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Assessing Different Treatment Options for Plastic Wastes from Discarded Television Sets in the Context of LCA

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In the present work, the energy recovery and the mechanical recycling, i.e. two treatment options for plastic wastes from the discarded TV sets have been assessed and compared in the context of the life cycle assessment methodology (LCA). The environmental impact of each option was assessed by calculating the following impact indicators : *energy depletion* (ED), *depletion of abiotic resources* (ADP), and *global warming potential* (GWP). Then, the indicators were compared and the option with the smaller environmental impact was selected. The main finding of this study was that mechanical recycling of plastics is more attractive treatment option in environmental terms than incineration for energy recovery.

Key Words : life cycle assessment (LCA), plastic wastes, mechanical recycling, energy recovery, separation.

1. INTRODUCTION

Final management of "end-of-life" electronic products includes disposal, recycling or sale of scrap parts. All appliances (including TV sets) require some form of end-of-life management at some point. Thus, the question is not "if" we will manage these appliances, but "when" and "how" to reuse, recycle, or properly dispose this appliances.

Figure 1 shows the composition of a TV set, [1]. It can be seen that glass is the main component (51 wt%), followed by steel (12 wt%), copper (8 wt%), aluminium (2 wt%) and circuit board (3 wt%) from electric components. In addition, there are also three types of plastics (10.5 wt%) from the TV cabinet, namely polystyrene (PS), polyvinyl chloride (PVC) and polyethylene (PE).

Generally speaking, the recycling of discarded TV sets has made good progress. The panel glass and funnel glass are recycled to make new cathode ray tubes. The steel and other metals are also recycled to make other new products. The plastic materials, on the other hand, are generally incinerated.

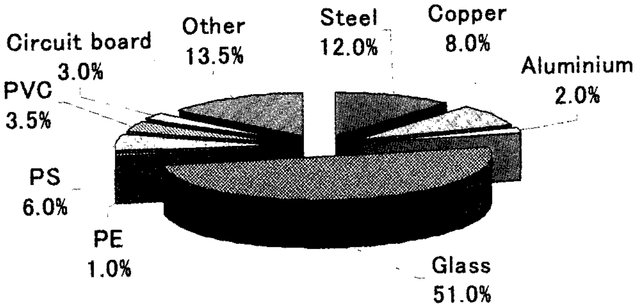

Figure 1 Materials composition of a TV set (wt%), indicating the production in 2002, in Japan.

Several treatment options are primarily being considered when dealing with plastic wastes. At present, there are three main alternatives in addition to landfilling :

(1) *energy recovery* (also know as thermal recycling), i.e. direct incineration of plastic wastes for energy recovery.
(2) *mechanical recycling* (also known as material recycling), i.e. the method by which plastic wastes are recycled into new resources without affecting the basic structure of the material ;
(3) *feedstock recycling* (also know as chemical recycling), i.e. the technique that break down polymers into their constituent monomers, which in turn can be used again in refineries or petrochemical and chemical production.

In the present work, (1) the energy recovery and (2) the mechanical recycling of the plastic wastes from the discarded TV sets are assessed and compared in the context of the life cycle assessment methodology (LCA).

2. LCA METHODOLOGY

Life cycle assessment (LCA) is a method for evaluating the environmental performance of a product or process, starting from raw material extraction, through manufacture and final disposal [2, 3, 12]. LCA is generally carried out in four steps, (Figure 2):

(1) *goal definition and scope*, i.e.
  a) define and describe the subject of the study ;
  b) determine the so-called "*functional unit*" i.e. the unit of comparison that assures that the options to be compared

provide an equivalent level of function or service ;

c) specify the processes required in the manufacture, use and eventual disposal of the products ;

d) develop a flow diagram of the processes to be evaluated ;

e) identify the boundaries and environmental effects to be reviewed for the assessment ;

(2) *inventory analysis*, i.e. identifying and quantifying energy, materials usage and environmental releases (e.g. atmospheric emission, waterborne emissions, etc.) for the entire life-cycle ;

(3) *impact assessment*, i.e. assessing the human and ecological effects of energy, material usage and the environmental releases identified in the inventory analysis ;

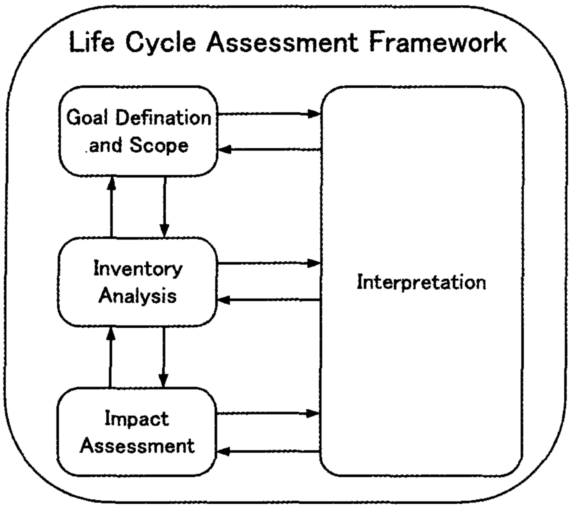

Figure 2 Phases of an LCA, [3, 12].

(4) *interpretation*, i.e. evaluating the results of the inventory analysis and assessing the impact of each option under investigation in order to select the preferred one.

3. LCA OF TREATMENT OPTIONS FOR PLASTIC WASTES FROM THE DISCARDED TV SETS

3.1 Goal Definition and Scope

The first important step in caring out the LCA was the goal definition, (Figure 2). In this work, two treatment options for plastic wastes, generated from the efforts to recycle "old" TV sets, have been considered :

Option 1 : incineration of plastic wastes for energy recovery (i.e. electricity production) ;

Option 2 : separation of plastic wastes for mechanical recycling.

To quantify the environmental impact associated with each recycling options, the *functional unit* f_u was taken "10 years use of color TV sets". It is assumed that each TV set (screen : 25 inches ; weight : 30 kg) contains of 1.8 kg of PS, 1.05 kg of PVC and 0.30 kg of PE. Moreover, the amount of the discarded TV sets (*d*) was considered to be 1.2 million sets per year, i.e. similar to the production of colour TV sets in Japan in 2002, [4].

A simplified life-cycle of plastics for production of colour TV sets, indicating the system boundary and describing the relation between processes involved, is shown in Figure 3. A look at Figure. 3 shows that the life-cycle of plastics starts with the extraction of resources (i.e. crude oil, coal, etc) needed for production of electricity and the production of PS, PVC and PE. Then, the plastics (i.e. PS, PVC, and PE) are used as raw materials in the manufacturing process for colour TV sets. After being used, the "old" TV sets are collected. It is assumed that the collection rate of the discarded TV sets is 100%. The discarded TV sets are then dismantled, and their parts are sorted for recycling

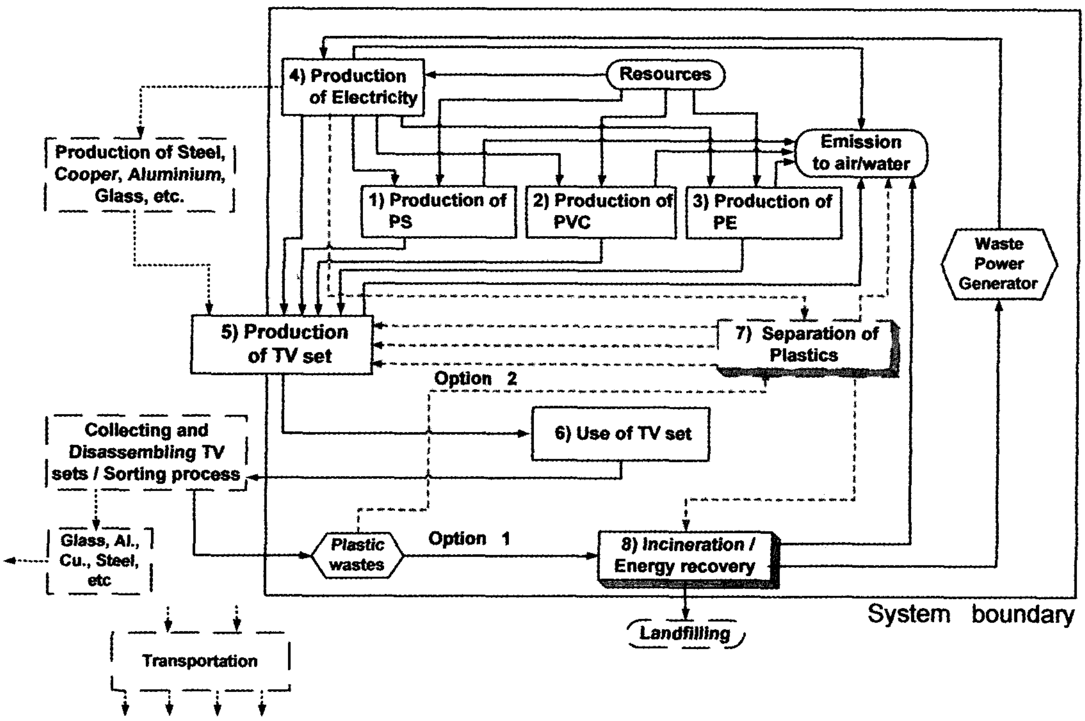

Figure 3 A simplified life-cycle of plastics for TV sets, indicating the system boundary.

purpose. The sorting process results in production of a mixed plastic product. It is also assumed that the sorting process is able to recovery 100% of plastics being used for production of TV sets. Finally, there are only two possible treatment options for plastic wastes, i.e.: (1) direct incineration for electricity production (i.e. energy recovery) or (2) separation of plastics according to their types, for reuse in production of TV sets (i.e. mechanical recycling).

It is important to note that (a) processes for production of steel, copper, and aluminium; (b) the process for production of TV; as well as (c) the process for collecting and dismantling TV sets followed by sorting their parts according to the type of materials have not been included in the following inventory analysis, as these processes have the same influence on the life-cycle of plastics, regardless the treatment option under investigation. A second important simplification is that the landfilling of the incinerator ash was excluded from the analysis due to lack of data. Moreover, the last important simplification was that transportation was also excluded from the inventory analysis, assuming that the incinerator together with the waste power generated and/or the facility for separation of plastics are located in the vicinity of the collection point for "old" TV sets, which on the other hand is located in the same area with the facility for the production of colour TVs.

3.2 Inventory Analysis

Inventory analysis, known as life cycle inventory (LCI), was the second phase in LCA (Figure 2). It consists of quantifying energy and raw material requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of the plastics for colour TV sets. Steps of LCI were as follows:

(a) collect data, and

(b) create a computer model to evaluate the environmental loads, related to each option under investigation.

The diagram shown in Figure 3 provided the road map for data to be collected. The data on "manufacturing process of PS", "manufacturing process of PVC", "manufacturing process of PE", "production of electricity" and "manufacturing process of a TV set" were obtained from the LCA database of the Japan Environmental Management Association for Industry (JEMAI), [5].

With regard to the incineration of plastics for energy recovery (i.e. option 1), the energy generated from the incineration of plastics has been calculated based on their calorific values, (Table 1). Power generating efficiency (t) from the incineration of plastics is considered to be 15%, [6]. Furthermore, the emission of CO_2 gas during the incineration of plastics was considered to be 2.64 kg CO_2/kg, [7].

On the other hand, a two-stage dry process that combines triboelectric separation and air tabling has been proposed for separation of plastic wastes prior to mechanical recycling (i.e. option 2). It should be also noted that the data on the separation process were from the experimental work carried out by the authors and published elsewhere, [8]. Figure 4 shows the simplified flowsheet of the process. A triboelectric separator can be employed for the first stage of the process to collect a PS-rich positively charged fraction and a PE/PVC negatively charged fraction. In the second stage, the PE/PVC fraction can be separated by means of an air table, by taking advantage of

Table 1 Calorific value of plastics, (option 1), [6]

Type of plasti	Calorific value, (kcal/kcg)
PS	9,604
PVC	4,300
PE	11,140

differences in specific gravities. It was estimated that the electricity requirement (v) for this process, which is able to collect ca. 67% of each plastic with a grade of 96% or higher, is approximately 0.74kWh/kg, (Table 2). It is important to note that the rest of the plastics (i.e. middlings), which have not been recovered (i.e. less than 33%), is not re-cycled in the system but is incinerated instead. In other words, the authors have chosen to calculate LCI for a mechanical recycling ratio (R_M) of 67%. This was done in order to simplify the calculation of LCI. Nevertheless, should the recovery of plastics or the ratio of mechanical recycling be higher than 67%, the middling can be re-processed to fulfil the requirement.

Next, the data on the processes were organized in vector notations in a way, which resembles the classical input-output analysis [9]. The material balance principle and matrix algebra were combined to give an explicit formula [10]:

$$g = BA^{-1}f \quad (1)$$

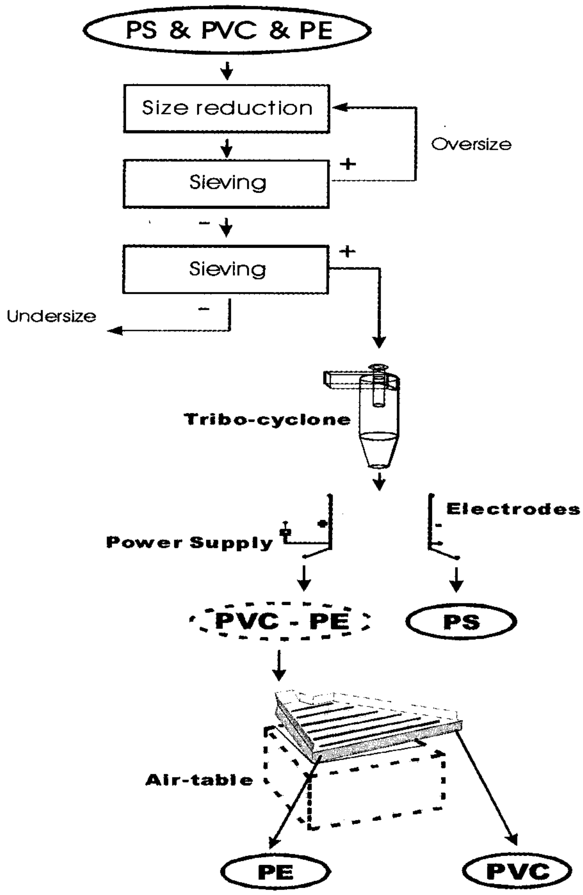

Figure 4 Simplified flowsheet of the process for separation of plastics according to their type.

Table 2 Electricity requirement for separation of plastics (option 2): syste

Unit Process	Electricity, (kWh/kg)
Triboelectrostatic separation	0.04
Air tabling	0.66
Size reduction	0.02
Sieving	0.02

where g was the vector of the environmental loads; the matrix B represented the flow of environmental releases (e.g. CO_2 emission, etc.); the matrix A represented the flow of products and materials (e.g. electricity, materials usage, etc); the vector f (know as demand vector) represented a special process where f_u was an output; the superscript -1 denoted that the matrix A was inverted. Matrixes A and B as well as the vector f of the system under evaluation are defined in Tables 3, 4 and 5 respectively. Tables 3-5 describe the relation between the processes involved, showing the relative magnitude of the flows. A sign of conversion was adopted: the inputs of flows were expressed by negative coefficients, whereas the outputs by positive coefficients.

The outcome of the inventory analysis (Eq. 1) was the vector g, which is a list the containing the quantities g_i of pollutants released to the environment and the amount of energy and materials consumed during the life-cycle of plastics, i.e.:

$$g=\begin{pmatrix} g_1 \\ \vdots \\ g_i \\ \vdots \\ g_n \end{pmatrix} \quad \text{for} \quad i=1,2,\cdots,n \tag{2}$$

The results of the inventory analysis for each treatment option under the evaluation are given in Table 6.

3.3 Impact Assessment

Impact assessment, known as life cycle impact assessment (LCIA), was the third phase in LCA (Figure 2) that was comprised of the following issues:

(a) *selection* of environmental impact categories, e.g., abiotic resources, global warming, etc.;

(b) *classification* i.e. assigning LCI results (i.e. the environmental loads g_i) to the environmental impact categories (e.g. classifying CO_2 emissions to global warming, etc.),

(c) *characterization* i.e. expressing LCA results in a way that can be compared (e.g. comparing the global warming impact of CO_2 and CH_4, etc.) and calculating the overall impact indicator of each impact category;

In this work, the environmental impact has been assessed by calculating the impact indicator I_j of the following categories:

(1) *energy depletion*,

(2) *abiotic resources*, and

(3) *global warming*.

The impact indicators I_j have been characterized using the following equations:

$$I_{i(j)}=g_i \times k_{i(j)}, \quad i=1,2,\cdots,n \tag{3}$$

$$I_j=\sum_{i=1}^{n} I_{i(j)}, \quad j=1,2,\cdots,q \tag{4}$$

In other words, the environmental loads g_i of the substances grouped in a category, were expressed in terms of equivalent units by multiplying them by a characterization factor $k_{i(j)}$, (Eq. 3), [11]. The resulting impact indicators $I_{i(j)}$ were then aggregated to give an overall indicator I_j of the environmental impact category, (Eq. 4).

3.3.1 Energy depletion

By quantifying the amount of the energy from now-renewable resources, extracted during the life-cycle of plastics, and the energy generated from incineration of plastic wastes, it was possible to establish an energy balance and to see which option requires the most energy. The results are shown in Figure 5, which also indicate the energy depletion (*ED*) of each treatment options under the investigation.

Considering the results (Figure 5), it can be seen that the option 1 generates 126.03 x 10^9 kcal more than the option 2. It can also be seen that option 1 also consumes 982.79 x 10^9 kcal more than the option 2. In turn, the energy depletion for thermal recycling (i.e. energy recovery: option 1) is however 27.2 x 10^9 kcal smaller when compared with material recycling (i.e. mechanical recycling: option 2), (Figure 5).

3.3.2 Depletion of abiotic resources

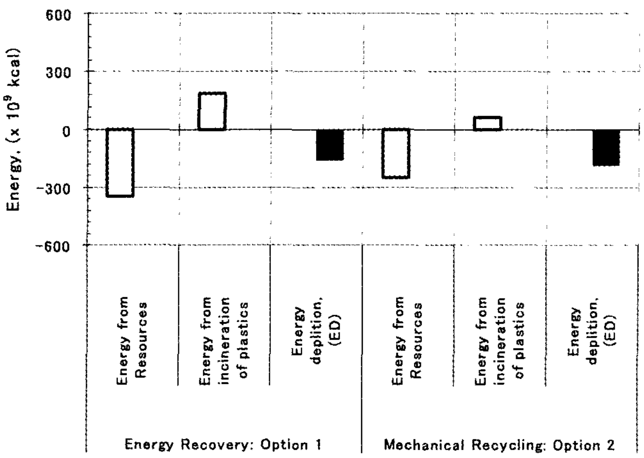

Figure 5 Energy depletion.

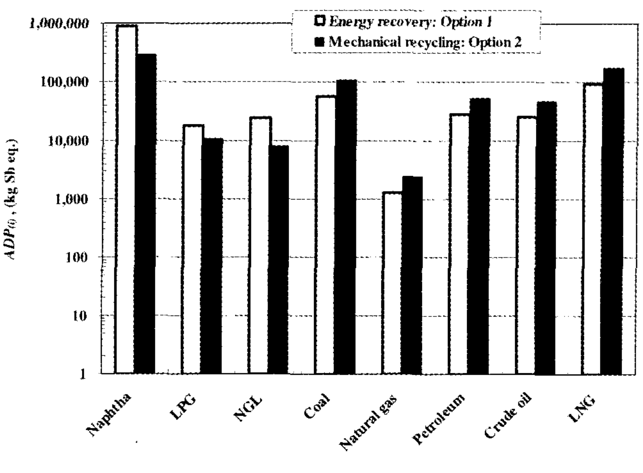

Figure 6 $ADP_{(i)}$ of various abiotic resources.

Table 3 Technology matrix A

	Flow	Process 1: Manufacturing process of PS (1kg)	Process 2: Manufacturing process of PVC (1kg)	Process 3: Manufacturing process of PE (1kg)	Process 4: Production of electricity	Process 5: Manufacturing process of TV set	Process 6: Use of TV sets	Process 7: Separation of plastics for mechanical recycling	Process 8: Incineration of plastics for energy recovery
1	PS, (kg)	$a_{1,1}$	0	0	0	$-a_{1,5}$	0	$M_{in}\left(\frac{a_{1,5}}{a_{1,5}+a_{2,5}+a_{3,5}}\right)R_M$	0
2	PVC, (kg)	0	$a_{2,2}$	0	0	$-a_{2,5}$	0	$M_{in}\left(\frac{a_{2,5}}{a_{1,5}+a_{2,5}+a_{3,5}}\right)R_M$	0
3	PE, (kg)	0	0	$a_{3,3}$	0	$-a_{3,5}$	0	$M_{in}\left(\frac{a_{3,5}}{a_{1,5}+a_{2,5}+a_{3,5}}\right)R_M$	0
4	Electricity, (kWh)	$-a_{4,1}$	$-a_{4,2}$	$-a_{4,3}$	$a_{4,4}$	$-a_{4,5}$	0	$-(M_{in}-M_{mid})\cdot v$	$1.16\cdot10^{3}\left[t\cdot d(1-R_M)\frac{(a_{1,5}\cdot H_1+a_{2,5}\cdot H_2+a_{3,5}\cdot H_3)}{a_{5,5}}\right]$
5	TV set, (No)	0	0	0	0	$a_{5,5}$	$-d$	0	0
6	Plastics collected for separation, (kg)	0	0	0	0	0	M_{in}	$-M_{in}$	0
7	Plastics collected for incineration, (kg)	0	0	0	0	0	M_w	M_{mid}	$-M_e$
8	Provision of TV sets, (yrs.)	0	0	0	0	0	1	0	0

Table 4 Environmental matrix *B*

Flow		Process 1: Manufacturing process of PS (1kg)	2: Manufacturing process of PVC (1kg)	3: Manufacturing process of PE (1kg)	4: Production of electricity	5: Manufacturing process of a TV set	6: Use of TV sets	7: Recovery of plastics	8: Incineration of Plastics
1	Energy from resources, (kcal)	$-b_{1,1}$	$-b_{1,2}$	$-b_{1,3}$	$-b_{1,4}$	$-b_{1,5}$	0	0	0
2	Energy from combustion, (kcal)	0	0	0	0	0	0	0	$d(1-R_M)\frac{(a_{1,5}\cdot H_1+a_{2,5}\cdot H_2+a_{3,5}\cdot H_3)}{a_{5,5}}$
3	Naphtha, (kg)	$-b_{3,1}$	$-b_{3,2}$	$-b_{3,3}$	0	0	0	0	0
4	Liquefied petroleum gas, (LPG), (kg)	$-b_{4,1}$	$-b_{4,2}$	$-b_{4,3}$	$-b_{4,4}$	0	0	0	0
5	Natural gas liquid (NGL), (kg)	$-b_{5,1}$	$-b_{5,2}$	$-b_{5,3}$	0	0	0	0	0
6	Oxygen gas, (kg)	$-b_{6,1}$	$-b_{6,2}$	0	0	0	0	0	0
7	Coal, (kg)	0	0	0	$-b_{7,4}$	0	0	0	0
8	Natural gas, (kg)	0	0	0	$-b_{8,4}$	0	0	0	0
9	Petroleum, (L)	0	0	0	$-b_{9,4}$	0	0	0	0
10	Crude oil, (L)	0	0	0	$-b_{10,4}$	0	0	0	0
11	Liquefied natural gas (LNG), (kg)	0	0	0	$-b_{11,4}$	0	0	0	0
12	CO_2, (g)	$b_{12,1}$	$b_{12,2}$	$b_{12,3}$	$b_{12,4}$	$b_{12,5}$	0	0	$b_{12,8}\left[\frac{(a_{1,5}+a_{2,5}+a_{3,5})\,d(1-R_M)}{a_{5,5}}\right]$

Table 4 Environmental matrix *B*

(*Continue*)

	Flow	Process 1: Manufacturing process of PS (1kg)	2: Manufacturing process of PVC (1kg)	3: Manufacturing process of PE (1kg)	4: Production of electricity	5: Manufacturing process of a TV set	6: Use of TV sets	7: Recovery of plastics	8: Incineration of Plastics
13	CH_4, (g)	$b_{13,1}$	0	$b_{13,3}$	0	0	0	0	0
14	HCF, (g)	0	0	0	$b_{14,4}$	0	0	0	0
15	N_2O, (g)	$b_{15,1}$	$b_{15,2}$	$b_{15,3}$	$b_{15,4}$	0	0	0	0
16	SF_6, (g)	0	0	0	$b_{16,4}$	0	0	0	0
17	NO_x, (g)	$b_{17,1}$	$b_{17,2}$	$b_{17,3}$	$b_{17,4}$	$b_{17,5}$	0	0	0
18	SO_x, (g)	$b_{18,1}$	$b_{18,2}$	$b_{18,3}$	$b_{18,4}$	$b_{18,5}$	0	0	0
19	Dust, (g)	$b_{19,1}$	$b_{19,2}$	$b_{19,3}$	$b_{19,4}$	0	0	0	0
20	HCl, (g)	$b_{20,1}$	$b_{20,2}$	$b_{20,3}$	0	0	0	0	0
21	CO, (g)	0	$b_{21,2}$	0	0	0	0	0	0
22	Chemical Oxygen Demand (COD), (mg)	$b_{22,1}$	$b_{22,2}$	$b_{22,3}$	$b_{22,4}$	0	0	0	0
23	T-P, (mg)	$b_{23,1}$	$b_{23,2}$	$b_{23,3}$	0	0	0	0	0
24	T-Ni, (mg)	$b_{24,1}$	$b_{24,2}$	$b_{24,3}$	0	0	0	0	0
25	Phenol, (mg)	$b_{25,1}$	$b_{25,2}$	$b_{25,3}$	0	0	0	0	0

Table 5 The demand vector f

Index	Flows	Amount
1	PS, (kg)	0
2	PVC, (kg)	0
3	PE, (kg)	0
4	Electricity, (kWh)	0
5	TV set, (No)	0
6	Plastics collected for incineration, (kg)	0
7	Plastics collected for separation, (kg)	0
8	Provision of colour TV sets, (yrs.)	f_u

Depletion of abiotic resources was assessed by calculating the *ADP* indicator (Eqs. 3 and 4), which indicates the extraction of non-renewable raw materials such as naphtha, natural gas, petroleum, crude oil, etc. Figure 6 shows the normalized $ADP_{(i)}$ indicators of various non-renewable raw materials extracted during the life-cycle of plastics, needed for production of colour TV sets.

A look at Figure 6 shows that the $ADP_{(i)}$ varies with the type of raw material, and the treatment option for plastic wastes. It can be seen that the naphtha is the resource depleted the most and consequently has the greatest environmental impact. It can also be seen that LNG and coal, which are used for production of electricity, have relatively a great environmental impact.

Table 6 Environmental loads, g_i

	Category	Flow		Environmental loads: Energy Recovery : Option 1, (R_M=0%)	Environmental loads: Mechanical Recycling : Option 2, (R_M=67%)
1	Energy	Energy from resourceses, (kcal)	$-g_1$	-346,909,896,260.76	-248,122,522,245.61
2	Energy	Energy from combustion, (kcal)	g_2	188,101,440,000.00	62,073,475,212.60
3	Depletion of resources	Naphtha, (kg)	$-g_3$	-44,568,900.00	-14,707,737.00
4	Depletion of resources	Liquefied petroleum gas, (LPG), (kg)	$-g_4$	-904,593.88	-565,669.82
5	Depletion of resources	Natural gas liquid (NGL), (kg)	$-g_5$	-1,301,400.00	-429,462.00
6	Depletion of resources	Oxygen gas, (kg)	$-g_6$	-2,732,400.00	-901,692.00
7	Depletion of resources	Coal, (kg)	$-g_7$	-5,750,732.07	-10,783,713.20
8	Depletion of resources	Natural gas, (kg)	$-g_8$	-70,615.09	-132,416.68
9	Depletion of resources	Petroleum, (L)	$-g_9$	-1,406,270.61	-2,637,024.08
10	Depletion of resources	Crude oil, (L)	$-g_{10}$	-1,245,439.09	-2,335,434.48
11	Depletion of resources	Liquefied natural gas (LNG), (kg)	g_{11}	-4,935,517.30	-9,255,030.91
12	Atmospheric emissions	CO_2, (g)	g_{12}	451,228,644,294.46	334,343,918,628.8
13	Atmospheric emissions	CH_4, (g)	g_{13}	28,004,400.00	9,241,452.00
14	Atmospheric emissions	HCF, (g)	g_{14}	1,306.76	2,450.42
15	Atmospheric emissions	N_2O, (g)	g_{15}	1,301,351.37	755,622.15
16	Atmospheric emissions	SF_6, (g)	g_{16}	4,422.87	8,293.71
17	Atmospheric emissions	NO_x, (g)	g_{17}	235,265,346.10	207,984,924.22
18	Atmospheric emissions	SO_x, (g)	g_{18}	615,369,058.08	617,249,269.17
19	Atmospheric emissions	Dust, (g)	g_{19}	115,834,045.80	39,374,617.92
20	Atmospheric emissions	HCl, (g)	g_{20}	2,194,938.00	724,329.54
21	Atmospheric emissions	CO, (g)	g_{21}	117,936.00	38,918.88
22	Waterborne emissions	Chemical Oxygen Demand (COD), (mg)	g_{22}	7,363,397,955.08	2,453,219,625.67
23	Waterborne emissions	T-P, (mg)	g_{23}	297,810,000.00	98,277,300.02
24	Waterborne emissions	T-Ni, (mg)	g_{24}	7,236,000,000.00	2,387,880,000.48
25	Waterborne emissions	Phenol, (mg)	g_{25}	30,807,000.00	10,166,310.00

The normalized indicators $ADP_{(i)}$ were then combined to calculate the overall impact indicator of abiotic depletion (*ADP*) for each treatment option, i.e. $ADP = \Sigma ADP_{(i)}$, (Eq. 4). The results are given in Figure 7, which shows that separation of plastic wastes for mechanical recycling (i.e. option 2) has a lower environmental impact to the abiotic depletion, when compared with incineration of plastics wastes for energy recovery (option 1).

3.3.3 Global warming

Global warming was assessed by calculating the *global warning potential*, i.e. *GWP* indicator (Eqs. 3 and 4), which indicates the amount of greenhouses gases emitted in the Earths atmosphere. Figure 8 shows $GWP_{(i)}$ indicators of various greenhouses gases emitted during the life-cycle of plastics, needed for production of colour TV sets.

A look at Figure 8 shows that the $GWP_{(i)}$ varies with the type of greenhouse gas, and the treatment option for plastic wastes. It can be seen that the emission of CO_2 has the greatest environmental impact. It can also be seen that CH_4, which is mainly emitted during the production of PE, and NO_2 have a relatively great impact on global warming.

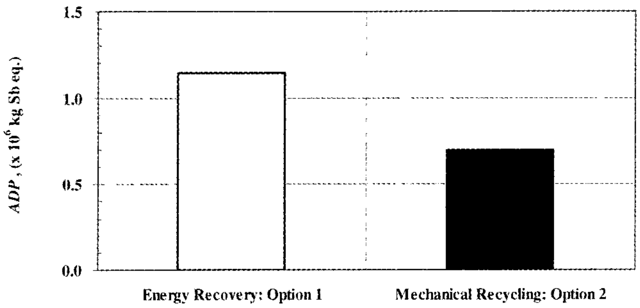

Figure 7 Depletion of abiotic resources, (*ADP*).

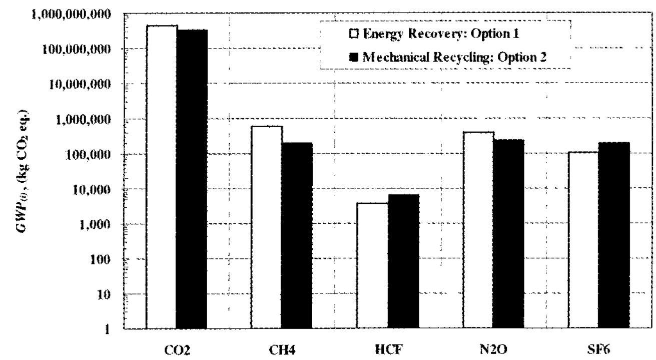

Figure 8 $GWP_{(i)}$ of various greenhouses gases.

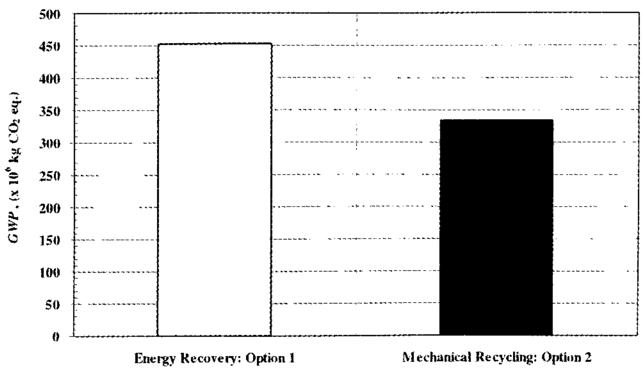

Figure 9 Global warming potential, (*GWP*).

Table 7 Comparing the environmental indicators for energy recovery (option 1) and mechanical recycling (option 2)

Environmental Indicators	Option 1, (Energy recovery, $R_M = 0\%$)	Option 2, (Mechanical recycling, $R_M = 67\%$)
Energy depletion (*ED*), kcal	158,808,456,261	186,049,047,033
Abiotic depletion potential (*ADP*), kg Sb. eq.	1,143,091	698,156
Global warming potential (*GWP*), kg CO_2 eq.	452,329,521	334,977,313

The normalized indicators $GWP_{(i)}$ were then combined to give the overall impact indicator of global warming (*GWP*) for each treatment option i.e. $GWP = \Sigma GWP_{(i)}$, (Eq. 4). The results are given in Figure 9, which shows that separation of plastic wastes for mechanical recycling (i.e. option 2) has a lower environmental impact to the global warming.

3.4 Interpretation

Interpretation i.e. evaluation of results was the last phase of the LCA, (Figure 2). The objective was to analyze results, and reach conclusions based on the findings of the preceding phases of the LCA.

Table 7 compares all environmental indicators that have been calculated for each treatment option under the assessment. Since the results indicated that both options have a negative balance of energy (Figure 5), the energy depletion (i.e. *ED* indicator) was not used as a base for comparison. Table 7 also shows the overall impact indicators of the environmental impact categories, i.e. *ADP* indicator and *GWP* indicator. It can be seen that both *ADP* and *GWP* indicators of option 2 are smaller when compared with those of option 1. These results indicated that the separation of plastics for mechanical recycling (i.e. option 2) is a more environmental-friendly alternative for treatment of plastic wastes from the discarded colour TV sets.

4. CONCLUSIONS

The energy recovery and the mechanical recycling of plastic wastes from the discarded TV sets were compared in the context of LCA. The results showed that the energy recovery is an option that generated more energy due to the incineration of plastic wastes. Nevertheless, this option also uses more resources and emits a larger quantity of greenhouse gases. The separation of plastics for mechanical recycling, on the other hand, is more effective alternative, because it consumes fewer energy and resources, as well as has a lower environmental impact on global warming.

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Nomenclature

A	Technology matrix
B	Environmental matrix
d	Number of the discarded TV sets
f	Demand vector
f_u	Functional unit
g	Vector of environmental loads
g_i	Environmental load of substance i
H_1, H_2, H_3	Calorific value of plastics, (kcal)
$I_{i(j)}$	Impact indicator
I_j	Impact category indicator
$k_{i(j)}$	Characterization factor
M_e	Mass of plastic wastes, entering the thermal recycling process, (kg)
M_{in}	Mass of plastic wastes that enter the separation process, (kg)
M_{mid}	Mass of middling generated from the separation process, (kg)
M_w	Mass of plastics that did not enter the separation process, (kg)
R_M	Ratio of mechanical recycling, (%)
t	Efficiency of the waste power generator, (%)
v	Electricity requirement of a single-step separation process, (kWh/kg)

Subscripts

i	Burden or substance released/extracted from environment
j	Environmental impact category
n	Number of burdens or substances released/extracted from environment
q	Number of environmental impact categories

Superscripts

-1	Indicates that the respective matrix should be inverted

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