-assessment standard. In general, they

- rely on aggregated and allocated mass and

energy inventory data;
- introduce subjective weighting factors, in order to quantify impact by category;
- introduce subjective approaches for ranking the overall environmental impact with a single score;
- introduce social and economic indicators that obscure the quantification and interpretation of measurable environmental impact.

DIS 14040 explicitly states that the findings of the life-cycle assessment may not be boiled down to a single score for comparative assertion. It also reinforces the fact that social and economic factors are not part of the life-cycle assessment.

According to DIS 14043, the interpretation phase of the life-cycle assessment must include the following steps (Figure 7):
- Identify significant environmental issues.
- Evaluate the issues by
  - completeness check;
  - sensitivity check;
  - consistency check;
  - other checks.
- Draft conclusions and recommendations for the final report.

Limitations of CD 14042, as based on ISO/DIS 14041

The introduction to the current draft of ISO/CD 14042 states that the life-cycle impact assessment "has limitations that are related to both the system-wide efforts and energy and mass functional unit approach. The inventory-accounting convention may omit or not provide spatial, temporal, threshold and linear/non-linear and other environmental information."[2]

The key limitations that result from the current technical framework are: data treatment; aggregation (spatial resolution, temporal resolution, threshold and linear/non-linear modeling); allocation (general allocation procedures, recycling allocation procedures); normalization; reliance on modeled, averaged data; no link to receiving environment; and omission of critical impact.

Data treatment

Input and output data are converted into mass and energy unit values. However, when this is done, all connections to vital characterization data are lost, such as the concentration and rate of emission flows. Also, converting the data into mass and energy values builds a mass bias into subsequent calculations. This practice encourages the premature aggregation of certain output data. For instance, volatile organic compounds (VOC) are commonly aggregated at the outset, without consideration for the varying magnitude of impact that a compound or mixture of compounds might have.

Aggregation

The aggregation of mass and energy values for input and output across all unit operations removes most of the spatial, temporal, threshold and linear/non-linear information that is needed to characterize actual effects.
- *Spatial resolution.* Crucial information that could link input and output data to regional and localized effects is lost when data from different unit operations are combined.
  Example: Vital product components are obtained from many parts of the world. Some figure is used to account for the water that went into the process of manufacturing each component. However, this figure tells us nothing about the supply of water in the different parts of the world; neither does it suggest the fate of the water after its use.
- *Temporal resolution.* The aggregation of data is equally problematic from a temporal point of view, since environmental processes and their responses to emissions loading occur over different time scales. Data aggregation erases all temporal information, obscuring differences in production rates, emission rates and environmental persistence, which may vary from site to site. Example: Some releases of organic molecules into air and water disappear almost immediately, having only a negligible environmental effect. Other releases, which are environmentally potent, persist a long time in nature.

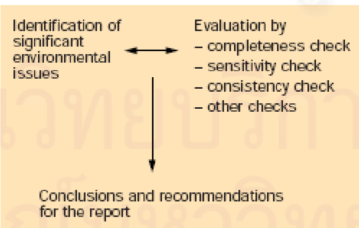


Figure 7
Steps in the interpretation phase of the life-cycle assessment.

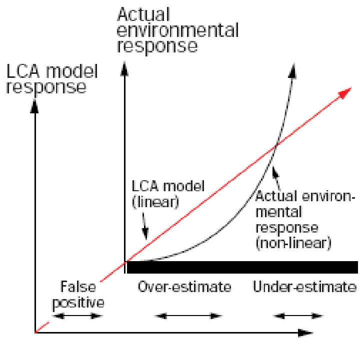


Figure 8
Presumptions about linear relationships can be very misleading.

- *Threshold and linear/non-linear modeling.* Aggregation obscures the linearity or non-linearity of responses to stressors and to the existence of thresholds. Impact modeling that is based on unit or cumulative mass and energy values creates false positives (Figure 8) when loads fall below a response threshold – the level at which adverse environmental responses may first be observed. Moreover, thresholds are not necessarily constant but may vary from site to site. Above a threshold, impact modeling based on mass and energy inventory loads cannot account for non-linear responses and may significantly underestimate the impact. Dioxins are a typical example.

Allocation

- *General allocation procedures.* The allocation of mass and energy values among the co-products of a given unit operation automatically assumes the existence of a linear relationship to environmental effects between the relative masses of co-products and their associated input and output. Although variations of the allocation approach, such as stochiometric allocation, are embedded into DIS 14041, they nonetheless retain the same subjective assumption. Example: Besides producing steel, steel-production systems also generate slag – a waste product that has found a secondary-use market and is now considered a co-product. A typical allocation of mass assigns 30% of all system input and output to slag, since that is its proportional mass relative to the total system. Nonetheless, the correlated reduction in input and output assigned to steel (100%-70%=30%) is purely arbitrary, given that the amount of iron ore or coke required to make steel has not changed.
- *Recycling allocation procedures.* The allocation of mass and energy values among virgin materials and corresponding recycled materials in an extended system assumes the existence of a linear relationship to effects between the original input and output of the virgin system and the input and output of subsequent recycling steps. However, this assumption is erroneous. With the exception of same-site closed-loop recycling systems, open-loop and closed-loop system processes do not occur in the same time period; they do not operate in the same receiving environments; and they seldom use the same technologies. Thus, identical emissions from different sites may result in a different magnitude of environmental effects.

Normalization

Mass and energy balances tend to dominate among the practice of life-cycle assessments that aim to study industrial efficiencies. Not surprisingly, then, normalization has also been geared towards this end, with the appropriate functional units of measure being per joule and per kilogram. However, the normalization of allocated and aggregated mass and energy values to corresponding functional units of mass and energy severs the links between input and output data and effects. Functional units have no relationship to the size of a manufacturing plant or to its total output. Therefore, they preclude environmental assessment, which clearly requires a different kind of normalization than what is used for studying efficiency. Example: Only a very small percentage of the output of a large refinery may be devoted to a particular solvent. In turn, only a small percentage of the solvent that is produced may be shipped for use in the system being studied. Thus, the inventory in no way represents the actual emission and environmental effects of the refinery.

Reliance on modeled, averaged data

Most life-cycle inventories rely on generic modeled-data sets for a portion of their data, often without reference to the origin of the data. Reliance on generic data can substantially increase the uncertainty of the study since the range of particular input and output data can vary greatly per functional unit. For example, the oil industry has been very good at providing generic information on their unit operations, which is an effective way of hiding low performers, since no one sees or even thinks to look for variability.

No link to the receiving environment

The only way to settle the environmental relevance of input and output data is to establish mechanistic links between input and output and actual environmental effects. Under the SETAC framework reflected in 14040, 14041 and 14042, the life-cycle assessment is disconnected from the receiving environment and cannot provide these links. Thus, it does not contain any procedures for characterizing measurement endpoints or appropriate nodal indicators.

Establishing equivalent impact potentials, such as global warming potentials (GWP) or photochemical ozone-creation potentials (POCP), is not synonymous with establishing system links to the receiving environment.

Omission of critical impact

The focus of the mass and energy framework on input and output data excludes the examination of other system activities that might cause environmental effects. For instance, although it is seldom tracked through input and output calculations, habitat depletion – as a result of land usage – is clearly a system impact. Man's use of automobiles claims vast areas of land for paved highways, which are completely devoid of biodiversity.

Together, these factors severely restrict the usefulness of the life-cycle inventory assessment in assessing the environment. Citing once again from CD 14042: "LCA based on mass and energy balances does not identify, measure or represent actual environmental impacts; does not predict potential environmental impacts, or estimate threshold exceedance; and is not a measure of safety margins or risks."[2]

Thus, while the mass- and energy-orientated life-cycle inventory is a useful engineering tool for tracking material and energy flows in industrial systems, it generally does not provide the framework for fulfilling the need of environmental management, which is to shed real guiding light on the relationship between a company's industrial activities and actual environmental effects.

Need of integrated impact assessment

Despite the shortcomings of mass- and energy-orientated life-cycle inventories for environmental management, the life-cycle assessment remains the only true scientific method being standardized within ISO 14000. Its inherent cradle-to-grave scope of assessment represents the only possible basis for comparative assessment, environmental performance evaluation and environmental labeling.

Today, CD 14042 describes the life-cycle impact assessment as being one of many tools, suggesting that LCIA emission loading and resource indicators may be used "to indicate where other environmental techniques may provide complementary data and information to decision-makers."[2]

However, it does not clarify how or when such techniques should be used in conjunction with life-cycle assessment results. The position that the life-cycle impact assessment cannot be used for assessing impact on the environment has been met with skepticism and a growing disenchantment with the entire life-cycle assessment process.

The general scientific fields of environmental assessment are well developed, ranging across a broad spectrum of environmental disciplines and techniques. Many assessment methods are sophisticated and widely practiced, collecting valuable spatial, temporal, threshold and linear/non-linear characterization information that can be applied directly for assessing the environmental significance of emissions and used resources. Moreover, the types of data these techniques generate are often readily available through government or other databases.

The integration of these techniques into the cradle-to-grave scope of the life-cycle assessment, reorients the life-cycle assessment, enabling it more effectively to meet the needs of environmental performance evaluation, environment labeling and other environmental management activities. The need of new types of data, for evaluating en-

Table 2

Resource depletion	**Emission loading**
Water	Greenhouse gases
Wood and wood fiber	Acidification
Fossil fuels, biofuels, nuclear fuels	Ground-level ozone
Oil and gas (non-fuel usage)	Stratospheric ozone layer
Metal ores (specific)	Aquatic oxygen depletion
Minerals (specific)	Human health effects from hazardous chemicals (specific)
Direct habitat depletion (from land usage)	
Marine resources	Eco-toxic (specific)

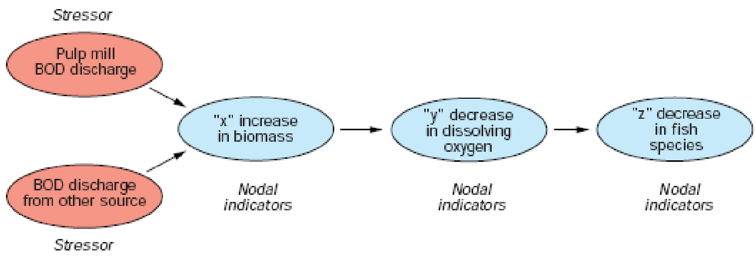


Figure 9
In this simplified stressor-effect network schematic, pulp-mill discharges combine with discharges from other sources, leading to a measurable decline in the fish population.

vironmental impact, has long been recognized within the LCA framework, as reflected, for instance, in the major findings of the SETAC workshop on life-cycle impact assessment:

"The potential for use of such data within the LCA framework can be illustrated by the example of releases that can potentially cause acidification effects. While acidification is largely attributable to SO_x and NO_x emissions, only a small fraction of given point-source emissions may actually result in a measurable acidification loading on the environment. Characterization data has been used to map out exceedances of acidity threshold by specific geographic information system (GIS) grids; such data have been compiled for much of Europe, the United States, Africa and parts of Asia. These data can be used to accurately partition out the portion of total SO_x emissions which actually results in acidification, rather than focus on the total amount released by the system.

"There are no inherent technical barriers to actually integrating useful environmental assessment techniques and their resulting environmental characterization data into the LCA framework. Equally important, by integrating these data in a formal manner, practitioners and users will be guided in a rational, consistent approach to their use."[3]

Emergence of the LCSEA – goals

The life-cycle stressor-effects assessment is the first cradle-to-grave assessment framework specifically developed for enhancing the role of the life-cycle assessment as an environmental performance evaluation and decision-making tool that complies with the objectives of ISO 14000. It is a multidisciplinary tool that explicitly integrates the life-cycle assessment into other environmental assessment techniques.

The objectives of the life-cycle stressor-effects assessment are:

- to enable users to determine the environmental significance of environmental effects caused by the input and output of industrial systems across every stage of a life cycle;
- to produce a cumulative resource-depletion and emission-loading profile of the system being studied, which can subsequently be normalized to functional units that reflect the environmental assessment objectives of the study;
- to provide necessary information for evaluating environmental performance, analyzing design and management options, and for making accurate environmental claims and product declarations;
- to satisfy the requirements of DIS 14040 and CD 14042 for comparative assertion and product declarations;
- to eliminate, at an early stage, all unnecessary life-cycle inventory work, concentrating instead on environmentally significant parts – which greatly increases cost effectiveness.

Stressor-effects networks

The stressor-effects assessment becomes the driving force of the LCA process in the LCSEA (Figures 9 and 10). Stressor-effects networks are the interlocking physical, biological and chemical events that connect a system's input, output or activity (that is, the stressor) to an observed effect on resources, the natural environment, or on human health. Stressor-effect networks may be simple or complex; often several intermediate effects, biological processes or chemical processes – called nodes – can be identified along the pathway between the initial stressors and the effect (for example, the measurement endpoint).

Stressor-effects networks may be triggered by any system-related activity. The most familiar stressor-effects networks are associated with environmental releases; for example, ground-level ozone, which is formed in the following manner:

$$VOC + NO_x + O_2 \xrightarrow{\text{UV (sunlight)}} VOC_{-1} + CO_2 + O_3 + NO_x$$

where NO_x acts as a catalyst in the presence of sunlight, oxidizing hydrocarbons into ozone. The reaction is non-linear, with a sharp spike of ozone formation when hydrocarbons (HC) or nitrous oxides (NO_x) are first introduced. Ground-level ozone has been linked to two major types of environmental effect: phytotoxicity and respiratory system effects, such as asthma in humans. In the above example, releases of NO_x and VOCs from an industrial system are stressors; the formation of ground-level ozone is a nodal indicator along the stressor-effects network; documented phytotoxicity or respiratory illness is the measurement endpoint.

A single stressor may trigger multiple effects in series or in parallel. For instance, the release of NO_x into the environment results in acidification (series effect). This in turn, increases nutrient loading in a receiving body of water, which leads to eutrophication (second series effect). Similarly, a portion of the original NO_x release lands directly on water, causing immediate eutrophication (parallel effect).

A group of stressors may also contribute to a single effect, as in the case of greenhouse gases.

Stressor-effects networks are also associated with resource extraction. Habitat depletion, for example, is caused by the bulldozing and refilling of roads that are used for harvesting timber resources. The digging and subsequent refilling of a mining pit is another example, which has significant effects on habitat and ground water. These effects, which are clearly linked to the system, would be overlooked entirely if we worked exclusively from input and output data. However, by identifying early on the stressor-effects networks associated with a given system, we can

- help ensure that the right data (data needed for drawing meaningful conclusions) is collected;
- avoid costly analysis of inventory data that has no environmental relevance.

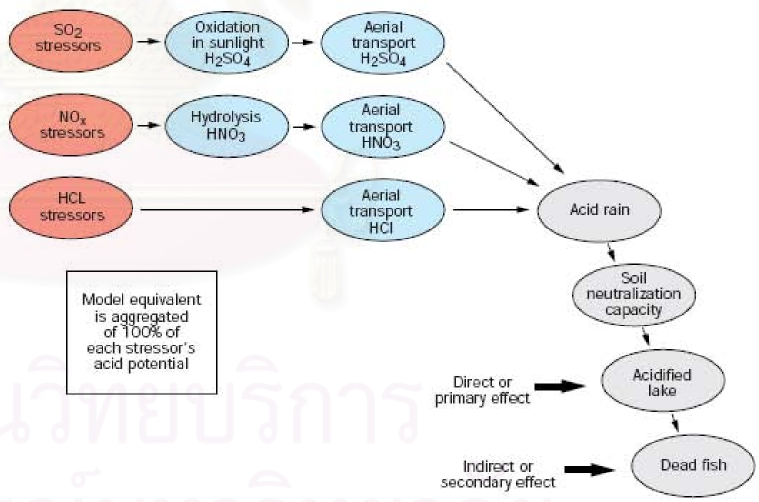
Not all system-related input and output exceed an actual threshold. When this is so, the input or output is not considered a stressor. Thanks to the stressor-effect framework, we have a systematic approach for settling this issue.

Integrating other assessment techniques into an expanded LCA framework

The life-cycle stressor-effect assessment benefits from the research and methods practice that have evolved in other areas of environmental assessment, by integrating them under the umbrella of a unified life-cycle assessment framework. Its cradle-to-grave scope ensures total-system assessments, while the integration of data generated by site-orientated impact and risk assessment techniques adds certainty to the relationship between calculated loading and effects. The extent of assessment tools and techniques that may be employed reflects the range of scientific disciplines involved in addressing environmental issues. These include resource management, toxicology, hydrology, field ecology, soil science, medical research, meteorology, climatology, and physics.

The life-cycle stressor-effects assessment condenses all information into several recognized categories of environmental impact, which are based on resource depletion and emission loading (Table 2).

Figure 10
Acid rain, which is the end result of virtually all burning processes, ultimately leads to water acidification and the death of fish.



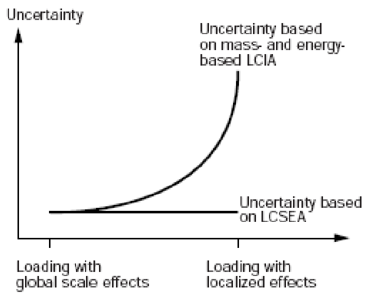


Figure 11
Using LCSEA instead of the LCIA dramatically improves the reliability of end results.

The uncertainty that plagued SETAC LCA development may largely be eliminated. Previously, the level of uncertainty was quite high for all but a few impact categories, owing to the lack of spatial, temporal, threshold and linear/non-linear resolution in traditional life-cycle impact assessments based on mass- and energy-oriented life-cycle inventories.

The only impact categories that surmount the inherent shortcomings (spatial, temporal, response shape, and threshold) of the inventory process are climate change and ozone depletion[4].

The purpose of the LCSEA framework is to reduce uncertainty by explicitly returning spatial, temporal, threshold and linear/non-linear characterization to the process (Figure 11).

Strategic significance and application of LCA techniques

The life-cycle stressor-effects assessment completes the necessary LCA toolbox, enabling stakeholders to ensure that their strategic direction into the next century is based on a sound environmental foundation. In principle, a telecommunications company needs only conduct the life-cycle stressor-effects assessment once. The results of the assessment identify – in qualitative as well as in quantitative terms – where and to what extent environmental problems exist. The assessment also identifies environmental benefits. Currently, Ericsson and AT&T are jointly conducting a life-cycle stressor-effects assessment.

Another feature of the life-cycle stressor-effects assessment is that it facilitates true comparison of the relative environmental load associated with fulfilling basic human needs for transportation, lodging, food and clothing. This information will be valuable in promoting IT-based solutions for lowering the total environmental load of societal activities in developed parts of the world (Figure 12). The life-cycle stressor-effects assessment may be used to prove the environmental superiority of telecommunication solutions.

Given the findings of a comprehensive life-cycle stressor-effects assessment, the life-cycle impact assessment and the life-cycle inventory may be practiced within a very narrow scope, in principle concentrating only on known problem areas. Preferably, all product systems will use the life-cycle impact assessment.

In general, product systems undergo a product-development phase regardless of whether the product function is expanded or not. During this phase, it is interesting to compare, from an environmental point of view, the system functionality of old and new products (Figure 13). Ericsson and Telia are currently engaged in a study of this kind (green telecom services).

After the product system has been investigated, and necessary or desirable areas of improvement have been identified, designers may apply information from the life-cycle inventory, designing for the environment. Design and engineering departments are frequently called upon to improve a product under short lead times. To aid them, special software applications are being developed that contain world environmental legislation.

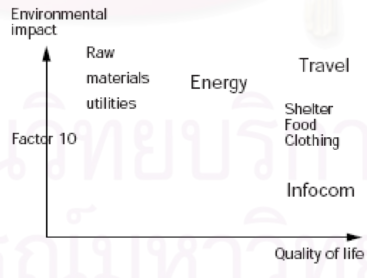


Figure 12
Compared with all other branches of industry whose aim is to satisfy basic human needs, the infocom industry has an enviable environmental position.

Future challenge

In general, normal technical development and improved environmental performance neither exclude nor contradict one another.

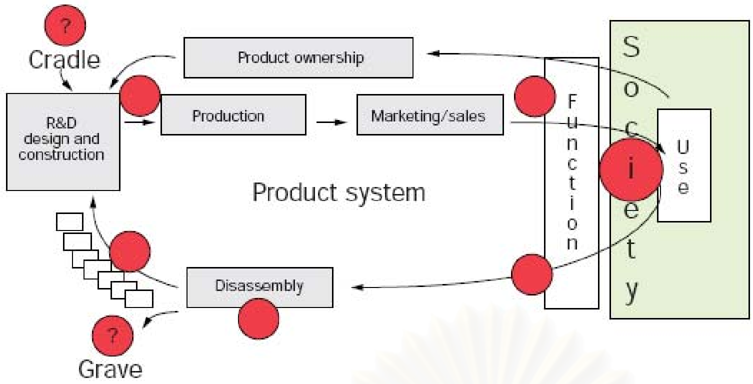


Figure 13
The contribution of environmental load from a typical product system of infocom products is represented by the areas colored in red.

Whereas the main yardstick of technical development is cost-benefit analysis, environmental improvement is measured in terms of dematerialization (services instead of mass), design for environment, and end-of-life (EOL) treatment. Offering customers more useful services that consume less mass and energy is a common denominator that also satisfies environmental requirements. However, environmental requirements restrict

- the use of certain kinds of mass (mercury, cadmium, etc.);
- the waste of energy;
- emissions of environmentally harmful waste materials.

The life-cycle assessment has not matured to the point that it can handle connections between industrial product systems and their environmental effects and economic implications. Where industry is concerned, the real value of the life-cycle assessment will manifest itself when the LCA produces a credible link between molecular and money-accounting principles.

End of Part 2. Part 1 dealt with various international perspectives of the environmental issue[5]. Part 3 describes how Ericsson can apply findings from the life-cycle assessment, designing for the environment and labeling products and services according to various developing ISO standards.

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Appendix B

Mercury and Refrigerant

Mercury

At ordinary temperatures and pressures, it is a liquid metal. More importantly, it is a reactive element. Since it was first isolated, mankind has developed and increasingly vast array of uses for mercury. Over time we have slowly become aware of the dangers of occupational mercury poisoning, but only recently have we deduced some of the actual mechanisms involved. The advances in mercury toxicology have led us full circle: we now know that the real danger for the general public lies in naturally occurring mercury compounds that accumulate in the food chain. This danger presents itself as a chronic, low-level intake of mercury compounds. However, most of our knowledge of mercury poisoning comes from studies of cases of acute poisoning. There is very little known about chronic exposure.

Most people are familiar with mercury in its elemental, liquid state. Liquid mercury can be found right in your home, either in the house's thermostat, or in a thermometer. Amalgams of mercury have been used for metallurgical purposes, and more recently for dental fillings. In fact, you probably have mercury amalgam fillings right in your mouth! Mercury also exists in many forms in nature, both as mercury vapor and in many compounds and minerals.

Mercury also exists as monomethylmercury (MeHg). This form of mercury is particularly toxic, as is participates directly in biochemical reactions. MeHg is created both by humans and by the environment. Industry uses MeHg, and in the past there have been poisonings due to industrial discharge. MeHg is also created through biomethylation processes in the environment, and this MeHg bioaccumulates primarily in fish. The greatest source of MeHg is natural biomethylation, and fish consumption is the principal source of MeHg intake for most people.

Mercury was first mined in the Spanish Almaden over 2,000 years ago. From this time, it was known that the miners would eventually get sick and usually die. This was okay, as they were prisoners and slaves. Unfortunately, man's uses of mercury grew much faster than the knowledge of the risks of mercury poisoning.

Mercury was a favorite substance of the early alchemists, and was frequently involved in the continual search for a transmutation to gold. Interestingly, mercury also found widespread use in the amalgamation process used in the refining of mined gold. This process was common until the early part of this century, and in fact continues today in mining operations in the Brazilian Amazon.

Mercury was also extensively used in the manufacture of felt hats until the early 1900's. There was a prolonged battle between industrial interests and health concerns. Mercury poisoning from felt hat production is believed to be the source of the term, "Mad as a hatter".

Mercury amalgams have been used for dental filling since the turn of century, although there has been ongoing debate over safety concerns.

MeHg has also had an unfortunate history. An industrial discharge of MeHg into Minamata Bay in Japan lead to the poisoning of local fishermen and their families in the 1950's. A similar incident occurred in Iraq in 1972 when MeHg-fungicide treated grain was released for human consumption. This led to neurological damage to several thousand people and death to several hundred. The study of cases of MeHg poisoning has led to much of our current understanding of mercury toxicity.

Mercury compounds vapor can enter the body through various pathways, including inhalation of vapor, ingestion, and skin contact. Most of our exposure to elemental mercury comes from inhalation of mercury vapor, while most of our exposure to MeHg comes from ingestion.

If we keep in mind that mercury vapor is a nonpolar, monatomic gas, and therefore lipid-soluble, it is easier to follow its journey through the body and to the brain. For example, let's follow the path of inhaled mercury vapor. From the lungs it dissolves in blood plasma, and from there it has access to diffuse into any cell in the body. Once inside a cell, mercury vapor, itself unreactive, is oxidized to the highly toxic mercury (+2) ion. This is also known as divalent mercury. This oxidation process is mediated by the enzyme catalase. Catalase normally functions in a two-step process to remove hydrogen peroxide from cells. However, in the second step of this process, mercury vapor can be oxidized to divalent mercury.

Although this seems to be an unfortunate reaction, it helps to protect the brain from mercury exposure. This is because a lot of the mercury vapor we inhale is oxidized by, and trapped in, red blood cells. This keeps most inhaled mercury vapor from ever reaching the brain.

However, some elemental mercury vapor does reach the brain, and there it is also oxidized to divalent mercury. This divalent mercury in the brain leads to strange symptoms, including erethism (mad hatterís disease). However, the process by which this happens is still not known. It is believed that divalent mercury attaches to receptors in the brain, but this is only a piece in the puzzle linking mercury in the brain to behavioral symptoms.

Monomethylmercury (MeHg) is an estimated 100 to 1000 times more toxic (than elemental mercury) to humans. In fact, MeHg seems to specifically target the advanced Central Nervous System (CNS). Until recently, this was a mystery, as the CNS enjoys the protection of the Blood Brain Barrier (BBB). The BBB consists of tightly packed endothelial cells that line the walls of the blood capillaries in the CNS. The key to understanding why MeHg is so toxic is to see that structural similarities in biochemical reactions can lead to active transport of toxins. In the case organisms with a highly advanced CNS, like humans, this active transport can lead a brain accumulation of MeHg.

As mentioned before, most of our exposure to MeHg comes from bioaccumulations in fish. When we eat contaminated fish, this ingested MeHg easily passes through the intestines and into the bloodstream. The pathway of MeHg from the bloodstream to the brain is complicated, and we think it is easiest to understand the pathway through a list of the various processes involved:

- MeHg in blood plasma can combine with cysteine, forming a compound that is structurally similar to the amino acid methionine
- This MeHg-cysteine compound is actively transported into the endothelial cells in the BBB, on the methionine carrier.
- A high level of reduced glutathione is maintained in the endothelial cells, and the MeHg switches from a cysteine carrier to a glutathione carrier.
- MeHg-glutathione is actively transported out of the endothelial cells and into the brain.
- In the brain, the hydrolysis of MeHg-glutathione generates MeHg-cysteine.

This MeHg-cysteine can now enter nerve cells in the brain, where it accumulates. The reason why it accumulates is unknown, but it is known that reduced glutathione levels are low in some neurons. It is thought that this low level of reduced glutathione might allow MeHg-cysteine to remain in the cells, unlike in the endothelial cells.

Furthermore, since MeHg-cysteine is structurally similar to the amino acid methionine, it may interfere with protein synthesis in nerve cells. This is especially likely, since methionine is always the first amino acid involved with protein synthesis. However, the exact process is not yet fully understood.

The toxicity of MeHg in the developing brain is even more complicated. MeHg has been shown to affect proteins that are involved in the assembly of microtubules in the nerve cell's cytoskeleton. By noting that microtubules are essential for nerve cell division and migration, we see how MeHg can affect brain growth and development. This is why the fetal brain is particularly sensitive to MeHg. Also, the BBB of the fetal brain is about three times more active in amino acid transport, which only makes the MeHg brain concentration rate higher.

MeHg also produces subtle changes in the production and secretion of neurotransmitters in the developing brain, which alters brain development in subtle ways. For example, MeHg has been shown to accumulate in astrocyte cells in the developing brain. One role of astrocytes is to regulate levels of the amino acid glutamate in the developing brain. It happens that glutamate is toxic to the developing brain. Since an inhibition of astrocyte cell function will enchance glutamate levels, we can see an indirect path for mercury poisoning in the brain. This is a very complex subject, and very little is known about the exact developmental changes that are expected from MeHg contamination.

The standard methods for determining the concentration of mercury compounds in the body involve urine, blood, and hair samples. The problem with these methods is that they only show a recent history of mercury exposure, whereas mercury is a cumulative toxin. Since these tests cannot account for past exposures, they are only valid indicators of recent, acute exposure. This is part of the reason that there is so little known about chronic, low-level MeHg contamination.

Can we treat mercury poisoning? Unfortunately, by the time symptoms appear, usually the damage is already done. This is complicated by the fact that mercury poisoning is difficult to diagnose. However, when mercury contamination is diagnosed and there is still a concentration of mercury in the body, chelation therapy may help. Chelation therapy involves the formation of a complex of mercury with a chelate ligand. EDTA is such a chelating ligand, and it has been used in the treatment of mercury poisoning. Doses of chelating agents increase the blood and urine concentrations of mercury, and thus help eliminate it from the body.

Since our greatest source of MeHg is from bioaccumulations in fish, we are all at risk. Fish contamination is the reason that the Great Lakes fishing industry has dissolved. Freshwater fish consumption advisories are commonplace, although we are starting to understand that MeHg levels have remained relatively steady through history, independent of human activity. There is a strong natural pathway for environmental biomethylation of mercury, and for bioaccumulation in fish.

Conclusion: It's interesting how the study of mercury toxicology has showed us that the true danger of MeHg poisoning in humans lies in the food chain. Knowledge of the effects of MeHg poisoning is still limited, though. Current areas of research include the study of the effects of MeHg on the immune system, on particular organs, on brain growth and development, and on behavioral patterns. Most of the effects involve complex biochemical reactions that are affected by the presence of mercury compounds. Particularly, there is virtually nothing known about long term, low-level exposure to MeHg. This is an important area of study, as the most common mode of MeHg intake is the long term, low-level exposure from dietary fish consumption.

Refrigerant

Chlorofluorocarbons (CFCs) are nontoxic, nonflammable chemicals containing atoms of carbon, chlorine, and fluorine. They are used in the manufacture of aerosol sprays, blowing agents for foams and packing materials, as solvents, and as refrigerants. CFCs are classified as halocarbons, a class of compounds that contain atoms of carbon and halogen atoms. Individual CFC molecules are labeled with a unique numbering system. For example, the CFC number of 11 indicates the number of atoms of carbon, hydrogen, fluorine, and chlorine (e.g. CCl3F as CFC-11). The best way to remember the system is the "rule of 90" or add 90 to the CFC number where the first digit is the number of carbon atoms (C), the second digit is the number of hydrogen atoms (H), and the third digit is number of the fluorine atoms (F). The total number of chlorine atoms (Cl) are calculated by the expression: Cl = 2(C+1) - H - F. In the example CFC-11 has one carbon, no hydrogen, one fluorine, and therefore 3 chlorine atoms.

Refrigerators in the late 1800s and early 1900s used the toxic gases, ammonia (NH3), methyl chloride (CH_3Cl), and sulfur dioxide (SO_2), as refrigerants. After a series of fatal accidents in the 1920s when methyl chloride leaked out of refrigerators, a search for a less toxic replacement begun as a collaborative effort of three American corporations- Frigidaire, General Motors, and Du Pont. CFCs were first synthesized in 1928 by Thomas Midgley, Jr. of General Motors, as safer chemicals for refrigerators used in large commercial appilications1. Frigidaire was issued the first patent, number 1,886,339, for the formula for CFCs on December 31, 1928. In 1930, General Motors and Du Pont formed the Kinetic Chemical Company to produce Freon (a Du Pont tradename for CFCs) in large quantities. By 1935 Frigidaire and its competitors had sold 8 million new refrigerators in the United States using Freon-12 (CFC-12) made by the Kinetic Chemical Company and those companies that were licensed to manufacture this compound. In 1932 the Carrier Engineering Corporation used Freon-11 (CFC-11) in the worldís first self-contained home air-conditioning unit, called the "Atmospheric Cabinet".; Because of the CFC safety record for nontoxicity, Freon became the preferred coolant in large air-conditioning systems. Public health codes in many American cities were revised to designate Freon as the only coolant that could be used in public buildings. After World War II, CFCs were used as propellants for bug sprays, paints, hair conditioners, and other health care products. During the late 1950s and early 1960s the CFCs made possible an inexpensive solution to the desire for air conditioning in many automobiles, homes, and office buildings. Later, the growth in CFC use took off worldwide with peak, annual sales of about a billion dollars (U.S.) and more than one million metric tons of CFCs produced.

Whereas CFCs are safe to use in most applications and are inert in the lower atmosphere, they do undergo significant reaction in the upper atmosphere or stratosphere. In 1974, two University of California chemists, Professor F. Sherwood Rowland and Dr. Mario Molina, showed that the CFCs could be a major source of inorganic chlorine in the stratosphere following their photolytic decomposition by UV radiation. In addition, some of the released chlorine would become active in destroying ozone in the stratosphere. Ozone is a trace gas located primarily in the stratosphere (see ozone). Ozone absorbs harmful ultraviolet radiation in the wavelengths between 280 and 320 nm of the UV-B band which can cause biological damage in plants and animals. A loss of stratospheric ozone results in more harmful

UV-B radiation reaching the Earth's surface. Chlorine released from CFCs destroys ozone in catalytic reactions where 100,000 molecules of ozone can be destroyed per chlorine atom.

A large springtime depletion of stratospheric ozone was getting worse each following year. This ozone loss was described in 1985 by British researcher Joe Farman and his colleagues. It was called ìthe Antarctic ozone holeî by others. The ozone hole was different than ozone loss in the midlatitudes. The loss was greater over Antarctic than the midlatitudes because of many factors: the unusually cold temperatures of the region, the dynamic isolation of this ìholeî, and the synergistic reactions of chlorine and bromine. Ozone loss also is enhanced in polar-regions as a result of reactions involving polar stratospheric clouds (PSCs) and in midlatitudes following volcanic eruptions. The need for controlling the CFCs became urgent.

In 1987, 27 nations signed a global environmental treaty, the Montreal Protocol to Reduce Substances that Deplete the Ozone Layer that had a provision to reduce 1986 production levels of these compounds by 50% before the year 2000. This international agreement included restrictions on production of CFC-11, -12, -113, -114, -115, and the Halons (chemicals used as a fire extinguishing agents). An amendment approved in London in 1990 was more forceful and called for the elimination of production by the year 2000. The chlorinated solvents, methyl-chloroform (CH_3CCl_3), and carbon tetrachloride (CCl_4) were added to the London Amendment.

Large amounts of reactive stratospheric chlorine in the form of chlorine monoxide (ClO) that could only result from the destruction of ozone by the CFCs in the stratosphere were observed by instruments onboard the NASA ER-2 aircraft and UARS (Upper Atmospheric Research Satellite) over some regions in North America during the winter of 19927,8. The environmental concern for CFCs follows from their long atmospheric lifetime (55 years for CFC-11 and 140 years for CFC-12, CCl2F2) which limits our ability to reduce their abundance in the atmosphere and associated future ozone loss. This resulted in the Copenhagen Amendment that further limited production and was approved later in 1992. The manufacture of these chemicals ended for the most part on January 1, 1996. The only exceptions approved were for production within developing countries and for some exempted applications in medicine (i.e., asthma inhalators) and research. The Montreal Protocol included enforcement provisions by applying economic and trade penalties should a signatory country trade or produce these banned chemicals. A total of 148 signatory countries have now signed the Montreal Protocol. Atmospheric measurements CFC-11 and CFC-12 reported in 1993 showed that their growth rates were decreasing as result of both voluntary and mandated reductions in emissions. Many CFCs and selected chlorinated solvents have either leveled off or decreased in concentration by 19,949.

The demand for the CFCs was accomodated by recycling, and reuse of existing stocks of CFCs and by the use of substitutes. Some applications, for example degreasing of metals and cleaning solvents for circuit boards, that once used CFCs now use halocarbon-free fluids, water (sometimes as steam), and diluted citric acids. Industry developed two classes of halocarbon substitutes- the hydrochlorofluorocarbons (HCFCs) and the hydrofluorocarbons (HFCs). The HCFCs include hydrogen atoms in addition to chlorine, fluorine, and carbon atoms. The advantage of using HCFCs is that the hydrogen reacts with tropospheric hydroxyl (OH), resulting in a shorter atmospheric lifetime. HCFC-22 ($CHClF_2$) has an atmospheric lifetime of about 13 years and has been used in low-demand home air-conditioning and some refrigeration applications since 1975. However, HCFCs still contain chlorine which makes it possible for them to destroy ozone. The Copenhagen amendment calls for their production to be eliminated by the year 2030. The HFCs are considered one of the best substitutes for reducing stratospheric ozone loss because of their short lifetime and lack of chlorine. In the United States, HFC-134a is used in all new domestic automobile air conditioners. For example, HFC-134a is growing rapidly in 1995 at a growth rate of about 100% per year with an atmospheric lifetime of about 12 years. (The "rule of 90" also applies for the chemical formula of HCFCs and HFCs.)

Use of the CFCs, some chlorinated solvents, and Halons should become obsolete in the next decade if the Montreal Protocol is observed by all parties and substitutes are used. The science that became the basis for the Montreal Protocol resulted in the 1995 Nobel Prize for Chemistry. The prize was awarded jointly to Professors F. S. Rowland at University of California at Irvine, M. Molina at the Massachusetts Institute of Technology, Cambridge, and Paul Crutzen at the Max-Planck-Institute for Chemistry in Mainz, Germany, for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone (in particular, by the CFCs and oxides of nitrogen).

Appendix C
Clean Development Mechanism

Naturally, Earth's atmosphere consists of various gases especially Green House Gases such as carbon dioxide (CO_2), CH_4 and N_2O. These Gas layers are like a blanket cover the earth, preventing the reflection of solar radiation outside the earth that make the earth's temperature appropriate for human and other life. However, in the last century human use fossil fuels such as petroleum, charcoal and natural gas to produce energy. CO_2, the most important green house gas, was emitted in the combustion of these fossils. It thickens the earth's blanket - atmosphere, therefore the heat on the earth's surface is accumulated and this cause Greenhouse Effect which make the earth hotter. The climate change has a big impact to the human and life on earth for example the temperature increased will melt polar icecaps and rise sea level, land will be replaced by water, islands will be disappeared, ecosystems will be changed, mangrove - a residence of coastal life will be damaged, coast will be eroded, sea water will invade to water source and cause problems in agriculture, sea level will be rising and cause the flood.

From the above effects of Climate change, it is necessary to find the way to solve problems by reducing and controlling level of GHGs emission produced in human activities. Therefore, in the 3rd session of the Conference of the Parties to the United Nations Framework Convention on Climate Change: COP in 1997, Tokyo, the Kyoto Protocol was adopted. Under this Kyoto Protocol, the industrialized countries agreed with a stronger commitment in the form of law which targets to reduce 6 types of GHGs emission: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFC), erfluorocarbons (PFC) and sulphur hexafluoride (SF_6). This Kyoto Protocol commitment was set up according to the Group of the countries which are:

Annex I countries:	Industrialized countries and undergoing the process of transition to a market economy countries
Annex II countries:	Developed and rich countries
Non-Annex I countries:	Developing countries and low developing countries

The Kyoto Protocol increase commitment only to the Annex I countries for the reason that the climate change problem concerned closely to the increment of GHGs emission produced by Annex I countries during the Industrial Revolution period. Therefore the countries in Annex I shall be responsible more than Non-Annex I countries which still have to develop life quality of its citizens.

Under Kyoto Protocol, the Annex I countries have to reduce the GHGs emitted at least 5% of the total emission level in 1990 and this target has to be fulfilled in 2008-2012. In order to achieve this target, the following mechanisms for GHGs emission reduction could be supported apart from the domestic action:

1. Joint Implementation: JI
2. Emission Trading: ET
3. Clean Development Mechanism: CDM

With JI and ET mechanisms, the countries in Annex I can coordinate among them and even trade or exchange the unit of GHGs emission. For CDM Mechanism, it allows countries in Annex I to set up the GHGs Emission Reduction project in Non-Annex I countries with the systems called “Carbon Credit”.

CDM is a mechanism under Kyoto Protocol which support the countries in Annex I (countries that agreed with the GHGs Emission Reduction targets) to achieve the commitment with the cooperation of Non Annex I countries.

“The main objective of CDM is to help Non-Annex I countries of the Kyoto Protocol or developing countries to enhance sustainable development and to be part of the process to reach the target that is to maintain the level of GHGs in atmosphere to be harmless for human and help the Annex I countries or industrialized countries to achieve their commitment in reducing GHGs emission concretely”

From the above paragraph, CDM mechanism allows industrialized countries governments or private sector to set up the GHGs Emission Reduction Project in developing countries. Besides, it is also to support the sustainable development in developing countries because CDM project support the use of new technologies; innovation and support the problem solving which is “environmentally harmonized”. CDM Project will also deliver a Certified Emission Reduction (CERs), a certificate of GHGs emission reduced from CDM project. It is an additional benefit for the Project operator and provides the possibility to run the non-cover expense project. It is also to motivate the investors from Annex I countries to invest in the project because the industrialized countries can use this CERs as a credit to fulfill their commitment under Kyoto Protocol. Meanwhile its investment helps in developing new technologies that reduce, for sustain, GHGs in developing countries.

Regulation for participation in CDM Project

1. The participation to the project under CDM should be voluntary of all parties
2. The country who can participate to the project under CDM has to be a member of Kyoto Protocol
3. Operation of the project under CDM will reduce GHGs emission concretely and measurably.
4. Operation of the project will support sustainable development in host countries or developing countries, and in the other hand it is the development with good effect to the environment, society and economic.
5. Operation of CDM project lead to the more GHGs emission reduction additional to the other projects operated previously.

To reach item 5, the baseline scenario should be imposed in order to compare the level of GHGs emission before the existing of CDM project and the one under CDM project. The investors or CDM project owner is the imposer of this baseline scenario, which should process with methodologies and has to be approved by the Executive Board of CDM.

Projects which could be part of CDM

- Enhancing efficiency of energy generation and transportation project
- Renewable energy project

- Fuel switching project
- Agricultural project (which aim to reduce N_2O and CH_4)
- Industrial process improvement project (CO_2 from cement and other GHGs in HFCs, PFCs, SF_6 group)
- Absorption project (only for afforestation and reforestation)

Thailand had given a ratification to be member of Kyoto Protocol on 28 August 2002. Since Thailand is developing country it is ranged in Non-Annex I of the United Nations Framework Convention on Climate Change therefore Thailand has no commitment to reduce GHGs in terms of duration and quantity. In any case Thailand has high risks to the impact of the climate change, the participation of this Kyoto Protocol give the chance to coordinate with internationals in solving the climate change problem as well as to have a chance to get technology transfer, sustainable development by clean technology, knowledge of research and development from Annex I countries including information exchange for the operation on climate change. In addition, Thailand could participate in project under Clean Development Mechanism after considered that it truly effect an advantage to the country.

From the National Strategy Study on Clean Development Mechanism of the Ministry of Natural Resources and Environment founded that in 1998 the total GHGs emission in Thailand was 297.6 million tons per year of which the CO_2 was emitted the most, equal to 68%. The energy sectors produced 51% of the total GHGs emission. The study result also shows that Thailand has potential in participating to three activities of CDM which are the reduction of CO_2 emission from energy sector, the reduction of methane from agricultural sector and the increment of absorption of CO_2 by the Forestry sector.

Generally, the advantage of participating to CDM Project is that Thailand will get more invest from foreign countries, as well as technology transfer and capacity building, sustainable development and other benefit such as pollution management. Nevertheless, without well consideration, the country will get risk to be depended on industrialized countries technology. In the future, if Thailand has a commitment on GHGs reduction, the country will have limited way to reach the target. Apart from this, CDM has a complicate way to operate and has an additional operation cost from the project in general as well.

UNFCCC CDM Executive Board had register 547 projects from 42 countries. In the primary market, newly-issued CERs are reported trading between €15 and €16, the variation in that range mainly down to moves in the EUA (European Union Allowance) market. Emission reduction purchase agreements are valuing CERs from projects yet to be registered at €8 to €11, according to Tradition Financial Services. CERs from projects that have reached CDM registration stage are being valued between €11.50 and €14. As well as the normal variations in pricing for buyer's share of risk and payment terms, TFS says there is now a premium for projects outside China and India as buyers look to spread their portfolios.

The buyers now are three groups

- Annex I Government (Dept for Env UK, GTZ, Danida, Japan, and EU)
- Carbon Fund (World bank, Netherlands European Carbon Facility, Italian Carbon Fund, Danish Carbon Fund, Japan Carbon Finance)

- Carbon Broker (Asia Carbon Exchange – Singapore, Traditional Finance Service UK, and Trading Emision PLC UK, North pole, and etc)

The general range in Thailand is 5-15€/CER depending on the upfront or development project paid by the buyers. Factors governing the price are the demand, crediting period, penal ty from the European Emission Trading Scheme (40€/CER before 2007 and become 100 €/CER during 2007-2011). In Thailand there are 42 projects at different phases (47% biogas, 27% biomass, 8% landfill, 8% energy efficiency, 5% biofuel, 5% thermal).

<u>Sellers in Thailand (DNA Approval 30 Jan 07)</u>

- Dan Change Bio-Energy Cogeneration Project
- Phu Khieo Bio-Energy Cogeneration Project
- A.T.Biopower Rice Husk Power Project
- Khon Kaen Sugar Power Plant Project
- Rubber Wood Residue Power Plant in Yala, Thailand
- Korat Waste to Energy Project, Thailand
- Ratchaburi Farms Biogas Project

<u>Sellers in Thailand (DNA Approval 28 Aug 07)</u>

- Suratthani Biomass Power Generation Project in Thailand
- Surin Electricity Company Limited
- Wastewater Treatment with Biogas System (UASB) in a Starch Plant for Energy and Environment Conservation at Nakorn Ratchasima
- Wastewater Treatment with Biogas System (AFFR) in a Starch Plant for Energy and Environment Conservation at Chachoengsao
- Northeastern Starch (1987) Co.,Ltd. – LPG Fuel Switching Project Chumporn Applied Biogas Technology for Advanced Waste Water Management, Thailand
- Natural Palm Oil Company Limited–1 MW Electricity Generation and Biogas Plant Project
- Jaroensompong Corporation Rachathewa Landfill Gas to Energy Project in

Only Phu Kieo and Dan Chang projects (hilighted above) are available and recomended at 12-15 €/CER for without upfront from buyer

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Source: 1. Ministry of Natural Resources and Environment
2. Collaborating Centre on Energy and Environment (UCCEE), UNEP

Appendix D

EXTERNALITY AND MONETIZED RISK

Externality costs are included in the economic production costs for the RE plants as well as for conventional production. The assessment of these environmental related costs imply two elements:

- Damage costs related to impact from local emissions
- Induced costs of GHG emissions related to the global environment

The assessment is done in a few steps. First, is the specific emissions for the RE technologies and the alternative conventional power production plants evaluated – as shown in the table below.

Specific Emissions - kg per MWh

Technology	CO2 kg/MWh	SO2 kg/MWh	NOX kg/MWh	N2O kg/MWh	CH4 kg/MWh	Particles kg/MWh	CO2-equiv. kg/MWh
RE Plants							
Municipal solid waste	68.2	0.562	0.540	0.0144	0.0216	0.478	73.3
Biomass back pressure, 1 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass back pressure 5 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass Combined Cooling and Power	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass condensing, 20 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass condensing, 5 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass condensing, 10 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biomass steam boiler, 7,5 MW	0.0	0.169	0.468	0.0144	0.1152	0.478	7.1
Biogas electricity generation	0.0	0.069	1.944	0.0018	1.0800	0.000	24.0
Biogas steam boiler, 2,5 MW	0.0	0.090	0.101	0.0072	0.0144	0.000	2.6
Mini hydro (200 kW - 6 MW)	0.0	0.000	0.000	0.0000	0.0000	0.000	0.0
Micro Hydro < 50 kW	0.0	0.000	0.000	0.0000	0.0000	0.000	0.0
Wind farm, 20 MW	0.0	0.000	0.000	0.0000	0.0000	0.000	0.0
Solar PV large scale	0.0	0.000	0.000	0.0000	0.0000	0.000	0.0
Solar PV Residential	0.0	0.000	0.000	0.0000	0.0000	0.000	0.0
Conventional power production units							
Conventional production (fuel mix)	254.0	1.049	0.775	0.0056	0.0157	0.008	256.1
Steam boiler (steam production mix)	280.8	4.187	0.540	0.0072	0.0108	0.075	283.3
Diesel Generation (small scale)	266.4	0.842	0.360	0.0072	0.0054	0.007	268.8
Natural Gas PP, 100 MW	204.8	0.001	0.605	0.0036	0.0216	0.007	206.5

Specific emission factors for the set of investigated RE technologies and for the alternative conventional production options

Then is the weighted **damage costs** calculated based on estimated damage cost for Denmark, although two adjustments are made:

- A weighted average is composed assuming that 500,000 inhabitants are living close to the power plants
- The costs are converted to the Thai context, through a PPP-based conversion[2] – reducing the costs by a factor of approximately 4.

Damage costs	CO2 THB/kg	SO2 THB/kg	NOx THB/kg	N2O THB/kg	CH4 THB/kg	PM2,5 THB/kg	Inhabitants
Rural	0.20	86	133	62	4.2	184	62,579,000
Areas close to power plants	0.20	1,634	145	62	4.2	3,636	500,000
Weigthed average	**0.2**	**98.4**	**133.4**	**62.4**	**4.2**	**211.0**	**63,079,000**

Weighted average of damage costs per kg emission

[2] PPP: Purchase Power Parities. Used for conversion of costs

The costs of the **GHG**[3] **effect** cannot be assessed directly. Hence, these costs are assumed to be the carbon price on the CDM market[4]. For the timeframe of the analysis a price of 8 EUR/ton (404 THB/ton) has been adopted. Consequently, the externality costs of emissions can be aggregated as shown in Table below.

Externalities	CO2	SO2	NOX	N2O	CH4	Particles
	Baht/kg	Baht/kg	Baht/kg	Baht/kg	Baht/kg	Baht/kg
Damage costs - regional/local	0.20	98.41	133.37	62.43	4.23	211.04
GHG value - global	0.40	0.00	0.00	129.15	8.74	0.00
Total	**0.60**	**98.41**	**133.37**	**191.58**	**12.97**	**211.04**

Externality cost of emission

RE Plants	CO2	SO2	NOX	N2O	CH4	Particles	Externality costs
	BHT/kWh	BHT/kWh	BHT/kWh	BHT/kWh	BHT/kWh	BHT/kWh	BTH/kWh
Municipal solid waste	0,0408	0,0553	0,0720	0,0028	0,0003	0,1010	**0,272**
Biomass back pressure, 1 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass back pressure 5 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass Combined Cooling and Power	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass condensing, 20 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass condensing, 5 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass condensing, 10 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biomass steam boiler, 7,5 MW	0,0000	0,0167	0,0624	0,0028	0,0015	0,1010	**0,184**
Biogas electricity generation	0,0000	0,0068	0,2593	0,0003	0,0140	0,0000	**0,280**
Biogas steam boiler, 2,5 MW	0,0000	0,0089	0,0134	0,0014	0,0002	0,0000	**0,024**
Mini hydro (200 kW - 6 MW)	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	**0,000**
Micro Hydro < 50 kW	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	**0,000**
Wind farm, 20 MW	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	**0,000**
Solar PV large scale	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	**0,000**
Solar PV Residential	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	**0,000**
Conventional power production units							
Conventional production (fuel mix)	0,1521	0,1032	0,1034	0,0011	0,0002	0,0016	**0,362**
Steam boiler (steam production mix)	0,1681	0,4120	0,0720	0,0014	0,0001	0,0159	**0,670**
Diesel Generation (small scale)	0,1595	0,0829	0,0480	0,0014	0,0001	0,0014	**0,293**

Aggregated costs of emissions including local damage costs and global GHG effects

Finally are the aggregated costs of emissions calculated for the RE technologies and for the conventional power production units. As seen in table 23 the conventional production (Thai fuel mix) shows higher costs related to emissions than most other RE technologies. The exceptions are the biogas-fired units and incineration plants for municipal solid waste that exhibit emission costs close to those for conventional production. For biomass Fig.s around half of the values for conventional production prevails. Hydro, wind and solar power production are in this context defined as neutral to the environment.

Monetized Risk

MOI notification enforces 10 million Baht insurance/situation in transportation of Hazardous waste. Situation 2004, there were 6 accidents from hazardous waste transportation. (ONEP, 2004) = 6 times or days/365 days x Insurance payment 10,000,000 Baht/year per 100 kg minimum hazardous waste transportation (end of life) =1,644 Baht/kg/10 years

[3] GHG: Green House Gas
[4] CDM: Clean Development Mechanism- one of the mechanisms under the Kyoto Agreement

Appendix E

WEEE and RoH

3 Options of WEEE compliance

1. Go it alone. The producer must register individually with the Registration Body in each state (and sometimes provincial administrations with a State), set up contracts with logistics and recycling companies, ensure proof of this being adequately carried out is supplied to the Registration Body, ensure targets are achieved and reported in the right format and at the right time.
2. Join national compliance schemes in each State. These should take on your legal liability for take back, in most cases will also register for you and ensure all the above is achieved.
3. Join one or more pan-European scheme which will provide the same service as 2 across several states. There are few candidates here; ERP and EcologyNet Europe although a few schemes operate across 2 or 3 states.

Summary of RoH document

Code	Title	Description
IEC Guide 113, 1st Ed 2000-10	Materials declaration questionnaires - Basic Guidelines	Not RoHS specific. General guidance on content of a materials declaration.
IEC 61906 draft 3/750/PAS 2004-12	Procedure for the declaration of materials in products of the electrotechnical and electronic industry	Not RoHS specific. Defines information required in a declaration including declaration of absence of restricted substances. Includes some superfluous data like masses rather than %. Defines breakdown of product. Also defines electronic data construction to be standardised with IEC 61360. Consistent with IEC 113
JIG-101 : 2005-04	Joint Industry Guide (JIG), Material Composition Declaration for Electronic Products	Defines materials and substances in EEE parts to be disclosed on materials declaration, data fields and provides examples of declarations. Considers more than just RoHS substances. - Level A Disclosure: List of substances which are prohibited, restricted or require reporting in regulations - Level B Disclosure: List of substances which have significant environmental/health/safety impact, trigger hazardous waste management regulations. or could have negative impact on EOL management

		RoHS materials with limits are contained in the Level A list. Limits are as per RoHS except 75ppm for Cd and covers all PBDEs in Level A as one category. If decaBDE is exempted from scope of RoHS this may need to be changed.
IPC 1751: 2005-05 final draft	Generic Requirements for Declaration Process Management	Methodology for materials declaration process between customers and their suppliers including creation of document that will serve as legal commitment between trading partners and may be used to establish due diligence in any dispute
IPC 1752 : 2005-05 final draft	Material Declaration Management	For parts, components, HDD, power supplies, raw materials and product. Conforms with RoHS definitions. Materials Declarations Format. Cites JIG-101. Three levels of declaration: - General: RoHS Yes/No Compliance: - Class 1: RoHS/JIG Material Content Disclosure. - Class 2: Customer specified disclosure.. Provides standard declaration text in Section 8 plus brief guidance on audit, verification of supplier's processes and sampling.
IPC 1065, 2005-01	Material Declaration Handbook	To aid PCB manufacturers and users in completing Material Declarations that follow the format and guidance of JIG-101. Supersedes drafting done under IPC 1401.
EN ISO/IEC 17050-1&2: 2004	Conformity assessment - supplier's declaration of conformity. 1: General Requirements 2: Supporting documentation	Defines general content of declaration of conformity irrespective of sector involved. Not RoHS specific but gives an idea of content and format.
JGPSSI ZVEI Version 2.1, 2004-10	Information on substances and materials in products	Developing Excel-based materials declaration Part A: umbrella specs - guidelines and forms, Part B - examples of completed specs. This version does not conform with RoHS requirements in a number of ways - % by weight of component. Contains no declaration specific to RoHS compliance

Situation of WEEE in EU

Registration and compliance schemes of EU countries

Country	Registration body	Compliance schemes
Austria	Umweltbundesamt Register online at https://www2.ubavie.gv.at/edm_ portal/index.jsp by 30 Sept 2005 Tel: (+43 1) 31 304 / 8000	EFH-Umweltforum Haushalt (UFH), all products,: +43 (0)800/10 44 10, info@ufh.at ERP - all except lighting. Not set up yet Elektro Recycling Austria, +43 (1) 485 31 49, a.rockenbauer@elektro.at
Belgium	Must complete an "Entry Agreement "with Recupel or register directly in Wallonia, Flanders, and Bruxelles capital Entry level agreements are with schemes on right	Register now. RECUPEL, 0800 40.387, info@recupel.be • BW Rec (Large household appliances) • Recupel AV (Audio-visual appliances) • Recupel ICT (IT, telecommunication and office equipment) • Recupel SDA (Small household appliances) • Recupel ET & Garden (Electrical Tools and Gardening equipment) • LightRec (Lighting equipment) • MeLaRec (Medical devices and laboratory equipment)
Cyprus	Environmental Service of the Ministry of Agriculture, Natural Resources and Environment. Registration system does not exist yet	Recovery Organisations (Compliance Systems) - none yet
Czech Republic	Ministry of Environment (may delegate) REMA are offering Entry Agreement like Recupel. +420224454224, info@weee.cz	Legislation transposed but no register yet. Deadline for registration is 15 October 2005 RETELA (Cat 3, 4, 6, 8, 9 and possibly 7),. Jaroslav Vladik, vladik@prospeksa.cz, 251 564 622 REMA - Cat 3(IT), 4, 6 and possibly 7 (i.e. IT, AV, Electric tools and garden equipment ET&ZT, Other appliances OS) Ing. David Bene_, benes@weee.cz , 2244 5 4422 ELEKTROWIN – Cat 1,2 and possibly 3,4,6. Ing. Jana Nebusová, tel. 261 217 880, jana.nabusova@cecedcz.cz
Sweden	Swedish EPA, +46 8 698 1000, gunnar.fredriksson@naturvardsverket.se Register through El-Kretsen	Existing El-Kretsen scheme., +46 8 545 212 90, Jorgen Schultz, jorgen.schultz@el-kretsen.se
Switzerland (not EU)	Responsibility of Environment Ministry but no register?	- Swico - consumer, office, IT , dental - SENS -household appliances, 0900 90 60 30, 1.49, entsorgung@sens.ch
UK	UK Environment Agencies (EA plus Scottish and Welsh devolved authorities) - but system not set up yet	The DTI has stated that it will start registration from 1 Jan 2006. Several compliance schemes are being established including by: B2B Compliance, primarily at Categories 8 and 9. 01691 676124, : action@b2bcompliance.org.uk REPIC – primarily white goods Valpak (includes IT and office equipment), info@valpak.co.uk

		Ekolamp. – cat. 5, lamps, Ing. Eva Sm__ná, smesna@ekolamp.cz ERP via Austria/Germany AREO - appliances (Czech Association of Recyclers of Electronic Waste)
Denmark	Responsibility of Danish EPA Not possible to register yet Must register direct even if member of compliace scheme	EPA Elretur Denmark - all categories
Estonia	May be Estonian Environment Information Centre . Enforcement probably by Ministry of Environment through The Environmental Inspectorate Regulation on register yet to be passed	EES-Ringlus, an association of producers, 6 307 300, 50 66 100, margus.vetsa@eesringlus.ee
Finland	Producer data register maintained by: Pirkanmaa Regional Environmental Centre	Registration by 15 May 2005 - Can fulfill obligations though: - ELKER Oy (Umbrella organisation and service provider) MD Mr.Veikko Hintsanen, tel. +358 50 4088956, veikko.hintsanen@elker.fi - SELT (Electrical and electronic equipment producer organisation forlighting equipment, heaters, professional electronics (monitors and surveillance equipment), others (additionally, producers that do not belong to the above groups, such as chain stores, belong to SELT)) Representative Ms. Tarja Hailikari, tel. +358 9 6963 722, tarja.hailikari@sstl.fi - ICTTuottajaosuuskunta (teleinformatic and telecommunication) Mr. Klaus Katara, tel. +358 9 6824 1311, klaus.katara@tkl.fi - Finnish Lamp Importers and Producers (FLIP) (lamps) Mr. Markku Nikki, Tel. +358 400 445 623, markku.nikki@philips.com - SERTY Oy (WEEE Producer Community) MD, Mr. Timo Valkonen, tel. +358 9 2705 2840, timo.valkonen@sertuottajayhteiso.fi - Federation for the technology industry is planning to be set up for B2B compliance?
France	Adème (Environment Agency) .See Registration not possible yet	Historical B2B WEEE: Final holder responsible (not producer) Alliance Tics: Cat 3. Eco-Systèmes - Cat 1,4 ERP France - all except Cat 5
Germany	Ministry of Environment responsibility Clearing house and registration is being delegated to Elektro-Altgeräte Register (EAR) Registration stated to be possible from July 2005 but can only do test now	Producer-funded takeback and treatment are now expected to begin on 1 March 2006 European Recycling Platform (ERP) - all except Cat 5 Elektro-Geraete Recycling GmbH also focuses on WEEE recycling:but perhaps not compliance scheme

	info@stiftung-ear.de, Tel: +49 911 76 66 50	ProReturn - Compliance Philips/Sharp/Loewe, Cat 3, 4 but not TV producers, Klaus Petri, 040/2852-4208, klaus.petri@philips.com Landbell (packaging scheme) also planning WEEE scheme. +49 6131 23 56 52-0, info@landbell.com EcologyNet Europe, Set up by Panasonic. B2B except Cat 5, Info@ecologynet-eu.com
Greece	Ministry of Environment, Planning and Public Works Registration not possible yet	National Scheme Recycling of Appliances SA being set up
Hungary	National Environmental Inspectorate Registration not possible yet	Electro-Coord White goods, Tóth Zoltán,: z.toth@electro-coord.hu Elektro-waste: IT, (1) 373-0491 Ökomat - gaming/vending, 06-1-236-0506 Re-elektro
Ireland	The National WEEE Registration Body, P.O. Box 10262, Dublin 2. Tel: (01) 2409320/1 The aplication to register deadline has now passed. Guarantees required and financial responsibility starts 13th Aug. 2005. Can register now. Registration is by emailing for a registration form to weeeregister@gmail.com	Distance sellers i.e. those who sell EEE via the Internet or by telephone/mail order must register Two approved compliance schemes in Ireland so far Both will deal only with "household WEEE" initially. Membership of a compliance scheme is accepted as having a guarantee: WEEEIreland - WEEE Ireland, +353 (0) 1 2999320, info@weeeireland.ie B2Bcompliance in the UK is in discussion with the Irish government with a view to setting up a similar compliance scheme in Ireland ERP - 00.32.2.777.0538, info@erp-recycling.org
Italy	To be set up close to Ministry of Environment. Registration with Chamber of Commerce Registration not yet possible	La Federazione Nazionale imprese elettrotecniche ed elettroniche (ANIE) is setting up compliance schemes though none appear targeted at business WEEE EcoR'It - business and domestic compljance scheme in development
Latvia	State Environmental, Geological and Meteorological Agency and http://www.lva.gov.lv/lea Not clear if can register thorugh LZE yet	Compliance schemes being set up: - CECED -Latvia - Latvian Green Elektrons (Latvijas Za_ais Elektrons) (LZE), Tel: +7320628; info@lze.lv
Lithuania	Responsibility of Ministry of Environment or Environment Agency Vilma Karosien_, Tel. +370 5 266 35 13, v.karosiene@am.lt Registration not yet possible	Setting up compliance schemes but do not appear active - CECED Lithuania - INFOBALT (ICT), +370 52 62 26 23, office@infobalt.lt - Green Dot Lithuania (_aliasis ta_kas) -packaging scheme possibly considering setting up WEEE scheme, (+370) 5-233 11 52, office@zaliasistaskas.lt
Luxembourg	Ministry of the Environment Ecotrel is responsible for handling registration too, (00352) 26098-731 Mr. Serge Less at the Ministry of Environment: +352 40 56 56 52-2	Compliance scheme ECOTREL
Malta	The Malta Environment and Planning Authority (MEPA) responsible for setting up register. Not in place yet. weee@mepa.org.mt Vincent Gauci, ncent.gauci@mepa.org.mt	Development of compliance schemes is the responsibility of producers.

Netherlands	VROM responsible. Senternovem is responsible for handling registration: evoa@senternovem.nl NVMP is responsible for registering importer/ manufacturer who markets product for the first time.	NVMP (consumer electronics mostly), Tel: +31 79 353 1123, nvmp@fme.nl ICT Milieu or ICT Office (ICT products, computers, telephones etc.), Tel: +31 348 49 36 36 , marian.oppelaar@N0SPAM.ictoffice.nl Stichting Lightrec -lighting
Norway (not EC)	Norwegian Pollution Control Authority (SFT) , (under Ministry of the Environment).	Producer must join take back scheme under existing regulations. - Elretur all types, +47 23 06 07 40, adm@elretur.no - Renas industrial and commercial. 22 13 52 00, renas@renas.no already in existence and likely to continue as main compliance scheme.
Poland	Responsibility of the Chief Inspector of Environmental Protection -may be delegated Ms. Izabela Szadura, Head of Market Inspection, +48 22 59-28-105, : i.szadura@gios.gov.pl	CECED Poland is working with Polish Chamber of Electronics and Telecommunication (KIGEiT) and Philips (lamps) to form joint or possibly separate organisations. ERP
Portugal	Body to be set up under by producer associations and collective compliance system under licence from Instituto dos Residuos (INR) which is setting up a web portal but not functioning yet isabel.andrade@inresiduos.pt, tel: +351 218 424 047 All producers must register even if in compliance scheme.	Collective or takeback systembeing developed but not operational Amb3E - air con? APIRAC ((Portuguese Association of Refrigeration and Air Conditioning Industry), Tel. +351 213 224 260, E-mail: apirac@metcabo.pt
Slovakia	The Ministry of Environment, +421 2 59561111, 59562383, 59562388, info@enviro.gov.sk Registration possible now. From 1 September 2005 onwards, companies not registered may be banned from selling their products in Slovakia.	CECED Slovakia setting up scheme http://www.cecedslovakia.sk/ Envidom - Large household and Small household appliances (Cat 1 and 2). +421 2 50 221 300, info@envidom.sk Sewa - IT and Telecom equipment and Consumer equipment (Cat 3 and 4) . Ing. Ji_i Mikulenka, mikulenka@sewa.sk or sewa@sewa.sk, +421 (02) 55 64 23 28 Ekolamp, lights, lighting equipment (Cat 5). 274 810 481, info@ekolamp.cz
Slovenia	Ministry of Environment and Spatial Planning	Large household - Gorenje may be setting up scheme Lamps - European Lamp Federation possibly
Spain	Ministry of the Environment One national register yet to be set up, but the regional level registration deadline has now passed.	SIG lámparas AMBILAMP -lighting - +34 91 5669712 ECOTIC - includes sub schemes for consumer, professional, telecom and other ecotic@ecotic.org ECOLEC - domestic electrical, Tel: 91 418 5022, ecolec@ecolec.es ECOFIMATICA - office electrical - AFEC, 91 417 08 90, asimelec@asimelec.es TRAGAMOVIL -mobiles, 91 417 08 90, asimelec@asimelec.es ECOPILAS - batteries, by ASIMELEC, +: 91 417 08 90, asimelec@asimelec.es SIGCLIMA - air conditioning - set up by AFEC, +34 91 402 73 83

Appendix F Detail Scope of ENVIROGY

Table F.1 Detail scope of ENVIROGY's components "E" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	Design, Transport, and Manufacture	Retrofit (Saving)	Operate (Consumption)	Collect and Transport to Recycle Plant	Recycle and Disposal
Energy consumption and saving : Retrofitting of office buildings shows the cost-effective energy savings 20-30%. (Dascalaki and Santamouris, 2002) 1 kWh:3.6 MJ 1 kWh:2.5 Baht 1 MJ: 0.7 Baht	*Fluorescent Lamp* 34 MJ or 1% of energy consumption occurs during design and manufacturing phase (Masoni, 2005) *Air-conditioner* 122 MJ 34 kWh for production of one air conditioner (Chen and Hussein, 2005)	*Fluorescent Lamp* 378 MJ (105 kWh) *Air-conditioner* *44,701MJ* (12,417 kWh) (ECCT, 2000) Cost of energy, efficiency, impact on air pollution, and policy in Nigeria were studied and come out with the recommendations for improving the energy supply situation (Anozie et al., 2007)	*Fluorescent Lamp* 3,405 MJ (946 kWh) *Air-conditioner* *103,478 MJ* (28,744 kWh) (ECCT, 2000) Energy consumption is used as an indicator in the rating methodology for classifying of the office building (Santamouris and Dascalaki, 2002: Lim 1977) The energy savings in the order of 20-30% can be achieved in office buildings. (Dascalaki and Santamouris, 2002)	*Fluorescent Lamp* 0.07 MJ 100 km 3.5 ton truck (GaBi, 2006) *Air-conditioner* 11.6 MJ 100 km 3.5 ton truck (GaBi, 2006)	*Fluorescent Lamp* 0.15 MJ (GaBi, 2006) *Air-conditioner* 6.9 MJ (GaBi, 2006) Remark: Aluminum recycle reduces energy consumption 80% compared to the production of virgin material (Gao W, 2001) and likewise 50% for steel (Peuportier B.L.P. 2001)

Table F.2 Detail scope of ENVIROGY's components "N" (practically and homogeneously summing for 10 year lifetime: shaded is domin

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Net waste recycling cost: energy efficiency must be done by considering waste management (Dasgupta, 1999)	No recycle LCA models of waste management often calculate the environmental burdens per kg of waste by neglecting the production and use of the materials. This simplification is sometime called the "zero burden assumption". (Ekvall 2007)	No recycle The electronics and telecommunication industries recycle a wide range of used products, combine in-house collection and transport services. (Fthenakis, VM, 2000)	No recycle	There is some cost from collecting to the recycling factory. 4,500 Baht/3 tons, 200 km or 1.5 Baht/kg (GENCO, 2007) A landfill site for ultimate disposal is being selected westward in Ratchaburi about 100 km from the Center (Lohwongwatana 1990)	Recycling cost in USA per ft is about 4 Baht (Energy Service, 2004) and is 1 Baht/lamp for Thailand (PCD 2004) Average cost is 2.5 Baht and 2.86 from allocation of energy consumption for each type of material. Recycling cost of air-conditioner from a factory type 106 (DIW, 2002) is 1,225 Baht and 1,236 Baht from allocation of energy consumption for each type of material recycle. The scrap value is assumed from 75% recyclable parts and the value is 5% of new value. For fluorescent lamp 75% x 70 Baht x 5% = 2.6 Baht. For air-conditioner 75% x 20,000 Bahtx5% = 750 Baht

Table F.3 Detail scope of ENVIROGY's components "V" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Violence impact or disposal cost of hazardous waste (assumed that no leakage and proper disposal): There are direct (people and property) and indirect damage (residents in vicinity and ecological effect) from the consequent impacts of material spills. (Abkowitz and Cheng, 1998)	Before retrofit	No leakage	No leakage	No leakage	The mercury contained in disposed lamps is a toxic metal, can affect human's health. However, current recycling of FLs captures the mercury. (Tharumarajah, 2005) The volume of waste electrical appliances that is actually disposed will be reduced from the increased continuous percentage of recycle (Lee, 2007) Genco charges 9,000 Baht/ton of lamp and 5,800 Baht/ton of air-conditioner (GENCO, 2007)

Table F.4 Detail scope of ENVIROGY's components "I" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Investment cost for retrofitting in alternative system can save 20% or even exceed 40% (Santamouris et al., 1996)	Before retrofit	Equipment and Labor for alternative cooling system and advance fluorescent lighting can save 20% or even exceed 40% saving (Santamouris et al., 1996)	Maintenance cost has been added at the beginning of retrofitting (Santamouris et al., 1996)	Normally not in the investment cost	Option to account investment of recycling plant per lamp

Table F.5 Detail scope of ENVIROGY's components "R" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Risk costing: RCB (Risk Cost Benefit) objective function: Revenue = NPV (Benefit + Cost + Risk or probability of failure x cost of failure x uncertainty of cost of failure) (Khadam and Kaluarachchi, 2003) A set of 47 experts in the field of risk analysis and assessment were approached.	Before retrofit	Risk assessment becomes fundamental to all phases of the development of waste management facilities but this is assumed of no risk (Pollard, 2006)	The cost of residual risk from operation remained in nature is a function of the risk level and the exposed population C=f(R, P). The actual cost of risk to receptors would equal their willingness to pay to avoid the risks. Risk measurement is important when we attempt to use indirect cost measure, which reflect human response to perceived risk. e.g. diminished property values around landfills reflect perceived risk. (Farber, 1992) It is assumed that there is no risk during operation	In planning of hazardous waste management, the estimation of cost/risk (total cost should include cost/risk of transportation, treatment and disposal of wastes) (Misra and Pandey, 2004) Risk in terms of transportation cost hazardous material is used in the optimization to minimize both risk and cost (Abkowitz and Cheng, 1998) From the Report on Environment Quality Situation 2004, there were 6 accidents from hazardous waste transportation. (ONEP, 2004)	The use of Hg in lamps is declining in EU because of the shifting of technology to energy efficient lamp. Risk assessment and proposal for risk management of Hg in waste among the population in the EU the European Inventory of Existing Commercial Chemical Substances (EIECCS) are urgently required. (Mukherjee, A.B. et. al, 2004) Risk needs to be reduced from the beginning of product design to reduce the risk from used product (Mukherjee, A.B. et. al, 2004)

Table F.5 (Continued)

ENVIROGY	Design, Transport, and Manufacture	Retrofit (Saving)	Operate (Consumption)	Collect and Transport to Recycle Plant	Recycle and Disposal
Each expert was asked to give perceived risk value of management activities associated with different waste types. (Ahuluwalia and Nema, 2007)				The risk of accident is estimated in terms of mathematical expectation. However, this can provoke a serious loss of information, especially when a low probability event has an associated large effect as in the case of major nuclear accidents. (Romerio, 1998) MOI notification enforces 10 million Baht insurance/situation in transportation of Hazardous waste (0.1% payment from budget) =6 times or days/365 days x Insurance payment 100,000 Baht/year (end of life) =1,644 Baht	

Table F.6 Detail scope of ENVIROGY's components "O" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Operating impact: Electrical and Electronics Institute (EEI Thailand) in 2005 had studied LCA for air conditioner The major impact is occurred from operation because of the power mix used in energy consumption (93% CO2 eimiision)	Before retrofit environmental impact is 193 points where as 1.9 point from manufacturing, and -0.15 point from recycling (with the impact category of Eco-indicator 95 i.e. GHG, ODP, acidification, eutrophication, heavy metal, carcinogen, photochemical oxidant formation, energy resources consumption, and solid waste)	CO2 is selected as one of the multi-criteria approaches of an architectural and technical issue in the evaluation of office building retrofitting strategies. CO2 emission is accounted from the emission of energy supply to equipment. (Rey, 2004:) The emission factor for CO2 eq. is 1 whereas the factor is 1,700 and 4,000 for HCFC 22 and CFC 11 respectively (Scheuer C. et al., 2003) Jointness and externality were long seen as accidental coincidences occurring through certain economic activities (Mann, 2007)	Environment impact, cost, and perceived risk are considered and traded off to develop the optimization model for management of waste using life cycle basis. (Ahuluwalia and Nema, 2007) CO2 emission is calculated in order to be used for the comparison of technologies./ (Pacca: Kirkeby JT et al: and Kanan R et al.:Josa, 2007: Ardente F. Et al., 2003,: Shimazaki, 2003: Sretha RM, 2007: Lu, 2007). Externalities had been established in economics, but few consideration of energy. (Krewitt, 2002)	Greenhouse Gases (GHGs) and especially CO2 emissions released from fossil fuel combustion constitute another source of social damages, in particular to forthcoming generations. (Diakoulaki et al., 2007) External cost, pollution damage (CO2 emission included), is accounted in the life cost analysis of alternative fuels in Thailand (Goedecke, 2007) 0.2% CO2 emission during transportation in the LCA of air-conditioner (EEI, 2005)	2.8% of CO2 emission during recycling of air-conditioner (EEI, 2005)

Table F.6 (continued)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
Externality by direct approach (Contingent Valuation Method) asks individuals for their willingness to pay to avoidenvironmental risks whereas indirect approach relates marketed to goods. (Diakoulaki et al., 2007)	LCA of fluorescent lamp show the same corresponding results (Tantemsapya and Yossapol 2005) 3.5% CO_2 emission during manufacturing of air-conditioner (EEI, 2005)	In the beginning of the 1990, the European Commission's Fifth Environmental Action Program "Towards Sustainability" requires the integration of the environmental dimension in other policy areas. One of key elements of this Program was to get prices right and to ensure that environmental externalities are accounted for in market mechanisms. (Krewitt, 2002)	The study of emissions generated at specific sources and, and their impacts on receptors known as ExternalE (External cost of energy) by European Commission 2003 had finalized the impact in terms of kg CO_2 equivalent/kWh (Fthenakis VM., 2007) The economic assessment of windfarm in Scotland had included externality (Moran and Sherrington, 2007: Srinivasan, 2007). Externality cost from power generation to environment and social is calculated from abatement plus damage costing approach and converted to financial value.		

Table F.6 (continued)

ENVIROGY	**Design, Transport, and Manufacture**	**Retrofit (Saving)**	**Operate (Consumption)**	**Collect and Transport to Recycle Plant**	**Recycle and Disposal**
			. In Thailand, the EFE foundation had studied the externality for each type of renewable energy whereas the PRET project by the Department of Alternative Energy Development and Efficiency had converted the externality from European countries to Thailand by the power purchase parity (GDP Thai / GDP European countries). The result shows the Externality 0.362 Baht/kWh of electricity consumption (PRET, 2005)		

Table F.7 Detail scope of ENVIROGY's components "G" (practically and homogeneously summing for 10 year lifetime: shaded is dominant)

ENVIROGY	Design, Transport, and Manufacture	Retrofit (Saving)	Operate (Consumption)	Collect and Transport to Recycle Plant	Recycle and Disposal
Government intervention; Policy instruments such as subsidies, income tax deduction and a carbon tax, as well as potential future cost degression of energy efficiency measures (Amstalden, 2007) The conservation incentive can be affected by the uncertainty of government aspects. (Koskela, 2007)	Before retrofit	30% investment subsidy had been paid for energy conservation in government buildings (ECCT, 2003). 1Investment tax is used as a part of energy conservation policy (Sparrow, 1979) To promote the use of E10 gasohol, the Thai government reduced the fuel tax (Goedecke, 2007) Without government intervention the biomass markets analysed might not have existed at all in France (Vollebergh H.) 30% subsidizes from Standard Measures Project in retrofitting of fluorescent and air-conditioner for commercial building (SM Project, 2002)	It is the major task of governmental policy to induce conservation before it is economically acceptable or possible. (Gool, 1980: Jehlickova and Morris, 2007)) Minimum Energy Performance Standard (MEPS) in Australia is mandated for appliance including air conditioner (Harrington and Wilkenfeld 1997) likewise in Japan (Nakagami, 1997)	Carbon tax in the UK is exempt from the tax of transportation sector (Torres and Pearson, 2000)	To impose a tax on waste generators or disposers to raise revenue for cleanup would be equivalent to public provision of insurance to past polluters (Segerson, 1987) The Taiwan government imposes a combined product charge and subsidy policy to provide enough economic incentive for recycling various kinds of packaging containers, such as iron, aluminum, paper, glass and plastic. (Bor YJ. et al., 2004)

Table F.8 Detail scope of ENVIROGY's components "Y" (practically and homogeneously summing for 10 year lifetime: shaded is dominant,

ENVIROGY	Design, Transport, and Manufacture	Retrofit (Saving)	Operate (Consumption)	Collect and Transport to Recycle Plant	Recycle and Disposal
Yield from CDM (CO_2 reduction) The dumping of carbon dioxide and ash into the atmosphere at rates much greater than those at present will not be desirable in future, in view of possible climate effect (Appleby AJ. 1976) The rapid economy development and increasing energy demand promptly intensify the environmental pollution.	Before retrofit	Cost per unit of CO_2 emission reduction from energy efficiency sector is averaged, in China, at 6 USD/ton CO_2 reduction (Oliviera, and Rosa 2003: Kaneko, 2006) and 10 USD/ton CO_2 reduction in Iran (Pour and Ardestani, 2007) 4-5 USD/ton from the project being implemented under the World Bank's Prototype Carbon Fund (Timilsina and Shrestha, 2006) 3-12 USD/ton CO_2 reduction from DANIDA 2007 and 8 USD from ERM Siam 2005 and 0.256 kg CO_2 equivalent/kWh (PRET, 2005)	Accounted in retrofitting	No CO_2 reduction	CO_2 is used as considered output in the economic analyses of waste disposal options inIndia (Aye L. and Widjaya ER., 2006) 30% of CO_2 emission will be reduced compared to the virgin feedstock emission of plastic production but neglect in this study related to the small amount of energy used in recycling (Willmott and Sarma, 2002)

Table F.8 (Continued)

ENVIROGY	Design, Transport, and Manufacture	Retrofit (Saving)	Operate (Consumption)	Collect and Transport to Recycle Plant	Recycle and Disposal
The Kyoto Protocol to the United Nation Framework Convention on Climate Change proposed the Clean Development Mechanism (CDM). It aims at assisting developing country parties to assisting developed countries to the obligation of reduction in the Kyoto Protocol in lower cost. (Dong and Hong, 2000: Uddin, 2006)		Cost per unit of CO_2 emission reduction from energy efficiency sector is averaged, in China, at 6 USD/ton CO_2 reduction (Kaneko, 2006)			

Appendix G

Category and Indicator in Environmental Design of Industrial Product

Bulk Waste in category and indicator in Environmental Design of Industrial Product (EDIP 1997)

Bulk waste
Aluminum (unspecified) [Consumer waste]
Auxiliary material [Consumer waste]
Bulky waste [Consumer waste]
Bulky waste from steel production [Consumer waste]
Calcium [Consumer waste]
Cardboard [Consumer waste]
Cardboard, fluting/liner (100% recycled) [Consumer waste]
Chloride (unspecified) [Consumer waste]
Dye house sludge (unspecified bulk waste) [Consumer waste]
Glass (unspecified) [Consumer waste]
Glass web (epoxy-impregnated) [Consumer waste]
Industrial waste for municipal disposal [Consumer waste]
inert chemical waste [Consumer waste]
Iron chips [Consumer waste]
Laminate for PCB, FR4 [Consumer waste]
Landfill, cabinet [Consumer waste]
Landfill, LiIon battery package [Consumer waste]
Landfilling of buttons and zippers [Consumer waste]
Landfilling of cotton [Consumer waste]
Landfilling of synthetic fibers [Consumer waste]
Landfilling of viscose [Consumer waste]
Liquid waste [Consumer waste]
Mineral waste [Consumer waste]
Municipal waste [Consumer waste]
Newsprint [Consumer waste]
Organic waste [Consumer waste]
Packaging waste (metal) [Consumer waste]
Packaging waste (plastic) [Consumer waste]
Paper (unspecified) [Consumer waste]
Polyethylene (PE, unspecified) [Consumer waste]
Polyethylene terephthalate (PET, unspecified) [Consumer waste]
Polypropylene (PP, unspecified) [Consumer waste]
Polystyrene (PS, unspecified) [Consumer waste]
Polyvinyl idenchloride (PVDC, unspecified) [Consumer waste]
Polyvinylchloride (PVC, unspecified) [Consumer waste]
Rubber [Consumer waste]

Category and indicator Environmental Design of Industrial Product (EDIP 1997) (Continued)

Sand from casting [Consumer waste]
Scrap waste [Waste for recovery]
Stainless steel cuttings [Consumer waste]
Steel (ECCS) [Consumer waste]
Unspecified biomass [Consumer waste]
Unspecified dust (harmless) [Consumer waste]
Unspecified grease lubricant [Consumer waste]
Unspecified industrial waste [Consumer waste]
Unspecified plastic, pure [Waste for recovery]
Unspecified scrap waste [Consumer waste]
Unspecified sludge [Consumer waste]
Unspecified waste from steel production [Consumer waste]
Unspecified waste from steel production (internal) [Consumer waste]
Waste (unspecified) [Consumer waste]
Wood, hard, dry matter (raw material) [Consumer waste]

Hazardous waste in catergory and indicator in Environmental Design of Industrial Product (EDIP 1997)

Hazardous waste
Zinc concentrate [Hazardous waste]
Unspecified oil waste [Hazardous waste]
Unspecified heavy metal sludge [Hazardous waste]
Unspecified dust with heavy metals [Hazardous waste]
Toxic chemicals (unspecified) [Hazardous waste for disposal]
Soil and sand containing heavy metals [Hazardous waste for disposal]
Sludge [Hazardous waste]
Slag [Hazardous waste]
Sewage sludge (waste water processing) [Hazardous waste]
Pesticides, unspecified [Hazardous waste]
Perchlorethylene (tetrachlorethene) [Hazardous waste]
Perchlor (tetrachlorethylene) [Hazardous waste]
Painting sludge [Hazardous waste]
Oil sludge [Hazardous waste]
Nontoxic chemicals [Hazardous waste]
Liquid hazardous waste [Hazardous waste]
Lead dross [Hazardous waste for disposal]
Inert chemical waste [Hazardous waste]
Heavy metal sludge [Hazardous waste]
Hazardous waste from steel production [Hazardous waste]
Hazardous waste (unspec.) [Hazardous waste]
Glass containing heavy metals [Hazardous waste]
Galvanic sludge from zinc electroplating [Hazardous waste for disposal]
Galvanic sludge [Hazardous waste]
Filter dust [Hazardous waste]
Ferriferous furnace slag [Hazardous waste]

Hazardous waste in catergory and indicator in Environmental Design of Industrial Product (EDIP 1997) (Continued)

Dust containing zinc [Hazardous waste]
Dust containing heavy metals [Hazardous waste]
Copper chloride, hazardous waste [Hazardous waste]
Cobalt [Hazardous waste]
Chromium [Hazardous waste]
Catalysts material [Hazardous waste]
Atrazine [Hazardous waste]

Radioactive waste in catergory and indicator in Environmental Design of Industrial Product (EDIP 1997)

Radioactive waste
Waste radioactive [Radioactive waste]
Uranium spent as residue [Radioactive waste]
Uranium depleted [Radioactive waste]
Plutonium as residual product [Radioactive waste]
Jacket and body material [Radioactive waste]
Highly-active fission product solution [Radioactive waste]
Highly radioactive waste [Radioactive waste]
Fission materials [Radioactive waste]

Slag and ashes in catergory and indicator in Environmental Design of Industrial Product (EDIP 1997)

Slag and ashes
Slag and ash (content zinc) [Stockpile goods]
Slag and ash (content FeOH3) [Stockpile goods]
Slag and ash (content copper) [Stockpile goods]
Table 5.3 (continued)
Slag and ash (content aluminium) [Stockpile goods]
Slag and ash (content Al2O3) [Stockpile goods]
Slag and ash [Stockpile goods]
Slag (unspecified) [Stockpile goods]
Slag (content manganese) [Stockpile goods]
Nickel containing slag [Hazardous waste for disposal]
HF in slag and ashes [Hazardous waste]
HCl in slag and ashes [Hazardous waste]
Furnace slags, harmless [Stockpile goods]
Fly ash (unspecified) [Stockpile goods]
Copper containing slag [Hazardous waste for disposal]
Chromium containing slag [Hazardous waste for disposal]
Ash [Stockpile goods]

Appenedix H

Manual of ENVIROGY Spreadsheet

1. To calculate ENVIROGY, there are many related parameters. Table of input below is preliminary used for calculation for fluorescent lamp and air-conditioner including its unit.

Input Table and Financial Factors

Parameter	Unit	Input	Composition (%)	Total Weight (kg)	% Recovery	Recovery Saving (kWh/kg)	Subsidy 0%
Investment FL & maintenance	Baht/FL	70					0%
Aluminum in FL	kg/FL	0.01	5		75%	17	
Glass in FL	kg/FL	0.18	90	0.20001	75%	1	
Hg 10e-5 + phosphor 10 e-2 kg	kg/FL	0.01001	5				
Labor cost	Baht/kg	0					
New Capacity	Watt/FL	36					
Compared capacity	Watt/FL	40					
Operating factor	%	40					
Hg recovery cost	Baht/FL	0					
revenue from glass	Baht/kg	0.50					
revenue from aluminum	Baht/kg	35					
revenue from other scrap	Baht/kg	0					
Collecting 200 km 3 ton truck	Baht/kg	1.5					
Investment AC & maintenance	Baht/AC	20000					0%
Aluminum in AC	kg/AC	1.7	5		75%	17	
Copper in AC	kg/AC	3.23	10		75%	7	
HCFCR22 in AC	kg/AC	1	3	31.6			
Plastic in AC	kg/AC	1.63	5		75%	6	
Steel in AC	kg/AC	24	76		75%	4	
Labor cost:remove & install	Baht/AC	4,000					
Compared kW/ton	kW/ton	1.25					
kW/ton of AC (12,000 Btu)	kW/ton	2.00					
Operating day	%	80					
On-off factor	%	80					
Operating factor-compressor	%	80					
Refrigerant recovery cost	Baht/AC	176					
revenue from refrigerant	Baht/kg	0					
revenue from compressor	Baht/kg	500					
revenue from scrap	Baht/set	160					
Collecting 200 km 3 ton truck	Baht/kg	1.5					
Externality cost CO2 equivalent	Baht/kWh	0.36					
CO2 equivalent emission	kg/kWh	0.26					
Price of a ton CO2 reduction	Baht/kg	0.32					
Disposal Cost for FL	Baht/kg	9.0					
Disposal Cost for AC	Baht/kg	5.8					
Average price of electricity	Baht/kWh	2.5					
Monetized risk - 10 yrs (R)	Baht/kg	1,644					

Financial Factors

Cost of Recycling	Baht	Discount	rate	
Recycling cost: Baht/FL	1	Inflation	(f)	3.5
Recycling cost: Baht/AC	1,236	Interest	(r)	3.0
		discount	(d)	-0.2

2. To conduct the sensitivity analysis for the calculation of ENVIROGY, each input parameter is varied to 5% and 10% both positive and negative direction. After that, the calculation of ENVIROGY varied to input will be calculated and find out of the sensitivity (changed amount related to the amount before varying of input parameter)

Variation of Input Parameters

Variation of Input for Sensivity Analysis					MCA
-10%	-5%	0%	5%	10%	0
63	67	70	74	77	70
0.0090	0.0095	0.0100	0.0105	0.0110	0.0100
0.16	0.17	0.18	0.19	0.20	0.18
0.009	0.010	0.010	0.011	0.011	0.010
0	0	0	0	0	0
32	34	36	38	40	36.0
36	38	40	42	44	40.0
36	38	40	42	44	40.0
0	0	0	0	0	0
0.45	0.48	0.50	0.53	0.55	0.50
32	33	35	37	39	35.0
0	0	0	0	0	0
1.4	1.4	1.5	1.6	1.7	1.5
18,000	19,000	20,000	21,000	22,000	20,000
1.5	1.6	1.7	1.8	1.9	1.7
2.9	3.1	3.2	3.4	3.6	3.23
0.9	1.0	1.0	1.1	1.1	1.00
1.5	1.5	1.6	1.7	1.8	1.6
22	23	24	25	26	24.0
3,600	3,800	4,000	4,200	4,400	4,000
1.13	1.19	1.25	1.31	1.38	1.25
1.80	1.90	2.00	2.10	2.20	2.00
72	76	80	84	88	80
72	76	80	84	88	80
72	76	80	84	88	80
158	167	176	185	194	176
0	0	0	0	0	0
450	475	500	525	550	500
144	152	160	168	176	160
1.35	1.43	1.50	1.58	1.65	1.50
0.33	0.34	0.36	0.38	0.40	0.36
0.23	0.24	0.26	0.27	0.28	0.26
0.29	0.30	0.32	0.34	0.35	0.32
8.1	8.6	9.0	9.5	9.9	9.0
5.2	5.5	5.8	6.1	6.4	5.8
2.250	2.375	2.500	2.625	2.750	2.5
1,480	1,562	1,644	1,726	1,808	1,644

Changed ENVIROGY

Parameter	Envirogy				
	-10%	-5%	0%	5%	10%
Investment FL & maintenance	-1473	-1478	-1483	-1488	-1492
Aluminum in FL	-1483	-1483	-1483	-1483	-1482
Glass in FL	-1483	-1483	-1483	-1483	-1483
Hg 10e-5 + phosphor 10 e-2 kg	-1483	-1483	-1483	-1483	-1483
Labor cost	-1483	-1483	-1483	-1483	-1483
New Capacity	-1195	-1339	-1483	-1627	-1771
Compared capacity	-1630	-1556	-1483	-1409	-1336
Operating factor	-1346	-1414	-1483	-1551	-1619
Hg recovery cost	-1483	-1483	-1483	-1483	-1483
revenue from glass	-1483	-1483	-1483	-1483	-1483
revenue from aluminum	-1483	-1483	-1483	-1483	-1483
revenue from other scrap	-1483	-1483	-1483	-1483	-1483
Collecting 200 km 3 ton truck	-1483	-1483	-1483	-1483	-1483
Investment AC & maintenance	-54572	-55572	-56572	-57572	-58572
Aluminum in AC	-56563	-56568	-56572	-56577	-56581
Copper in AC	-56561	-56567	-56572	-56577	-56583
HCFCR22 in AC	-56572	-56572	-56572	-56572	-56572
Plastic in AC	-56540	-56556	-56572	-56588	-56604
Steel in AC	-56500	-56536	-56572	-56608	-56644
Labor cost:remove & install	-56172	-56372	-56572	-56772	-56972
Compared kW/ton	-43776	-50078	-56572	-62681	-68983
kW/ton of AC (12,000 Btu)	-65974	-61273	-56572	-51871	-47170
Operating day	-53486	-55029	-56572	-58115	-59658
On-off factor	-53486	-55029	-56572	-58115	-59658
Operating factor-compressor	-53486	-55029	-56572	-58115	-59658
Refrigerant recovery cost	-56554	-56563	-56572	-56581	-56590
revenue from refrigerant	-56572	-56572	-56572	-56572	-56572
revenue from compressor	-56622	-56597	-56572	-56547	-56522
revenue from scrap	-56588	-56580	-56572	-56564	-56556
Collecting 200 km 3 ton truck	-56567	-56570	-56572	-56574	-56577
External cost CO2 equivalent	-55721	-56147	-56572	-56998	-57423
CO2 equivalent emission	-56688	-56630	-56572	-56514	-56457
Price of a ton CO2 reduction	-56688	-56630	-56572	-56519	-56457
Disposal Cost for FL	-1482	-1482	-1483	-1482	-1482
Disposal Cost for AC	-56563	-56563	-56572	-56563	-56563
Average price of electricity	-54258	-55415	-56572	-57729	-58886
Monetized risk - 10 yrs (R)	-56391	-56482	-56572	-56663	-56753

Sensitivity of Input Parameters

Parameter	Sensivity	%Change of ENVIROGY -10%	-5%	5%	10%	Source
Investment FL & maintenance	-98	-1	-0.3	0	1	DEDE 2003
Aluminum in FL	1	0	0	0	0	PCD, 2004
Glass in FL	0	0	0	0	0	PCD, 2004
Hg 10e-5 + phosphor 10 e-2 kg	0	0	0	0	0	PCD, 2004
Labor cost	0	0	0	0	0	DEDE, 2003
New Capacity	-2879	-19	-10	10	19	DEDE, 2003
Compared capacity	1469	10	5	-5	-10	DEDE, 2003
Operating factor	-1363	-9	-5	5	9	DEDE, 2003
Hg recovery cost	0	0	0	0	0	KKU, 2007
revenue from glass	0	0	0	0	0	KKU, 2007
revenue from aluminum	0	0	0	0	0	KKU, 2007
revenue from other scrap	0	0	0	0	0	KKU, 2007
Collecting 200 km 3 ton truck	0	0	0	0	0	GENCO, 2005
Investment AC & maintenance	-20000	-4	-2	2	4	DEDE, 2003
Aluminum in AC	-88	0	0	0	0	Bitwise 2004
Copper in AC	-107	0	0	0	0	Bitwise 2004
HCFCR22 in AC	0	0	0	0	0	Bitwise 2004
Plastic in AC	-319	0	0	0	0	Bitwise 2004
Steel in AC	-721	0	0	0	0	Bitwise 2004
Labor cost:remove & install	-4000	-1	0	0	1	DEDE, 2003
Compared kW/ton	-126032	-23	-11	11	22	DEDE, 2003
kW/ton of AC (12,000 Btu)	94019	17	8	-8	-17	DEDE, 2003
Operating day	-30858	-5	-3	3	5	DEDE, 2003
On-off factor	-30858	-5	-3	3	5	DEDE, 2003
Operating factor-compressor	-30858	-5	-3	3	5	DEDE, 2003
Refrigerant recovery cost	-176	0	0	0	0	Recycler 2004
revenue from refrigerant	0	0	0	0	0	Recycler 2004
revenue from compressor	500	0	0	0	0	Recycler 2004
revenue from scrap	160	0	0	0	0	Recycler 2004
Collecting 200 km 3 ton truck	-47	0	0	0	0	GENCO, 2005
External cost CO2 equivalent	-8509	-2	-1	1	2	PRET. 2005
CO2 equivalent emission	1155	0	0	0	0	PRET, 2005
Price of a ton CO2 reduction	1146	0	0	0	0	ERM, 2005
Disposal Cost for FL	0	0	0	0	0	GENCO, 2005
Disposal Cost for AC	-1	0	0	0	0	GENCO, 2005
Average price of electricity	-23143	-4	-2	2	4	DEDE , 2003
Monetized risk - 10 yrs (R)	-1809	0	0	0	0	MOI, 2006

3. Calculation of ENVIROGY buy summing from all components.

   - The monetized of risk here calculated from the multiplication of the cost of insurance per situation and the possibility of accident happening during the transportation of hazardous waste.

   - Retrofitting and recycling impact and operating impact in terms of money is calculated from the emission of equivalent Carbon-dioxide (kg) and the externality (Baht/kWh) and the emission of equivalent Carbon-dioxide from energy consumption (kWh/kg)

   - Yield from CDM is calculated from the reduction emission multiplied with the cost of CER (Credit Emission Reduction)

Calculation of ENVIROGY

	ENVIROGY Fluorescent Lamp	**LCA**	Baht/ 10yrs	Total (Baht)	Total 1 (%)	Total 2 (%)	Total 3 (%)
E	Energy saving from recycling		1.1				
	Energy saving from retrofitting		147				
	Energy consumption		-1322	-1175	**79**		
N	Revenue from material saving		1				
	Revenue from glass scrap		0.13				
	Revenue from Aluminum scrap		0.49				
	Revenue from other scrap		0				
	Recycling cost		-1.4				
	Collecting cost		-0.4	0	0	0	1
V	Disposal Cost of Hazardous Waste	HW amount	-0.13	-0.13	0	0	0
I	Equipment		-98				
	Labor cost		0	-98	7		
R	Risk Assessment	HW amount	-23	-23	2	11	**82**
O	Retrofitting-recycling impact	HW impact	-0.001				
	Operating impact (CO2 eq.)		-191	-191	13	**87**	
G	Government (Subsidy)		0	0	0	0	
Y	Yield from CO2 reduction		5	5	0	2	17
	Envirogy (all)		**-1,483**		100	100	100
	ENVIROGY Air-conditioner	**LCA**	Baht/ 10yrs	Total (Baht)	Total 1 (%)	Total 2 (%)	Total 3 (%)
E	Energy saving from recycling		543				
	Energy saving from retrofitting		35257				
	Energy consumption		-58762	-22962	**39**		
N	Refrigerant recovery cost		-176				
	Revenue from material saving		362				
	Revenue from compressor scrap		500				
	Revenue from other scrap		160				
	Recycling cost		-1,236				
	Collecting cost		-47	-437	1	4	13
V	Disposal Cost of Hazardous Waste	HW amount	-10	-10	0	0	0
I	Equipment		-20,000				
	Labor cost		-4,000	-24000	41		
R	Risk Assessment	HW amount	-1,809	-1809	3	15	**53**
O	Retrofitting-recycling impact	HW impact	-0.14				
	Operating impact (CO2 eq.)		-8,509	-8509	14	**71**	
G	Government (Subsidy)		0	0	0	0	
Y	Yield from CO2 reduction		1,155	1155	2	10	34
	Envirogy (all)		**-56,572**		100	100	100

TARIFF OF ELECTRICITY IN THAILAND

Type 1 Domestic
This schedule of tariff is applicable to household and other dwelling places, temples and other religion places of worship, including its compound, through a single Watt-hour meter

Type 2 Small Business
This schedule of tariff is applicable to a business enterprise, business enterprise cum residence, industrial and state enterprise or the alike, including its compound, with a maximum 15-minute integrated demand of less than 30 kilowatt through a single Watt-hour meter.

Type 3 Medium Business
This schedule of tariff is applicable to a business, industrial, and state enterprise, as well as the foreigner entities and international organisations including its compound, with a maximum 15-minute integrated demand from 30 to 999 kilowatts. Of which the average energy consumption for three (3) consecutive months through a single Watt-hour meter does not exceed 250,000 kWh per month.

Type 4 Large Business
This schedule of tariff is applicable to a business, industrial, government institutions, state enterprise, foreign entities and international organisations including its compound, with a maximum 15-minute integrated demand over1,000 kilowatt, or the energy consumption for three (3) average consecutive months through a single Watt-hour meter exceeds 250,000 kWh per month.

Type 5 Specific Business
This schedule of tariff is applicable to any hotel and other businesses providing lodging accommodation to their customers including its compound with a maximum 15-minute integrated demand of 30 kilowatt and over, through a single Watt-hour demand meter.

Type 1

RSD	<150 kWh	Energy On 9-22	Energy Off 22-9	Energy Partial -	Service
		Baht/kWh	Baht/kWh	Baht/kWh	Baht/month
TOD	<150 kW	2.7	0	0	8
	>150 kW	2.7	0	0	40
TOU	12-24 kV	3.6	1.2	0	228
	<12 kV	4.3	1.2	0	58

Type 2

S	<30 kW	Energy On 9-22	Energy Off 22-9	Energy Partial -	Service
		Baht/kWh	Baht/kWh	Baht/kWh	Baht/month
TOD	12-24 kV	2.5	0	0	228
	<12 kV	2.7	0	0	40
TOU	12-24 kV	3.6	1.2	0	228
	<12 kV	4.3	1.2	0	58

Type 3

M	<1000 kW	Energy On 9-22	Energy Off 22-9	Energy Partial -	Service	Demand
		Baht/kWh	Baht/kWh	Baht/kWh	Baht/month	Baht/kWh
TOD	>69 kV	1.6	0	0	0	176
	12-24 kV	1.7	0	0	0	196
	<12 kV	1.7	0	0	0	222
TOU	>69 kV	2.6	1.17	0	228	74
	12-24 kV	2.7	1.19	0	228	132
	<12 kV	2.8	1.22	0	228	210

Type 4

L	>1000 kW	Energy On 18.3-21.3	Energy Off 21.3-8	Energy Partial 8-18.3	Service	Demand On	Demand Off	Demand Partial	PF charge
		Baht/kWh	Baht/kWh	Baht/kWh	Baht/month	Baht/kWh	Baht/kWh	Baht/kWh	Baht/kVar excess
TOD	>69 kV	1.66			0	224	0	30	14
	12-24 kV	1.70			0	285	0	60	
	<12 kV	1.73			0	332	0	68	
		Energy On 9-22	Energy Off 22-9	Energy Partial -	Service	Demand On	Demand Off	Demand Partial	PF charge
TOU	>69 kV	2.61	1.17	0	228	74	0	30	14
	12-24 kV	2.69	1.19	0	228	133	0	60	
	<12 kV	2.84	1.22	0	228	210	0	68	

Type 5

Spec accomodation		Energy On 18.3-21.3	Energy Off 21.3-8	Energy Partial 8-18.3	Service	Demand On	Demand Off	Demand Partial	PF charge
		Baht/kWh	Baht/kWh	Baht/kWh	Baht/month	Baht/kWh	Baht/kWh	Baht/kWh	Baht/kVar excess
TOD	>69 kV	1.66			0	220			14
	12-24 kV	1.70			0	256			
	<12 kV	1.73			0	276			
		Energy On 9-22	Energy Off 22-9	Energy Partial -	Service	Demand On	Demand Off	Demand Partial	PF charge
TOU	>69 kV	2.61	1.17	0	228	74			14
	12-24 kV	2.69	1.19	0	228	133			
	<12 kV	2.84	1.22	0	228	210			

Biography

My name is Kua-anan Techato. I was born on the 1st April 1974 at Yala, Thailand. My bachelor degree (by a scholarship of Padaeng Industry) is from the Prince of Songkhla University in the Faculty of Engineering (Mechanical) was awarded in 1995. After that I graduated in industrial engineering for a master degree from Chulalongkorn University and Warwick University in 2000. I got a one-year scholarship from Carl Duisberg Gesellschaft (CDG) for training of renewable energy in Germany in 2001. For doctoral degree, the scholarship is granted from the National Resource Center (Environmental Hazardous Waste Management) and the Energy Research Institute of Chulalongkorn University. Hanns Seidel Foundation is a scholarship donor for my doctoral research in Germany. My working experience started at the Thai Petrochemical Industry (TPI) Rayong for one year and thereafter I had been working for 5 years in the Energy Conservation in State Own Building Project for Energy Conservation Center of Thailand (ECCT) and Energy Efficiency Institute Thailand (EEIT). Later on I had worked in the two projects under the co-operation between Danish International Development Agency (DANIDA) and Department of Alternative Energy Development and Efficiency of Thailand (DEDE) i.e. 1) the Adjustments to the Building Energy Code Project for 2 years through the host company named EEC Energetics and 2) the Promotion of Renewable Energy Technologies Project for another 1.5 years consecutively. I had worked as a research assistant in the Sustainable Metropolitan Energy and Environment (SMEE) with the Joint Graduate School of Energy and Environment (KMUTT/JGSEE) and another one is the to work as Energy Expert for the EU-Asia Pro Eco II B-Post-Tsunami Program, Pang-nga. Now I do the research about CDM for the Royal Danish Embassy.