CHAPTER IV
RESULTS AND DISCUSSION

This study aims to evaluate environmental impacts and energy consumption associated with end-of-life management options for discarded CRT television. The inventory data of CRT-TV end-of-life stage covered raw materials (or discarded component of CRT-TV, chemicals, energy, utilities and emissions. The primary and secondary data sources from existing disposal sites and recent research related television waste disposal were gathered and used for end-of-life analysis. The results were analyzed using LCA software, SimaPro 7.1, with Eco-Indicator 95 and CML 2 baseline 2000 methods. Five end-of-life treatment strategies were developed to evaluate theirs environmental impacts and compared with the results from the existing CRT-TV waste disposal in Thailand as a base case study. The environmental performances of each scenarios in terms of global warming impact (GWP), acidification potential (AP), acidification, energy resources and human toxicity were compared and discussed.

4.1 Life Cycle Boundary and Inventory

The system boundary of CRT-television starting from production of its raw materials to the final disposal at its end-of-life is presented in Figure 4.1. The boundary of this study covered production of raw material manufacturing, television set manufacturing, use of television set, transportation, and disposal. In addition, this study developed end-of-life inventory for five different CRT-television waste disposal scenarios combining various treatment technologies such as landfilling, incineration, and recycling. The functional unit of the end-of-life treatment of CRT-television was set to be one set of 25 inch CRT- television as routine disposed of by customer.

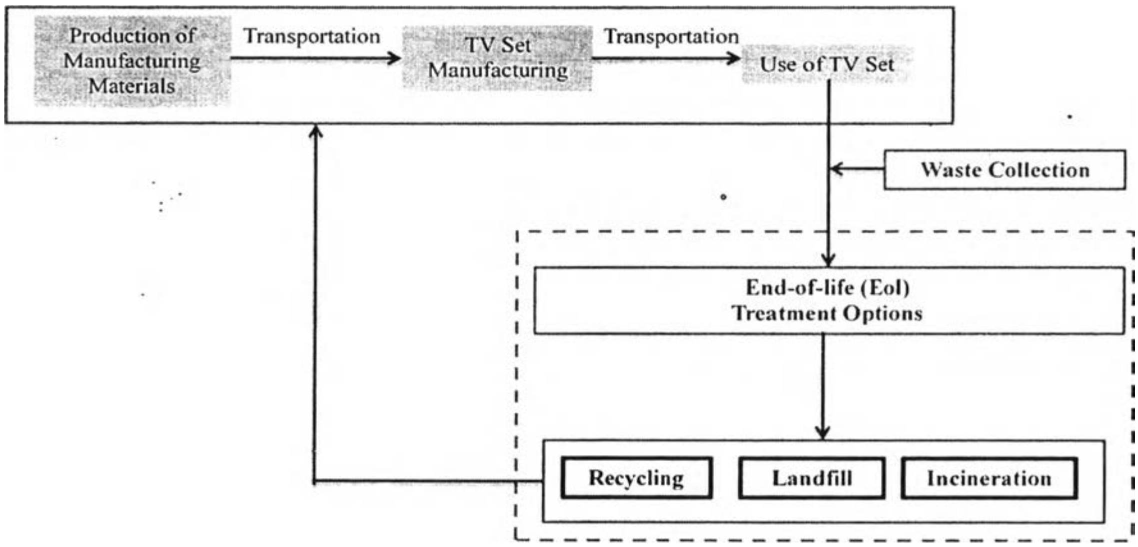

Figure 4.1 System boundary of this study (dashed line).

4.1.1 Production and Waste of Television

According to The Office of Industrial Economics (2013), the amount of CRT-television production in Thailand decreased from 5,236,000 sets in year 2000 to 139,000 sets in year 2013. Whereas, the discarded CRT-televisions were reported about 2.4 million sets in year 2013 (Pollution Control Department, 2011).

4.1.2 Components of Television Set

One set of CRT-television composes of 57 wt% glasses (funnel glass 19 %wt and panel glass 38 %wt), 10.5 wt% plastics and 17 wt% metal parts as shown in Table 4.1. Glass is the main component of television set followed by metal parts (steel, aluminum and copper), plastics (PE, PVC and PS), others components such as cables, and electronic parts.

Table 4.1 Components of CRT-television

Component of CRT-TV	Weight/TV%	Mass (kg)
Cathode Ray Tube*		
- Funnel Glass	19	5.7
- Panel Glass	38	11.4
Metal Parts		
- Steel	10	3
- Aluminum	2	0.6
- Copper	5	1.5
Cabinet (Plastics)		
- Polyethylene (PE)	1	0.3
- Polyvinyl chloride (PVC)	3.5	1.05
- Polystyrene (PS)	6	1.8
Cables	4.5	1.35
Electronic Parts	3	0.9
Others (Waste)	8	2.4
Total	**100**	**30**

4.2 Inventory Analysis

4.2.1 Data Collecting for Life Cycle Inventory

A life cycle inventory (LCI) is identification and quantification of the material and resource inputs, and product and emission outputs from the unit process through its in life cycle. All relevant input-output data used in this study include raw materials consumption, energy consumption, utilities consumption, air/solid emissions, and waste generations.

4.2.1.1 Sources of Data

The data were collected from the primary and secondary data as shown in Table 4.2.

Table 4.2 Sources of the inventory used in this study

Phase		Key Parameters	Data Sources
Production of Manufacturing Materials	Steel, Aluminum Copper, Glass, PE, PVC, PS	Energy consumption	Song et al., 2012
		Atmospheric emission	
		Water waste	
		Solid waste	
TV Set Manufacturing		Electricity consumption	Song et al., 2012
Transportation		Fuel consumption	Estimation, Thailand database, Pollution Control Department (PCD) (2011)
		Atmospheric emission	
Use of TV Set	Life time =10 yr.	Electricity consumption	Song et al., 2012 Thailand database
Waste Management (End-of-life)	Recycle	Solid waste	Recycle shop, Kalasin province, Thailand database, Pollution Control Department (PCD) (2011)
	Landfill	Atmospheric emission	
	Incineration		

For CRT-TV end-of-life options, the data collected for this study were either obtained from existing disposal sites and available database. All data used for calculation were analyzed using SimaPro v.7.1 with Eco-Indicator 95 and CML 2 baseline 2000 methods.

4.2.1.2 The Production of Manufacturing Materials

This study, the raw materials for CRT-TV included the production of steel, aluminum, copper, glass (panel and funnel), polyethylene (PE), polyvinyl chloride (PVC) and polystyrene (PS). All data, such as energy consumption, emissions, waste were gathered from published literatures (Song *et al.*, 2012) as shown in Appendix A.

4.2.1.3 TV Set Manufacturing

In this process, television set is manufactured from the materials obtained from the previous process. All data, such as energy consumption, emissions, waste, etc. were gathered from available published data from literatures (Song *et al.*, 2012) as shown in Appendix A.

4.2.1.4 Transportation of Raw Materials and TV Sets

All transportation data involved in this process are shown in Appendix B. The transportation data are selected from Thailand database. The assumption of transportations followed by:

- Truck 10 wheels with capacity of 16 ton
- Diesel engine truck (base on SAE J-313C)
- Total distance 150 km from Bangkok to Samutprakarn (37.5 km), transport raw material (75 km) and TV set (75 km)
- Limited speed 60-90 km/hr
- The one unit of television set and the raw material for production are transported.
- Two types of transportation : No load (return) and Full load (carry)

4.2.1.5 Use of TV Set

In this unit process, the use of TV was calculated based on electricity consumption. In typical, the TV set rated power is 0.12 kW, and each TV set works for 8 hours in 300 days per year, for 10 years.

Then, the total energy consumption in one TV set = $0.12 \times 8 \times 300 \times 10 \times 1$

= 2,880 kWh/TV set

The 2,880 kWh was used as energy consumption (for one set of TV) in SimaPro7.1 as shown in Appendix C.

4.2.1.6 Waste Management (End-of-life)

For end-of-life management, the discarded CRT-TV wastes are treated by the manual dismantling which is the most common treatment method. There are three typical flows for disposal ways of CRT-TV waste namely landfill, recycling and incineration. As an ultimate goal of waste dispodal, the CRT-TV waste management in proper ways will give lowest environmental and human health impacts.

4.2.2 Life Cycle Inventory Assessment of CRT-Television of Waste Management Site in Thailand

For the current waste management methods and amount of wastes generation of discarded CRT-TV, the data were gathered from the existing site at CRT-TV waste disposal facility in Bangkok (SueYai Uthit). Figure 4.2 shows current disposal pathway of discarded CRT-TV in Thailand. The most of the discarded TV components are recycled in manufacturing and deposed to landfill, and some of them are burnt such as cables to get rid of plastic insulator/sheath i.e., PVC. The collected data from walk-thru interviews at the recycle shops showed that all of the glass components were deposed to landfill. Moreover, the dismantling of CRT-TV is completed by the manual separation (or by hands) which technically is a low efficiency method. From survey, some of discarded items could not separate by manual dismantling (by hand), therefore there are many losses of value material, especially the metal parts, plastics, electronic parts.

According to the current end-of-life management of CRT-TV as shown in the diagram below, the percentages of dismantling and treatment of CRT-TV parts were estimated from data collected from visited disposal site. The percentages of dismantling of CRT-TV are divided into 2 parts. First, the components of CRT-TV waste as recovered materials that are recycled and deposed to landfill accounted for 80 % of total weight. Secondly, the waste part as rejected or remaining materials that are deposed to landfill accounted for 20 % of total weight as deposed to landfill. A half of recovered CRT-TV components (e.g. metal parts, plastics, cable, and electronic parts) are recycled as shown in Appendix A. Based on this, the amount and percentage of each part of discarded CRT-TV are showed in Table 4.3. It can be seen that the main component is glasses which is deposed to landfill (45.6 % of total waste). For this disposal scenario, the total percentage of discarded CRT-TV deposed to landfill is about 86 % of the total weight. In addition, the total percentage of the waste disposed by incineration is about 1.8 % of the total weight from the disposal of cables.

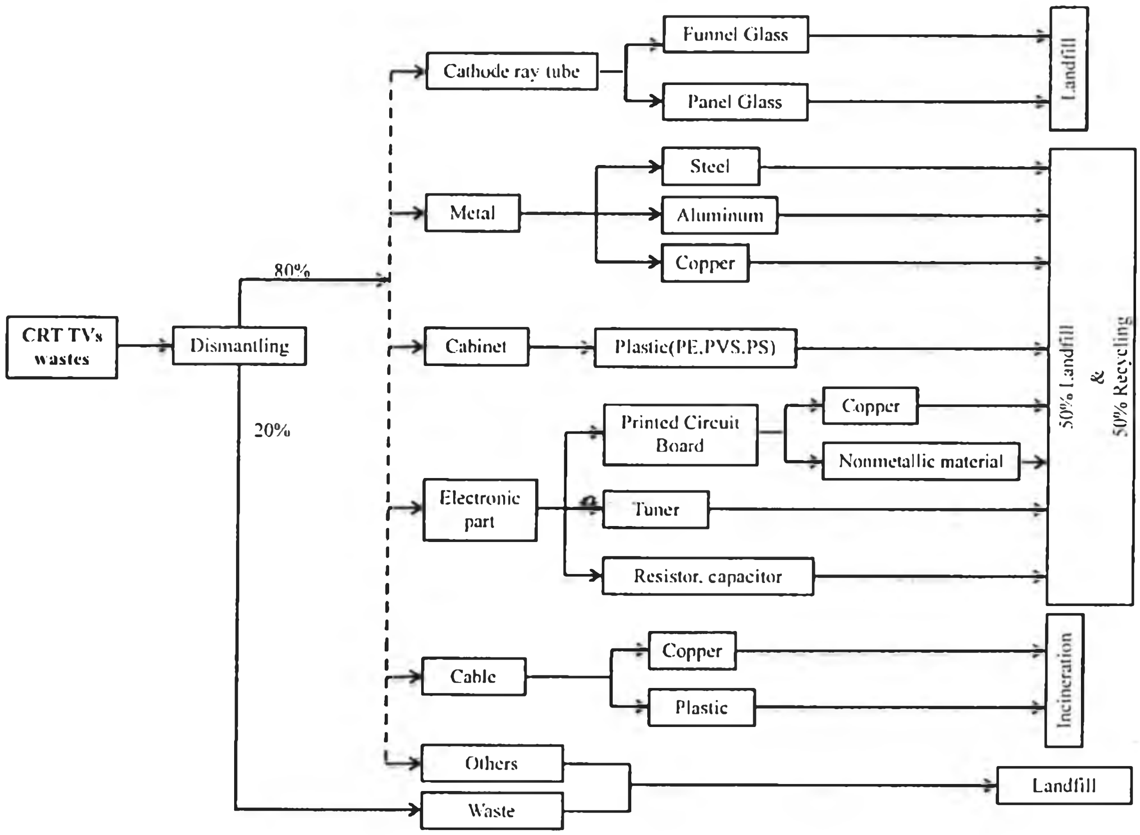

Figure 4.2 Current situation (Base Case) of waste management of CRT-TV in Thailand.

Table 4.3 Components of CRT-TV and end-of-life treatment methods (Interview in SueYai Uthit)

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste	Disposal (End-of-Life)
Cathode Ray Tube*			
- Funnel Glass	4.56	15.2	Landfill
- Panel Glass	9.12	30.4	Landfill
Metal Parts			
- Steel	1.20	4.0	Recycling
	1.20	4.0	Landfill
- Aluminum	0.24	0.8	Recycling
	0.24	0.8	Landfill
- Copper	0.60	2.0	Recycling
	0.60	2.0	Landfill
Cabinet (Plastics)			
- Polyethylene (PE)	0.12	0.4	Recycling
	0.12	0.4	Landfill
- Polyvinyl chloride (PVC)	0.42	1.4	Recycling
	0.42	1.4	Landfill
- Polystyrene (PS)	0.72	2.4	Recycling
	0.72	2.4	Landfill
Cable	0.54	1.8	Incineration
	0.54	1.8	Landfill
Electronic Parts	0.36	1.2	Recycling
	0.36	1.2	Landfill
Others (Waste)	2.40	8.0	Landfill
Remaining	5.52	18.4	Landfill
Total	**30.00**	**100.0**	

Table 4.3 Components of CRT-TV and end-of-life treatment methods (Interview in SueYai Uthit) (cont.)

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste	Disposal (End-of-Life)
Total of Recovered	**3.66**	**12.2**	
Total of Landfill	**25.80**	**86**	
Total of Incineration	**0.54**	**1.8**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

4.3 Life Cycle Impact Assessment (LCIA)

Environmental impacts of discarded CRT television were calculated based on Eco-Indicator 95 and CML 2 baseline 2000 methods using SimaPro. In this study, five potential environmental impact categories including acidification, abiotic depletion, greenhouse gas (GHG) emission, human toxicity, and energy resource were selected as potential environmental impacts from discarded CRT television options. Designated methodologies for CRT television end-of-life are showed in Table 4.4.

The CML 2 baseline 2000 method was used for life cycle impact assessment (LCIA) method in this study. This method is an example of a multi-step and fully aggregating method. The various environmental impacts examined within this method can be summed up into all categories.

Table 4.4 Designated environmental impacts of discarded CRT-TV under SimaPro v. 7.1

Indicators	Methodology	Unit
Abiotic Depletion	CML 2000	kg Sb eq.
Global Warming Potential (GWP 100)	CML 2000	kg CO_2 eq.
Human Toxicity Potential	CML 2000	kg 1,4-DB eq.
Acidification Potential	CML 2000	kg SO_2 eq.
Energy Resources	Eco-Indicator 95	MJ LHV

4.3.1 Life Cycle Environmental Impacts of CRT Television

The Comparison of environmental impacts through all life cycle phases starting from production of manufacturing materials, TV set manufacturing, use of TV set, transportation and end-of-life is shown in Figure below. It can be seen that the use of TV set phase had the highest impact over those from the other phases for all impact categories including abiotic depletion, global warming potential and acidification. Especially, abiotic depletion and global warming potential had a significant effect because of electricity production processes.

In addition, the use of TV set were contributed to the abiotic depletion about 93.77 %, global warming potential about 85.53 %, acidification about 66.82 % as shown in Table 4.5. When comparing among all processes, the human toxicity impact are mainly caused by production of manufacturing materials. It can be seen that, the major source of emissions to human toxicity impact came from aluminum production and copper production. For energy resources impact categories, the activity influencing energy resources came from production of manufacturing materials where steel production and glass production are the major source of emissions as shown in Appendix D.

Table 4.5 The summary of environmental impacts of CRT-TV the life cycle

Phase	Impact Categories				
	Abiotic Depletion	**Global Warming Potential**	**Human Toxicity**	**Acidification**	**Energy Resources**
Production of Manufacturing Materials	4.92 %	10.25 %	87.56 %	22.42 %	59.41 %
TV set Manufacturing	0.83 %	3.66 %	1.72 %	10.21 %	9.20 %
Transportation	0.05 %	0.06 %	0.06 %	0.11 %	0.59 %
Use of TV Set	93.77 %	85.53 %	6.49 %	66.82 %	25.83 %
End-of-Life	0.43 %	0.50 %	4.17 %	0.44 %	4.97 %

According to the Table 4.6, the environmental benefits of end-of-life treatment are driven by recycling of wastes. The benefits were calculated from the weight of recycling waste i.e., steel, aluminum, copper, PE, PVC, and PS which is highly potential recovered materials and used new material as shown in Appendix D. Moreover, it can be seen that the high percentage of recycling wastes gave the more environmental benefits in which the negative value represented a environmental benefit. The benefits in term of abiotic depletion, global warming potential, human toxicity, acidification, and energy resources are equal to -0.1940 kg Sb eq, -56.2304 kg CO_2 eq, -32.5951 kg 1,4-DB eq, -0.42 kg SO_2 eq, and -421.15 MJ LHV, respectively

Figures 4.3 to 4.7 show the environmental impacts and benefits in all categories of life cycle of CRT-TV. It can be seen that the impacts of end-of-life treatment were lower than that of the benefits (negative value) due to recycling of wastes. In addition, the impacts from production manufacturing materials and benefits due to recovered material recycling show that the recycling can be replaced or partial substitute the raw material used in production of manufacturing material. The results of abiotic depletion and energy resources indicated the reduction in about 21 %. In addition, the global warming potential, human toxicity, and acidification reduced about 25.09, 32.84 %, and 23.71 %.

Table 4.6 The environmental benefits of end-of-life treatment from recycling of waste

Impact Categories	Unit	Base Case
Abiotic Depletion	kg Sb eq	-0.1940
Global Warming Potential	kg CO_2 eq	-56.2304
Human Toxicity	kg 1,4-DB eq	-32.5951
Acidification	kg SO_2 eq	-0.4200
Energy Resources	MJ LHV	-421.1500

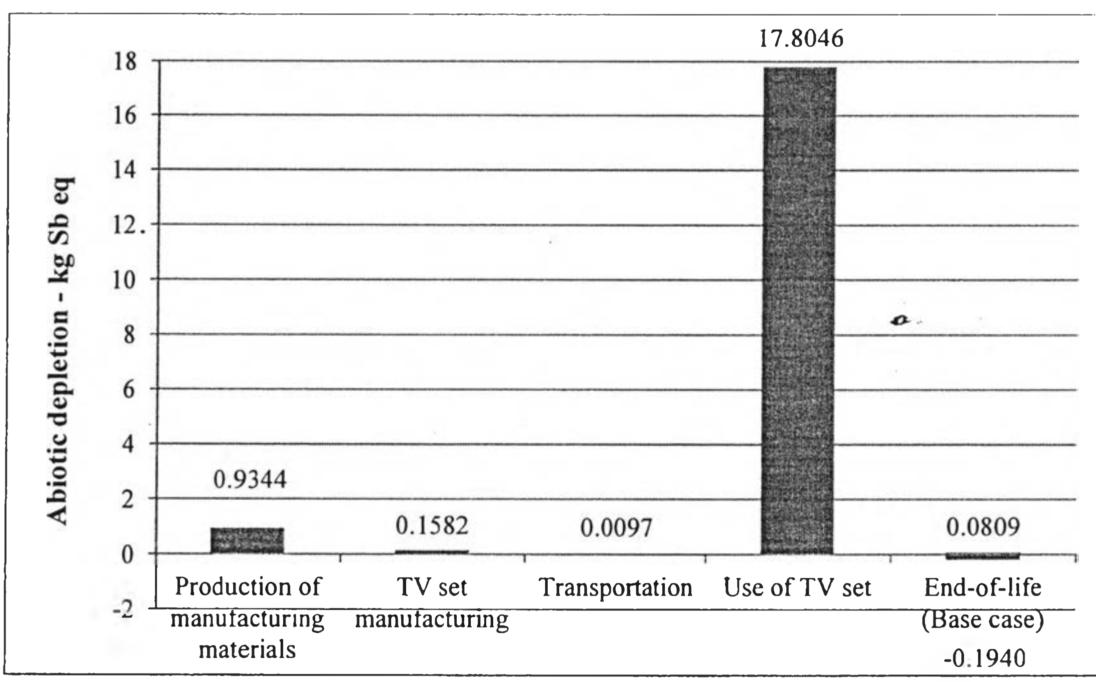

Figure 4.3 Abiotic depletion of life cycle of CRT-television using CML 2 baseline 2000 method.

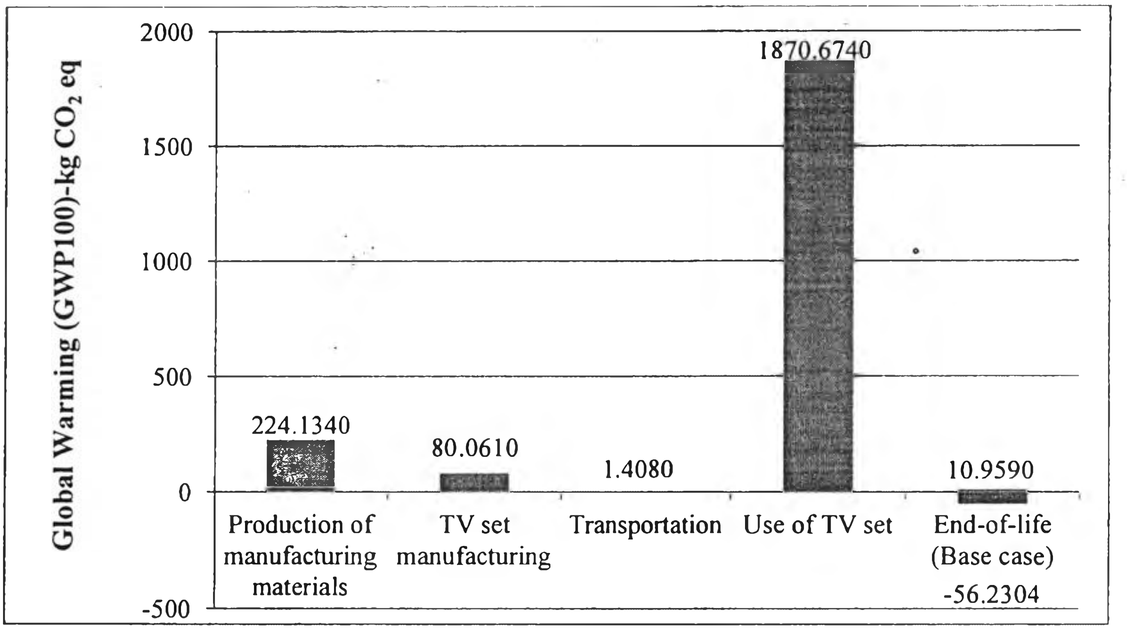

Figure 4.4 Global warming potential of life cycle of CRT-television using CML 2 baseline 2000 method.

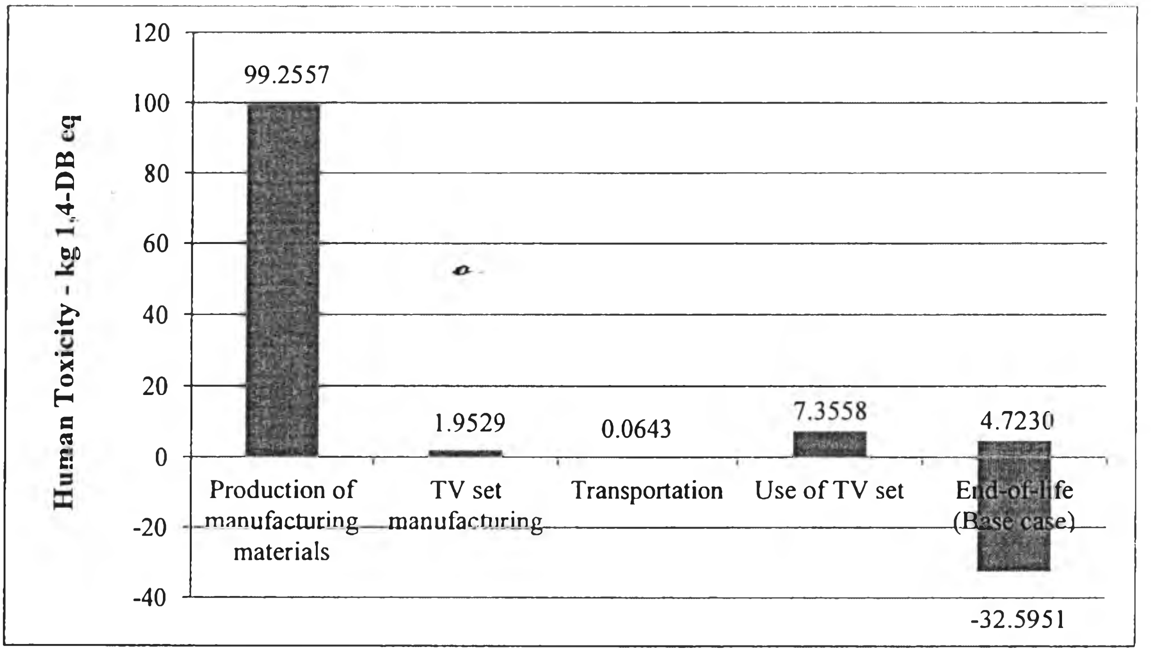

Figure 4.5 Human toxicity potential of life cycle of CRT-television using CML 2 baseline 2000 method.

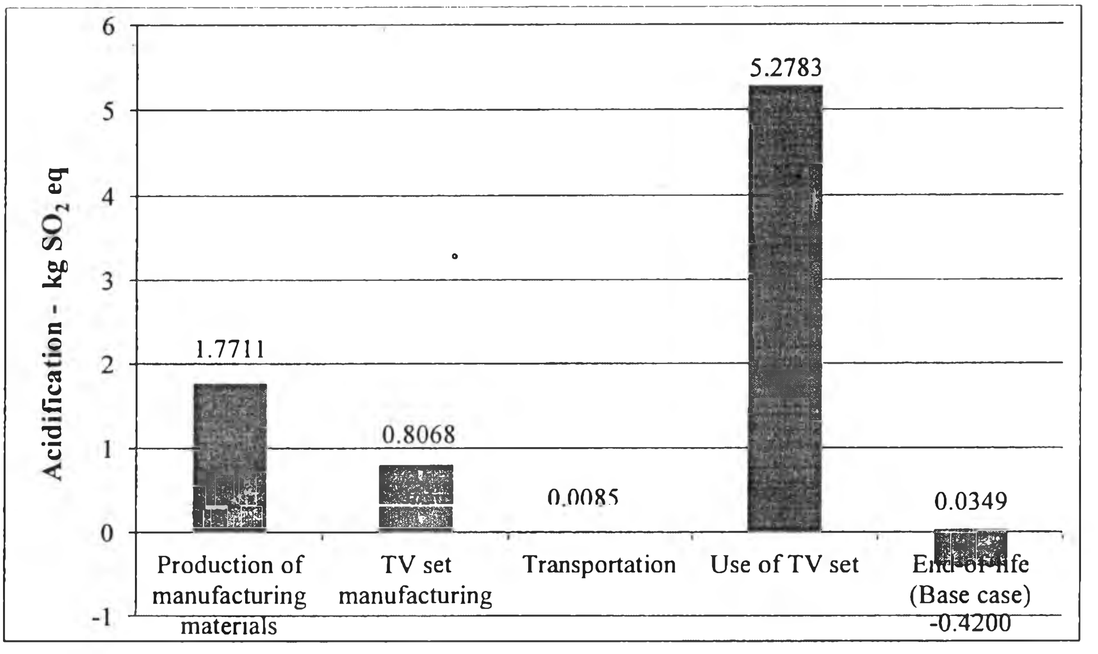

Figure 4.6 Acidification potential of life cycle of CRT-television using CML 2 baseline 2000 method.

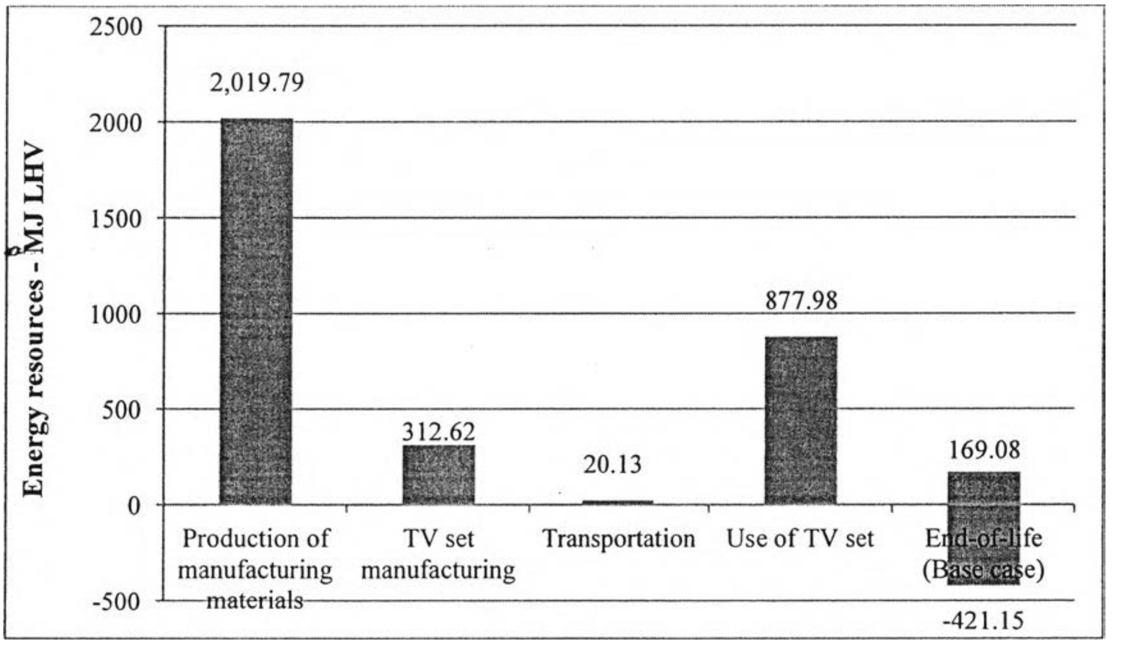

Figure 4.7 Energy resources of life cycle of CRT-television using Eco-indicator 95 method.

4.4 CRT-Television End-of-Life Treatment Scenarios

The results of life cycle of CRT-TV analysis indicated that the use of TV set and production of manufacturing materials phase caused high impacts in all categories. Nevertheless, at the moment, the end-of-life phase has been rising in attention because of inefficiency of CRT-TV waste solutions which lead to adverse environmental impacts and human health. This study aims to evaluate environmental performances of end-of-life treatment scenarios. In addition, the disposal technologies for waste management of CRT-TV i.e., landfilling and incineration were used for selecting end-of-life waste management scenarios to achieve appropriate scenarios for CRT-TV waste disposal.

In this section, five waste management scenarios were created by varying the percentages of different waste treatment technologies (recycling, landfilling, and incineration) in order to develop the best environmental end-of-life options as described belown and in Table 4.7. In addition, the current situation of CRT-television waste management in Thailand was set as Base case.

- Base case represents the current situation of CRT-TV waste management in Thailand (86 % land filling, 12.2 % recycling and 1.8 % incineration).
- Case 1 represents the improved current waste management by increasing the recycling of recovered materials from 12.2 % to 51.28 % (achieved by diverting funnel glass and panel glass disposed to landfill to be recycling at 30 % and 80 %, respectively).
- Case 2 represents the best achievable waste management of CRT-TV. In this case, we assumed that highest of recycled mass fraction are achieved which is accounted for 92 % (all of materials are managed by recycling, except only other wastes (8 %) that are still disposed to landfill).
- Case 3 (modified technology) assumed that the treatment scenario is obtained from current situation method of CRT-TV waste management in Thailand that combined with available CRT-TV waste disposal technologies

in China (Song *et al.,* 2012). This case study improves more recycling of funnel glass to 100 % and recycling of panel glass to 30 %.

- Case 4 (modified technology): assumed that the treatment scenario is obtained from current situation method of CRT-TV waste management in Thailand that combined with available recycling technology in Japan where the minimum recycling rate has been set to be 79 % regarding to the new regulation (Sony corporation, 2015).

Table 4.7 Five different scenarios of CRT-TV end-of-life treatments

Treatment Strategies	Base Case	Case 1 (Improvement)	Case 2 (Best)	Case 3 (modified tech.)	Case 4 (modified tech.)
Hazardous/Solid Waste Landfill	86 %	48.72 %	8 %	46.72 %	20.7 %
Recycling	12.2 %	51.28 %	92 %	53.28 %	79.3 %
Incineration	1.8 %	0 %	0 %	0 %	0 %

4.4.1 <u>End-of-Life Inventory Assessment of CRT-Television of Waste Management Scenarios</u>

4.4.1.1 Case 1

Case 1 is the improved current waste management by increasing recycling fraction from 12.2 % to 51.28 % of total recovered material, achieved by diverting funnel glass and panel glass from landfill to be recycled to 30 % of total and 80 % of total, respectively. The percentages of dismantling of CRT-TV that are recycled and disposed to landfill are 80 %. In addition, the remaining 20 % (waste) are deposed to landfill. The most of CRT-TV component are recycled (80 %) and the remaining materials are disposed to landfill (20 %).

This scenario, the recovered materials (i.e. glass) are more recycled comparing with current end-of-life situation of CRT-TV in Thailand (Base

Case). The most of the recovered materials from CRT-TV are recycled to be 80 %, except funnel glass is recycled about 30 % and none of them is disposed by incineration as shown in Figure 4.8.

According to the improved current waste management of CRT-TV as shown in the diagram above (Figure 4.8), the percentages of dismantling and treatment of CRT-TV were estimated and improved from current waste management. The glass composition (funnel glass and panel glass) are more recycled about 28.88 % from total of glass component (about 57 %). In addition, the cable which is disposed by incineration as presented in Base Case, is adapted to recover in some part, but a minor part is disposed to landfill. The amount and percentage of each CRT-TV component at its end-of-life are shown in Table 4.8. The total percentages of discarded CRT-TV component are recovered increasing from 12.20 % (Base Case) to 51.28 % of the total waste.

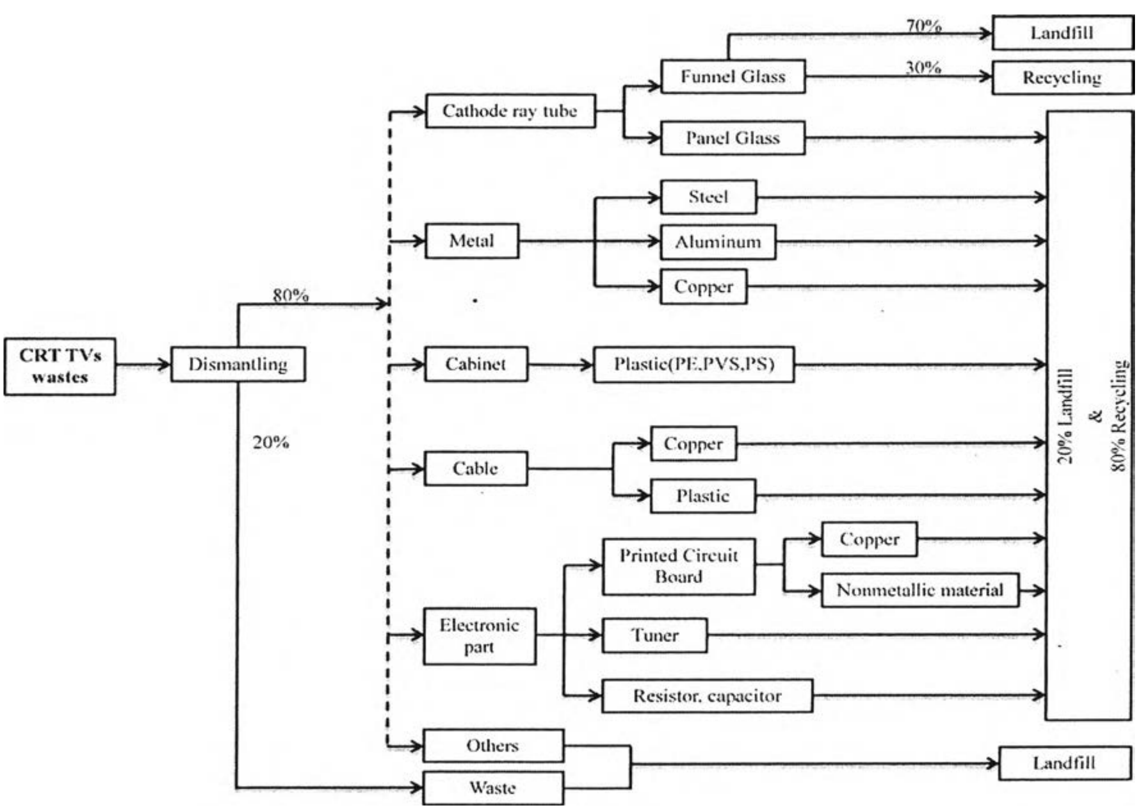

Figure 4.8 Improved current situation of waste management of CRT-TV in Thailand.

Table 4.8 Components of CRT-TV and improved current end-of-life treatment of CRT-TV wastes

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Cathode Ray Tube*			
- Funnel Glass	1.368	4.56	Recycling
	3.192	10.64	Landfill
- Panel Glass	7.296	24.32	Recycling
	1.824	6.08	Landfill
Metal Parts			
- Steel	1.920	6.40	Recycling
	0.480	1.60	Landfill
- Aluminum	0.384	1.28	Recycling
	0.096	0.32	Landfill
- Copper	0.960	3.20	Recycling
	0.240	0.80	Landfill
Cabinet (Plastics)			
- Polyethylene (PE)	0.192	0.64	Recycling
	0.048	0.16	Landfill
- Polyvinyl chloride (PVC)	0.672	2.24	Recycling
	0.168	0.56	Landfill
- Polystyrene (PS)	1.152	3.84	Recycling
	0.288	0.96	Landfill
Cable	0.864	2.88	Recycling
	0.216	0.72	Landfill
Electronic Parts	0.576	1.92	Recycling
	0.144	0.48	Landfill
Others (Waste)	2.400	8.00	Landfill

Table 4.8 Components of CRT-TV and improved current end-of-life treatment of CRT-TV wastes (cont.)

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Remaining	5.520	18.40	Landfill
Total	**30.00**	**100.00**	
Total of Recovered	**15.384**	**51.28**	
Total of Landfill	**14.616**	**48.72**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

4.4.1.2 Case 2

The Case 2 represents the best waste management option of CRT-TV in Thailand. The recovered materials from CRT-TV was assumed to be recycled except only other wastes (remaining) that were still disposed to landfill as shown in Figure 4.9.

The best achievable waste management scenario of discarded CRT-TV is shown in the diagram below; the percentages of dismantling of CRT-TV which are deposed to recycle are 100 %. However, the others waste or remaining are disposed to landfill as shown in Appendix A. The amount and percentage of each part of CRT-TV wastes being disposed by various means are shown in Table 4.9. The total percentages of CRT-TV are recovered about 92 for recycling and the remaining is about 8 % of total weight after dismantling.

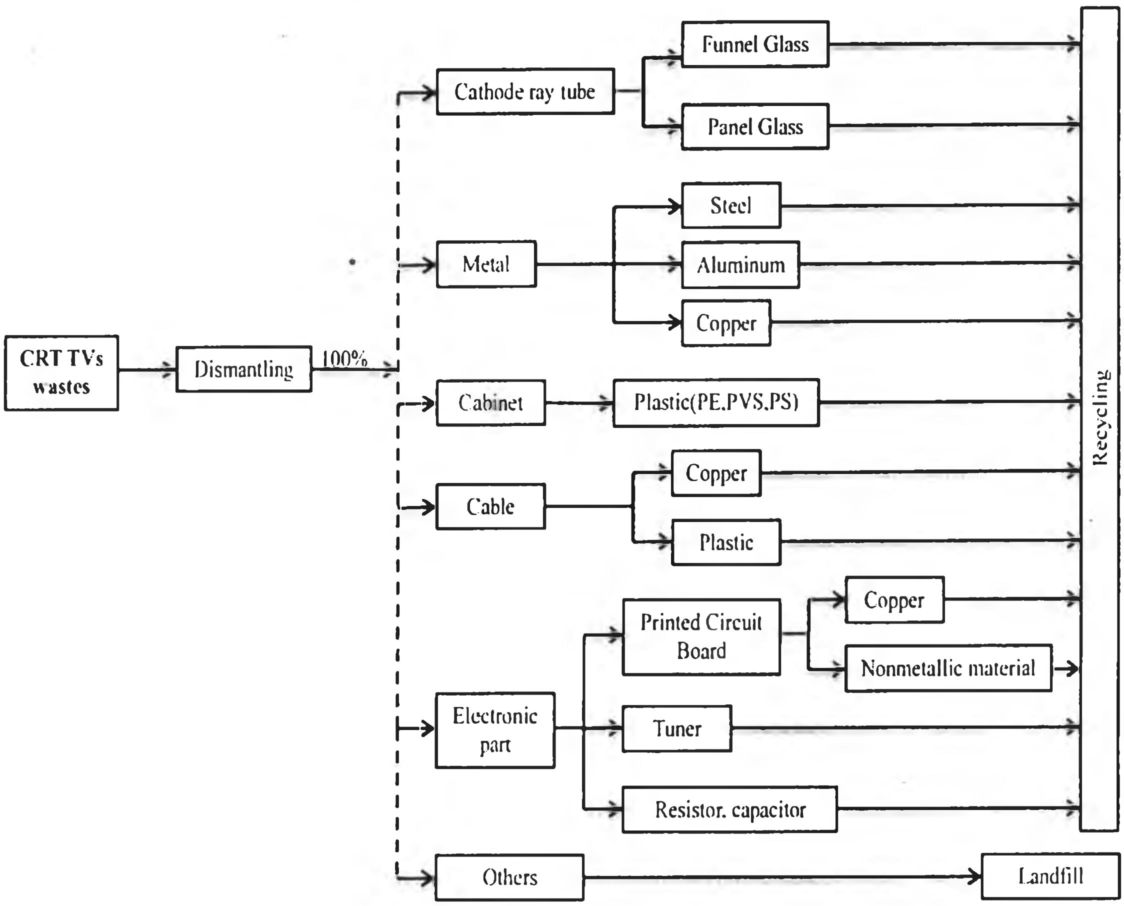

Figure 4.9 The best of waste management of CRT-TV in Thailand (Case 2).

Table 4.9 Components of CRT-TV and possible best end-of-life treatment of wastes

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Cathode Ray Tube*			
- Funnel Glass	5.70	19.0	Recycling
- Panel Glass	11.40	38.0	Recycling

Table 4.9 Components of CRT-TV and possible best end-of-life treatment of wastes (cont.)

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Metal Parts			
- Steel	3.00	10.0	Recycling
- Aluminum	0.60	2.0	Recycling
- Copper	1.50	5.0	Recycling
Cabinet (Plastics)			
- Polyethylene (PE)	0.30	1.0	Recycling
- Polyvinyl chloride (PVC)	1.05	3.5	Recycling
- Polystyrene (PS)	1.80	6.0	Recycling
Cable	1.35	4.5	Recycling
Electronic Parts	0.90	3.0	Recycling
Others (Waste)	2.40	8.0	Landfill
Total	**30.00**	**100.0**	
Total of Recovered	**27.60**	**92.0**	
Total of Landfill	**2.40**	**8.0**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

4.4.1.3 Case 3

The Case 3, modified technology of CRT-TV waste management using discarded of CRT-TV technology in China. The disposal of glass parts was improved by increasing the percentage of funnel glass recycling to be 100 % and recycling panel glass to be 30 wt% as shown in Figure 4.10. The previous study (Song *et al.*, 2012) showed that the disposal technology of glass parts in China could be recycled more than that of Thailand (Base Case) which are typically disposed to landfill. This scenario, most of the components from CRT-TV waste were recycled except the remaining waste that is disposed to landfill. The percentage of all recycled material increased from 12.2 % (base case) to 53.28 % and no material is disposed by incineration as shown in Figure 4.11. In addition, the percentages of recovered materials after dismantling are accounted for 80 %. The remaining waste (20 %) which cannot be recycled are deposed to landfill as shown in Appendix A. Based on this, the amount and percentage of each part of CRT-TV wastes being disposed by various means are shown in Table 4.10. It can be seen that the metals and plastics are recovery increasing from 6.8 % (Base Case) to 10.88 % of total weight (Case 3) and 4.2 of total weight (Base case) to 6.72 of total weight (Case 3). Moreover, the total recycled percentages of discarded CRT-TV is about 46.72 % of total waste and the total landfill percentages of discarded CRT-TV is about 53.28 % of total waste.

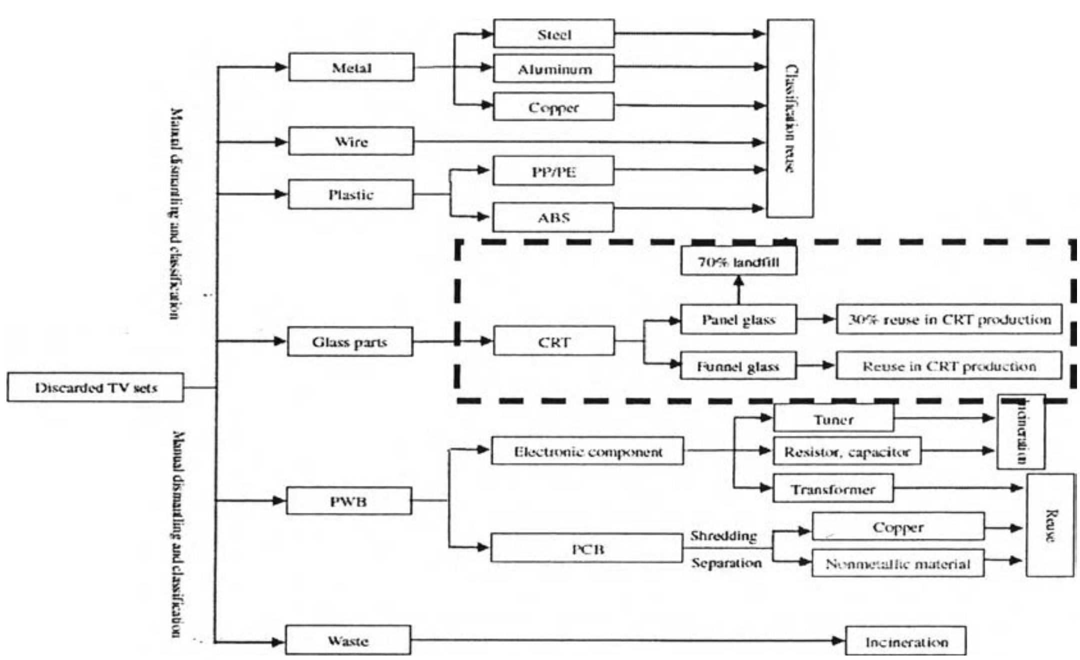

Figure 4.10 The available achievable technology from China (as shown in dashed line) using in waste management of CRT-TV in Thailand (Song *et al.*, 2012).

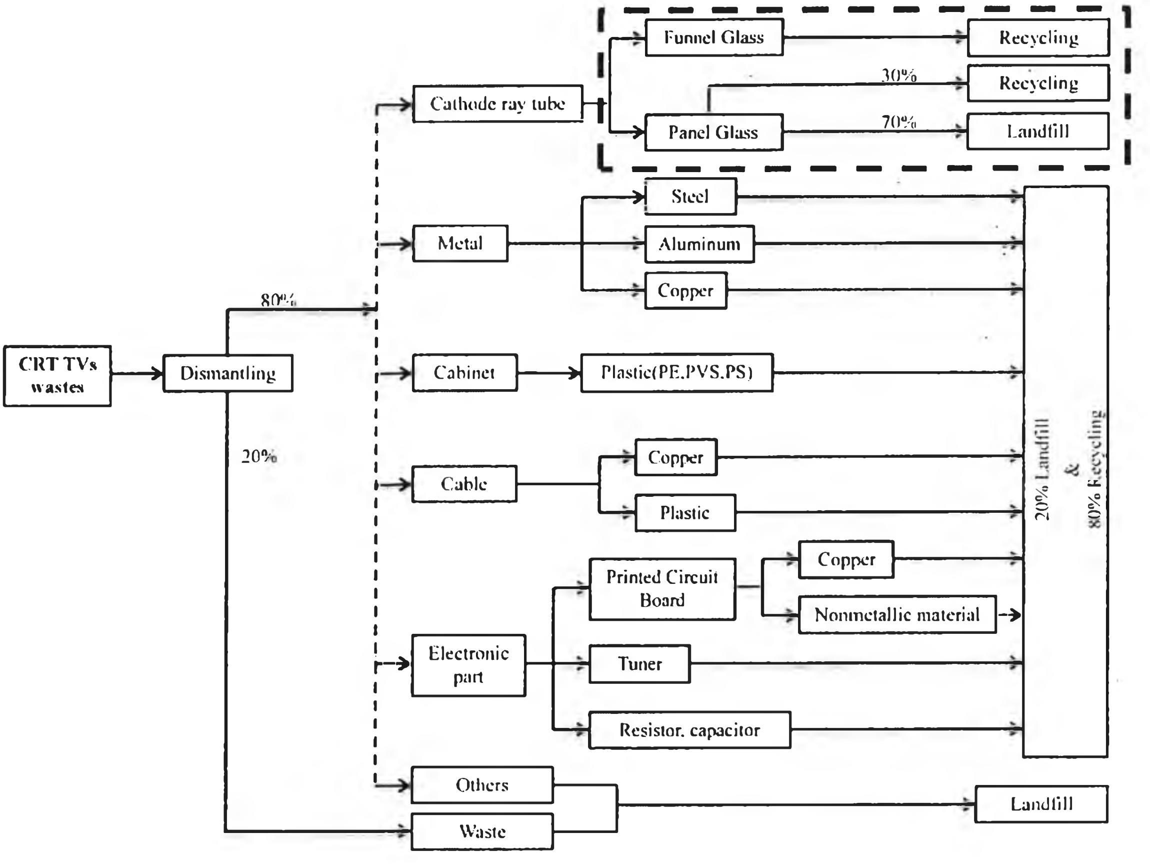

Figure 4.11 The completed modified technology of waste management of CRT-TV from available achievable technology of China (Case 3).

Table 4.10 Components of CRT-TV and available achievable technology from China end-of-life treatment of wastes

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Cathode Ray Tube*			
- Funnel Glass	4.560	15.20	Recycling
- Panel Glass	2.736	9.12	Recycling
	6.384	21.28	Landfill

Table 4.10 Components of CRT-TV and modified technology from China end-of-life treatment of wastes (cont.)

Component of CRT-TV	**Mass of Waste (kg)**	**% Wt of Waste (kg)**	**Disposal (End-of-Life)**
Metal Parts			
- Steel	1.92	6.40	Recycling
	0.48	1.60	Landfill
- Aluminum	0.384	1.28	Recycling
	0.096	0.32	Landfill
- Copper	0.960	3.20	Recycling
	0.240	0.80	Landfill
Cabinet (Plastics)			
- Polyethylene (PE)	0.192	0.64	Recycling
	0.048	0.16	Landfill
- Polyvinylchloride(PVC)	0.672	2.24	Recycling
	0.168	0.56	Landfill
- Polystyrene (PS)	1.152	3.84	Recycling
	0.288	0.96	Landfill
Cable	0.864	2.88	Recycling
	0.216	0.72	Landfill
Electronic Parts	0.576	1.92	Recycling
	0.144	0.48	Landfill
Others (Waste)	2.400	8.00	Landfill
Remaining	5.520	18.40	Landfill
Total	**30.000**	**100.00**	
Total of Recovered	**14.016**	**46.72**	
Total of Landfill	**15.984**	**53.28**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

4.4.1.4 Case 4

The Case 4 is represented modified disposal technology of CRT-TV waste using available recycling rate in Japan (Sony Corporation, 2015). This scenario, the data were collected from the literatures in which the Home Appliance Recycling Law obliges manufacturers to maintain recycling rates of at least 55 % for CRT-TV. The recycling rate advertised by Sony-manufactured or other manufacturing CRT-TV was 79 % as shown in Figure 2.22. The recycling rate of discarded CRT-TV is the percentage of CRT-TV that can be recovered to new raw materials. This scenario, the disposal of CRT-TV is assumed from the achievable recycling rate of 79.3 %. which is close to this scenario (Case 4). The percentage of all recycled material increased from 12.2 % (Base case) to 79.3 % and no material is disposed by incineration.

According to the achievable recycling rate of waste management of CRT-TV in Japan, the percentages of dismantling of CRT-TV parts are obtained at 100 %. The recycled percentages of funnel glass and panel glass disposal are 90 % of total weight. In addition, the recycled percentages of metal parts, plastics, cable, and electronic parts disposal are 80 %. While, the remaining wastes (20 %) are deposed to landfill as shown in Appendix A. Based on this, the amount and percentage of each part of CRT-TV wastes being disposed by various means are shown in Table 4.11. This scenario repressed high percentages of discarded CRT-TV (79.3 % of total weight) are recycled which could be adapted for disposal strategies of discarded CRT-TV model in Thailand by improved of CRT-TV recycling process technology in Japan as shown in Figures 2.18 to 2.21.

Table 4.11 Components of CRT-TV and available recycling technology in Japan end-of-life treatment of wastes

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Cathode Ray Tube*			
- Funnel Glass	5.13	17.1	Recycling
	0.57	1.9	Landfill
- Panel Glass	10.26	34.2	Recycling
	1.14	3.8	Landfill
Metal Parts			
- Steel	2.40	8.0	Recycling
	0.60	2.0	Landfill
- Aluminum	0.48	1.6	Recycling
	0.12	0.4	Landfill
- Copper	1.20	4.0	Recycling
	0.30	1.0	Landfill
Cabinet (Plastics)			
- Polyethylene (PE)	0.24	0.8	Recycling
	0.06	0.2	Landfill
- Polyvinylchloride	0.84	2.8	Recycling
(PVC)	0.21	0.7	Landfill
- Polystyrene (PS)	1.44	4.8	Recycling
	0.36	1.2	Landfill
Cable	1.08	3.6	Recycling
	0.27	0.9	Landfill
Electronic Parts	0.72	2.4	Recycling
	0.18	0.6	Landfill
Others (Waste)	2.40	8.0	Landfill

Table 4.11 Components of CRT-TV and modified technology from Japan end-of-life treatment of wastes (cont.)

Component of CRT-TV	Mass of Waste (kg)	% Wt of Waste (kg)	Disposal (End-of-Life)
Total	**30.00**	**100.0**	
Total of Recovered	**23.79**	**79.3**	
Total of Landfill	**6.21**	**20.7**	

*Cathode ray tube: Funnel glass = 1/3 of the total glass, Panel glass = 2/3 of the total glass

4.4.2 End-of-Life Environmental Impacts of CRT-Television Waste Management Scenarios

The inventory is calculated for each scenarios, then the life cycle impact assessment (LCIA) was applied for EoL assessment using LCA software; SimaPro 7.1 with CML 2 baseline 2000 and Eco-indicator 95 methods, in order to evaluate their performance of end-of-life treatment options for CRT-television. The environmental impact categories evaluated in this study are global warming potential (GWP), human toxicity, abiotic depletion (AD), acidification potential (AP), and energy resource impact (Eco-indicator 95) as discussed in the following sections.

For the end-of-life waste management were created by varying the percentage of different waste treatment technologies. The five end-of-life scenarios of of CRT-TV represented as Base case, Case 1, Case 2, Case 3, and Case 4 are showed in Table 4.12. Note that the metal parts presented in the Table consist of steel, aluminum and copper. In addition, plastics for the cabinet comprise of polyethylene (PE), polyvinylchloride (PVC) and polystyrene (PS).

Table 4.12 The end-of-life scenarios of CRT-TV components

Scenario		Component of CRT-TV							
		Funnel Glass	Panel Glass	Metal Parts	Plastics	Cable	Electronic Parts (Shredding)	Others (Waste)	Remaining
Base Case	% Land.	15.2	30.4	6.8	3.2	1.8	1.2	8	18.4
	% Recy.	-	-	6.8	3.2	-	1.2	-	-
	% Incin.	-	-	-	-	1.8	-	-	-
Case 1	% Land.	10.64	6.08	2.72	1.68	0.72	0.48	8	18.4
	% Recy.	4.56	24.32	10.88	6.72	1.92	1.92	-	-
Case 2	% Land.	-	-	-	-	-	-	8	-
	% Recy.	19	38	17	10.5	4.5	3	-	-
Case 3	% Land.	-	21.28	2.72	1.68	0.72	0.48	8	18.4
	% Recy.	15.2	9.12	10.88	6.72	2.88	1.92	-	-
Case 4	% Land.	1.9	3.8	3.4	2.1	0.9	2.4	8	-
	% Recy.	17.1	34.2	13.6	8.4	3.6	0.6	-	-

4.4.2.1 Base Case

The environmental impacts.of current end-of-life treatment for CRT-TV were divided into five categories including abiotic depletion, global warming, human toxicity, acidification, and energy resources as shown in Figure 4.12. It can be seen that the major impacts were caused by the disposal of metal parts, plastics, electronic parts, cable and others to landfill and the disposal of cable by incineration. Especially, the disposal of cables by incineration process had significant effect on global warming and human toxicity impacts even at a very low amount of disposed cables – in this case representing 1.35 kg (0.41 %) of total TV set. In addition, the impacts from the disposal of electronic parts (which is done by electronic scrap shredding and printed wiring boards separation) performed low effect to all impact categories. In addition, the recycling of plastics and metal parts caused a very low effect on environmental impacts because they can be recycled and then reused as new materials. When we investigated in to the details, the impacts of acidification, abiotic depletion and energy resources accounting for 85 % of total percentages were caused by deposal of wastes to landfill (from recovered materials and remaining waste after dismantling) as shown in Figure below.

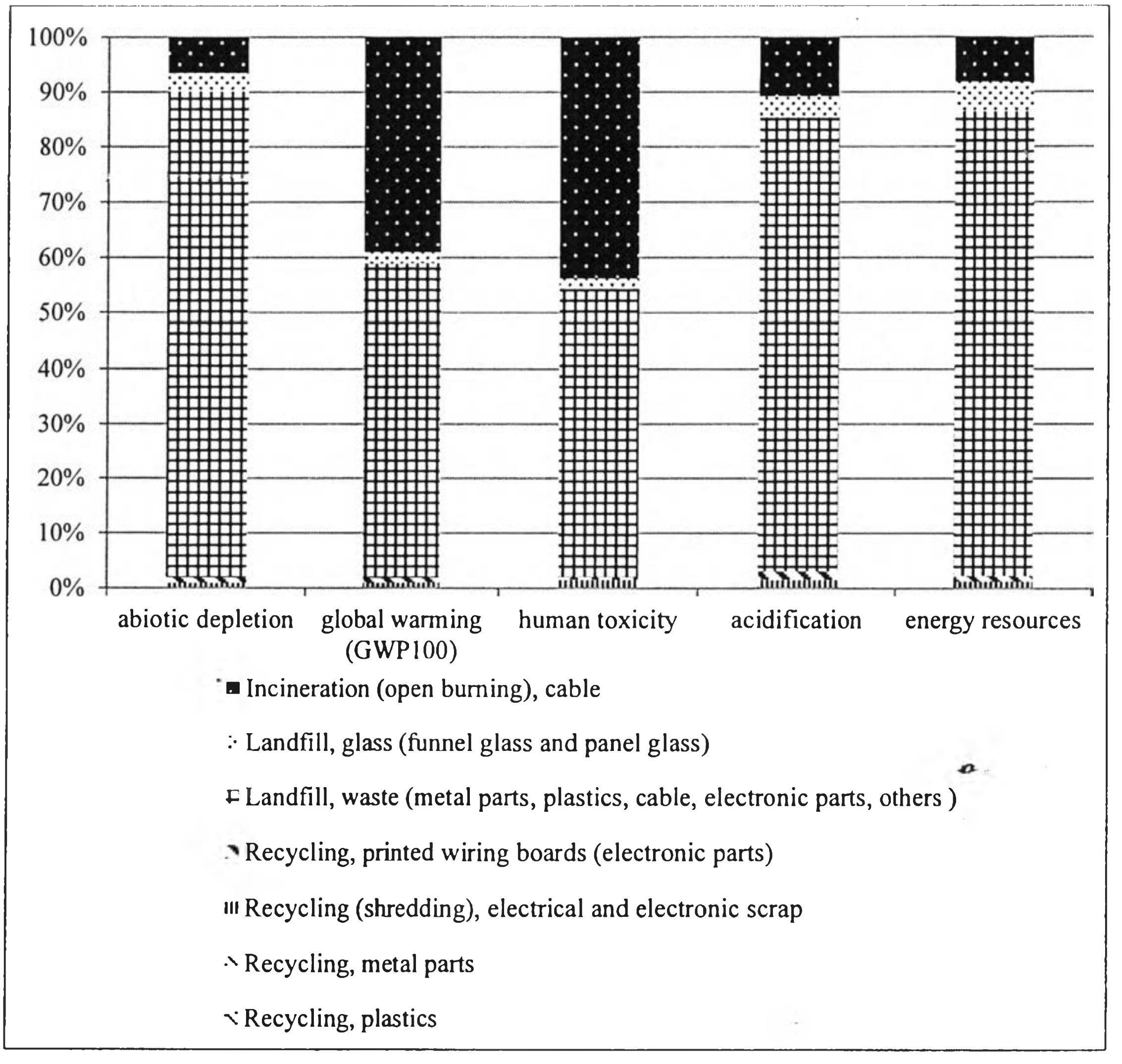

Figure 4.12 The environmental impacts of current situation of waste management of CRT-TV in Thailand.

4.4.2.2 Case 1

The environmental impacts of improved current end-of-life treatment for CRT-TV were divided into four categories as shown in Figure 4.13. This scenario, the cables wastes were recycled and used as a new material instead of deposed by incineration (as presented in Base case). Figure 4.13 showed the all impacts were caused by disposal of wastes (i.e., metals and electronic parts) to landfill, especially abiotic depletion and acidification. In addition, the disposal of cables by recycling had significant effect on global warming and human toxicity. It could be note that glass having relatively high fraction (16.72 % of total waste) showed a low effect to all impact categories.

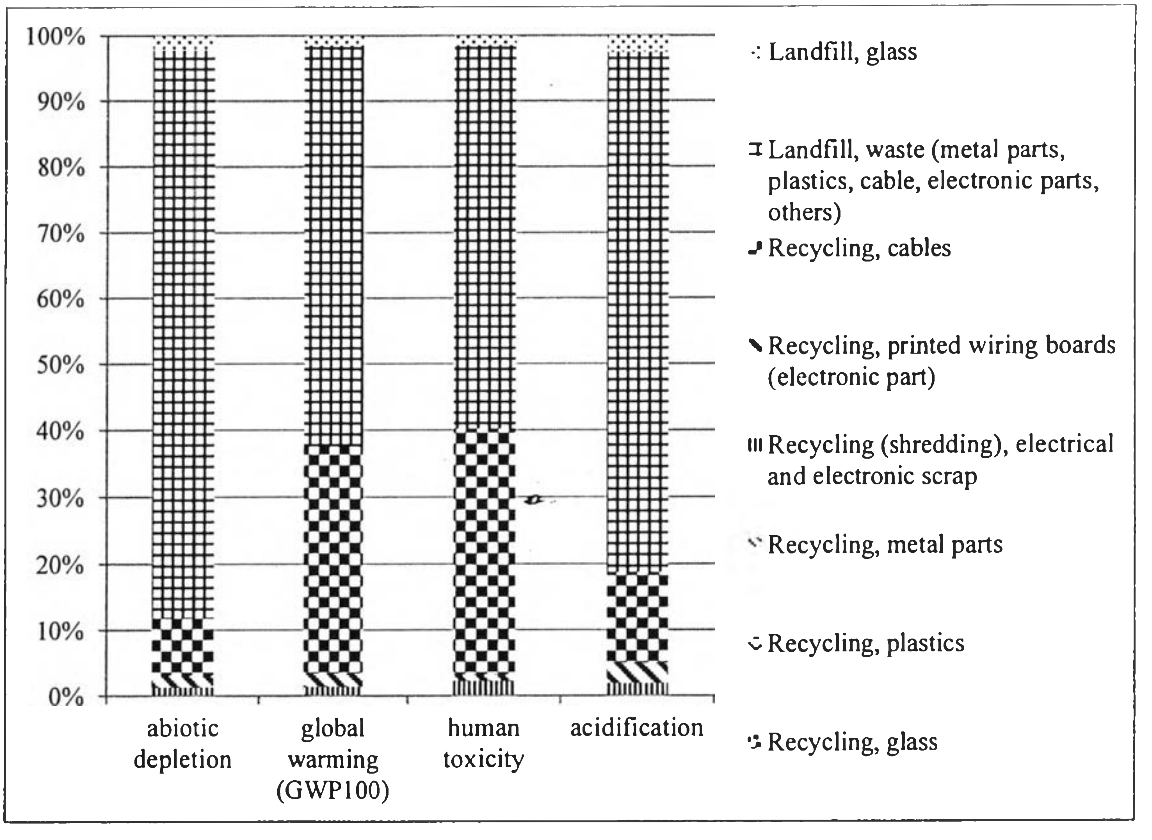

Figure 4.13 The environmental impacts of improved current (case 1) situation of waste management of CRT-TV in Thailand.

4.4.4.3 Case 2

In Case 2, all recovered materials were assumed to recycled increasing from 12.2 % (Base case) to 92 %. As a result, the impacts contributed from some recycling processes were become a dominant source of emission. It can be seen from Figure 4.14, the source of emissions were caused by the recycling of cables (4.5 % of total waste). However, the impacts from the deposal of remaining waste (others) had a significant effect on abiotic depletion and acidification similar with the result from the other case studies.

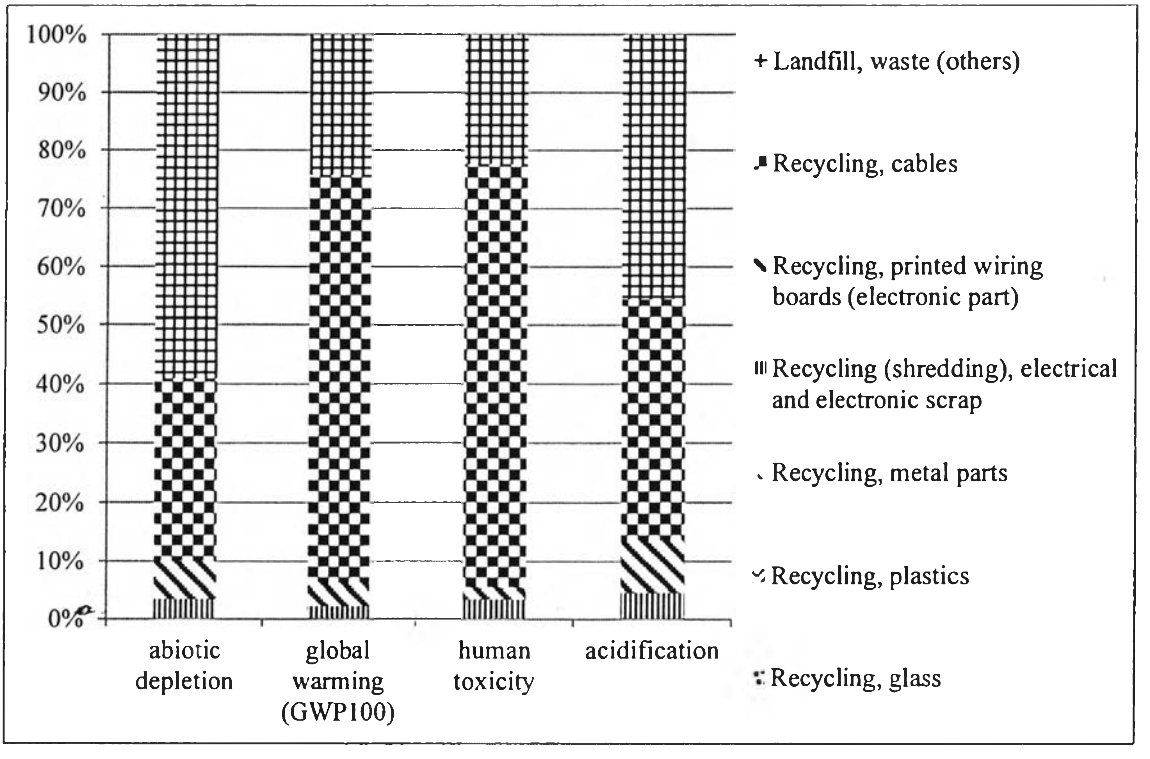

Figure 4.14 The environmental impacts of possible best of waste management of CRT-TV in Thailand.

4.4.2.4 Case 3

The environmental impacts of CRT-TV end-of-life treatment scenario by adapting technology from China to current technology in Thailand are shown in Figure 4.15. It can be seen that the major impacts contributed mainly from disposal of waste (i.e., metal parts, plastics, electronic parts, cable and others) to landfill. It is interesting to note that the disposal of waste and recycling of cables caused a significant attribution to the global warming and human toxicity impacts. On the other hand, the recycling of metal parts, plastics, and glass had less environmental impacts than the others because they are all recovered to produce new raw materials without any rejected or second waste that need further additional treatment.

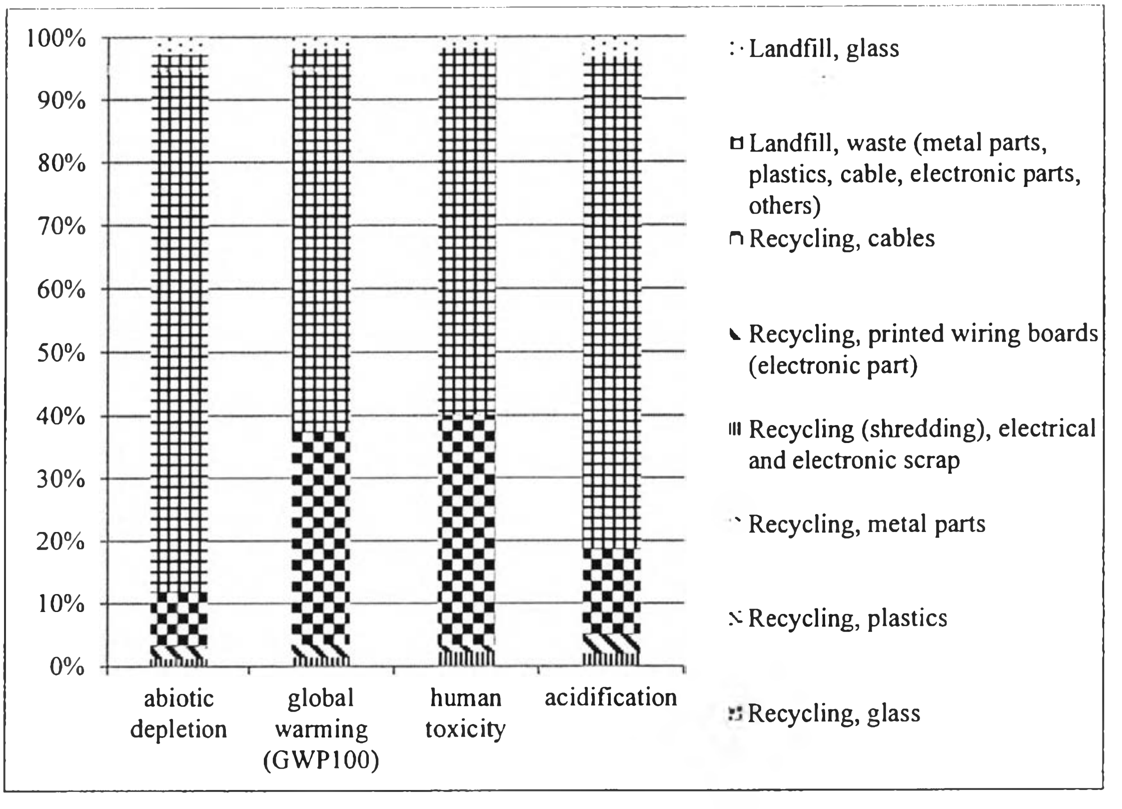

Figure 4.15 The environmental impacts of CRT-TV waste treatment scenario by adapting available recycling technology from China to current technology in Thailand.

4.4.2.5 Case 4

The environmental impacts of CRT-TV waste treatment scenario by adapting the current recycling rate to achievable recycling fraction in Japan end-of-life are shown in Figure 4.16. It can be seen that the impacts mainly caused by disposal of wastes (metals parts, plastics, cable, and electronic parts) to landfill and recycling of cables. The recycling of cables (about 3.6 %) contributed significant adverse impacts to global warming and human than other impact categories.

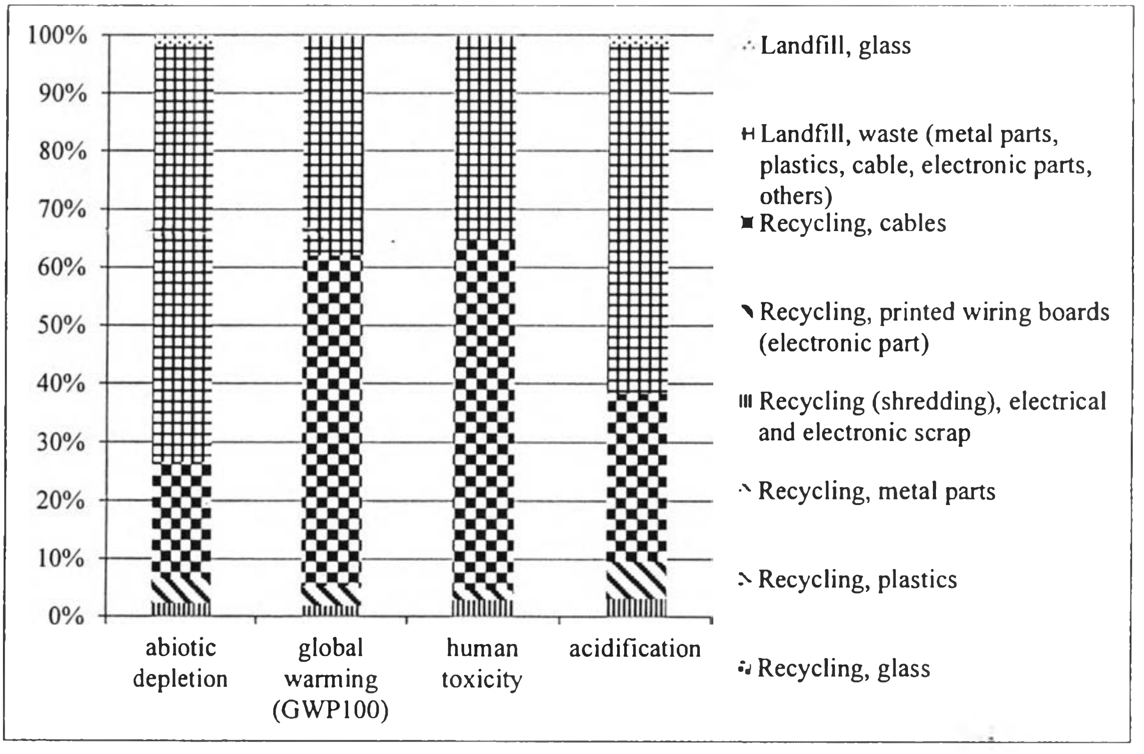

Figure 4.16 The environmental impacts of CRT-TV waste treatment scenario by adapting available recycling fraction in Japan.

The environmental impacts of five different end-of-life treatment scenarios of CRT-TV waste are shown in Table 4.13. It can be seen that the sources of all impact categories were mainly from the disposal of waste to landfill and the disposal of cables (either by incineration and recycling). The results show that the Case 2 having highest recycling fraction (92 %) and lowest landfill (8 %), had high global warming and human toxicity attributes. The source of emissions was mainly from disposal of cables. In addition, the disposal of glass had less effect to environmental impacts. This could be due to the fact that the total of panel glass and funnel glass are disposed by recycling method. The disposal of electronic parts contributed to low impacts because it required shredding process for various electronic scrap. Comparison between different modified technology scenarios, Case 3 (China) and Case 4 (Japan), the results show significant increasing environmental impacts on global warming and human toxicity from 33.95 % to 56.85 % and from 36.76 to 60.00 %, respectively.

Table 4.13 The environmental impacts of five end-of-life scenarios of components of CRT-TV

Scenario		**Component of CRT-TV**					
		Glass	**Metal Parts**	**Plastics**	**Cable**	**Electronic Parts**	**Others (Waste)**
Base Case	AD	3.35 %	0 %	0 %	4.45 %	1.97 %	90.23 %
	GWP	2.60 %	0 %	0 %	20.19 %	2.52 %	74.69 %
	HT	2.50 %	0 %	0 %	22.17 %	2.79 %	72.54 %
	AC	3.89 %	0 %	0 %	7.24 %	3.23 %	85.64 %
Case 1	AD	2.26 %	0 %	0 %	8.76 %	3.13 %	85.85 %
	GWP	1.50 %	0 %	0 %	34.1 %	3.43 %	60.97 %
	HT	1.43 %	0 %	0 %	36.90 %	3.30 %	58.37 %
	AC	2.54 %	0 %	0 %	13.76 %	5.00 %	78.70 %
Case 2	AD	0 %	0 %	0 %	30.85 %	10.15 %	59.00 %
	GWP	0 %	0 %	0 %	69.37 %	6.42 %	24.21 %
	HT	0 %	0 %	0 %	72.15 %	5.58 %	22.27 %
	AC	0 %	0 %	0 %	40.80 %	13.67 %	45.53 %
Case 3	AD	2.86 %	0 %	0 %	8.70 %	3.12 %	85.32 %
	GWP	1.91 %	0 %	0 %	33.95 %	3.42 %	60.72 %
	HT	1.81 %	0 %	0 %	36.76 %	3.29 %	58.14 %
	AC	3.21 %	0 %	0 %	13.67 %	4.96 %	78.16 %

Table 4.13 The environmental impacts of five end-of-life scenarios of components of CRT-TV (cont.)

Scenario		Component of CRT-TV					
		Glass	Metal Parts	Plastics	Cable	Electronic Parts	Others (Waste)
Case 4	AD	1.41 %	0 %	0 %	20.06 %	6.59 %	71.94 %
	GWP	0.67 %	0 %	0 %	56.85 %	5.28 %	37.20 %
	HT	0.63 %	0 %	0 %	60.00 %	4.65 %	34.72 %
	AC	1.45 %	0 %	0 %	28.76 %	9.63 %	60.16 %

4.4.3 Comparison of End-of-Life Environmental Impacts of CRT-Television Treatment Scenarios

4.4.3.1 Abiotic Depletion (AD)

Abiotic depletion is related to extraction of scarce minerals and fossil fuels. This impact considers energy and non-energy natural resources which encompasses both the use of non-renewable and renewable. A set of Antimony (Sb) is selected as a reference resource (BRE, 2005). Figure 4.17 shows that the highest environmental impact for all categories was observed in Base Case - which has lowest recycling and highest landfill fraction. In contrast, the lowest abiotic depletion impact was found in Case 2 - which has highest recycling and lowest landfill portions. The results showed that the Base Case scenarios had the highest abiotic depletion followed by Case 3, Case 1, Case2 and Case 4. Comparing abiotic depletion impacts among five end-of-life treatment scenarios, the impact contributed decreasing from Base case and Case 2 about 65.29 %

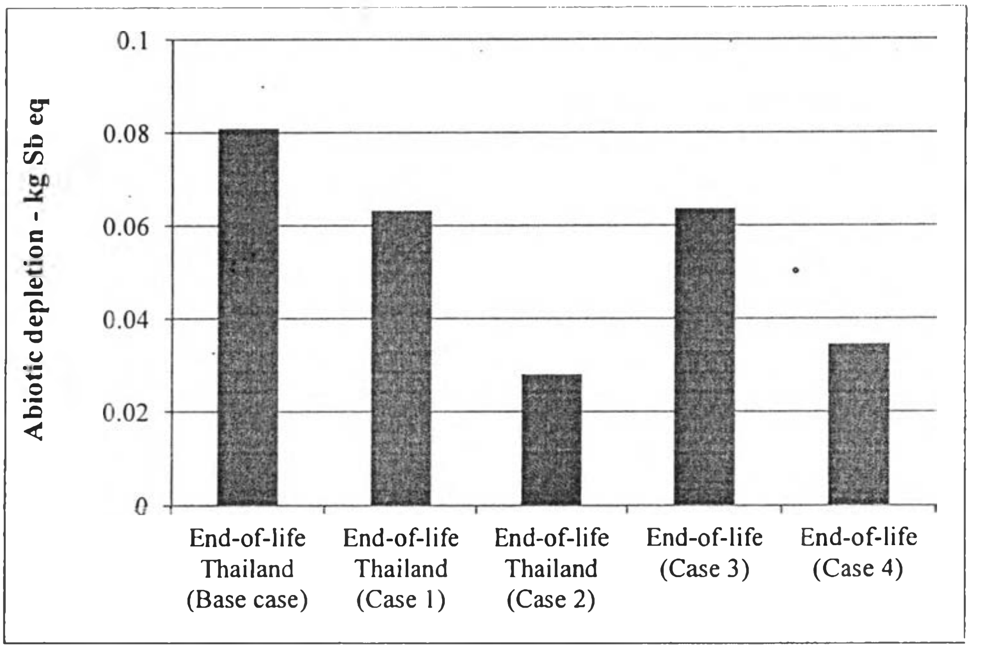

Figure 4.17 Abiotic depletion of end-of-life scenarios in this study of CRT-television by using CML 2 baseline 2000.

4.4.3.2 Global Warming Potential (GWP)

According to the Figure 4.18, the lowest GHG emission was observed from end-of-life waste management of CRT-TV in Case 2 - which uses highest recycling and lowest landfill fractions as disposal solution. In contrast, the highest GHG emission was the Base case which represents a current situation of CRT-TV waste management in Thailand. The Base Case had highest negative impact due to incineration and landfilling. In addition, the Base Case had the highest global warming potential which is equal to 10.959 kg CO_2 eq. followed by Case 3, Case 1, Case2 and Case 4 which are shown to be 7.876, 7.843, 6.023 and 5.879 kg CO_2 eq., respectively. Comparison of global warming potential among five end-of-life treatment scenarios, it can be seen that the global warming potential impact were reduced by 45.04 % if we could adapt the recycling fraction from the current technology to Case 2.

For modified technology for waste management of CRT-TV, it can be seen that developed countries like China and Japan have lower impacts in all categories than the current situation of waste management in Thailand. Therefore, Thais' governments or national agencies need to aware of the current end-of life treatment scheme as this current.scenario has relatively high impact on environment in all categories. The improved technologies having an increasing of recycling fraction play an important role to help develop for sustainable e-waste disposal in Thailand.

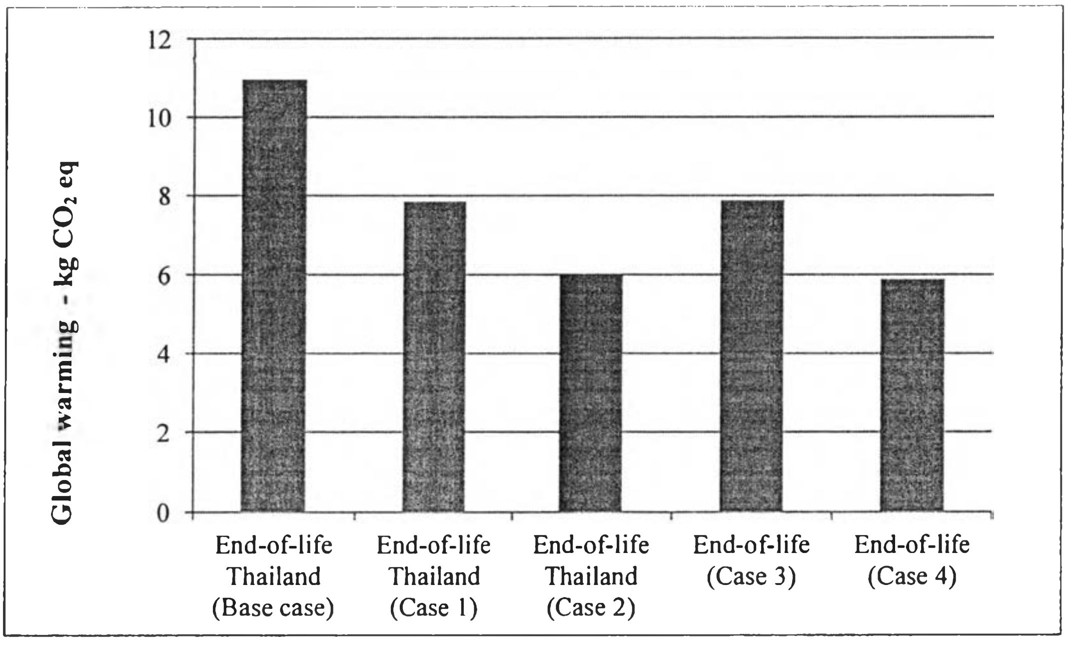

Figure 4.18 Global warming potential of end-of-life scenarios in this study of CRT-television using CML 2 baseline 2000 method.

4.4.3.3 Human Toxicity Potential

Human toxicity potential introduces to express the potential harm of chemical, physical or biological on human health. The emission of some substances can have impacts on human health. For each toxic substance, HTPs are expressed using the reference unit, kg 1,4-dichlorobenzene (1,4-DB) equivalents (BRE, 2005). In the CRT-TV end-of-life waste management scenario, the highest human toxicity impact was found in Base Case (Figure 4.19) which is equal to 4.722 kg 1,4-DB eq. and followed by Case 3, Case 1, Case2 and Case 4 which are 3.258, 3.245, 2.593 and 2.495 kg 1,4-DB eq., respectively. When we investigated in to the details, the human toxicity impact was dominated by the disposal of waste to landfill and the disposal of cable by incineration (see Figure 4.12). Comparison human toxicity potential of among five end-of-life treatment scenarios, it can be seen that the impact contributed decreasing from Base case to best achievedable (Case 2) about 45.09 %. For modified technology from Japan (Case 4), it performed lower human toxicity impact than others. Based on this findings, the impact to human health of current CRT end-of-life treatment can be reduced by increasing recycling rate.

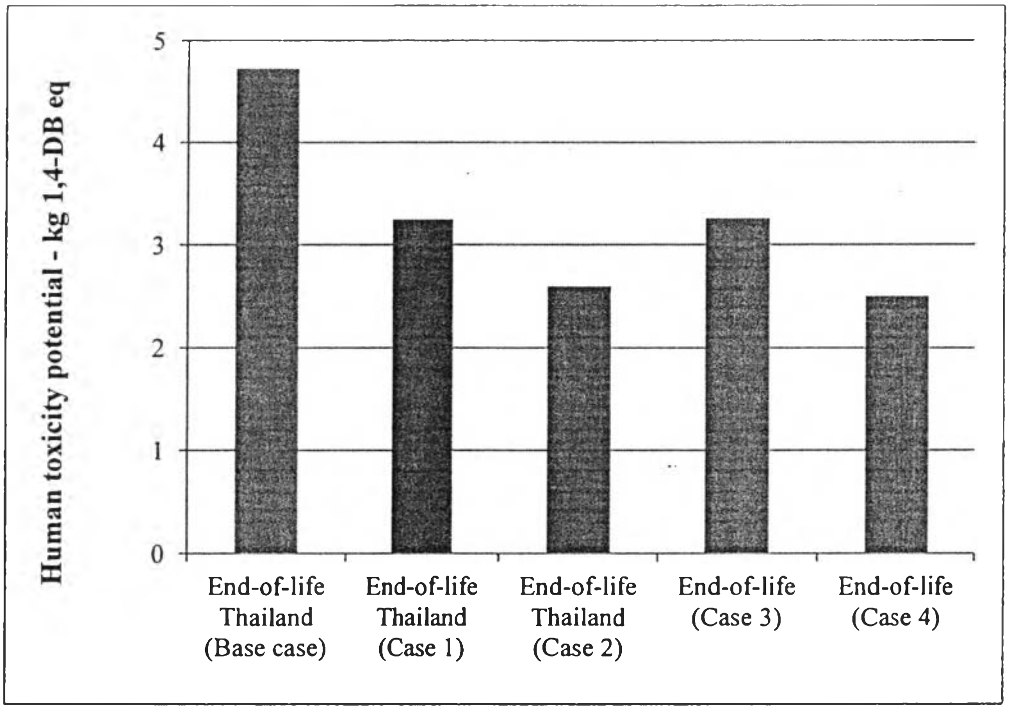

Figure 4.19 Human toxicity potential of end-of-life scenarios in this study of CRT-television by using CML 2 baseline 2000.

4.4.3.4 Acidification Potential (AP)

Acidification is caused by acid deposition that acid compounds (sulphur oxides, nitrogen oxides and ammonia) released in the air. Rainfalls may wash these acids and cause acid rains. Then, the acid compounds present in streaming waters and in watercourses. Thus, all emission compounds, which are likely to acidify the environment, are stated in kg SO_2 equivalent (BRE, 2005). For end-of-life scenarios, the highest acidification impact is base case as shown in Figure 4.20. Comparing acidification potential of five end-of-life treatment scenarios, it can be seen that the impact contributed decreasing between Base case and Case 2 about 58.19 %. When investigated in to the details, the main acidification impact in Base case came from disposal of waste to landfill and disposal of cable by incineration (1.8 %) as shown in Figure 4.12. The improvement method reducing, this impact has to realize the disposal of cable (open burning) as a priority solution.

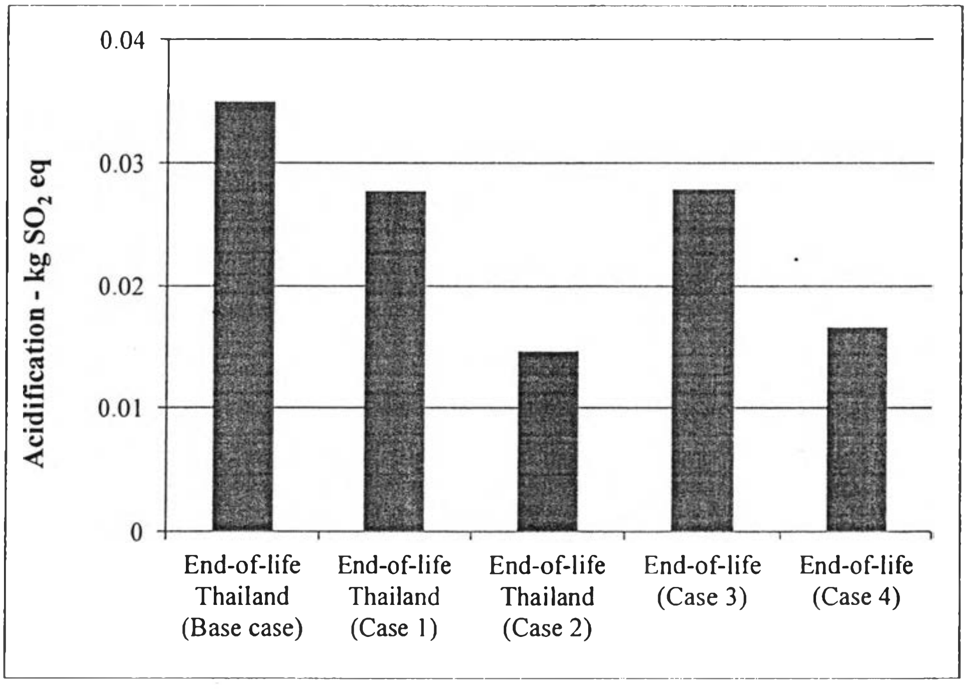

Figure 4.20 Acidification potential of end-of-life scenarios in this study of CRT-television by using CML 2 baseline 2000.

4.4.3.5 Energy Resources

The energy carriers are divided in renewable and non-renewable resources. The energy resource is determined by the energy content of resources depending on energy consumption. Figure 4.21 illustrates the results of energy resource in each end-of-life scenario of discarded CRT-television. It can be seen that the Base case consumed the highest amount of energy consumption. In five end-of life scenarios, the disposal of wastes used electricity as the main energy resource. The energy consumption of CRT-TV waste disposal in Case 2 and Case 4 consumed the lower amount of energy resources than the Base case, Case 1, and Case 3, respectively. The highest energy resource impact was found in Base Case, followed by Case3, Case1, Case4 and Case2, respectively.

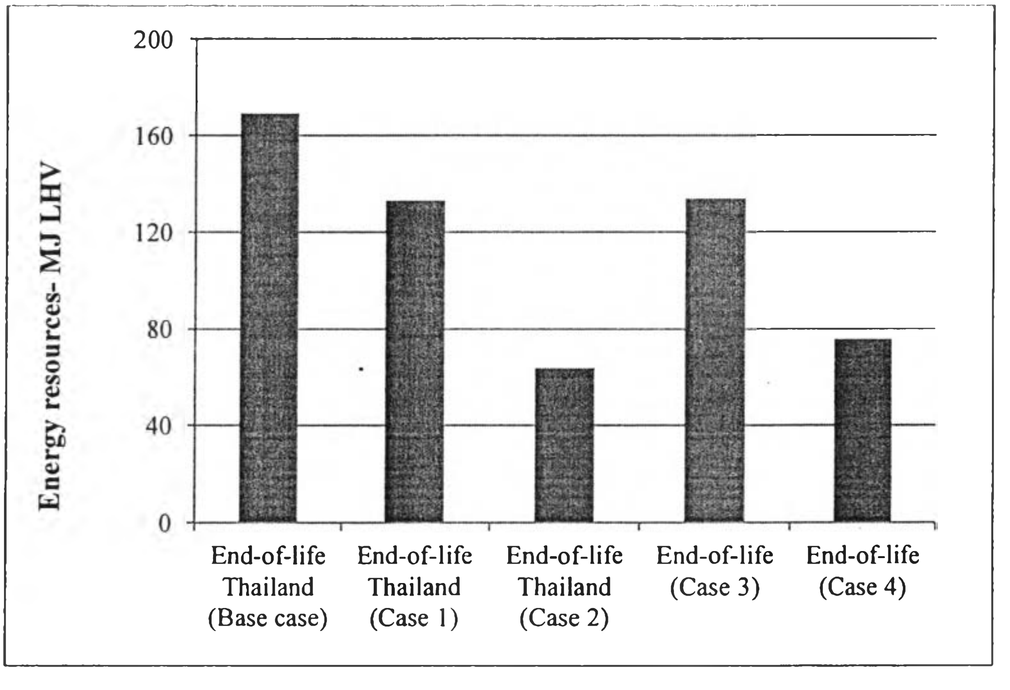

Figure 4.21 Energy resources of end-of-life scenarios in this study of CRT-television by using Eco-indicator 95.

As a result from the case study of developed countries, Japan (Case 4) and China (Case 3), the CRT-TV end-of-life treatment technology is mature and advanced, added with the attention of government. For the current situation of waste management of CRT-TV in Thailand, landfilling which is a simple and normal method but causes severe impacts to the environments should be reduced.

For CRT-TV waste disposal technology in China (Case 3), the disposal of glass parts indicated a strong point of view because the funnel glass and recycle panel glass can be recycled upto 70 %. According to the database of discarded CRT-TV technology in Japan, the disposal of glass parts was recycling at high percentages of funnel glass and panel glass, about 90 % of total weight. The result of environmental impact analysis showed the Case 3 (China) and Case 4 (Japan) had lower effect than that of Thailand. The reason is that the glass components are disposed to landfill.

Comparison environmental impacts at the end-of-life stage show in Figure 4.22, it can be seen that the Case 2 which has highest recycling (92 %) and lowest landfill (8 %) with no incineration performed the best case scenario, due to the highest recycling rate. When comparing the current waste management of Thailand (Base Case) and Case 2 (Best achievable technology) , the results showed significant reduction in the normalized environmental impacts on abiotic depletion, global warming, human toxicity and acidification of 65.28 %, 45.04 %, 45.09 %, and 58.19 %, respectively. In addition, the environmental impacts on abiotic depletion and global warming were sensitive impacts for CRT-TV end-of-life analysis. These impacts depend on recycling fraction of CRT-TV waste. In the other hand, the environmental impacts on human toxicity and acidification were less sensitive effect with increasing the percentages of recycling of CRT-TV waste.

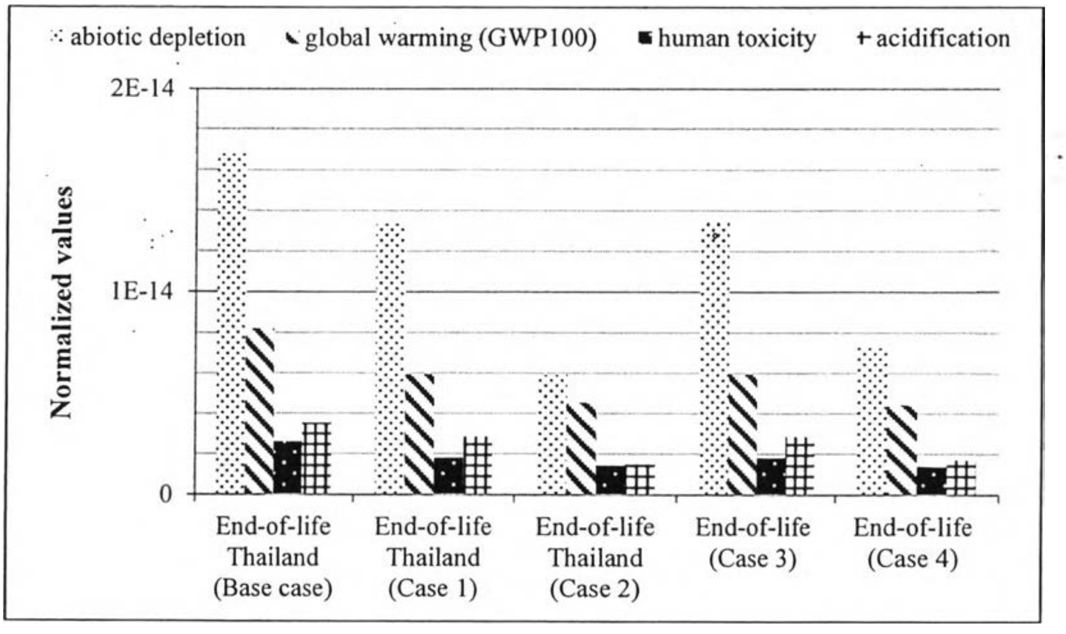

Figure 4.22 Normalized values for comparison of environmental impacts of end-of-life of CRT-television.