A Study on The Eco-efficiencies for Recycling Methods of Plastics Wastes

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1. Introduction
2. LCA
3. Eco-efficiency
   - Eco-cost
   - Cost-benefit Analysis
   - Eco-efficiency

Introduction

Industrial Waste Recycling R&D Center (IWRRC)

IWRRC was founded in 2000 to develop the recycling technologies of industrial wastes with economic efficiency for practical use.

Ministry of Science & Technology

Ministry of Environment

Industrial of Waste Recycling R&D Center

(Unit : million $)

	1st Phase			2nd Phase (2003~2005)	3rd Phase (2006~2009)	Sum
	2000	2001	2002			
Sum	9.8	10	10	31	42	103

Introduction

Project Road Map of IWRRC

Phase	1st Phase			2nd Phase			3rd Phase			
Objectives	Industry fundamentals of resource recycling			Establishing scale up of Commercial recycling			Upgrading recycling rate to 70%			
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009

Thermal Recycling	Fuel production / Gasification
Material Recycling	Separation by solvolysis / Complex recycled product Key technology for plastic recycling
Reutilization	Eco-materials from waste dust / Production of ceramics Material recycling from steel plant sludge
Metal Reclamation	Precious metals reclamation / Metal recovery of used battery Metal recovery from surface treating solution
Planning	Planning & Infrastructure : Environmental evaluation by Life Cycle Assessment

Introduction

Eco-efficiency

- The objective of sustainable waste management is to deal with society's waste in a way that is environmentally efficient, economically affordable and socially acceptable.

- To achieve sustainability or at least to move in the right direction, it is important to develop and improve methods that can be used to operationalize the guiding principle of sustainability.

- Eco-efficiency is recognized as "one of the primary way in which business can contribute to the concept of sustainable development".

- What is ultimately required are simple-to-use methods which give reliable results as a basis for decision.

Indicators for Eco-efficiency

- Needs for eco-efficiency indicators which analyze both environmental and economic aspects in an integrated fashion, since a good understanding and measurement of eco-efficiency is important.

- A significant number of indicators have been proposed around the world to measure the eco-efficiency. Most indicators attempt to incorporate one dimension (environment) into another dimension (affordability).

  - environmental sustainability index
  - eco-metrics
  - return on environment
  - GP index

$$\text{Eco-efficiency} = \frac{\text{Product or Service Value}}{\text{Environmental Influence}}$$

$$\text{ROE} = \frac{\text{Life Cycle Cost/Selling Price}}{\text{Scaled Impact Assessment}}$$

$$\text{GP Index} = \frac{\text{Selling Price/Life Cycle Cost}}{\text{Life Cycle Environmental Impacts}}$$

An eco-efficiency model with one dimension…

- To develop a model where benefits and risks of non-economic dimensions (environment) can be transferred into monetary units.

- EVR Model (Delft Univ. of Technology, 2002)

  - EVR (Eco-cost/Value Ratio); an indicator for eco-efficiency
  - Eco-cost; a LCA based single indicator for environmental impact
    - prevention costs (instead of damage based models); costs to prevent pollution and depletion of materials and energy to a level to make our society sustainable.
  - Marginal prevention costs of emissions; the maximum costs of emissions which are assumed to be sufficient to create a sustainable situation.

In this study,

- **an indicator with one same dimension…**

Eco-efficiency = net benefit/eco-cost

- **Net benefit is obtained from the Cost-Benefit Analysis (CBA).**
- **Eco-cost is calculated from the marginal prevention costs of emissions based on Life Cycle Assessment (LCA).**

- **A case study for different recycling methods of plastic waste is studied to illustrate the applicability of the indicator.**

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Goal & Scope Definition (1)

- **Goal :**

To compare the environmental potential impacts of plastic recycling methods, MR, CR, and TR

Recycling methods	Recycling systems
Material Recycling (MR)	The production of the secondary material
Chemical Recycling (CR)	Oil production by pyrolysis
Thermal Recycling (TR)	Incineration with heat recovery

- **Function & functional unit**

Function	recycling of the waste plastics
Functional unit	recycling of the waste plastics 1kg
Reference flow	waste plastic 1kg

Goal & Scope Definition (2)

Data quality requirement

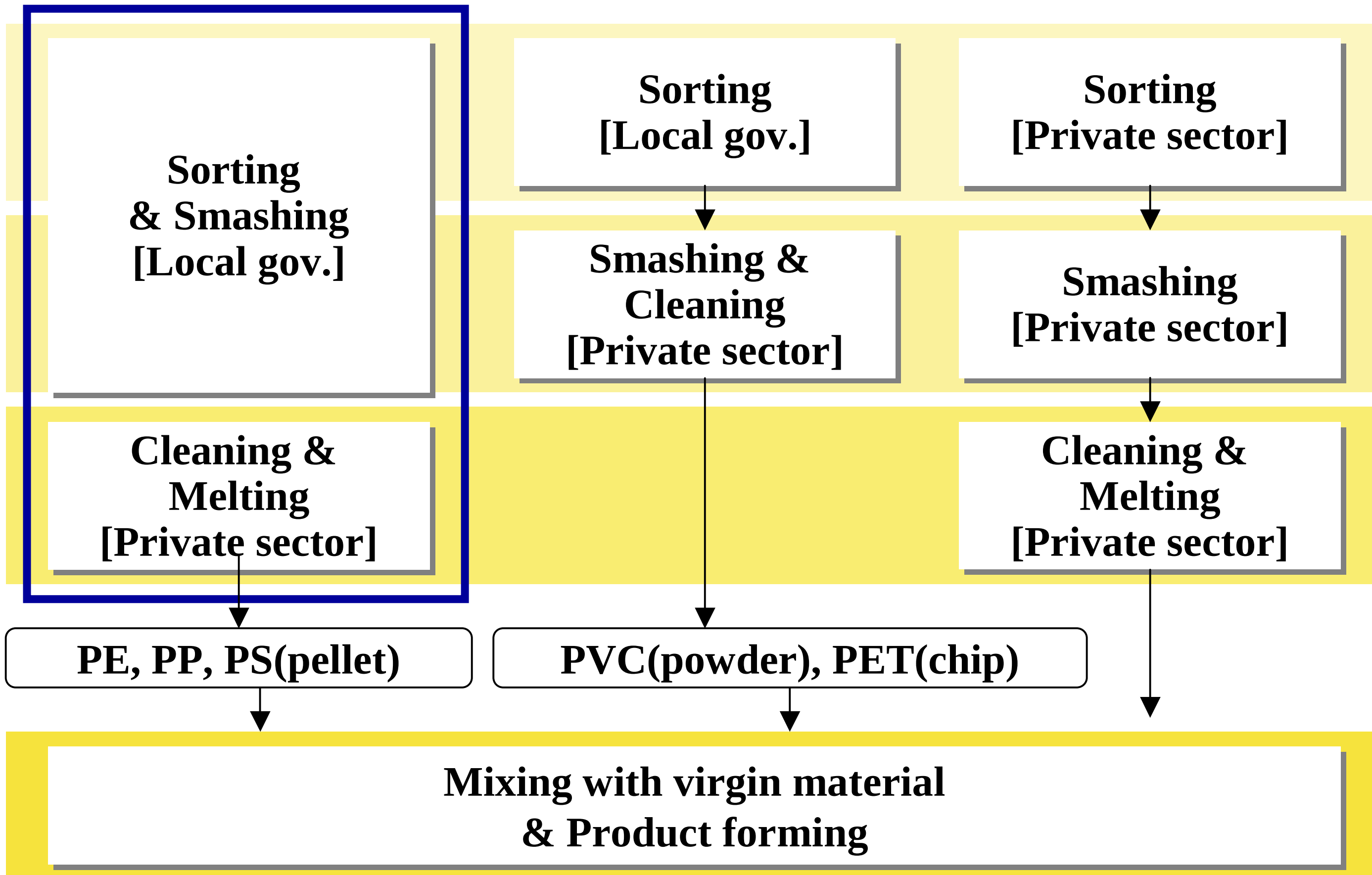
	On-site	Off-site(upstream, downstream)
Time-related coverage	2002	within the last 10 years
Geographical coverage	recycling processes in Korea	Korean DB : Electricity(KEPCO), Transportation(5ton Truck)
		overseas DB : Chemical , Oil, Plastics, Steam production
Technology coverage	average data	similar data with real process

LCIA methodology

- 7 Impact categories are considered.
  global warming, acidification, eutrophication, summer smog, winter smog, heavy metals, carcinogenics
- Normalization and weighting steps are not included.

MR - Data Collection

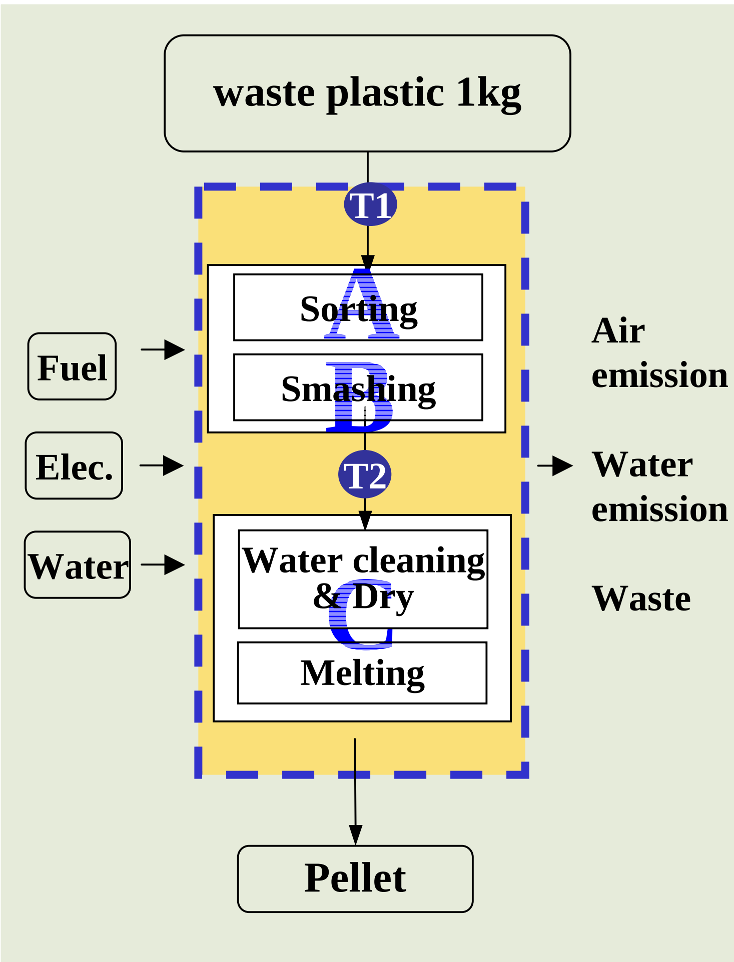
Types of the MR companies in Korea



Data collection from 30 companies → **Data treatment** → **Sum of the unit processes**

MR – LCI result

Process flow diagram & main inputs /outputs

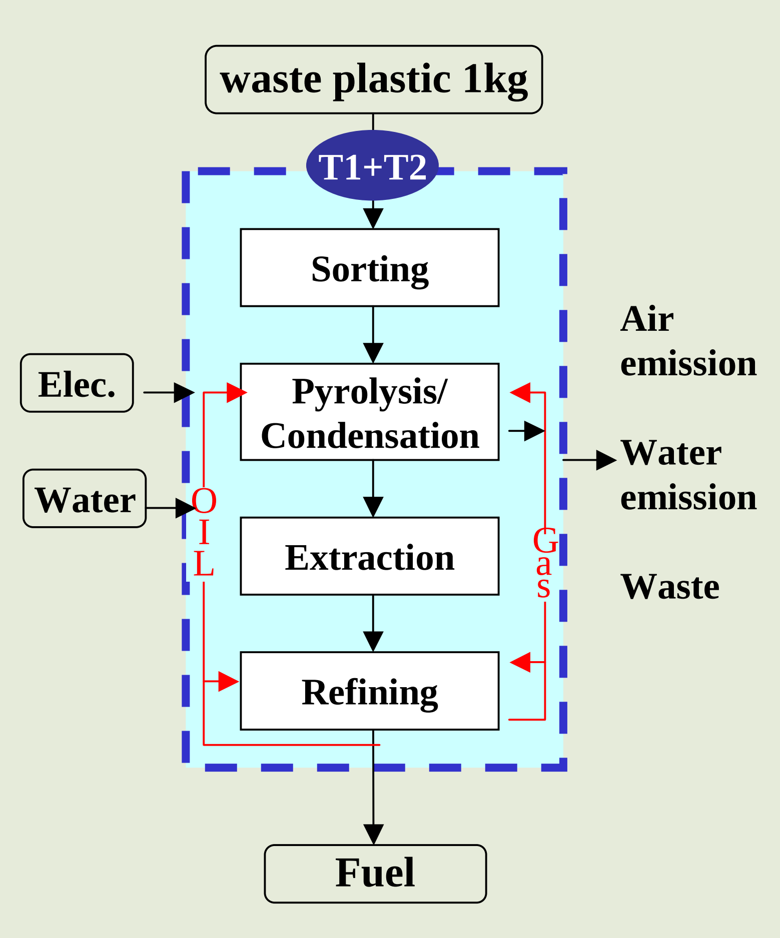


Inputs	total amount	unit	process (amount)
electricity	**0.438**	kWh	A (0.018)
			B (0.052)
			C (0.369)
diesel(T)	**0.018**	kg	**transport (T1+T2)**

Outputs	total amount	unit	process (yield & amount)
secondary material	**0.672**	kg	**A (** 70 %)
			B (100 %)
			C (96 %)
wastes	**0.328**	kg	**A (**0.300)
			B (0.000)
			C (0.028)
CO_2 emissions(T)	**0.069**	kg	**transport (T1+T2)**

CR – LCI result

Process flow diagram & main inputs /outputs



Inputs	amount	unit
electricity	0.259	kWh
diesel(T)	0.018	kg

Outputs	amount		unit
gasoline	0.299	0.571	kg
kerosene	0.115		
diesel	0.089		
heavy oil	0.068		
internal use in the CR	0.070		kg
loss (non-condensable gas)	0.081		kg
CO_2 emissions	0.449		kg
CO_2 emissions(T)	0.084		kg

Data Source : 2001 ROICO, which is performing chemical recycling in Korea, data

TR – Data collection

- **Data collection : 11 incineration with heat recovery facilities**
- **The heat recovery for the waste plastics was obtained based on the ratio of calorific values of MSW**

1. Weight % of the waste plastic in the MSW (20%)

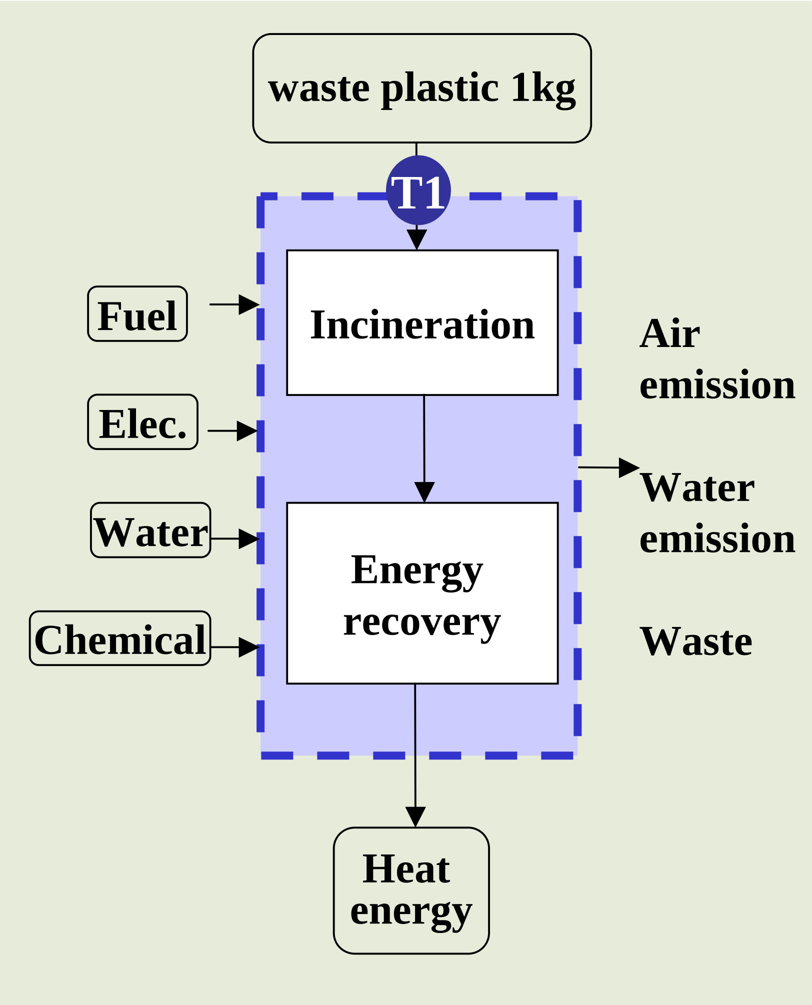
2. The ratio in calorific values between waste plastics and the MSW (2.7 : 1)

Allocation factor (0.54 to the MSW)

Data Source : The Status of Incineration facility operation for the Domestic Wastes in 2001, Ministry of Environment 2002

TR – LCI result

Process flow diagram & main inputs /outputs

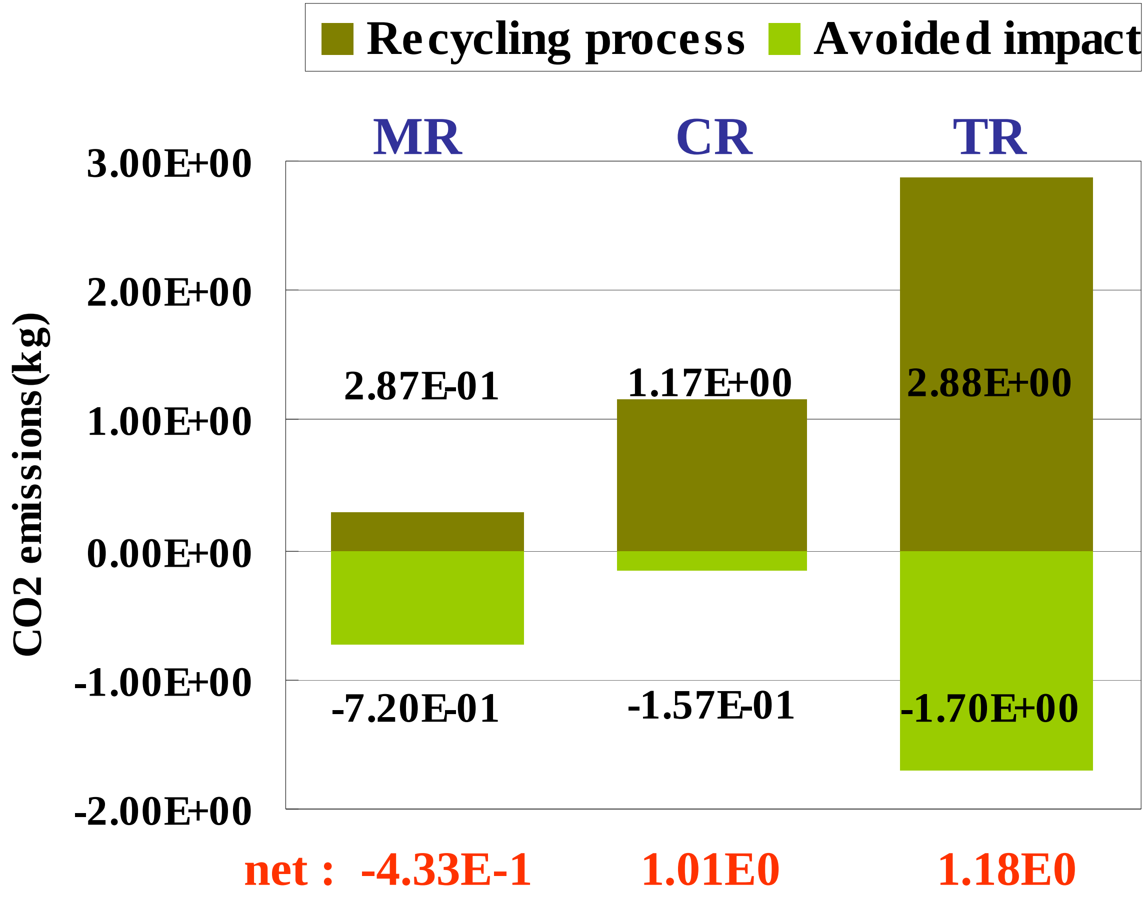


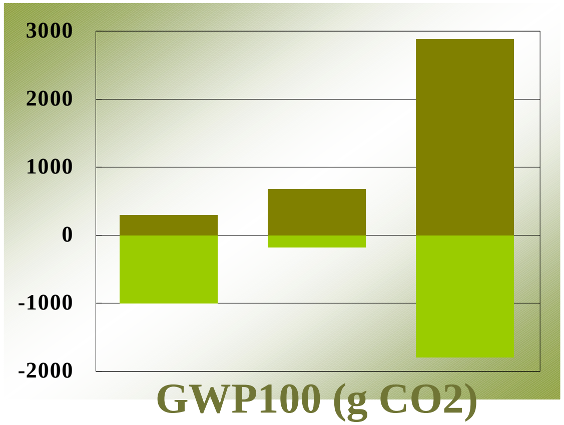
Inputs	amount	unit
electricity	0.089	kWh
diesel	<0.001	kg
diesel(T)	0.009	kg

Outputs	amount	unit
Heat Energy Recovery	19.440	MJ
CO_2 emissions	2.800	kg
CO_2 emissions(T)	0.033	kg

Comparison – LCI (1)

- **CO2 emissions from MR, CR and TR**





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3. **Eco-efficiency**
    - **Eco-cost**
    - **Cost-benefit Analysis**
    - **Eco-efficiency**

Eco-cost

Marginal Prevention Costs of Emissions

(The Netherlands)

- **Prevention global warming: 0.114 Euro/kg (CO_2 equivalent)**
- **Prevention of acidification: 6.40 Euro/kg (SO_x equivalent)**
- **Prevention of eutrofication: 3.05 Euro/kg (phosphate equivalent)**
- **Prevention of heavy metals: 680 Euro/kg (based on Zn)**
- **Prevention of carciogenics: 12.3 Euro/kg (PAH equivalent)**
- **Prevention of summer smog: 50.0 Euro/kg (based on VOC)**
- **Prevention of winter smog: 12.3 Euro/kg (based on fine dust)**

Eco-cost Results

Impact category	MR		CR		TR	
global warming	3.54E-01 (kg CO2 equiv.)	4.04E-2 (Euro)	7.31E-01 (kg CO2 equiv.)	8.33E-2	2.92E+00 (kg CO2 equiv.)	3.33E-1
acidification	1.59E-03 (kg SO4 equiv.)	1.02E-2	2.46E-03 (kg SO4 equiv.)	1.57E-2	1.16E-03 (kg SO4 equiv.)	7.42E-3
eutrophication	1.84E-04 (kg PO4 equiv.)	5.61E-4	3.75E-04 (kg PO4 equiv.)	1.14E-3	1.45E-04 (kg PO4 equiv.)	4.42E-4
heavy metals	2.61E-08 (kg Pb equiv.)	1.77E-5	1.54E-08 (kg Pb equiv.)	1.05E-5	6.62E-06 (kg Pb equiv.)	4.50E-3
carcinogenics	2.42E-11 (kg PAH)	2.98E-10	7.20E-12 (kg PAH)	8.86E-11	2.32E-09 (kg PAH)	2.85E-8
winter smog	6.09E-04 (kg SPM)	7.49E-3	4.44E-04 (kg SPM)	5.46E-3	2.90E-04 (kg SPM)	3.57E-3
summer smog	2.23E-04 (kgC_2H_4 equiv.)	1.12E-2	1.41E-04 (kgC_2H_4 equiv.)	7.05E-3	6.55E-05 (kgC_2H_4 equiv.)	3.28E-3
total eco-cost	6.99E-2 (Euro)		1.13E-1 (Euro)		3.52E-1 (Euro)	

Cost Benefit Analysis (CBA)

- Economic aspect of each recycling method was investigated from the CBA study.

		MR	CR	TR
Cost	collection and transportation (T1+T2)	labor cost for collection, and driving maintenance cost of vehicle		
	operation cost	depreciation and maintenance cost of facility labor cost miscellaneous costs		
Benefit	Selling benefit	selling of plastic pellet	selling of oil	selling of heat energy
	Indirect benefit*	benefit as substitution effect of landfill cost		
Net benefit (Benefits-Costs)		Net benefit of MR	Net benefit of CR	Net benefit of TR

Cost Benefit Analysis

Material Recycling

Cost		
	Item	**Amount (Euro)**
Operation cost	depreciation of facilities labor maintenance electricity wastes transportation	3.93E-2 4.54E-2 1.05E-2 3.21E-2 6.23E-3 1.65E-1
MR cost	**Total**	**2.98E-1**
Benefit		
	Item	**Amount (Euro)**
Benefit	plastic pellet selling	2.80E-1
	Social benefit (substitution for Landfill)	1.81E-1
MR benefit	**Total**	**4.61E-1**

Thermal Recycling

Cost		
	Item	**Amount (Euro)**
Operation cost	depreciation of facilities labor maintenance electricity wastes transportation others	2.06E-2 1.44E-2 3.51E-3 5.28E-3 3.27E-3 1.02E-1 9.31E-3
TR cost	**Total**	**1.58E-1**
Benefit		
	Item	**Amount (Euro)**
Benefit	Steam selling	1.39E-2
	Social benefit (substitution for Landfill)	1.81E-1
TR benefit	**Total**	**1.95E-1**

Cost Benefit Analysis

Chemical Recycling-1

(operating rate; 30%)

Costs		
	Item	**Amount (Euro)**
Operation cost	depreciation of facilities labor maintenance electricity wastes transportation	1.42E-1 1.81E-1 1.83E-2 5.89E-3 3.93E-3 1.65E-1
CR cost	**Total**	**5.15E-1**
Benefits		
Benefit	**Item**	**Amount (Euro)**
	Oil selling price	2.55E-1
	Social benefit (substitution for landfill)	1.81E-1
CR Benefit	**Total**	**4.36E-1**

Chemical Recycling-2

(operating rate; 90%)

Costs		
	Item	**Amount (Euro)**
Operation cost	depreciation of facilities labor maintenance electricity wastes transportation	5.54E-2 6.35E-2 1.06E-2 3.42E-3 2.28E-3 1.65E-1
CR cost	**Total**	**3.00E-1**
Benefits		
Benefit	**Item**	**Amount (Euro)**
	Oil selling price	2.55E-1
	Social benefit (substitution for landfill)	1.81E-1
CR Benefit	**Total**	**4.36E-1**

Eco-efficiency

<u>In this study,</u>

Eco-efficiency = Value/Eco-cost
(Benefit – Cost)/Eco-cost

✓ **Eco-efficiency**	**> 1**	**affordable,**	**sustainable**
	= 0-1	**affordable,**	**not sustainable**
	< 0	**not affordable,**	**not sustainable**

Eco-efficiency

	Benefit (Euro)	Cost (Euro)	Value (Euro)	Eco-cost (Euro)	Eco-efficiency
MR	4.61E-1	2.98E-1	1.63E-1	6.99E-2	2.33
CR-1	4.36E-1	5.15E-1	-7.90E-2	1.13E-1	-0.70
CR-2	4.36E-1	3.00E-1	1.36E-1	1.13E-1	1.20
TR	1.95E-1	1.58E-1	3.70E-2	3.52E-1	0.11

Summary-1

- **LCI DB for plastic recycling methods were constructed as one of the 1st phase projects in the IWRRC.**

- **Measurement framework of Eco-efficiency was discussed.**
  - An indicator for eco-efficiency was developed based on EVR (Eco-cost/Value Ratio) model.
  - Eco-cost is calculated from the marginal prevention costs of emissions (the Netherlands) based on the results of LCA.
  - Value is obtained from the CBA study.

- **While MR is better than CR and TR is the poorest in terms of the potential environmental impacts from the LCA study, MR was the best and CR was the worst from the perspective of eco-efficiency.**

Summary-2

- From the eco-efficiency indicator, MR is not only economically affordable but also sustainable, while TR is only economically affordable but not sustainable.
- At present, CR is neither affordable nor sustainable. CR can become affordable and sustainable by enhancing the operating rate up to 90%.
- The marginal prevention costs of emissions in Korea has to be developed so that the LCI results can take into account of the situation of the region where the emissions occur.
- In the next phase of this IWRRC project, the issues such as the differences in the quality and shape of waste plastics, data quality, and system boundary have to be considered to improve the reliability of the results.

Thanks for your attention.

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