Case Study of Using Life Cycle Impact Assessment in Environmental Impact Assessment

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***Abstract*—Environmental impact assessment (EIA) and strategic environmental assessment (SEA) are procedural tools for environmental management that identify, predict, evaluate and mitigate the environmental impact of development proposals or policies. Life cycle impact assessment (LCIA) is a common analytical tool for environmental management. The use of the LCIA for the preparation of EIA and SEA reports clearly shows the causal linkage for hazard–pathway–receptor–damage and better determines the significance of the impact. Firstly, the use of the LCIA for EIA and SEA is studies. Eco-indicator 99, IMPACT 2002+ and ReCiPe are the LCIA tools used in this study. Finally, a Taiwanese naphtha cracking plant is used as the example for an EIA and the Taiwanese solid waste policy as the case study for a SEA, in order to demonstrate the use of the proposed methodology.**

***Index Terms*—Environmental impact assessment, strategic environmental assessment, life cycle impact assessment.**

I. Introduction

An environmental impact assessment (EIA) is an environmental management plan for which scientific, objective and comprehensive surveys, forecasting, analysis and evaluations are conducted prior to project implementation, in order to determine the degree and scope of the potential impact of development activity or government policy on the environment, society, economy, culture and ecology of an area, and the public explanation and review of the plan. In Taiwan, development projects for which there is concern of an adverse impact on the environment must submit an environmental impact statement for the phase-I EIA and forward this environmental impact statement to a competent authority, for review. The developer must produce an environmental impact assessment report for the phase-II EIA, for those circumstances in which the result of the review of the environmental impact statement show concerns for a significant impact on the environment. The results of the review of environmental impact statements or environmental impact assessment reports are classified into three categories: Conditional approval, phase-II EIA, or rejection of the development plan [1].

In Taiwan, environmental impact statements and environmental impact assessment reports must evaluate the impact on the following environmental aspects:

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1) Physical and chemical environment
   - Topography, geology and soil
   - Water
   - Climate and air quality
   - Noise
   - Vibration
   - Odor
   - Waste
   - Excavation
   - Coverage
   - Energy
   - Radiation
2) Ecology
   - Terrestrial
   - Aquatic
   - Endangered species
   - Ecosystems
3) Landscape & Recreation
   - Scenic beauty
   - Recreation
4) Society & Economy
   - Land Use
   - Social environment
   - Transportation
   - Economic welfare
   - Social relationships
5) Culture
   - Educational, scientific
   - Historic, monumental
   - Cultural

A strategic environmental assessment (SEA) is a systematic process for evaluating the environmental consequences of proposed policies, plans or programs of initiatives, in order to ensure they are fully included and appropriately addressed at the earliest appropriate stage of decision making and are given a similar level of importance to economic and social considerations [2].

In Taiwan, the SEA and EIA procedures are very similar. However, the impact considered in SEA reports is more extensive, as follows:

1) Assimilative capacity of the environment
   - Air
   - Water
   - Soil
   - Waste
   - Noise
   - Non-ionizing radiation
2) Natural ecology and landscape
   - Terrestrial ecosystems
   - Aquatic ecosystems
   - Ecology of the landscape & habitat

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3) Human Health and Safety
- Toxic or harmful substances
- Risk of ionizing radiation
- Risk of chemical substances

4) Land resource
- Characteristics of land resources
- Mineral resource & debris
- Land use
- Landscape

5) Water resources
- Distribution of water use
- Water crowding effect
- Water resources

6) Cultural assets

7) International environmental regulations as defined by the following:
- The Montreal Protocol
- The Framework Convention on Climate Change
- The Basel Convention
- The Washington Convention
- The Convention on Biological Diversity
- The Ramsar Convention on Wetlands
- The Stockholm Convention
- The Rotterdam Convention

8) Society & Economy
- Population & Industry
- Transportation
- Energy use
- Economic benefits
- Public facilities & community development
- Public opinion & social acceptance

EIAs and SEAs are procedural tools for environmental management that identify, predict, evaluate and mitigate the environmental impact of development proposals or policies. Many analytical tools improve the analysis of environmental impact in EIA or SEA reports, such as a life cycle assessment (LCA). A life cycle impact assessment (LCIA) is one of steps in a LCA that takes account of the causal relationships between environmental hazards and damage. Using a LCIA to produce EIA and SEA reports extends the focus of the reports from regulatory compliance for environmental impact, to determining the significance of the environmental impact [3].

II. Methods and Materials

A. Life Cycle Impact Assessment

A life-cycle assessment assesses the environmental impact that is associated with all of the stages of a product's life, from raw material extraction through material processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. According to the ISO 14040 [4] and 14044 [5] standards, a Life Cycle Assessment has four distinct phases. The first phase is the 'Goal and scope', which requires an explicit statement of the goal and scope of the study. It establishes the context of the study and explains how and to whom the results are to be communicated. The second phase is a ‘Life cycle inventory (LCI)’, which involves the creation of an inventory of the flows from and to nature for a product system. Inventory flows include inputs of water, energy and raw materials, and releases to air, land and water. The third phase is a ‘Life cycle impact assessment (LCIA)’, which evaluates the significance of any potential environmental impact, based on the results for the LCI flow. A classical LCIA involves selection of the following mandatory elements: impact categories, category indicators and characterization models. In the classification stage, the inventory parameters are categorized and assigned to specific impact categories. In the impact measurement stage, the categorized LCI flows are characterized into common equivalence units, using one of many possible LCIA methodologies. These are then summed to provide a total overall impact. The last phase is ‘Interpretation’, which is a systematic technique that identifies, quantifies, checks and evaluates information from the results of the life cycle inventory and/or the life cycle impact assessment. The results of the inventory analysis and the impact assessment are summarized during the interpretation phase.

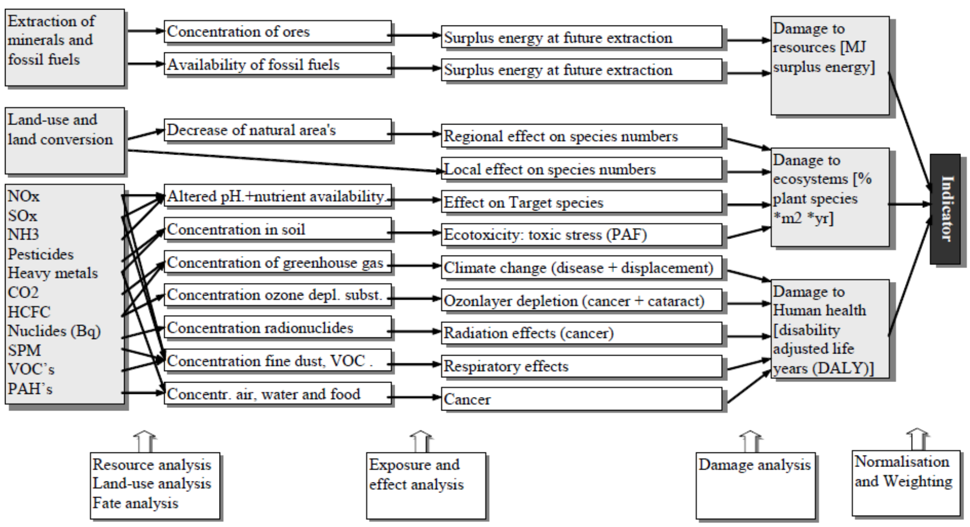

Fig. 1. The framework of Eco-indicator 99 [9].

Three LCIA methods are used for this study: Eco-indicator 99 [6], IMPACT 2002+ [7] and ReCiPe [8]. Eco-indicator 99 (Fig. 1) is one of the most widely used impact assessment methods for a LCA. It is the successor of Eco-indicator 95, the first endpoint impact assessment method, which allows the environmental load of a product to be expressed in a single score. The Life Cycle Impact Assessment methodology, IMPACT 2002+ (Fig. 2), suggests a feasible implementation of a combined midpoint/damage approach. These combinations link all types of Life Cycle Inventory (LCI) results, the elementary flows and other interventions, throughout the 14 midpoint categories, which are summed into four damage categories. ReCiPe (Fig. 3) is a fusion of these two methodologies, taking the midpoint indicators from CML and the endpoint indicators from Ecoindicator.

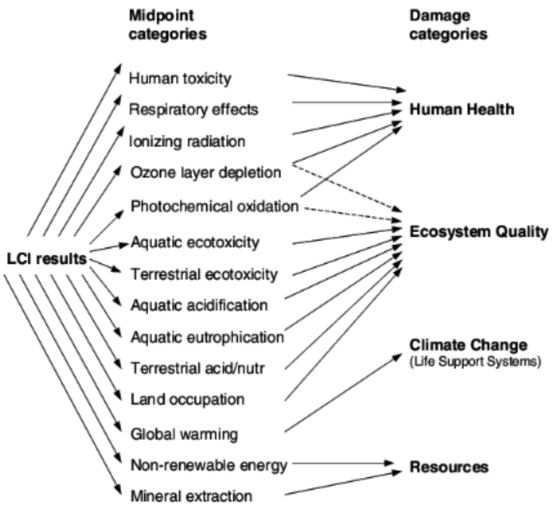

Fig. 2. The framework of IMPACT 2002+ [7].

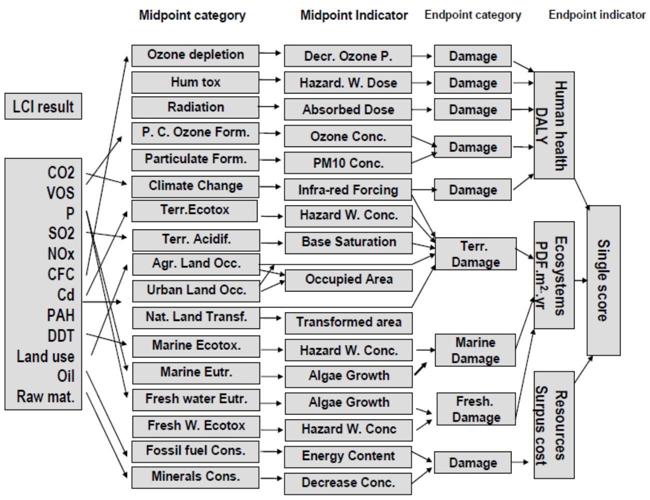

Fig. 3. The framework of ReCiPe [9].

B. *Case Study (1)*

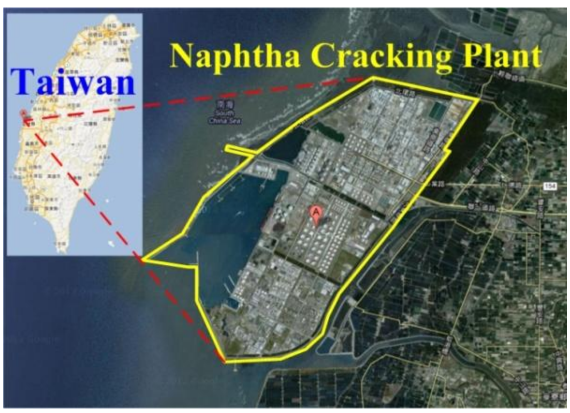

Fig. 4. The case study (1): A naphtha cracking plant in Taiwan.

TABLE I: THE INVENTORY DATA FOR CASE STUDY (1)

Category	Inventory Item	BE	AE	Unit
Resource	Water	1.261E+02	1.736E+02	Mton
Air	Total Suspended Particulate(TSP)	3.340E+00	4.320E+00	kton
	particulate matter (PM10)	1.690E+00	2.160E+00	kton
	Sulfur oxide(SOx)	1.600E+01	1.979E+01	kton
	Nitrogen oxide(NOx)	1.962E+01	2.388E+01	kton
	Volatile organic compounds(VOCs)	4.300E+00	5.390E+00	kton
	Carbon dioxide	6.757E+01	7.815E+01	Mton
	Butadiene	1.355E+03	1.723E+03	kg
	Benzene	3.969E+02	5.046E+02	kg
	Ethylene oxide	2.634E+02	3.349E+02	kg
	Formaldehyde	4.006E+02	5.093E+02	kg
	Ethene, chloro-	2.799E+02	3.558E+02	kg
	Ethene, trichloro-	9.820E+00	1.249E+01	kg
	Acetaldehyde	6.256E+01	7.953E+01	kg
	Acrylonitrile	6.622E+02	8.418E+02	kg
	Methane, tetrachloro-, CFC-10	1.151E+01	1.463E+01	kg
	Chloroform	1.340E+00	1.700E+00	kg
	Ethyl acrylate	3.750E+01	4.767E+01	kg
	Benzene, ethyl-	4.774E+01	6.069E+01	kg
	Ethane, 1,2-dichloro-	8.890E+01	1.130E+02	kg
	Naphthalene	1.921E+01	2.442E+01	kg
	Benzene, 1,4-dichloro-	1.099E+02	1.398E+02	kg
	Propylene oxide	4.353E+02	5.535E+02	kg
	Styrene	1.247E+03	1.586E+03	kg
	Vinyl acetate	8.377E+01	1.065E+02	kg
	Acrolein	5.872E+01	7.465E+01	kg
	Methane, monochloro-, R-40	1.776E+02	2.258E+02	kg
	Methanol	7.024E+02	8.930E+02	kg
	Carbon disulfide	1.140E+01	1.449E+01	kg
	Hexane	7.280E+02	9.255E+02	kg
	t-Butyl methyl ether	5.268E+01	6.697E+01	kg
	Xylene	9.603E+02	1.221E+03	kg
	Methyl methacrylate	3.073E+02	3.907E+02	kg
	Ethane, chloro-	4.792E+01	6.093E+01	kg
	Methyl ethyl ketone	1.079E+02	1.372E+02	kg
	Toluene	1.310E+02	1.665E+02	kg
	Benzene, chloro-	1.010E+02	1.284E+02	kg
	Dimethyl formamide	1.530E+00	1.950E+00	kg
Water	Wastewater	6.862E+01	1.111E+02	Mton
	suspended solids	8.400E-01	1.360E+00	kton
	Chloride	1.240E+00	2.000E+00	Mton
	Fluoride	8.715E+01	1.412E+02	ton
	Sulfate	1.900E-01	3.100E-01	Mton
	Sulfide	1.850E+00	3.000E+00	ton
	Chlorine	6.180E+00	1.000E+01	ton
	Biochemical oxygen demand	3.637E+02	5.891E+02	ton
	Chemical oxygen demand	2.240E+00	3.630E+00	kton
	Ammonia, as N	1.022E+02	1.656E+02	ton
	Nitrate	4.783E+02	7.747E+02	ton
	Nitrite	1.320E+00	2.130E+00	kton
	Phosphate	6.860E+00	1.111E+01	ton
	Phosphorus, TOTAL	1.510E+01	2.445E+01	ton
	Oils, unspecified	4.117E+01	6.669E+01	ton
	Cyanide	6.200E-01	1.000E+00	ton
	Phenols, unspecified	1.240E+00	2.000E+00	ton
	Arsenic	1.098E+01	1.778E+01	ton
	cadmium	9.600E-01	1.560E+00	ton
	Chromium	8.230E+00	1.334E+01	ton
	Copper	3.430E+00	5.560E+00	ton
	Mercury	7.000E-02	1.100E-01	ton
	Nickel	6.180E+00	1.000E+01	ton
	Lead	1.304E+01	2.112E+01	ton
	Selenium	1.029E+01	1.667E+01	ton
	Zinc	1.098E+01	1.778E+01	ton
	Iron	6.180E+00	1.000E+01	ton
	Manganese	3.430E+00	5.560E+00	ton
Waste	Incineration waste in incineration	1.532E+05	1.541E+05	ton
	Landfill waste in incineration	5.253E+04	9.009E+04	ton
	waste to recycling	1.893E+06	3.910E+06	ton
	Sludge	3.095E+05	0.000E+00	ton
	Coal ash	1.175E+06	0.000E+00	ton

Note: BE: before the expansion; AE: after the expansion.

The case study is a naphtha cracking plant that is located in Yunlin County, in Taiwan, as shown in Fig. 4. It is in an offshore industrial zone, with a total area of 2,603 hectares. Currently, as alternative BE (before expansion), 61 factories have an annual output of 6,221 tons. In response to market demand, the company proposes an expansion plan (alternative AE, after expansion) that will increase the number of factories to 77 and increase production to 8,174 tons per year, which is an increase of 31.4%. However, the expansion plan will also increase its emissions of TSP from 3,340 to 4,323 tons per year, SO_2 from 16,000 to 19,788 tons per year, NO_2 from 19,622 to 23,881 tons per year, VOC from 4,302 to 5,389 tons per year and waste-water from 188,000 to 304,500 tons per day. Its inventory flows, including inputs of water, energy and raw materials and releases to air, land, and water, are detailed in Table I.

C. Case Study (2)

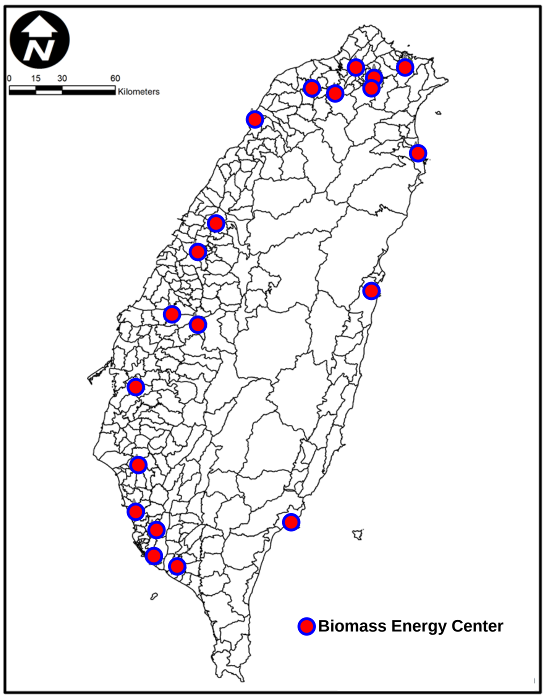

Fig. 5. The case study (2): 20 biomass energy centers in Taiwan.

TABLE II: THE INVENTORY DATA FOR CASE STUDY (2)

Category	Inventory Item	Z	A	B	Unit
Products	Electricity	1.877E+09	1.708E+09	3.017E+09	kWh
	Bio-coal		1.042E+06		ton
Resources	Water	2.256E+06	1.615E+06	2.652E+06	m^3
Fuels	Diesel, at refinery/l/US	2.097E+06	3.606E+08	3.497E+08	L
Electricity	Electricity	4.769E+05	2.775E+08	1.252E+09	kWh
Air	Sulfur oxides	3.430E+06	6.011E+05	4.591E+05	kg
	Nitrogen oxides	6.429E+06	1.213E+06	5.916E+06	kg
	TSP	3.834E+06	1.068E+05	1.298E+05	kg
	Arsenic	1.130E+02	1.300E+01	4.600E+00	kg
	Cadmium	2.930E+01	2.900E+01	2.950E+01	kg
	Chromium	2.420E+02	1.360E+02	3.620E+01	kg
	Lead	5.410E+02	6.100E+01	9.220E+02	kg
	Dioxin, 1,2,3,7,8,9-hexachlorodibenzo-	1.000E-03	6.430E-05	5.120E-04	kg
	Carbon monoxide	2.150E+04	1.910E+04	2.910E+04	kg
	Carbon dioxide	3.660E+05	3.030E+05	3.410E+05	ton
Water	Suspended solids, unspecified		2.910E+04		kg
	BOD5, Biological Oxygen Demand		2.910E+04		kg
	COD, Chemical Oxygen Demand		9.690E+04		kg
	Chloride		4.840E+02		kg
	Arsenic		4.840E+02		kg
	Cadmium		2.910E+01		kg
	Chromium		1.940E+03		kg
	Lead		9.690E+02		kg
Waste	Waste, inorganic		5.893E+04	8.880E+05	ton
	Fly ash	2.711E+04			ton

Note: Z: zero alternative; A: alternative (A); B: alternative (B).

In Taiwan, about 3.5 million tons of biomass garbage is generated each year, with a potential energy of more than 100 tons of natural coal. At present, a total of 24 incineration plants are in operation and their power generation efficiency is only 20%, which is much lower than 35% for coal-fired plants. The current incineration of solid waste is the reference point, zero alternative (Z). Two policy alternatives, (A) and (B), are proposed, to improve the efficiency of power generation and thereby allow the integration of energy and resource, sustainable recycling, energy saving and carbon reduction. Alternative (A) transforms the current incineration plants into 20 biomass energy centers (Fig. 5) by using new waste and biomass energy utilization technologies. Alternative (B) transforms the current incineration plants by integrating refuse derived fuel plants (RDF) and RDF burning power plants. Their inventory flows, including inputs of water, energy and raw materials and releases to air, land and water, are detailed in Table II.

III. RESULTS

A. LCIA for EIA: Case Study (1)

TABLE III: THE USE OF LCIA TOOLS FOR EIA EVALUATION ITEMS

EIA Evaluation Item	Eco-indicator99	IMPACT 2002+	ReCiPe
(A) Physical and chemical			
•Topography, geology & soil	Acidification/ Eutrophication	Terrestrial acid/nutri	Terrestrial acidification
	Minerals	Mineral extraction	Metal depletion
•Water	Acidification/ Eutrophication	Aquatic acidification	
•Climate and air quality	Ozone layer	Ozone layer depletion	Ozone depletion
	Respiratory organics	Respiratory organics	Photochemical oxidant formation
	Respiratory inorganics	Respiratory inorganics	Particulate matter formation
	Climate change	Global warming	Climate change Human Health
•Noise			
•Vibration			
•Odor			
•Waste			
•Excavation			
•Coverage			
•Energy	Fossil fuels	Non-renewable energy	Fossil depletion
•Radiation	Radiation	Ionizing radiation	Ionising radiation
(B) Ecology			Climate change Ecosystems
•Terrestrial	Ecotoxicity	Terrestrial ecotoxicity	Terrestrial ecotoxicity
•Aquatic	Ecotoxicity	Aquatic ecotoxicity	Freshwater ecotoxicity
•Endangered			
•Ecosystem	Acidification/ Eutrophication	Aquatic eutrophication	Freshwater eutrophication
(C) Landscape & Recreation			
•Scenic beauty			
•Recreation			
(D) Society & Economy			
•Land Use	Land use	Land occupation	Urban land occupation Agricultural land occupation Natural land transformation
•Social environment			
•Transportation			
•Economic level			
•Social relationships			
(E) Culture			
•Educational, scientific			
•Historic, monumental			
•Cultural			

Note: Z: zero alternative; A: alternative (A); B: alternative (B).

In Taiwan, evaluation items for an EIA are: (1) physical and chemical, including topography-geology-soil, water, climate and air quality, noise, vibration, odor, waste, excavation, coverage, energy and radiation; (2) ecology, including terrestrial, aquatic, endangered and ecosystem; (3) landscape & recreation, including scenic beauty and recreation; (4) society & economy, including land use, social environment, transportation, economic level and social relationships; (5) culture, including educational, scientific, historic, monumental and cultural. Table III summarizes the use of the three LCIA methods, Eco-indicator 99, IMPACT 2002+ and ReCiPe, to assess evaluation items in the EIA. Some items are not evaluated by the three LCIA methods such as noise, vibration, odor, waste, excavation, coverage, endangered, scenic beauty, recreation, social environment, transportation, economic level, social relationships, educational, scientific, historic, monumental and cultural.

TABLE IV: THE RESULTS FOR THE USE OF LCIA TOOLS FOR CASE STUDY (1)

Eco-indicator 99				
Impact Category	Unit	BE	AE	Increase
Carcinogens	DALY	1.030E-01	1.309E-01	+27.1%
Respiratory organics	DALY	2.785E+00	3.491E+00	+25.4%
Respiratory inorganics	DALY	3.255E+03	4.018E+03	+23.4%
Climate change	DALY	1.419E+04	1.641E+04	+15.6%
Radiation	DALY			
Ozone layer	DALY	1.825E-02	2.320E-02	+27.1%
Ecotoxicity	PDF*m^2*yr	6.756E+06	1.094E+07	+61.9%
Acidification/ Eutrophication	PDF*m^2*yr	1.287E+08	1.570E+08	+22.0%
Land use	PDF*m^2*yr			
Minerals	MJ surplus			
Fossil fuels	MJ surplus			
Human Health	DALY	1.745E+04	2.043E+04	+17.1%
Ecosystem Quality	PDF*m^{2}yr	1.355E+08	1.679E+08	+23.9%
Resources	MJ surplus			
IMPACT 2002+				
Impact Category	Unit	BE	AE	Increase
Carcinogens	DALY	3.561E+03	4.528E+03	+27.2%
Non-carcinogens	DALY	1.132E+07	1.834E+07	+62.0%
Respiratory inorganics	DALY	5.176E+06	6.419E+06	+24.0%
Ionizing radiation	DALY			
Ozone layer depletion	DALY	1.195E+01	1.520E+01	+27.2%
Respiratory organics	DALY	1.307E+06	1.639E+06	+25.4%
Aquatic ecotoxicity	PDF*m^2*yr	5.869E+10	9.501E+10	+61.9%
Terrestrial ecotoxicity	PDF*m^2*yr	6.481E+03	8.239E+03	+27.1%
Terrestrial acid/nutri	PDF*m^2*yr	1.237E+08	1.508E+08	+21.9%
Land occupation	PDF*m^2*yr			
Aquatic acidification	PDF*m^2*yr	2.997E+07	3.688E+07	+23.1%
Aquatic eutrophication	PDF*m^2*yr	1.023E+05	1.658E+05	+62.1%
Global warming	kg CO_2 eq	6.757E+10	7.815E+10	+15.7%
Non-renewable energy	MJ primary			
Mineral extraction	MJ primary			
Human Health	DALY	1.782E+07	2.642E+07	+48.3%
Ecosystem Quality	PDF*m^{2}yr	5.884E+10	9.520E+10	+61.8%
Resources	MJ surplus			
ReCiPe				
Impact Category	Unit	BE	AE	Increase
Climate change Human Health	DALY	2.372E+05	2.743E+05	+15.6%
Ozone depletion	DALY	2.774E-02	3.526E-02	+27.1%
Human toxicity	DALY	3.020E+04	4.892E+04	+62.0%
Photochemical oxidant formation	DALY	8.159E-01	9.940E-01	+21.8%
Particulate matter formation	DALY	2.394E+03	2.957E+03	+23.5%
Ionising radiation	DALY			
Climate change Ecosystems	species.yr	1.264E+03	1.461E+03	+15.6%
Terrestrial acidification	species.yr	4.254E-01	5.222E-01	+22.8%
Freshwater eutrophication	species.yr	7.699E-04	1.247E-03	+62.0%
Terrestrial ecotoxicity	species.yr	1.574E-03	2.485E-03	+57.9%
Freshwater ecotoxicity	species.yr	2.670E-04	4.324E-04	+61.9%
Marine ecotoxicity	species.yr	9.640E-03	1.562E-02	+62.0%
Agricultural land occupation	species.yr			
Urban land occupation	species.yr			
Natural land transformation	species.yr			
Metal depletion	$			
Fossil depletion	$			
Human Health	DALY	2.698E+05	3.262E+05	+20.9%
Ecosystem Quality	species.yr	1.264E+03	1.462E+03	+15.7%
Resources	$			

BE: before the expansion; AE: after the expansion.

The results for the use of Eco-indicator 99, IMPACT 2002+ and ReCiPe to assess case study (1) are shown in Table IV. In Table IV, The results evaluated by Eco-indicator 99 show the most negative impact on human health is 'climate change', and the most negative impact on ecosystem quality is 'acidification/ eutrophication'. The results evaluated by IMPACT 2002+ show the most negative impact on human health is 'non-carcinogens', and the most negative impact on ecosystem quality is 'Aquatic ecotoxicity'. The results evaluated by ReCiPe show the most negative impact on human health is 'climate change human health', and the most negative impact on ecosystem quality is 'Climate change ecosystems'. Compared to each other, the magnitude of impact evaluated by the three LCIA methods differs up to three orders for human health and two orders for ecosystem quality. For example, as for AE the impact of human health is 2.043E+04 DALY by Eco-indicator 99, but it raises up to 2.642E+07 DALY by IMPACT 2002+. Meanwhile, as for AE the impact of ecosystem quality is 1.679E+08 PDF*m^{2}yr by Eco-indicator 99, but it turns into 9.520E+10 PDF*m^{2}yr by IMPACT 2002+. The difference among LCIA methods primarily comes from their inconsistent characterization models and it makes users confused because they use different models, geographic conditions, time horizons and receptors etc.

B. LCIA for EIA: Case Study (2)

In Taiwan, evaluation items for an SEA are: (1) assimilative capacity of the environment, including air, water, soil, waste, noise and non-ionizing radiation; (2) natural ecology and landscape, including terrestrial ecosystems, aquatic ecosystems and ecological landscape & habitat; (3) human health and safety, including toxic or harmful substances, risk of ionizing radiation and risk of chemical substances; (4) land resource, including characteristics of land resources, mineral resource & debris, land use and landscape; (5) water resource, including distribution of water use, water crowding effect and water resource; (6) cultural assets; (7) international environmental regulations, including montreal protocol, framework convention on climate change, washington convention, convention on biological diversity, ramsar convention on wetlands, stockholm convention and rotterdam convention; (8) society & economy, including population & industry, transportation, energy use, economic benefits, public facilities & community development and public opinion & social acceptance. Table V summarizes the use of the three LCIA methods, Eco-indicator 99, IMPACT 2002+ and ReCiPe, to assess evaluation items in the SEA.

Some items are not evaluated by the three LCIA methods such as waste, noise, non-ionizing radiation, ecological landscape & habitat, risk of chemical substances, landscape, distribution of water use, water crowding effect, water resource, basel convention, washington convention, convention on biological diversity, ramsar convention on wetlands, stockholm convention, rotterdam convention, population & industry, transportation, economic benefits, public facilities & community development and public opinion & social acceptance.

The results for the use of Eco-indicator 99, IMPACT 2002+ and ReCiPe to assess case study (2) are shown in Table VI. In Table IV, The results evaluated by Eco-indicator 99 show the most negative impact on human health is 'Respiratory inorganics', the most negative impact on ecosystem quality is 'acidification/ eutrophication', and the most negative impact on resource is 'Fossil fuels'. The results evaluated by IMPACT 2002+ show the most negative impact on human health is 'Respiratory inorganics', the most negative impact on ecosystem quality is 'Terrestrial acid/nutri', and the most negative impact on resource is 'Non-renewable energy'. The results evaluated by ReCiPe show the most negative impact on human health is 'Human toxicity', and the most negative impact on ecosystem quality is 'Terrestrial acidification'. Compared to each other, the magnitude of impact evaluated by the three LCIA methods differs up to three orders for human health, eight orders for ecosystem quality and one order for resource. For example, as for A the impact of human health is 8.575E+01 DALY by IMPACT 2002+, but it raises up to 1.404E+04 DALY by ReCiPe. Meanwhile, as for A the impact of ecosystem quality is -3.139E+00 PDF*m^2yr by ReCiPe, but it turns into -5.161E+08 PDF*m^2yr by IMPACT 2002+. The impact of resource is -1.331E+09 MJ surplus by Eco-indicator 99, but it turns into -2.042E+10 MJ surplus by IMPACT 2002+. The difference among LCIA methods primarily comes from their inconsistent characterization models and it makes users confused because they use different models, geographic conditions, time horizons and receptors etc.

TABLE V: THE USE OF LCIA METHODS FOR SEA EVALUATION ITEMS

SEA Evaluation Item	Eco-indicator99	IMPACT 2002+	ReCiPe
(A) Assimilative capacity of the environment			
• Air	Climate change	Global warming	Climate change Human Health
	Ozone layer	Ozone layer depletion	Ozone depletion
			Photochemical oxidant formation
			Particulate matter formation
• Water	Acidification/ Eutrophication	Aquatic acidification	
		Aquatic eutrophication	Freshwater eutrophication
• Soil	Acidification/ Eutrophication	Terrestrial acid/nutri	Terrestrial acidification
• Waste			
• Noise			
• Non-ionizing radiation			
(B) Natural ecology and landscape	Ecotoxicity	Terrestrial ecotoxicity	Terrestrial ecotoxicity
• Terrestrial ecosystems			Climate change Ecosystems
	Ecotoxicity	Aquatic ecotoxicity	Freshwater ecotoxicity
• Aquatic ecosystems			Marine ecotoxicity
• Ecological landscape & habitat			
(C) Human Health and Safety	Carcinogens	Carcinogens	Human toxicity
• Toxic or harmful substances		Non-carcinogens	
	Respiratory organics	Respiratory organics	
	Respiratory inorganics	Respiratory inorganics	
• Risk of ionizing radiation	Radiation	Ionizing radiation	Ionising radiation
• Risk of chemical substances			
(D) Land resource	Land use	Land occupation	Agricultural land occupation
• Characteristics of land resources			Urban land occupation
			Natural land transformation
• Mineral resource & debris	Minerals	Mineral extraction	Metal depletion
• Land use	Land use	Land occupation	Agricultural land occupation
• Landscape			
(E) Water resource			
9) Distribution of water use			
10) Water crowding effect			
11) Water resource			
(F) Cultural assets			
(G) International environmental regulations	Ozone layer	Ozone layer depletion	Ozone depletion
• Montreal Protocol	Climate change	Global warming	Climate change Human Health
• Framework Convention on Climate Change			Climate change Ecosystems
• Basel Convention			
• Washington Convention			
• Convention on Biological Diversity			
• Ramsar Convention on Wetlands			
• Stockholm Convention			
• Rotterdam Convention			
(H) Society & Economy			
• Population & Industry			
• Transportation			
• Energy use	Fossil fuels	Non-renewable energy	Fossil depletion
• Economic benefits			
• Public facilities & community development			
• Public opinion & social acceptance			

IV. DISCUSSION AND CONCLUSION

TABLE VI: THE RESULTS FOR THE USE OF LCIA TOOLS FOR CASE STUDY (2)

Eco-indicator 99				
Impact Category	Unit	Z	A	B
Carcinogens	DALY	5.192E+00	-3.504E+02	2.845E+01
Respiratory organics	DALY	-7.221E-02	5.937E-01	8.646E-01
Respiratory inorganics	DALY	6.606E+02	1.668E+02	6.427E+02
Climate change	DALY	-4.950E+01	-6.602E+01	-1.425E+01
Radiation	DALY	-7.322E-02	-1.879E+00	-6.885E-02
Ozone layer	DALY	-2.943E-03	-6.816E-02	-2.726E-03
Ecotoxicity	PDF*m^2yr	1.902E+06	-8.061E+06	2.927E+06
Acidification/ Eutrophication	PDF*m^2yr	3.685E+07	9.063E+06	3.802E+07
Land use	PDF*m^2yr	0.000E+00	-9.779E+06	0.000E+00
Minerals	MJ surplus	-2.318E+05	-9.950E+05	-2.179E+05
Fossil fuels	MJ surplus	-4.512E+08	-1.330E+09	8.387E+08
Human Health	DALY	6.161E+02	-2.510E+02	6.577E+02
Ecosystem Quality	PDF*m^2yr	3.876E+07	-8.777E+06	4.094E+07
Resources	MJ surplus	-4.514E+08	-1.331E+09	8.385E+08
IMPACT 2002+				
Impact Category	Unit	Z	A	B
Carcinogens	DALY	-2.594E-01	-1.551E+01	3.909E-01
Non-carcinogens	DALY	3.108E+00	-2.925E+01	2.135E+02
Respiratory inorganics	DALY	1.094E+03	1.643E+02	6.456E+02
Ionizing radiation	DALY	-7.438E-02	-1.879E+00	-6.995E-02
Ozone layer depletion	DALY	-3.118E-03	-6.915E-02	-2.885E-03
Respiratory organics	DALY	-7.221E-02	5.929E-01	8.638E-01
Aquatic ecotoxicity	PDF*m^2*yr	1.458E+05	-5.026E+08	2.569E+07
Terrestrial ecotoxicity	PDF*m^2*yr	-4.938E+05	-1.273E+07	-4.922E+05
Terrestrial acid/nutri	PDF*m^2*yr	3.682E+07	9.055E+06	3.798E+07
Land occupation	PDF*m^2*yr	0.000E+00	-9.779E+06	0.000E+00
Aquatic acidification	PDF*m^2*yr			
Aquatic eutrophication	PDF*m^2*yr			
Global warming	kg CO_2 eq	-2.134E+08	-1.546E+08	-6.672E+07
Non-renewable energy	MJ primary	-5.769E+09	-2.042E+10	1.076E+10
Mineral extraction	MJ primary	-2.318E+05	-9.950E+05	-2.179E+05
Human Health	DALY	1.052E+03	8.575E+01	8.463E+02
Ecosystem Quality	PDF*m2yr	3.647E+07	-5.161E+08	6.318E+07
Resources	MJ surplus	-5.769E+09	-2.042E+10	1.076E+10
ReCiPe				
Impact Category	Unit	Z	A	B
Climate change Human Health	DALY	-7.517E+02	-5.896E+02	-2.575E+02
Ozone depletion	DALY	-4.945E-03	-1.626E-01	-4.574E-03
Human toxicity	DALY	3.436E+02	1.452E+04	6.755E+04
Photochemical oxidant formation	DALY	2.391E-01	8.751E-02	2.872E-01
Particulate matter formation	DALY	4.748E+02	1.154E+02	4.285E+02

Ionising radiation	DALY	-5.926E-02	-1.478E+00	-5.573E-02
Climate change Ecosystems	species.yr	-4.004E+00	-3.138E+00	-1.372E+00
Terrestrial acidification	species.yr	1.004E-01	2.784E-02	8.359E-02
Freshwater eutrophication	species.yr	-7.506E-05	-2.507E-03	-7.059E-05
Terrestrial ecotoxicity	species.yr	-2.864E-03	-2.441E-02	-1.356E-03
Freshwater ecotoxicity	species.yr	5.396E-07	-3.816E-04	1.017E-03
Marine ecotoxicity	species.yr	5.518E-05	-8.725E-04	1.794E-02
Agricultural land occupation	species.yr	0.000E+00	0.000E+00	0.000E+00
Urban land occupation	species.yr	0.000E+00	0.000E+00	0.000E+00
Natural land transformation	species.yr	0.000E+00	0.000E+00	0.000E+00
Metal depletion	$	-4.596E+04	-5.210E+05	-4.323E+04
Fossil depletion	$	-2.163E+09	-7.831E+09	4.139E+09
Human Health	DALY	6.682E+01	1.404E+04	6.772E+04
Ecosystem Quality	species.yr	-3.907E+00	-3.139E+00	-1.271E+00
Resources	$	-2.163E+09	-7.831E+09	4.139E+09

Note: Z: zero alternative; A: alternative (A); B: alternative (B).

This study demonstrates the use of LCIA to assess impact in an EIA and a SEA. However, inconsistency in the results for impact using Eco-indicator 99, IMPACT 2002+ and ReCiPe arise partially because they use different models, geographic conditions, time horizons and receptors.

For case study (1), Table IV shows that the rates of increase in both the quality of the ecosystem and human health are less than 23.9% if Eco-indicator 99 and ReCiPe are used, but these values increase to more than 48.3%, if IMPACT 2002+ is used. The rate of increase in the quality of the ecosystem is greater than that for human health, if Eco-indicator 99 and IMPACT 2002+ are used, but the rate is less if ReCiPe is used.

For case study (2), Table VI shows that the impact of alternative (A) is the least, if Eco-indicator 99 and IMPACT 2002+ are used, but the least impact falls to the value for the zero alternative, if ReCiPe is used. It should be noted that the negative numbers in Table VI that show a positive impact, are for electricity and coal produced by alternative means. The impact of emissions, consumed diesel, consumed electricity, produced electricity and produced coal are detailed in Table VII.

TABLE VII: THE ECO-INDICATOR 99 RESULTS FOR ALTERNATIVE (A) IN CASE STUDY (2)

Impact Category	Unit	Total	Emissions	Consumed Diesel	Consumed Electricity	Produced Electricity	Produced Coal
Carcinogens	DALY	-3.504E+02	4.235E+00	2.675E+01	2.512E-01	-1.546E+00	-3.801E+02
Respiratory organics	DALY	5.937E-01	0.000E+00	9.668E-01	1.151E-02	-7.084E-02	-3.138E-01
Respiratory inorganics	DALY	1.668E+02	1.409E+02	1.908E+02	1.488E+01	-9.159E+01	-8.825E+01
Climate change	DALY	-6.602E+01	6.364E+01	3.418E+01	1.871E+01	-1.152E+02	-6.735E+01
Radiation	DALY	-1.879E+00	0.000E+00	0.000E+00	1.083E-02	-6.664E-02	-1.823E+00
Ozone layer	DALY	-6.816E-02	0.000E+00	4.346E-05	4.352E-04	-2.679E-03	-6.596E-02
Ecotoxicity	PDF*m^2yr	-8.061E+06	1.145E+06	9.537E+05	1.222E+05	-7.523E+05	-9.530E+06
Acidification/ Eutrophication	PDF*m^2yr	9.063E+06	7.557E+06	7.236E+06	5.154E+05	-3.173E+06	-3.072E+06
Land use	PDF*m^2yr	-9.779E+06	0.000E+00	0.000E+00	0.000E+00	0.000E+00	-9.779E+06
Minerals	MJ surplus	-9.950E+05	0.000E+00	0.000E+00	3.427E+04	-2.110E+05	-8.183E+05
Fossil fuels	MJ surplus	-1.330E+09	0.000E+00	1.309E+09	6.783E+07	-4.176E+08	-2.289E+09
Human Health	DALY	-2.510E+02	2.088E+02	2.527E+02	3.386E+01	-2.085E+02	-5.379E+02
Ecosystem Quality	PDF*m^2yr	-8.777E+06	8.702E+06	8.189E+06	6.376E+05	-3.926E+06	-2.238E+07
Resources	MJ surplus	-1.331E+09	0.000E+00	1.309E+09	6.786E+07	-4.178E+08	-2.290E+09

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