CHAPTER IV
RESULTS AND DISCUSSION

4.1 Life Cycle Inventory

The inventory data of polyethylene shopping bag production including raw material input, utilities (electricity, water) used and all of emissions such as solid waste and liquid waste throughout the entire life cycle of one kilogram of shopping bag were collected in this study.

The inventory data covered three types of product, which were conventional polyethylene, polyethylene-starch, and polyethylene-photo additive shopping bag. All data were collected from factories in Thailand. Allocation of data was used in this research depending on amount of shopping bag production of these factories.

Three types of shopping bag product were polyethylene bag but they were different in constituent and physical properties such as PE-starch and PE-photo additive had higher degradability than conventional PE bag. The main raw material of these shopping bag productions was high density polyethylene (HDPE). It was transported from Rayong province by 10-wheel truck. The production phase divided into three main steps which were mixing, blowing and printing, and cutting.

Firstly all of, components were mixed in a mixing machine to give formulated pellets. The formulated pellets were blown into film shape by blowing machine and printed by a printing machine. Finally, the printed bag was cut and sealed into shopping bag shape.

The recycling process was used for producing plastic pellets from all of plastic scrap discharged from each steps of production phase. Some of the recycled products were reused to be one of the components of shopping bag production.

All of factories studied, used blown film process to produce shopping bags. Figure 4.1 shows a typical shopping bag production process that these factories employed.

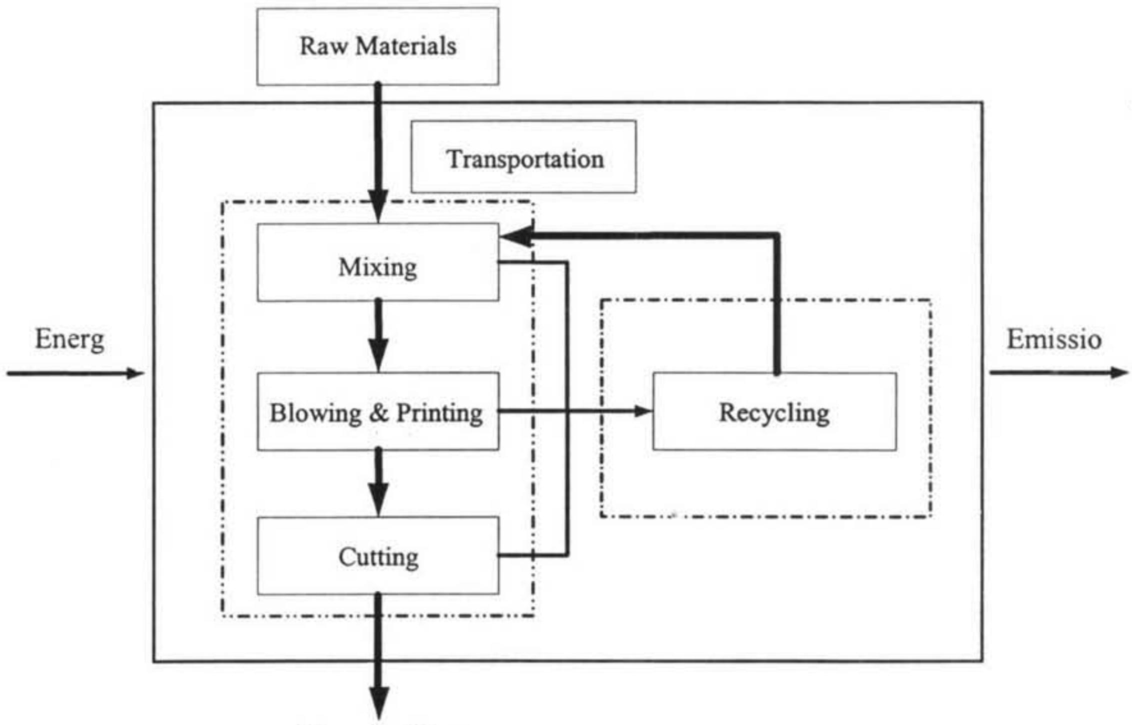

Figure 4.1 Polyethylene shopping bag production process.

4.1.1 Conventional Polyethylene Shopping Bag Inventory

Conventional polyethylene shopping bag was produced from mixing of a number of additives and raw materials. All companies provided information for this research did not produce these raw materials themselves but they were supplied by a number of suppliers both in Thailand and other countries. Conventional polyethylene shopping bag inventory concluded all processes which involves in producing 1 kg of conventional shopping bag. Raw materials input, mixing process, blowing and printing process, cutting, recycling, and all emissions were involved in this inventory. Conventional PE shopping bag production employed processes as shown in Figure 4.1. Details of input and output data collection of conventional PE bag production are shown in Table 4.1. Input and output data of mixing, blowing and printing, cutting, and recycling steps for producing 1 kg of polyethylene bag are described in Figure 4.2-4.5 respectively. The details of each production step and transportation are described in Table 4.2-4.10. The overall data of conventional PE shopping bag inventories are presented in Figure 4.6.

Table 4.1 Input-output data of conventional polyethylene bag production

Input Data		
Raw Material	**Amount**	**Unit**
HDPE	0.874	kg
LLDPE	0.128	kg
Calcium	0.068	kg
Masterbatch	0.036	kg
Recycle Pellet	0.066	kg
Utilities	**Amount**	**Unit**
Electricity	0.862	kWh
Water	1.381	kg

Output Data		
Product	**Amount**	**Unit**
Plastic Bag	1.000	kg
Emission	**Amount**	**Unit**
Scrap	0.169	kg

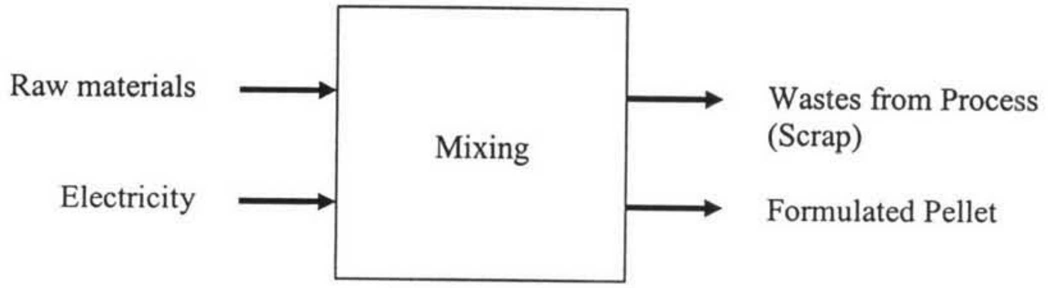

Figure 4.2 Input-output of mixing process.

Table 4.2 Input details of mixing process

Mixing		
Input	**Amount**	**Unit**
HDPE	0.874	kg
LLDPE	0.128	kg
Masterbatch	0.036	kg
Recycle Pellet	0.066	kg
Calcium	0.068	kg
Electricity	0.001	kWh

Table 4.3 Output details of mixing process

Mixing		
Output	**Amount**	**Unit**
Formulated Pellet	1.172	kg
Scrap	0.00	kg

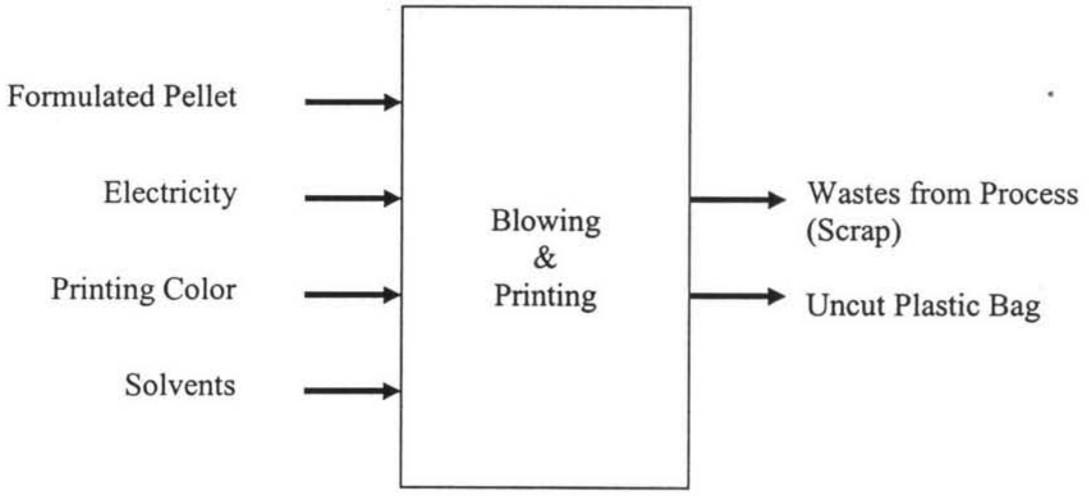

Figure 4.3 Input-output of blowing and printing process.

Table 4.4 Input details of blowing and printing process

Blowing and Printing		
Input	**Amount**	**Unit**
Formulated Pellet	1.168	kg
Electricity	0.356	kWh
Printing Color	0.015	kg
Toluene	0.034	kg
Isopropyl Alcohol	0.017	kg
Ethyl Acetate	0.006	kg

Table 4.5 Output details of blowing and printing process

Blowing and Printing		
Output	**Amount**	**Unit**
Uncut Plastic Bag	1.142	kg
Scrap	0.025	kg

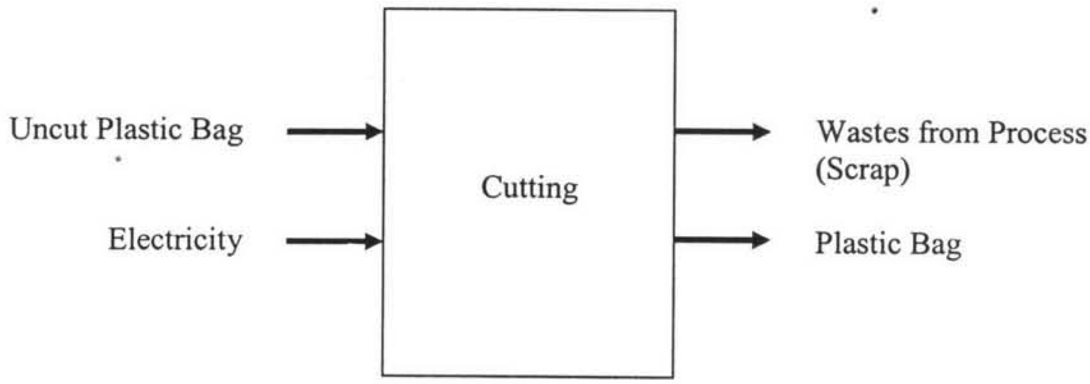

Figure 4.4 Input-output of cutting process.

Table 4.6 Input details of cutting process

Cutting		
Input	**Amount**	**Unit**
Uncut Plastic Bag	1.142	kg
Electricity	0.080	kWh

Table 4.7 Output details of cutting process

Cutting		
Output	**Amount**	**Unit**
Plastic Bag	1.000	kg
Scrap	1.420	kg

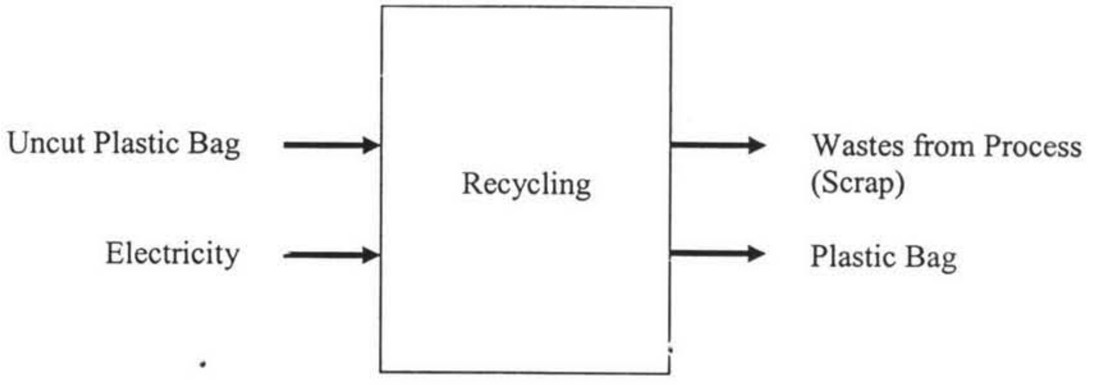

Figure 4.5 Input-output of recycling process.

Table 4.8 Input details of recycling process

Recycling		
Input	**Amount**	**Unit**
All Scraps in Process	1.000	kg
Electricity	0.426	kWh
Water	1.381	kg

Table 4.9 Output details of recycling process

Recycling		
Output	**Amount**	**Unit**
Recycle Pellet	1.000	kg

Table 4.10 Transportation details of raw materials and shopping bag product

Transportation		
Type	**Amount (kgkm)**	**Transport by**
Raw Materials	169.45	10-wheel Truck
Scrap	50	10-wheel Truck
Shopping Bag	72.98	10-wheel Truck

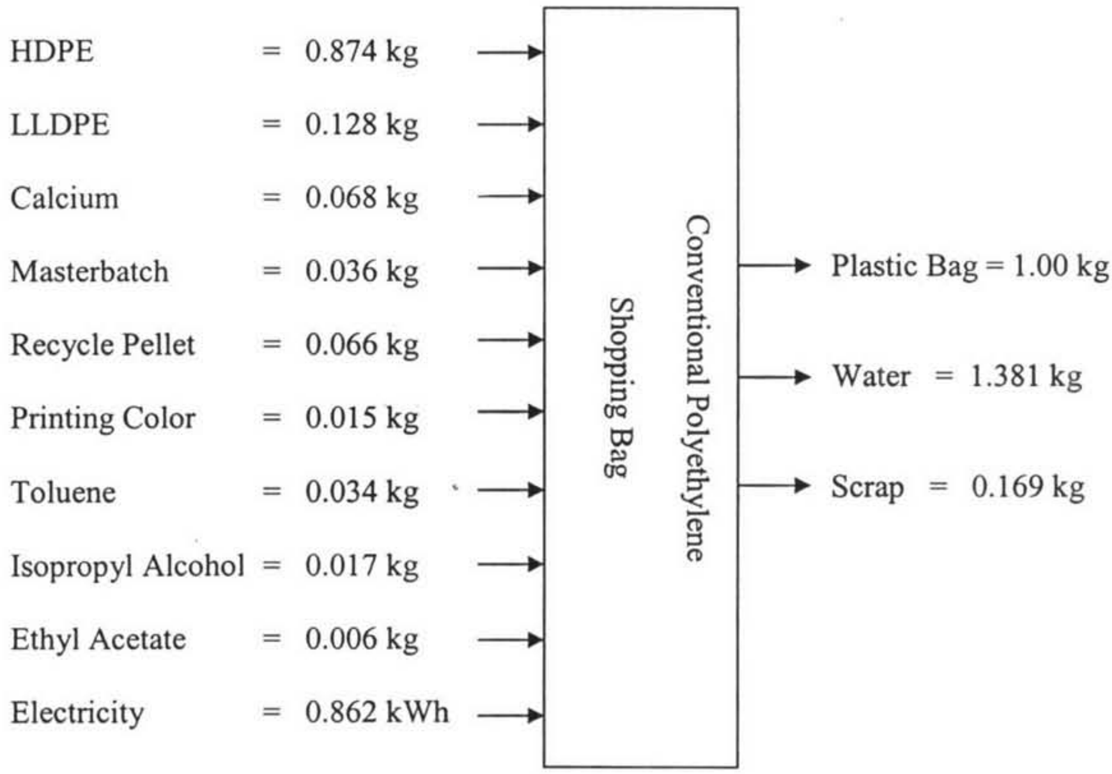

Figure 4.6 Inventory of life cycle of conventional polyethylene shopping bag.

4.1.2 Polyethylene-Starch Shopping Bag Inventory

Polyethylene-starch shopping bag was produced from mixing of a number of additives and raw materials. All companies provided data for this research did not produce these additives and raw materials but they were supplied by a number of suppliers both in Thailand and overseas. Polyethylene-starch shopping bag inventory concluded all processes which involves in producing 1 kg of polyethylene-starch shopping bag. Raw materials input, mixing process, blowing and printing process, cutting, recycling, and all of emissions were involved in this inventory. Polyethylene-starch bag production process is shown in Figure 4.1. Details of input and output data collection of polyethylene-starch bag production are shown in Table 4.11. Input and output data for producing 1 kg of polyethylene-starch bag are shown in steps (Figure 4.7-4.10), according to steps in the production process: mixing, blowing and printing, cutting, and recycling. The details of each production step and transportation are described in Tables 4.12-4.20. The overall PE-starch bag production inventories are concluded in Figure 4.11.

Table 4.11 Input-output data of polyethylene-starch bag production

Input Data		
Raw Material	**Amount**	**Unit**
HDPE	0.743	kg
LLDPE	0.183	kg
LDPE	0.018	kg
Calcium	0.065	kg
Starch	0.084	kg
Masterbatch	0.039	kg
Utilities	**Amount**	**Unit**
Electricity	0.945	kWh
Water	1.381	kg

Output Data		
Product	**Amount**	**Unit**
Plastic bag	1.000	kg
Emission	**Amount**	**Unit**
Scrap	0.133	kg

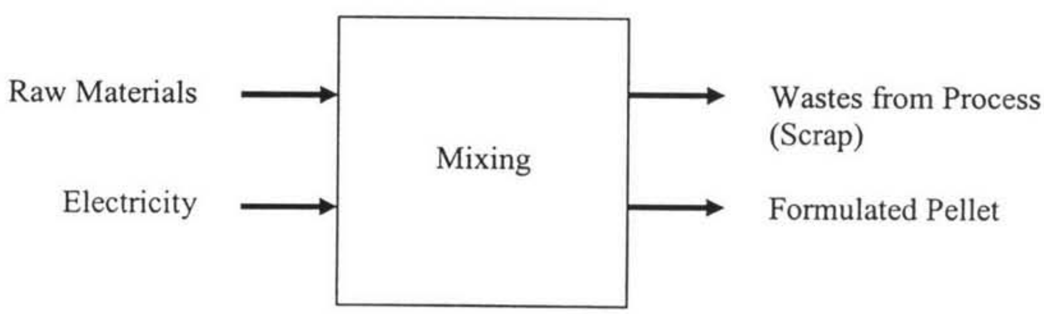

Figure 4.7 Input-output of mixing process.

Table 4.12 Input details of mixing process

Mixing		
Input	**Amount**	**Unit**
HDPE	0.743	kg
LLDPE	0.183	kg
LDPE	0.018	kg
Starch	0.084	kg

Masterbatch	0.039	kg
Photo Additive	0.004	kg
Calcium	0.065	kg
Electricity	0.001	kWh

Table 4.13 Output details of mixing process

Mixing		
Output	**Amount**	**Unit**
Formulated Pellet	1.133	kg
Scrap	0.000	kg

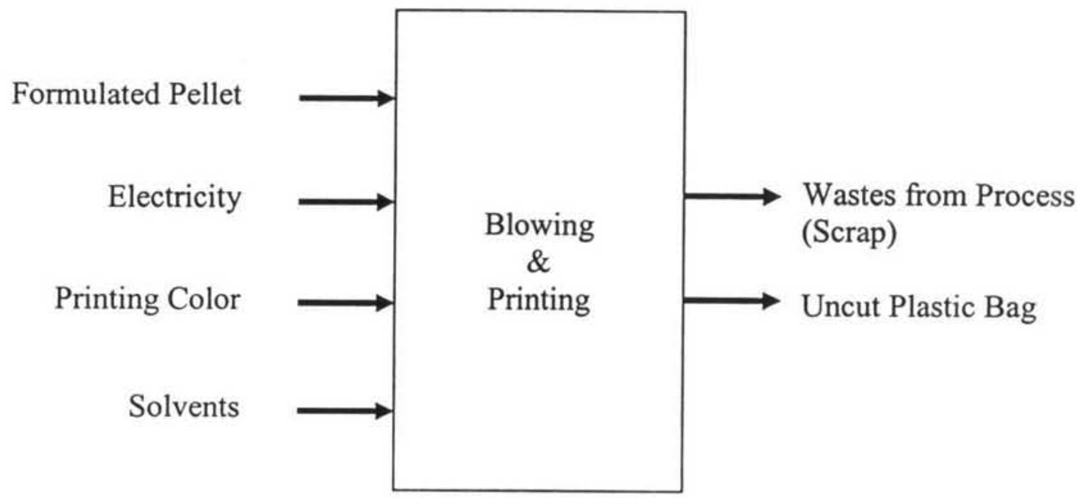

Figure 4.8 Input-output of blowing and printing process.

Table 4.14 Input details of blowing and printing process

Blowing and Printing		
Input	**Amount**	**Unit**
Formulated Pellet	1.133	kg
Electricity	0.449	kWh
Printing Color	0.018	kg
Toluene	0.053	kg
Isopropyl Alcohol	0.026	kg
Ethyl Acetate	0.009	kg

Table 4.15 Output details of blowing and printing process

Blowing and Printing		
Output	**Amount**	**Unit**
Uncut Plastic Bag	1.102	kg
Scrap	0.031	kg

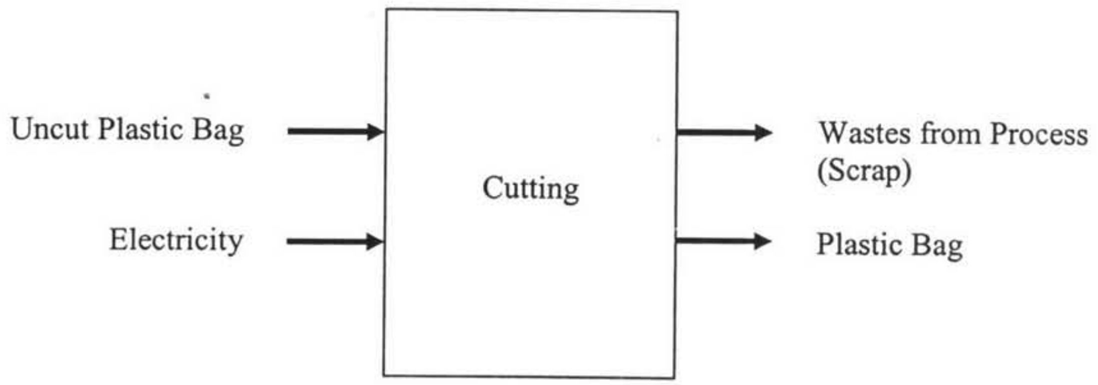

Figure 4.9 Input-output of cutting process.

Table 4.16 Input details of cutting process

Cutting		
Input	**Amount**	**Unit**
Uncut Plastic Bag	1.102	kg
Electricity	0.070	kWh

Table 4.17 Output details of cutting process

Cutting		
Output	**Amount**	**Unit**
Plastic Bag	1.000	kg
Scrap	0.102	kg

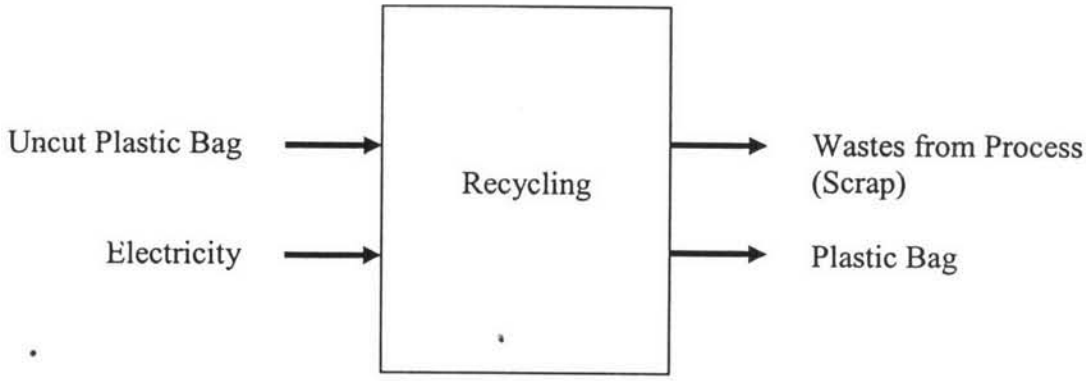

Figure 4.10 Input-output of recycling process.

Table 4.18 Input details of recycling process

Recycling		
Input	**Amount**	**Unit**
All Scraps in Process	1.000	kg
Electricity	0.426	kWh
Water	1.381	kg

Table 4.19 Output details of recycling process

Recycling		
Output	**Amount**	**Unit**
Recycle Pellet	1.000	kg

Table 4.20 Transportation details of raw materials and shopping bag product

Transportation		
Type	**Amount (kgkm)**	**Transport by**
Raw materials	166.77	10-wheel Truck
Scrap	50	10-wheel Truck
Shopping bag	69.37	10-wheel Truck

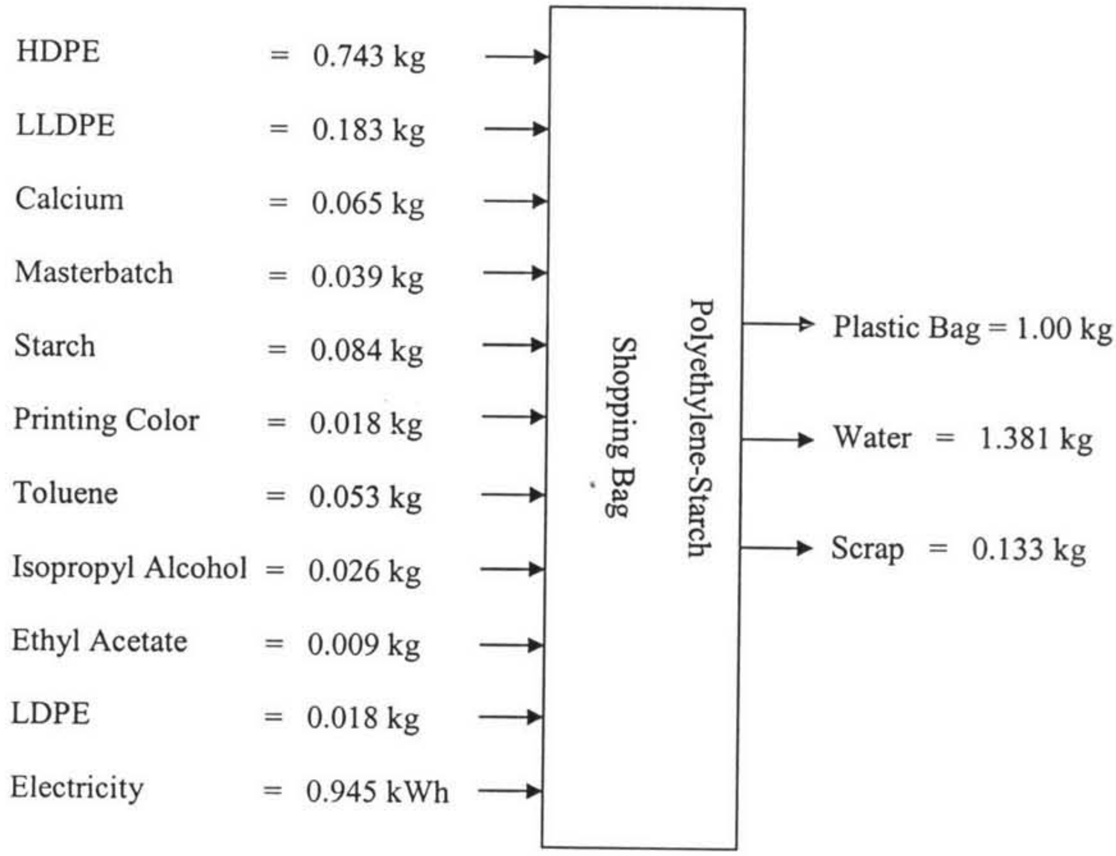

Figure 4.11 Inventory of life cycle of polyethylene-starch shopping bag.

4.1.3 Polyethylene-Photo Additive Shopping Bag Inventory

Polyethylene-photo additive bag production process was similar to that of conventional PE bag production process and PE-starch bag production process. Polyethylene-photo additive bag was produced from mixing photo additive such as metal carboxylate, aliphatic poly hydroxyl-carboxyl acid and other additives such as calcium oxide and stabilizer to polyethylene. All manufacturers took part in this research did not produce these additives and raw materials but were provided by suppliers both in Thailand and other countries. Polyethylene-photo additive shopping bag inventory concluded all processes which involves in producing 1 kg of polyethylene-photo additive shopping bag. Raw materials input, mixing process, blowing and printing process, cutting, recycling, and all emissions were involved in this inventory. Polyethylene-photo additive bag production used similar production process to that shown in Figure 4.1. Details of input and output data collection of PE-photo additive bag production are shown in Table 4.21. Input and output data of mixing, blowing and printing, cutting, and recycling steps for producing 1 kg of PE-photo additive bag are described in Figure 4.12-4.15. The details of each production step and transportation are described in Tables 4.22-4.30. The overall PE-photo additive bag inventories are presented in Figure 4.16.

Table 4.21 Input-Output data of photo additive-polyethylene bag production

Input Data			Output Data		
Raw Material	**Amount**	**Unit**	**Product**	**Amount**	**Unit**
HDPE	0.839	kg	Plastic Bag	1.000	kg
LLDPE	0.168	kg			
Photo Additive	0.018	kg			
Calcium	0.112	kg			
Masterbatch	0.049	kg			
Utilities	**Amount**	**Unit**	**Emission**	**Amount**	**Unit**
Electricity	0.791	kWh	Scrap	0.185	kg
Water	1.381	kg			

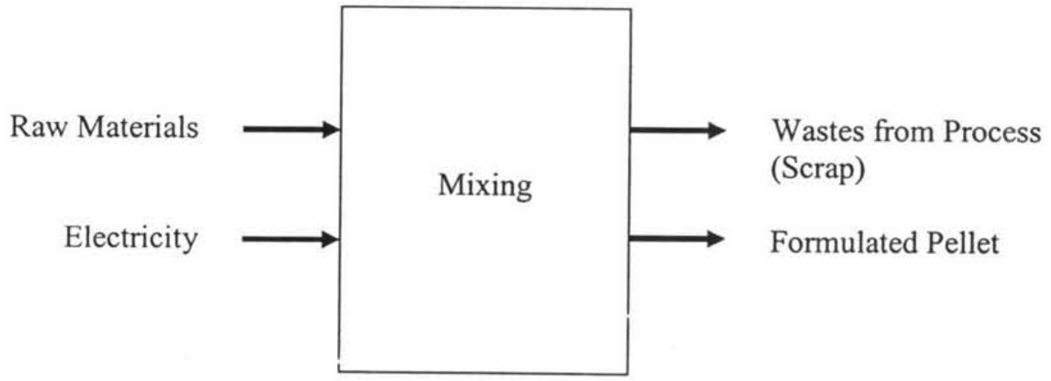

Figure 4.12 Input-output of mixing process.

Table 4.22 Input details of mixing process

Mixing		
Input	**Amount**	**Unit**
HDPE	0.839	kg
LLDPE	0.168	kg
Masterbatch	0.049	kg
Photo Additive	0.018	kg
Calcium	0.112	kg
Electricity	0.001	kWh

Table 4.23 Output details of mixing process

Mixing		
Output	**Amount**	**Unit**
Formulated Pellet	1.185	kg
Scrap	0.000	kg

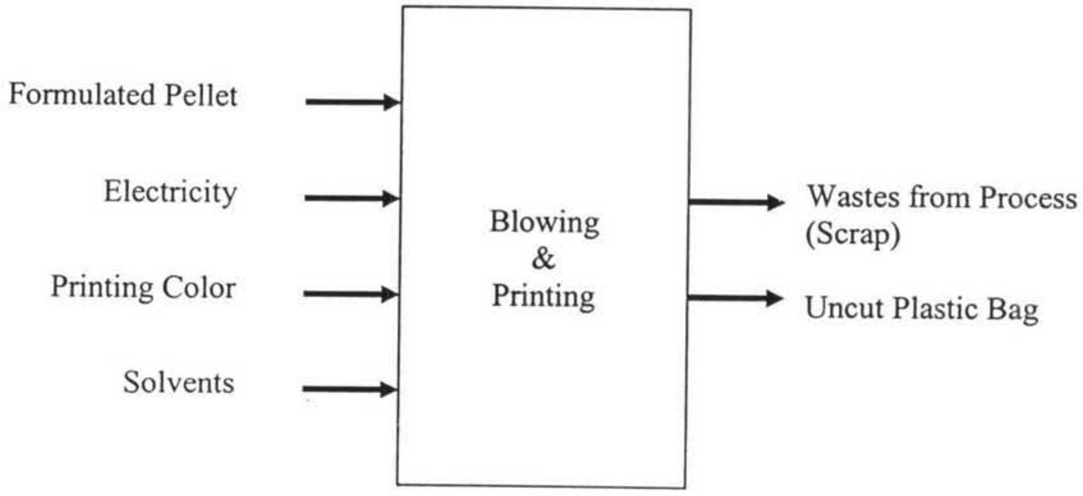

Figure 4.13 Input-output of blowing and printing process.

Table 4.24 Input details of blowing and printing process

Blowing and Printing		
Input	**Amount**	**Unit**
Formulated Pellet	1.185	kg
Electricity	0.293	kWh
Printing Color	0.012	kg
Toluene	0.036	kg
Isopropyl Alcohol	0.018	kg
Ethyl Acetate	0.006	kg

Table 4.25 Output details of blowing and printing process.

Blowing and Printing		
Output	**Amount**	**Unit**
Uncut Plastic Bag	1.156	kg
Scrap	0.029	kg

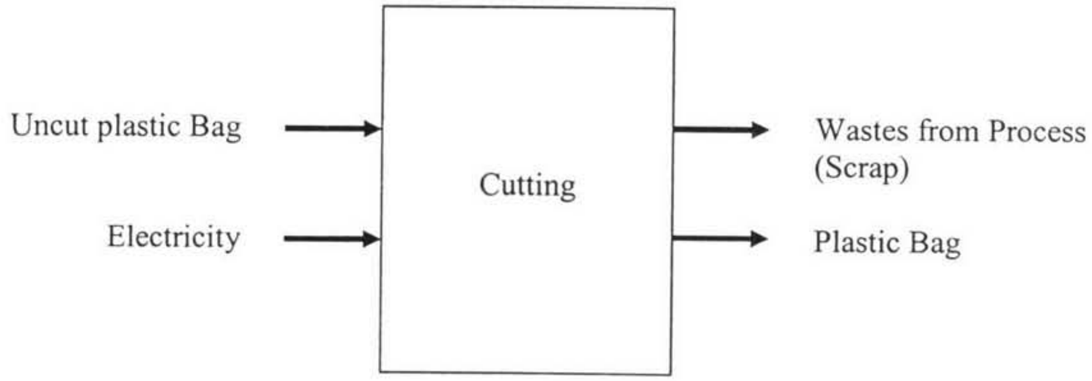

Figure 4.14 Input-output of cutting process.

Table 4.26 Input details of cutting process

Cutting		
Input	**Amount**	**Unit**
Uncut Plastic Bag	1.156	kg
Electricity	0.071	kWh

Table 4.27 Output details of cutting process

Cutting		
Output	**Amount**	**Unit**
Plastic bag	1.000	kg
Scrap	0.156	kg

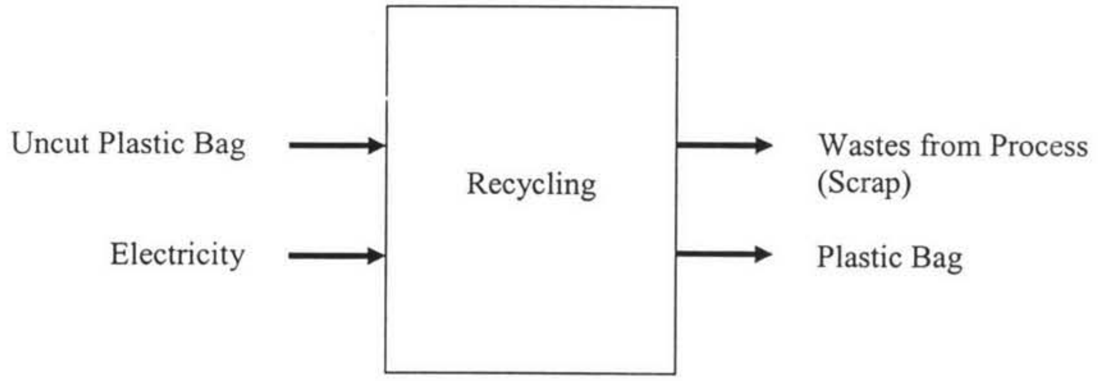

Figure 4.15 Input-output of recycling process.

Table 4.28 Input details of recycling process

Recycling		
Input	**Amount**	**Unit**
All Scraps in Process	1.000	kg
Electricity	0.426	kWh
Water	1.381	kg

Table 4.29 Output details of recycling process

Recycling		
Output	**Amount**	**Unit**
Recycle Pellet	1.000	kg

Table 4.30 Transportation details of raw materials and shopping bag product

Transportation		
Type	**Amount (kgkm)**	**Transport by**
Raw Materials	169.46	10-wheel Truck
Shopping Bag	98.74	10-wheel Truck

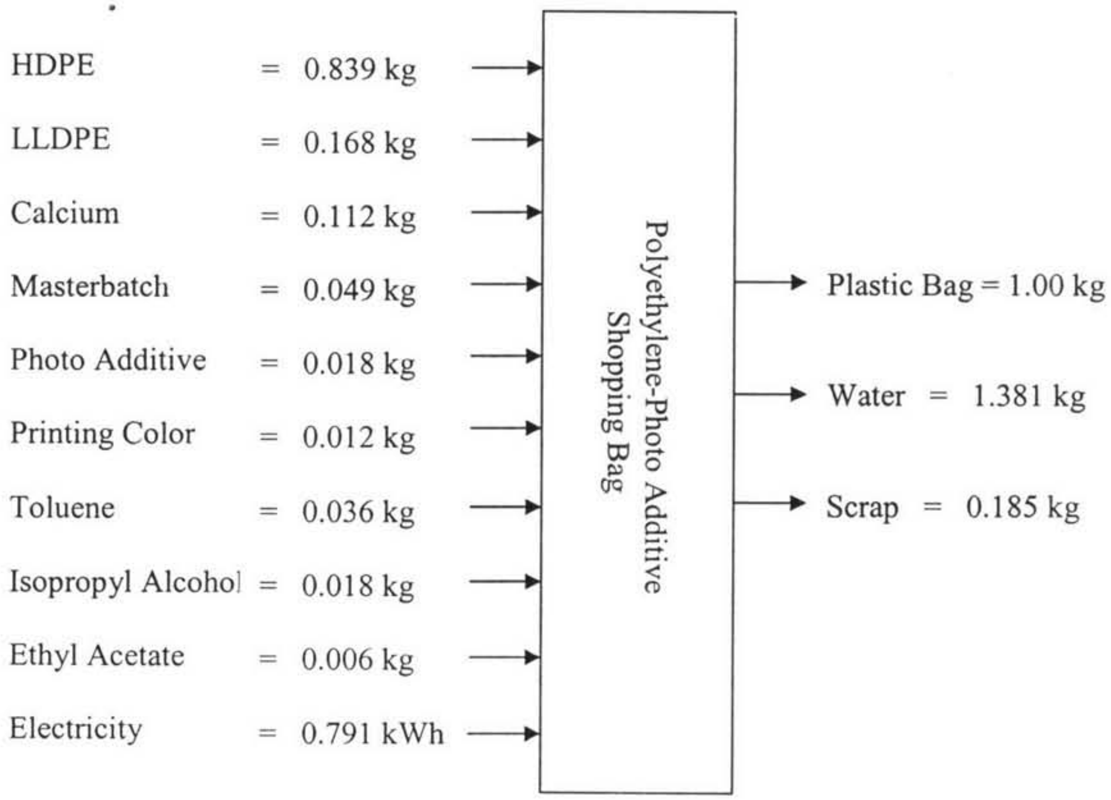

Figure 4.16 Inventory of life cycle of polyethylene-photo additive shopping bag.

4.2 Life Cycle Impact Assessment

After the life cycle inventory (LCI) step was carried out, life cycle impact assessment (LCIA) could then be performed based on the quantitative information attained from LCI study in order to identify the environmental impacts from the production of the three types of plastic bag products, conventional PE, PE-photo additive, and PE-starch. This was carried out by using the commercial LCA software, SimaPro 5.1, with Eco-Indicator 95 and Eco-Indicator 99 for environmental impact assessment. Eco-Indicator 95 is a mid-point approach to the impact assessment whereas Eco-Indicator 99 is an end-point approach. The environmental categories focused in this research were greenhouse effect potential, ozone layer depletion, acidification potential, eutrophication potential, human health damage, ecosystem quality, and resources depletion. In this part of the study, the results from Eco-Indicator 95 were firstly presented followed by the results from Eco-Indicator 99. In addition, the comparison between the two methods was also discussed.

The total amount of environmental impact potential and energy used in the life cycle of one kilogram of conventional PE, PE-starch, and PE-photo additive shopping bag are shown in Table 4.1, 4.11,and 4.21. The results of LCIA from Eco-Indicator 95 showed that the most important phase with respect to environmental impacts was raw material input phase. It was responsible for about 65 percent contribution to greenhouse effect potential, 70 percent contribution to acidification, and 60 percent contribution to eutrophication potential (see Figure 4.17, 4.19, and 4.20). Percent contributions of the impacts from each phase of all types of bag are shown in Table 4.31-4.33. The contributions to these impacts were due to the use of initial raw materials for production. The second important phase was recycling process. It was responsible about 20 percent contribution to greenhouse effect potential, acidification potential, and eutrophication potential (see Figure 4.17, 4.19, and 4.20). These impacts were mainly due to the emissions from the materials used for producing water in Thailand, this because large amount of water was used in the recycling process. For ozone layer depletion, transportation phase generated environmental effect quite similar to that from raw material phase at 45 percent contribution. This effect was caused from fuel used for transportation.

The impact categories of producing 1 kg of conventional PE, PE-starch and PE-photo additive bag are shown in Table 4.34-4.36 respectively. Examples of the results in Table 4.34 are the material input process produced green house effect potential equal to 2.05 kg CO_2 equivalent, 0.02 kg SO_2 equivalent in acidification, and 87.70 MJ LHV equivalents in energy resources. Table 4.35 and 4.36, show the environmental impact of raw material input phase, which are also high in greenhouse effect and acidification, in kg equivalent.

- Greenhouse effect was mostly come from CO_2 emissions from the use of raw material in the production. The remaining contributions mostly were due to CO_2 emission from electricity production.

- For Ozone layer depletion, the most important phases that affected to this impact were transportation and raw material phase. The emission of halon-1301 from diesel production for truck fuel was the reason for 45 percent contribution to the impact.

- The main source of acidification and eutrophication potential was NO_x and SO_2 emissions from the materials that were used for the shopping bag production. They were reason that about 70 and 60 percent contribution to these impacts came from raw material input phase.

- The main source of energy resources used came from the using of high density polyethylene from polymerization of ethylene. This was the important phase that affected more than 80 percent contribution to the impact.

- Solid waste generation was due to the waste generated from every bag production process such as scraps from faulty printing process, scraps from cutting ears of a bag from cutting process, and scraps from faults in blowing, printing and cutting process.

The comparisons of the total amount of environmental impacts among each phases of conventional PE, PE-photo additive, PE-starch bag are shown in Figure 4.24, 4.25, and 4.26 respectively. Figure 4.24-4.26 show that although three processes of mixing, blowing and printing and cutting are grouped into production phase, the raw material phase still generated the largest environmental burden. This was due to environmental burden from usage of crude oil and natural gas which were initial raw material for producing polyethylene. The recycling phase generated the second highest environmental burden because of high volume of water and electricity was used in the process.

Figure 4.27 shows comparison of the total amount of each impact categories between conventional PE bag, PE-starch bag, and PE-photo additive bag by Eco-indicator 95. Figure 4.28 shows the comparisons of single score among conventional PE bag, PE-starch bag, and PE-photo additive bag by Eco-indicator 95.

The contribution of production processes to the environmental effects was relatively similar among the production of three types of shopping bag as indicated in Figure 4.17-4.23. However, the total amount of each effect was different as observed from Figure 4.27. From the results, PE-starch bag generated approximately 4.34 percent less environmental burden than the conventional PE bag. This was due to lower HDPE used per functional unit and the use of starch to replace HDPE. PE-photo additive bag generated a little bit lower environmental effect than conventional PE bag; it generated approximately 2.12 percent lower as shown in Figure 4.28. This was due to calcium oxide and other substances used to replace HDPE.

From the single score of Eco-indicator 95 method, this method did not include the factor of energy resources usage and solid waste generation at normalization and weighting steps (see in Table A6) therefore, some uncertainties of the final weight scores (single score) were occurred. In the Eco-indicator 99 method, the resources factor was calculated in the normalization and weighting steps as shown in Table B6. Normalization and weighting steps were performed at what is known as a damage category level. There are three damage categories of the final weight scores:

1. *Human health*: this is measured in DALY (Disability adjusted life years); that is, the different disabilities caused by diseases are weighted.
2. *Ecosystem quality or ecotoxicity*: this is measured in PDF*m2yr, which is the Potentially Disappeared Fraction of plant species. In term of ecotoxicity, this is measured as the percentage of all species present in the environment living under toxic stress.
3. *Resources*: this final damage category is measured in MJ surplus energy.

The results from Eco-Indicator 99 showed that the most important phase with respect to environmental impacts was raw material input phase. It was responsible for about 65 percent contribution to human health damage, 50 percent contribution to ecosystem quality, and 83 percent contribution to resources depletion (see Figure 4.21, 4.22, and 4.23). The total amount of each impact categories of three types of product were shown in Table 4.37. Percent contributions of three impacts of each phase from all types of bag were shown in Table 4.38-4.40. The contributions to these impacts were due to the use of initial raw materials i.e. crude oil, and natural gas for production. The second important phase was recycling process. It was responsible about 22 percent contribution to human health damage, and 36 percent contribution to ecosystem quality (see Figure 4.21, 4.22, and 4.23). These impacts were due to the emissions from the material that was used for producing water in Thailand because large amount of water and electricity was used in the recycling process. However, the second important phase for resources depletion was blowing and printing process. It contributed about 10 percent and it was due to solvent and chemical substances used in the process

The final weight score of conventional PE, PE-photo additive, PE-starch bag are shown in Figure 4.29, 4.30, and 4.31 respectively. Figure 4.29-4.31 show that although three processes of mixing, blowing and printing and cutting are grouped together in the production phase, the raw material phase still generated the largest environmental burden. This was due to environmental burden of the crude oil and natural gas which were initial raw material for producing polyethylene. The recycling phase generated the second environmental burden for human health damage and ecosystem quality because of high volume of water and electricity were used.

Figure 4.32 show the comparisons of the total amount of each impact categories among conventional PE bag, PE-starch bag, and PE-photo additive bag by Eco-indicator 99. Figure 4.33 shows the comparison of final weight score between conventional PE bag, PE-starch bag, and PE-photo additive bag by Eco-indicator 99. Conventional PE bag generated much higher effect than the other two types of product, 3.11 percents for PE-photo additive bag, 5.33 percents for PE-starch bag.

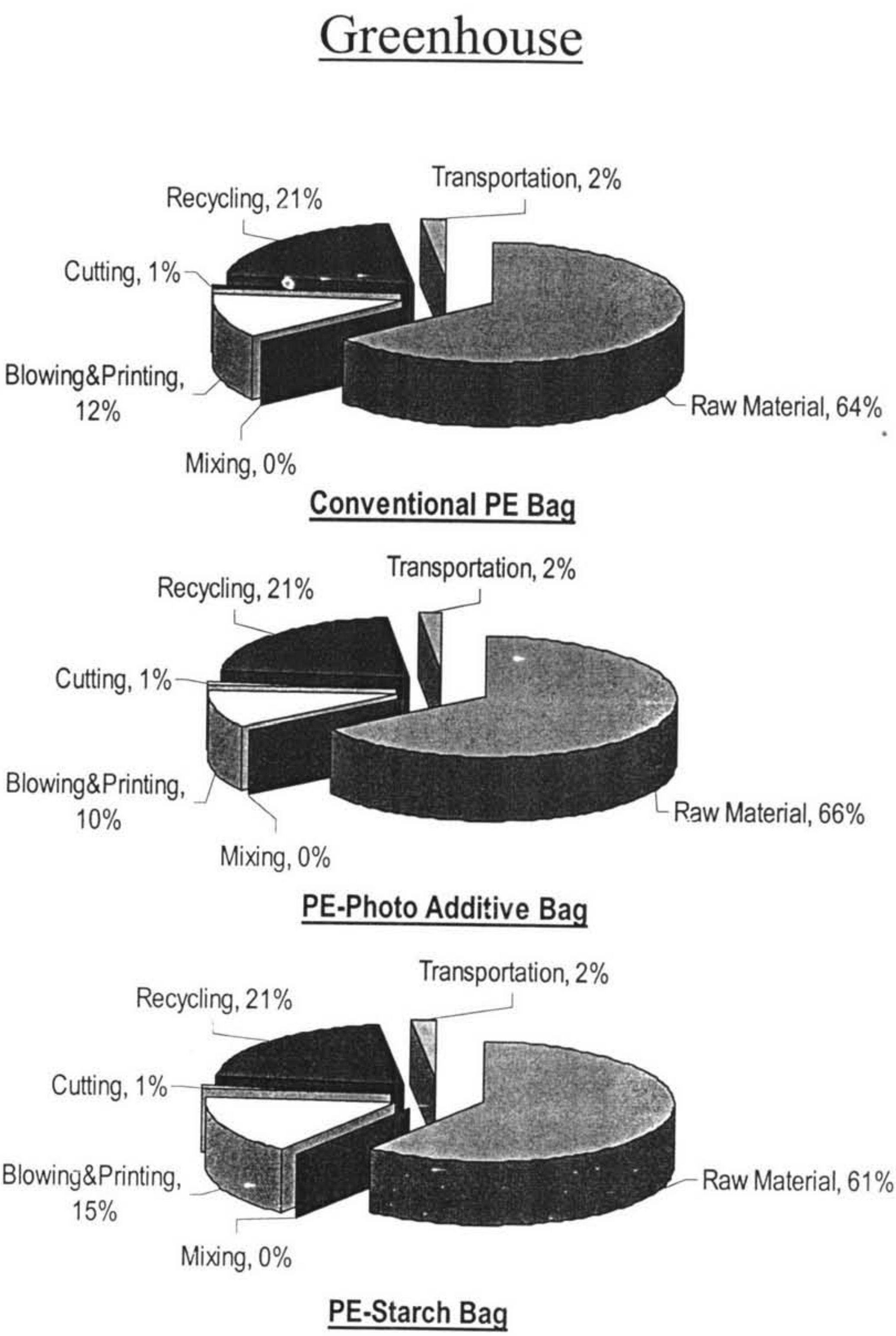

Figure 4.17 Percent contributions of each phase to greenhouse effect.

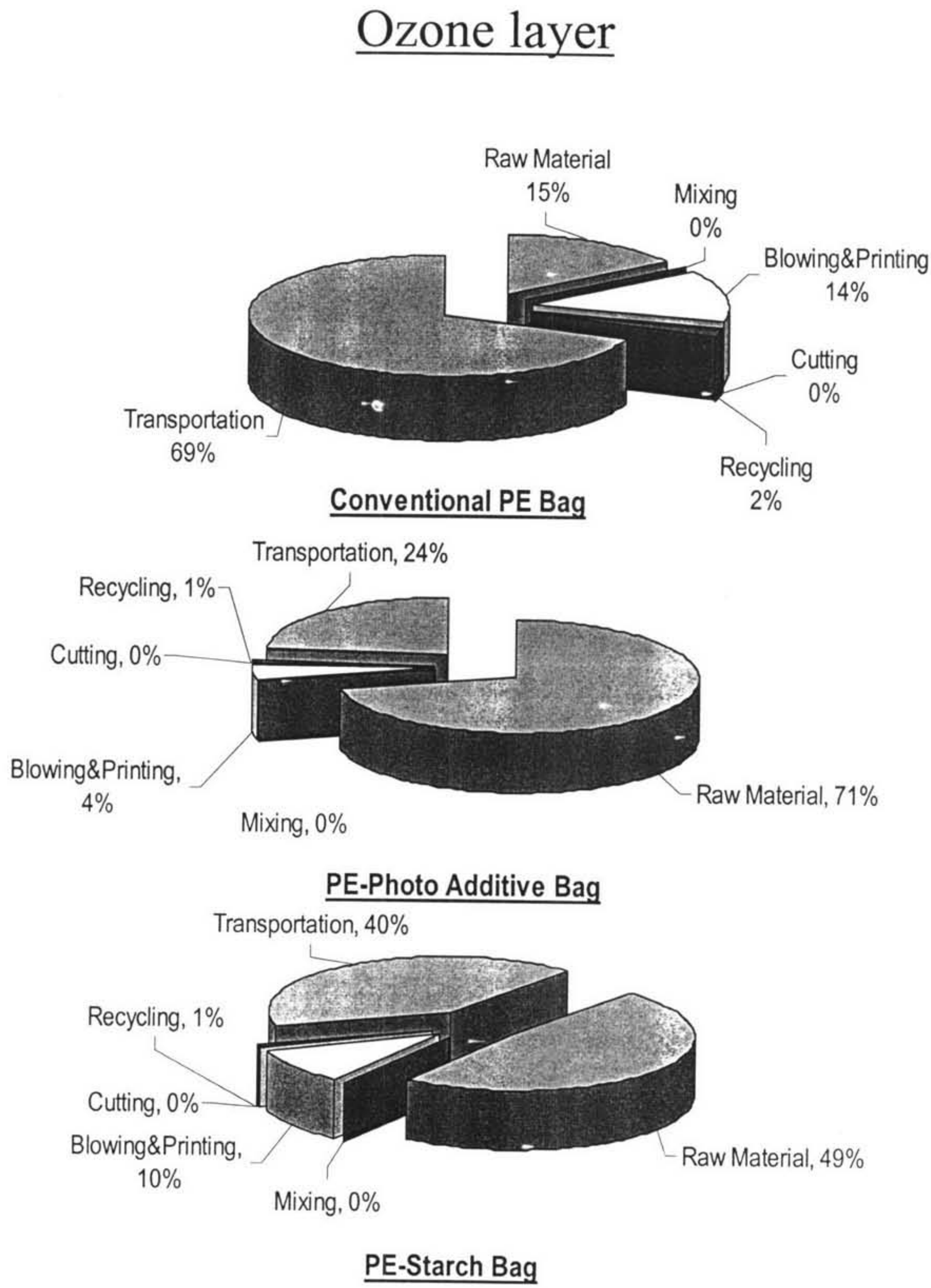

Figure 4.18 Percent contributions of each phase to ozone layer depletion.

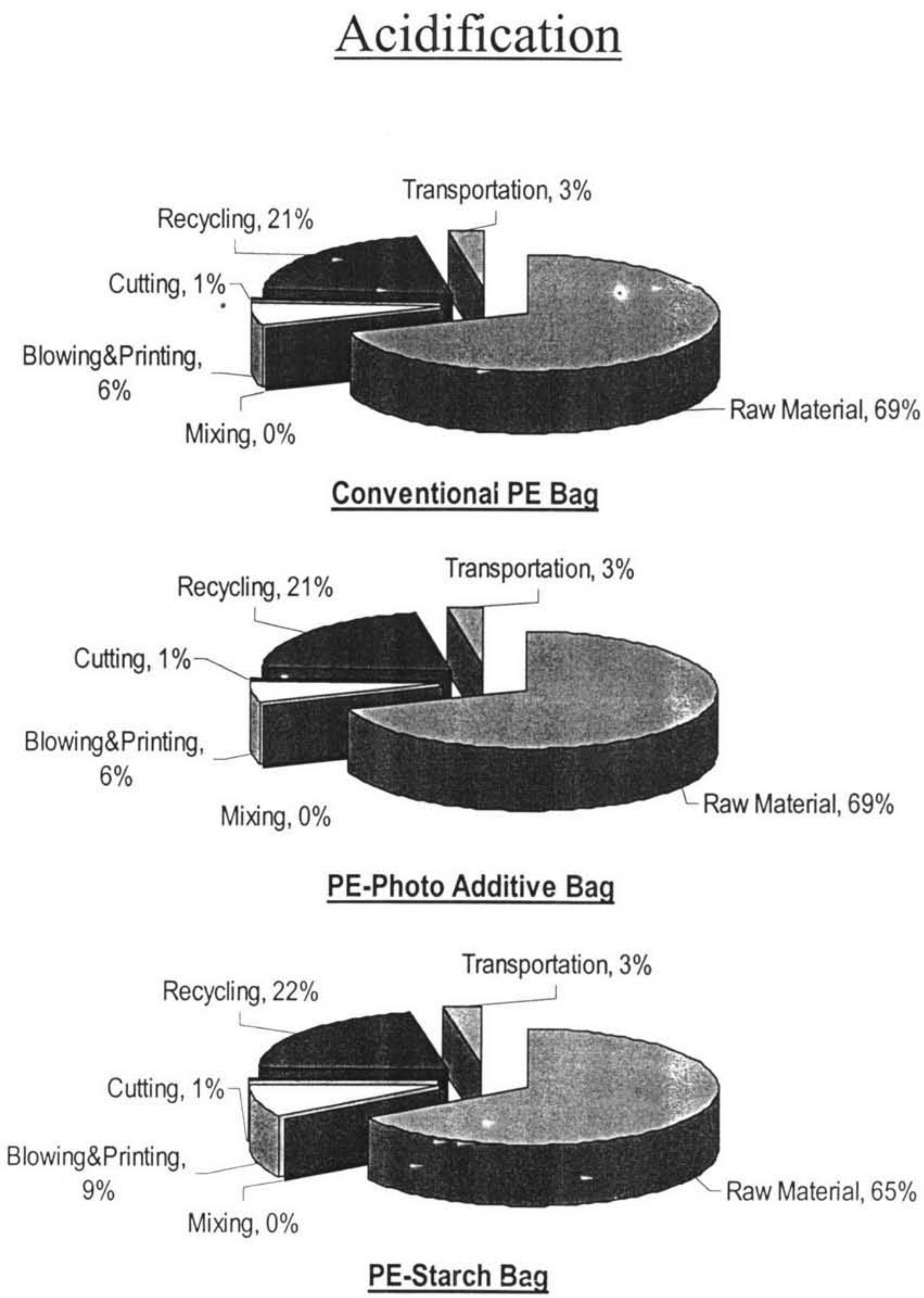

Figure 4.19 Percent contributions of each phase to acidification.

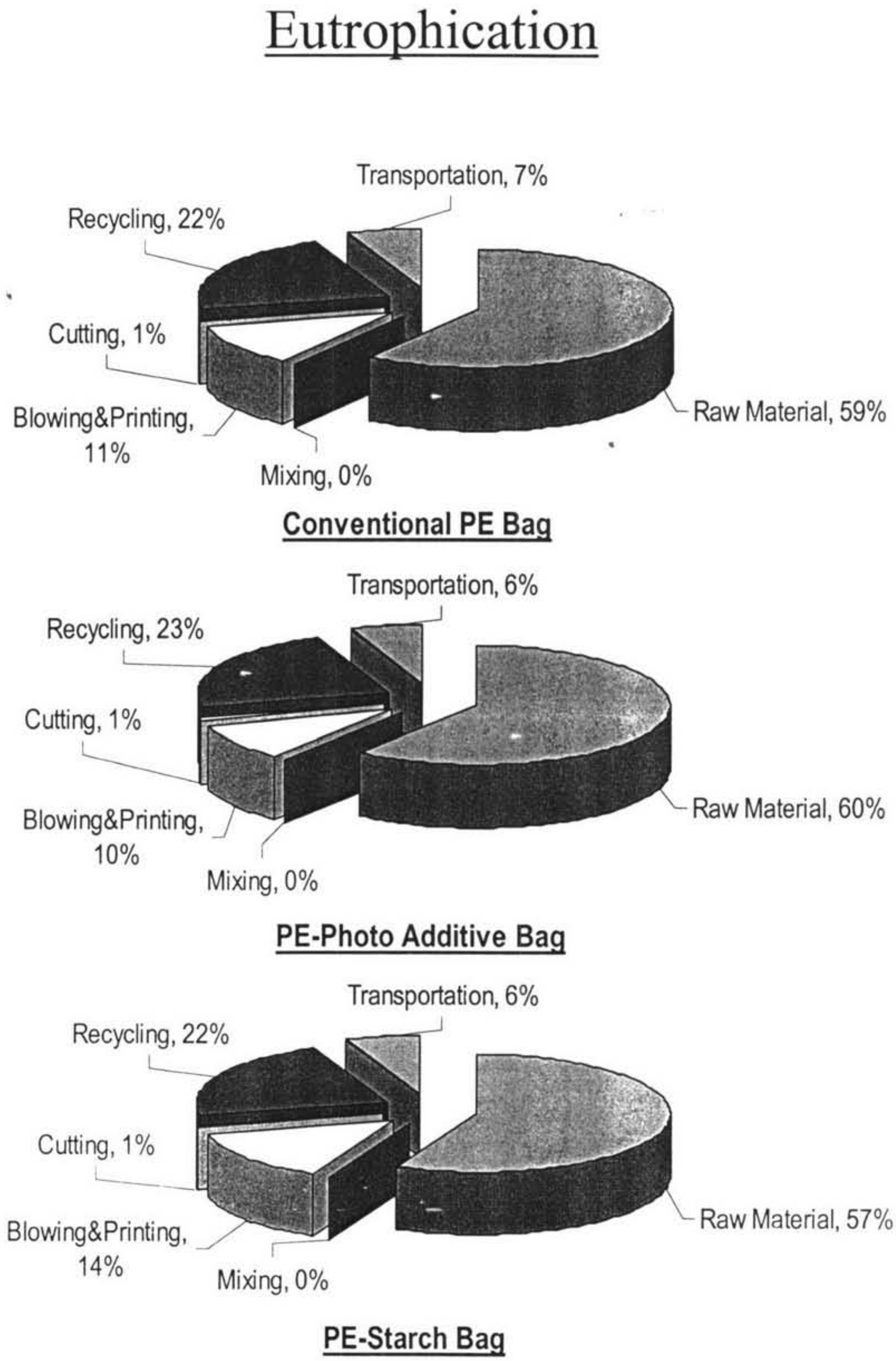

Figure 4.20 Percent contributions of each phase to eutrophication.

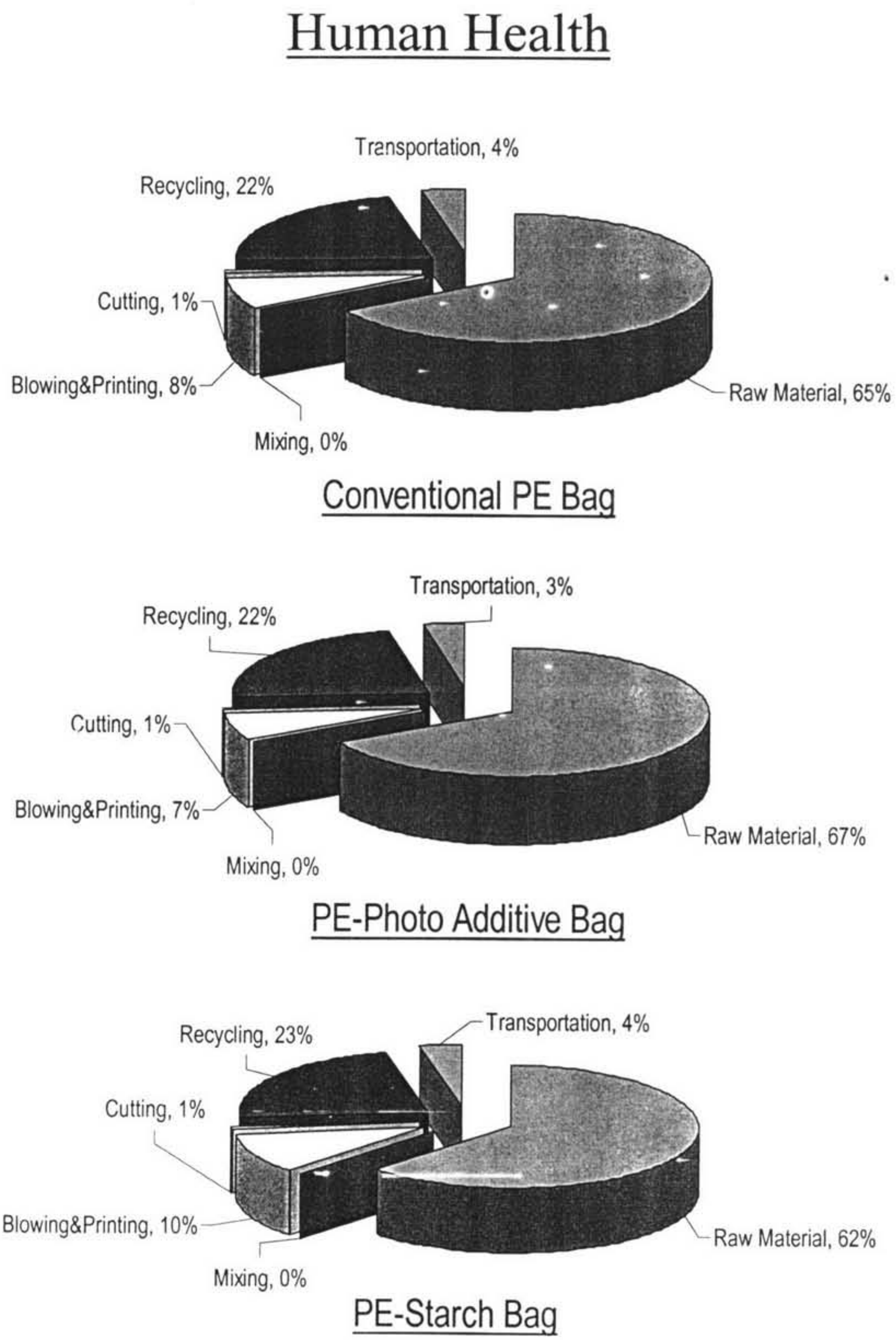

Figure 4.21 Percent contributions of each phase to human health.

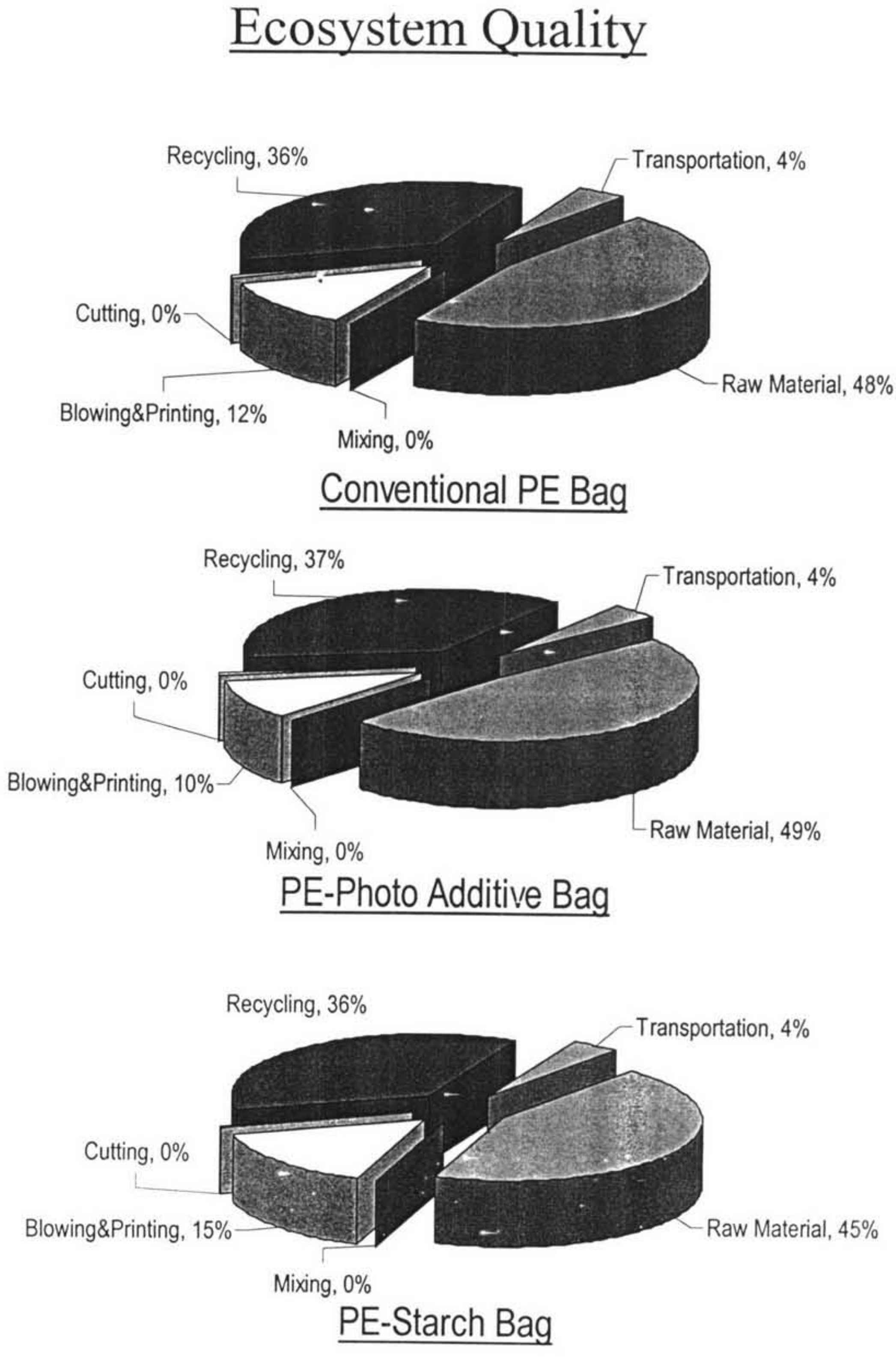

Figure 4.22 Percent contributions of each phase to ecosystem quality.

Resources

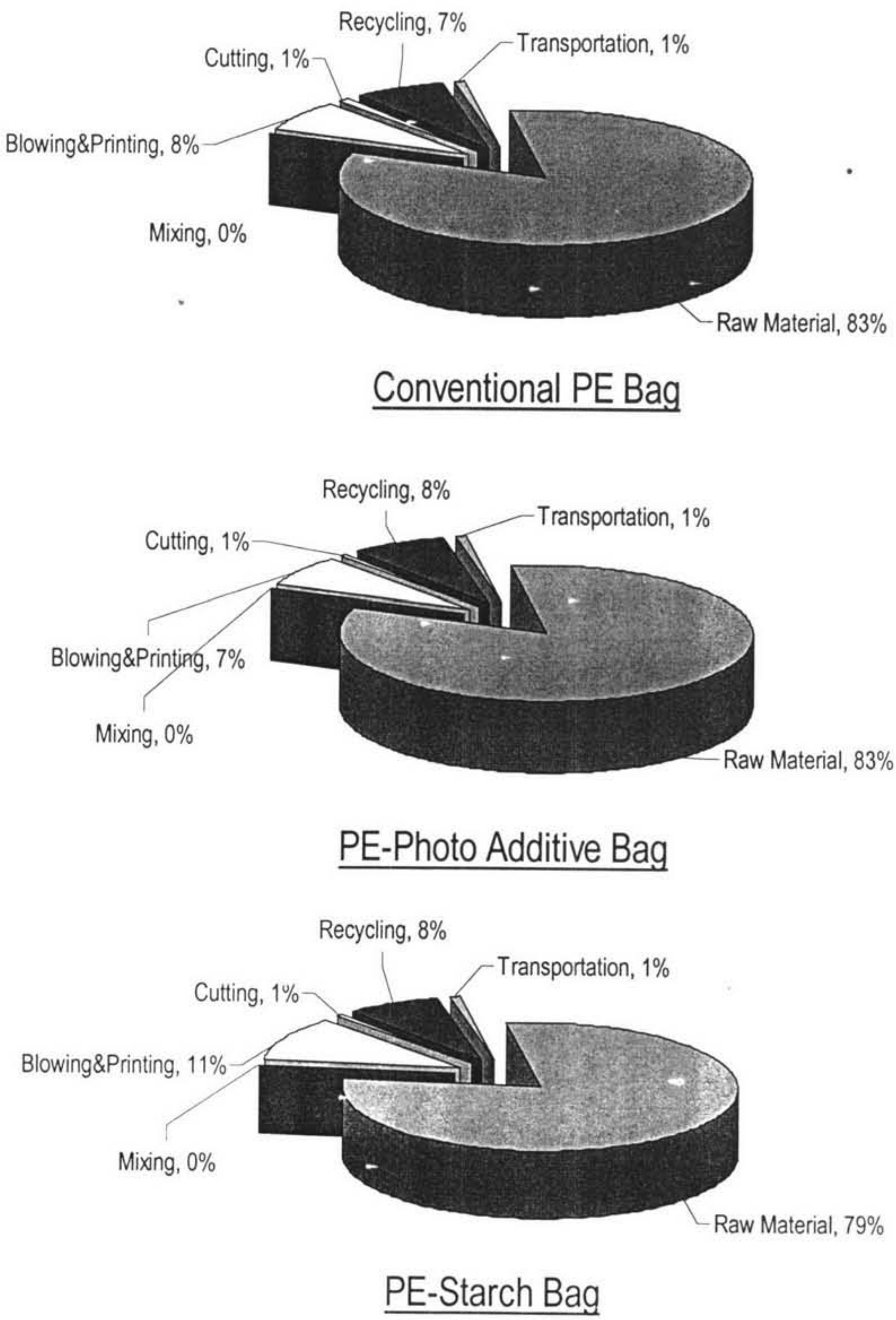

Figure 4.23 Percent contributions of each phase to resources.

Table 4.31 Percent contributions of impacts from each phase of conventional PE bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	59.4	0.0051	8.23	0.408	29.5	2.460
greenhouse	%	100	64.5	0.0109	11.7	0.870	20.8	2.140
ozone layer	%	100	15.4	5.75E-06	13.5	0.000	1.67	69.40
acidification	%	100	69.5	0.0068	6.30	0.547	20.5	3.140
eutrophication	%	100	59.7	0.0088	11.3	0.705	21.8	6.520
heavy metals	%	100	31.0	0.0002	15.1	0.018	53.2	0.717
carcinogens	%	100	3.95	0.0002	2.48	0.016	93.4	0.200
winter smog	%	100	69.5	0.0055	4.99	0.438	24.6	0.517
Summer smog	%	100	84.4	0.0015	3.12	0.117	7.43	4.910

Table 4.32 Percent contributions of impacts from each phase of PE-photo additive bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	60.2	0.0052	7.05	0.370	30.1	2.300
greenhouse	%	100	65.4	0.0112	10.3	0.794	21.5	2.020
ozone layer	%	100	71.2	2.16E-06	4.18	0.000	0.63	24.000
acidification	%	100	69.8	0.0071	5.59	0.501	21.2	2.970
eutrophication	%	100	60.5	0.0092	9.89	0.652	22.7	6.230
heavy metals	%	100	35.9	0.0002	11.8	0.015	51.6	0.638
carcinogens	%	100	4.95	0.0002	2.02	0.014	92.8	0.183
winter smog	%	100	69.5	0.0056	4.39	0.399	25.2	0.487
Summer smog	%	100	83.2	0.0017	3.23	0.118	8.38	5.080

Table 4.33 Percent contributions of impacts from each phase of PE-starch bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	55.6	0.0053	10.8	0.372	30.7	2.500
greenhouse	%	100	60.3	0.0111	15.4	0.779	21.3	2.140
ozone layer	%	100	48.6	3.43E-06	9.91	0.000	1.00	40.50
acidification	%	100	66.1	0.0072	8.59	0.504	21.6	3.230
eutrophication	%	100	56.8	0.0088	14.3	0.618	21.8	6.390
heavy metals	%	100	30.0	0.0002	17.7	0.015	51.6	0.681
carcinogens	%	100	4.32	0.0002	3.01	0.014	92.5	0.194
winter smog	%	100	65.4	0.0059	6.98	0.415	26.6	0.548
summer smog	%	100	79.7	0.0018	5.21	0.125	9.06	5.860

Table 4.34 Environmental impacts in kg Equivalent unit of 1 kg conventional PE bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
greenhouse	kg CO2	3.180	2.050	0.00035	0.3710	0.0276	0.6630	0.0679
ozone layer	kg CFC11	1.12E-07	1.72E-08	6.41E-15	1.51E-08	5.13E-13	1.86E-09	7.75E-08
acidification	kg SO2	0.030	0.021	2.05E-06	0.0019	0.0002	0.0061	0.0009
eutrophication	kg PO4	0.002	0.001	2.13E-07	0.0003	1.71E-05	0.0005	0.0002
heavy metals	kg Pb	1.47E-05	4.56E-06	3.28E-11	2.22E-06	2.62E-09	7.85E-06	1.06E-07
carcinogens	kg B(a)P	2.71E-07	1.07E-08	5.50E-13	6.70E-09	4.40E-11	2.53E-07	5.42E-10
winter smog	kg SPM	0.019	0.014	1.06E-06	0.0010	8.50E-05	0.0048	0.0001
summer smog	kg C2H4	0.004	0.003	5.20E-08	0.0001	4.16E-06	0.0003	0.0002
pesticides	kg act.subst	x	x	x	x	x	x	x
energy resources	MJ LHV	113.0	87.70	0.00955	9.0800	0.7640	14.300	0.9090
solid waste	Kg	0.293	0.098	0.00025	0.0446	0.1430	0.0073	x

Table 4.35 Environmental impacts in kg Equivalent unit of 1 kg PE-photo additive bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
greenhouse	kg CO2	3.090	2.020	0.00035	0.3190	0.0245	0.6630	0.0623
ozone layer	kg CFC11	2.96E-07	2.11E-07	6.41E-15	1.24E-08	4.55E-13	1.86E-09	7.10E-08
acidification	kg SO2	0.029	0.020	2.05E-06	0.0016	0.0001	0.0061	0.0009
eutrophication	kg PO4	0.002	0.001	2.13E-07	0.0002	1.51E-05	0.0005	0.0001
heavy metals	kg Pb	1.52E-05	5.46E-06	3.28E-11	1.79E-06	2.33E-09	7.85E-06	9.70E-08
carcinogens	kg B(a)P	2.72E-07	1.35E-08	5.50E-13	5.49E-09	3.91E-11	2.53E-07	4.97E-10
winter smog	kg SPM	0.019	0.013	1.06E-06	0.0008	7.55E-05	0.0048	9.20E-05
Summer smog	kg C2H4	0.003	0.003	5.20E-08	0.0001	3.70E-06	0.0003	0.0002
pesticides	kg act.subst	x	x	x	x	x	x	x
energy resources	MJ LHV	109.0	85.10	0.00955	8.2600	0.6780	14.300	0.8340
solid waste	Kg	0.306	0.098	8.57E-07	0.0449	0.1560	0.0073	x

Table 4.36 Environmental impacts in kg Equivalent unit of 1 kg PE-starch bag

Impact category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
greenhouse	kg CO2	3.100	1.870	0.000346	0.4790	0.0242	0.6630	0.0665
ozone layer	kg CFC11	1.87E-07	9.10E-08	6.41E-15	1.86E-08	4.49E-13	1.86E-09	7.58E-08
acidification	kg SO2	0.029	0.019	2.05E-06	0.0024	0.000143	0.0061	0.0009
eutrophication	kg PO4	0.002	0.001	2.13E-07	0.0003	1.49E-05	0.0005	0.0002
heavy metals	kg Pb	1.52E-05	4.56E-06	3.28E-11	2.69E-06	2.29E-09	7.85E-06	1.03E-07
carcinogens	kg B(a)P	2.73E-07	1.18E-08	5.50E-13	8.22E-09	3.85E-11	2.53E-07	5.31E-10
winter smog	kg SPM	0.018	0.012	1.06E-06	0.0013	7.44E-05	0.0048	9.82E-05
Summer smog	kg C2H4	0.003	0.002	5.20E-08	0.0002	3.64E-06	0.0003	0.0002
pesticides	kg act.subst	x	x	x	x	x	x	x
energy resources	MJ LHV	107.0	78.50	0.009550	12.400	0.668	14.300	0.8900
solid waste	Kg	0.250	0.086	8.57E-07	0.055	0.102	0.0073	x

Table 4.37 The total amount of each impact categories of conventional PE, PE-photo, and PE-starch that analyzed by Eco-indicator 99 method

Impact category	Unit	Conventional PE	PE-Photo	PE-Starch
Carcinogens	DALY	8.04E-08	9.83E-08	9.39E-08
Resp. organics	DALY	1.12E-08	9.79E-09	9.10E-09
Resp. inorganics	DALY	2.93E-06	2.83E-06	2.77E-06
Climate change	DALY	6.82E-07	6.64E-07	6.67E-07
Radiation	DALY	x	2.11E-10	4.69E-11
Ozone layer	DALY	7.98E-11	2.24E-10	1.32E-10
Ecotoxicity	PAF*m2yr	0.341	0.358	0.375
Acidification/ Eutrophication	PDF*m2yr	0.115	0.11	0.113
Land use	PDF*m2yr	0.0316	0.032	0.0325
Minerals	MJ surplus	0.0946	0.0942	0.0925
Fossil fuels	MJ surplus	14.2	13.7	13.3

Table 4.38 Percent contributions to three impacts from Eco-indicator 99 of conventional PE bag

Damage category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	78.8	0.00743	7.77	0.594	11.3	1.57
Human Health	%	100	66.3	0.00774	7.77	0.620	21.7	3.54
Ecosystem Quality	%	100	46.8	0.00592	12.3	0.473	36.3	4.04
Resources	%	100	83.6	0.00740	7.58	0.592	7.28	0.91

Table 4.39 Percent contributions to three impacts from Eco-indicator 99 of PE-photo additive bag

Damage category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	79.0	0.00766	7.32	0.544	11.7	1.49
Human Health	%	100	66.9	0.00797	6.86	0.566	22.4	3.34
Ecosystem Quality	%	100	48.6	0.00601	10.3	0.427	36.9	3.77
Resources	%	100	83.7	0.00764	7.33	0.543	7.52	0.86

Table 4.40 Percent contributions to three impacts from Eco-indicator 99 of PE-starch bag

Damage category	Unit	Total	Raw Material	Mixing	Blowing& Printing	Cutting	Recycling	Transportation
Total	%	100	74.7	0.00784	11.2	0.549	11.9	1.62
Human Health	%	100	62.5	0.00811	10.5	0.568	22.8	3.63
Ecosystem Quality	%	100	44.5	0.00586	15.2	0.410	36.0	3.92
Resources	%	100	79.6	0.00785	11.2	0.549	7.72	0.94

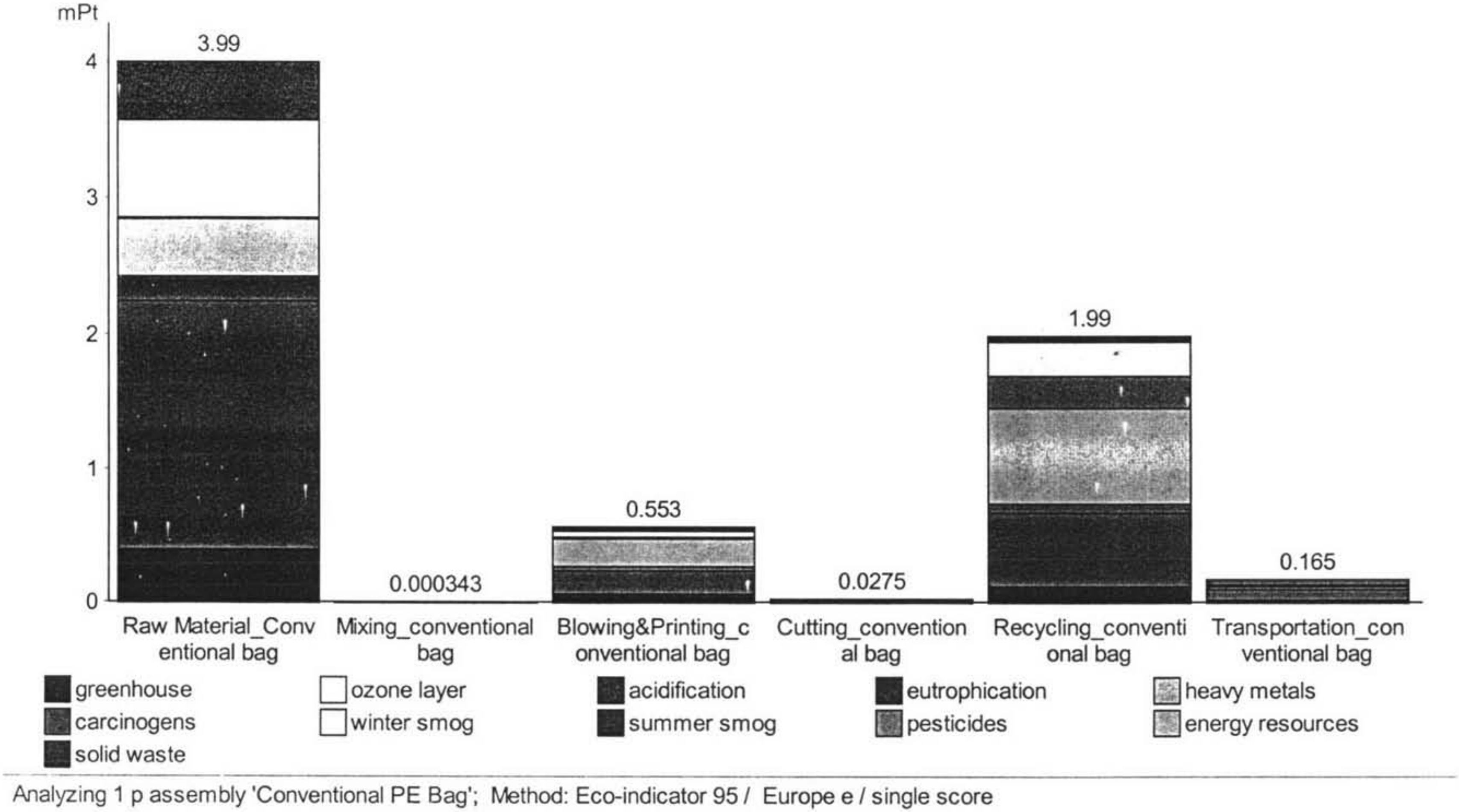

Figure 4.24 The comparison of the total amount of environmental impacts between each phase of conventional PE bag.

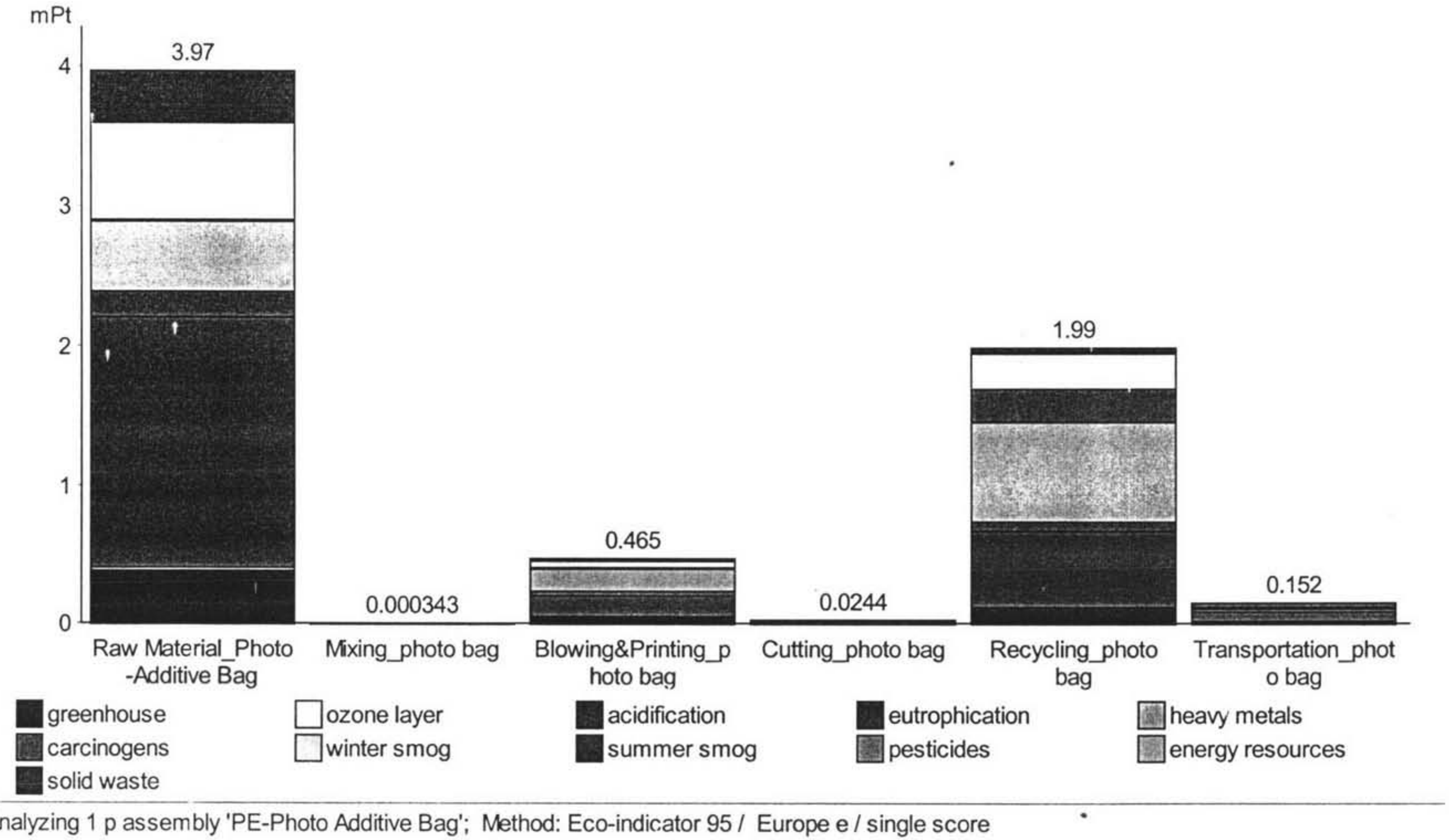

Figure 4.25 The comparison of the total amount of environmental impacts between each phase of PE-photo additive bag.

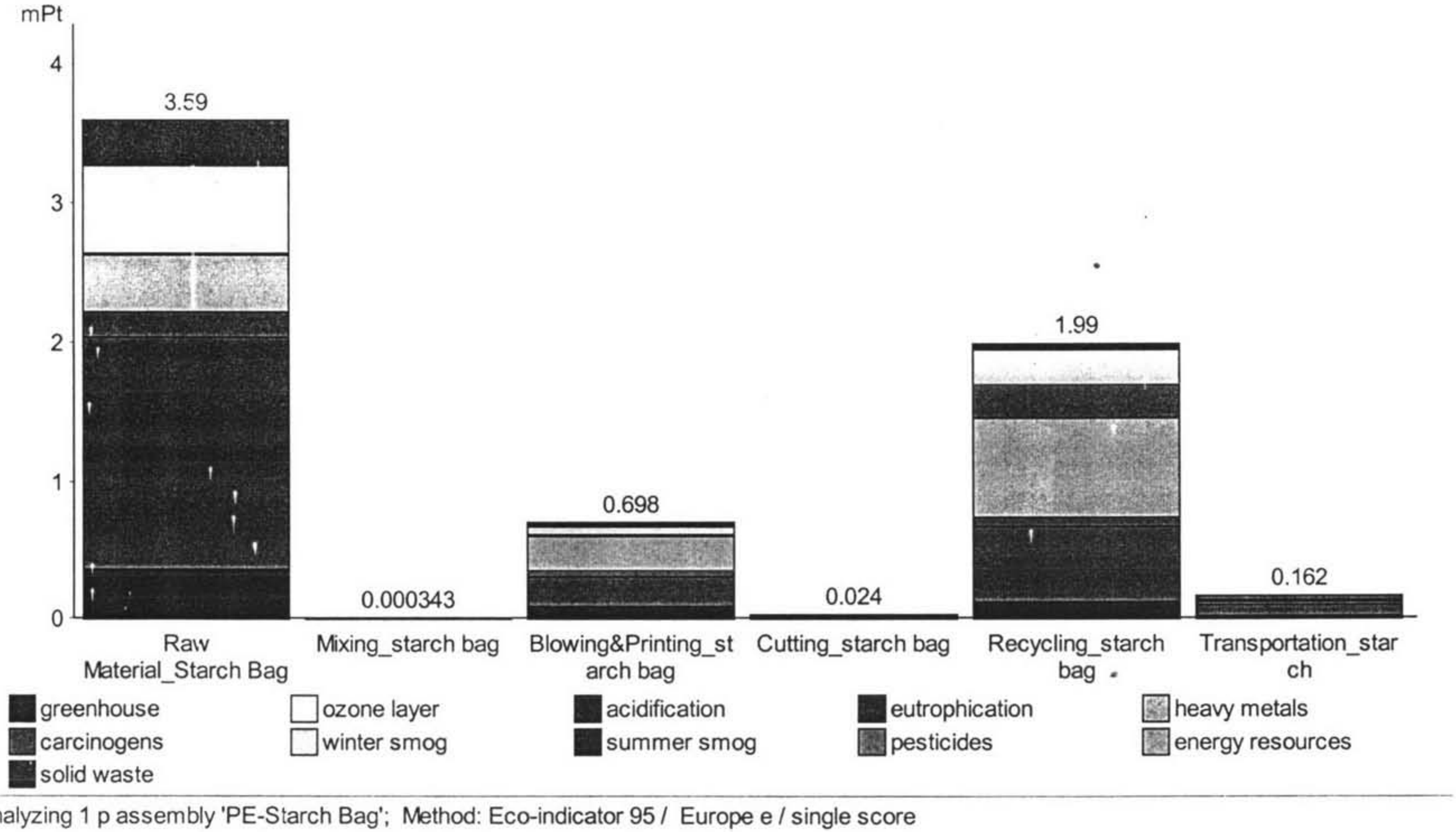

Figure 4.26 The comparison of the total amount of environmental impacts between each phase of PE-starch bag.

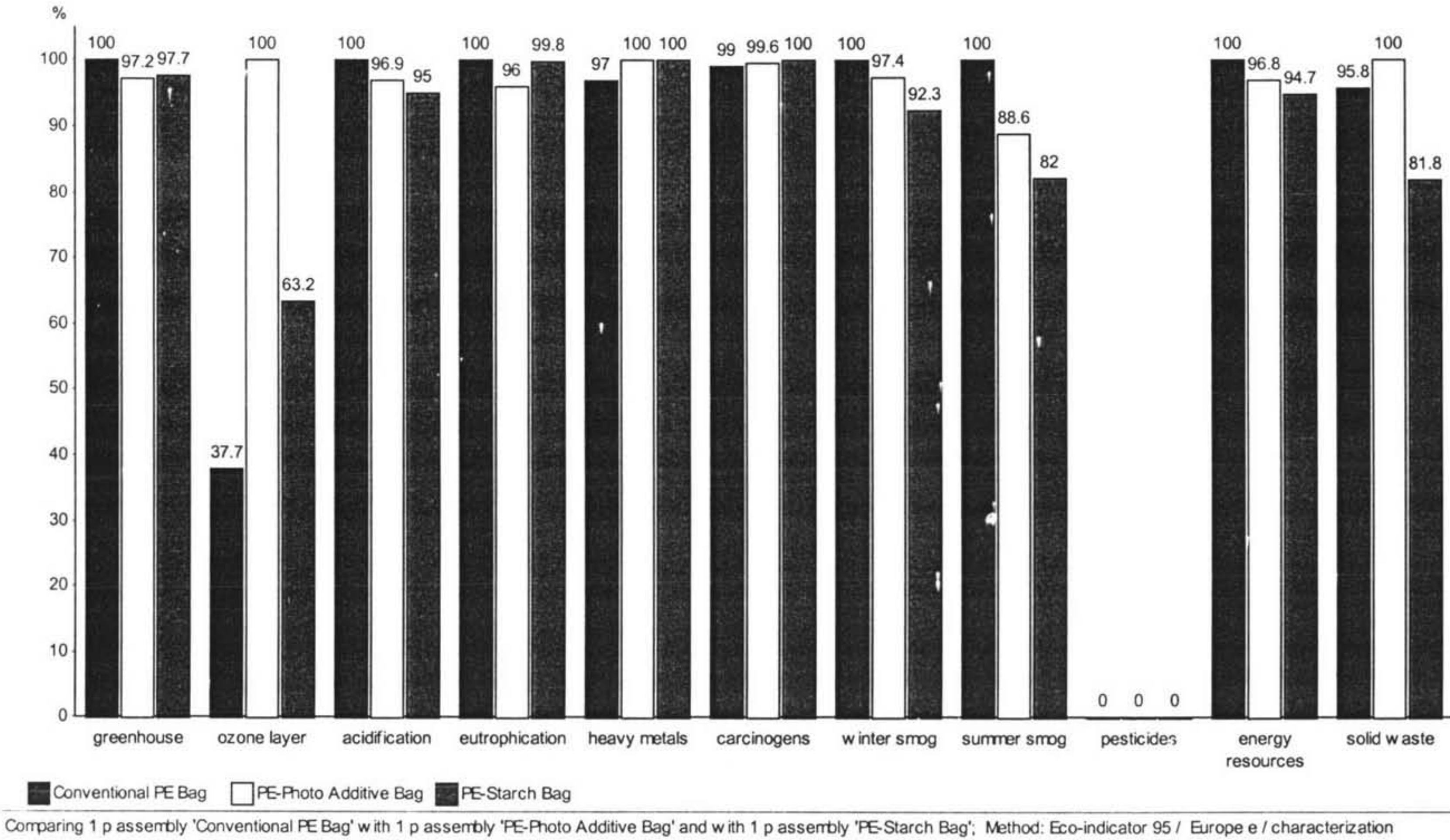

Figure 4.27 The comparisons of the total amount of each impact categories among three types of shopping bag by Eco-indicator 95.

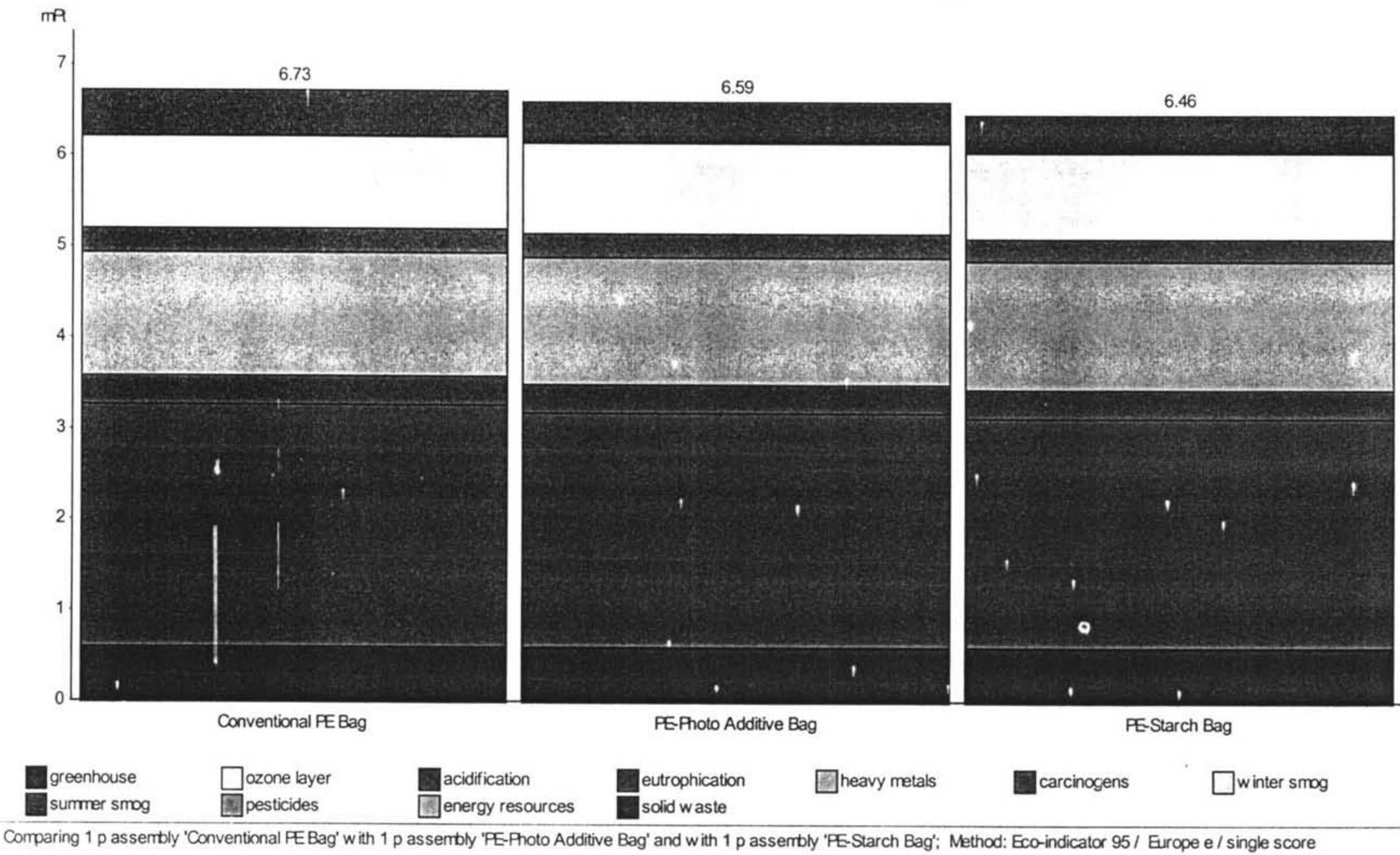

Figure 4.28 The comparisons of the single score among three types of shopping bag by Eco-indicator 95.

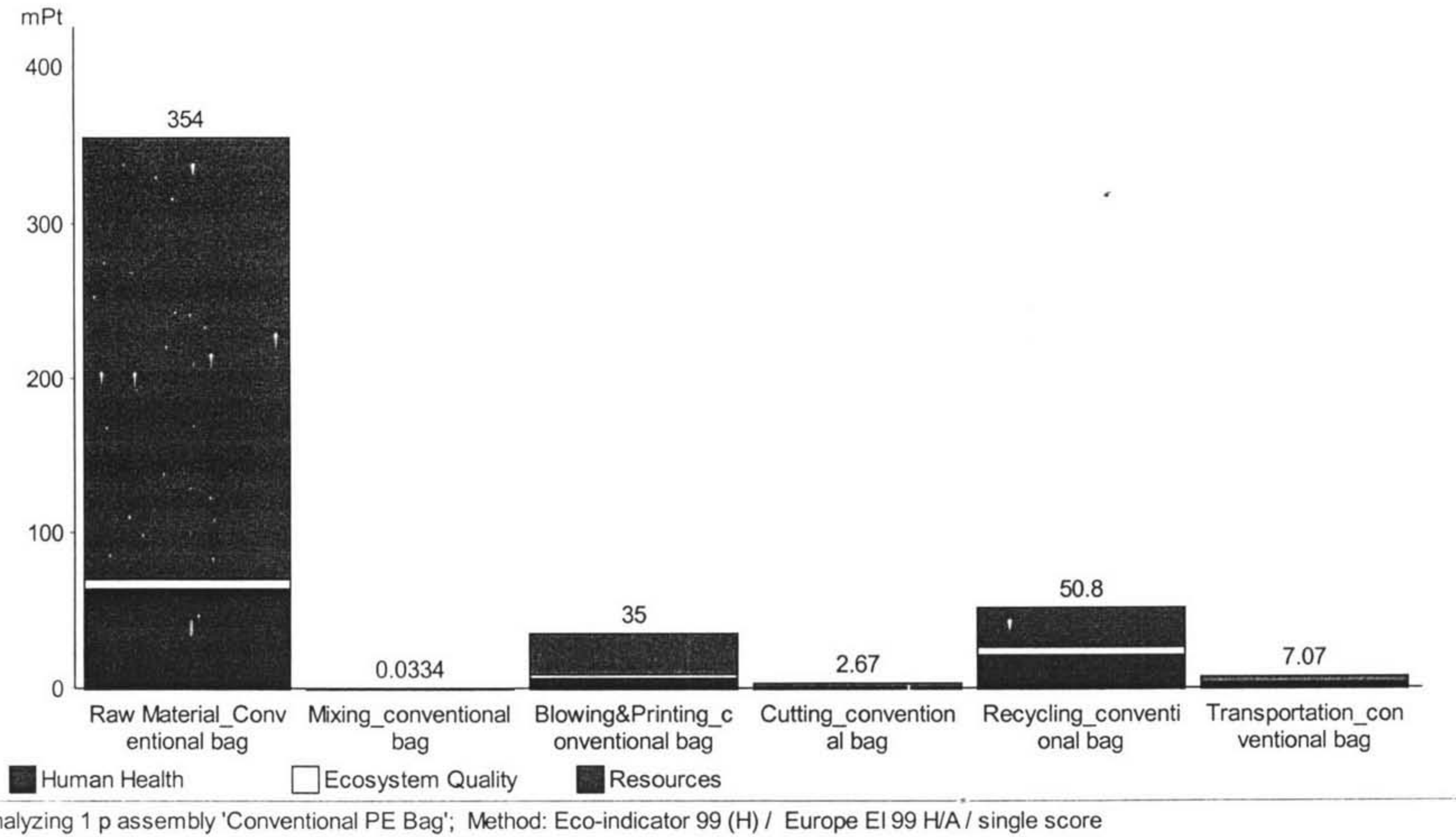

Figure 4.29 The final weight score of conventional PE bag by Eco-indicator 99.

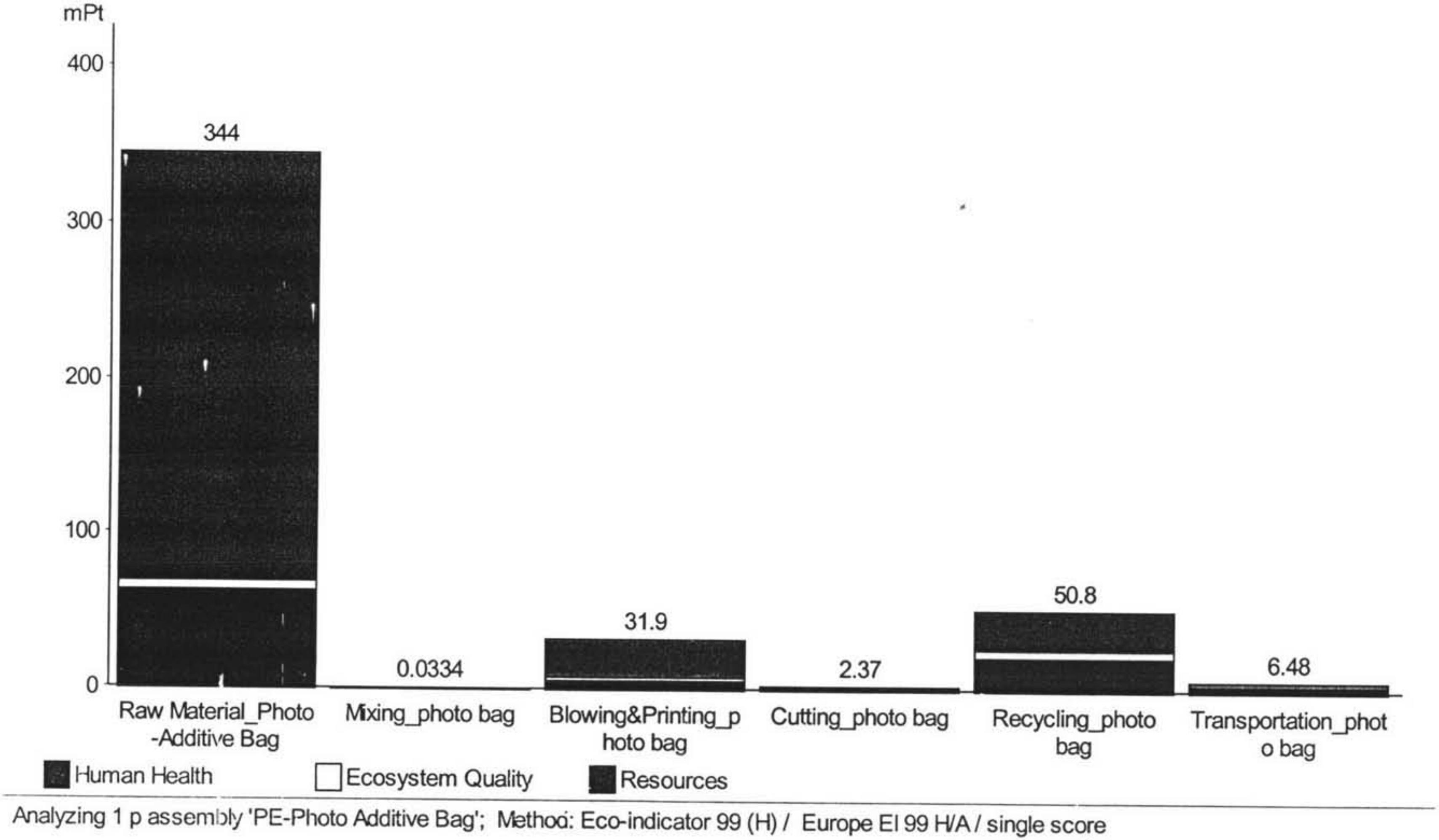

Figure 4.30 The final weight score of PE-photo bag by Eco-indicator 99.

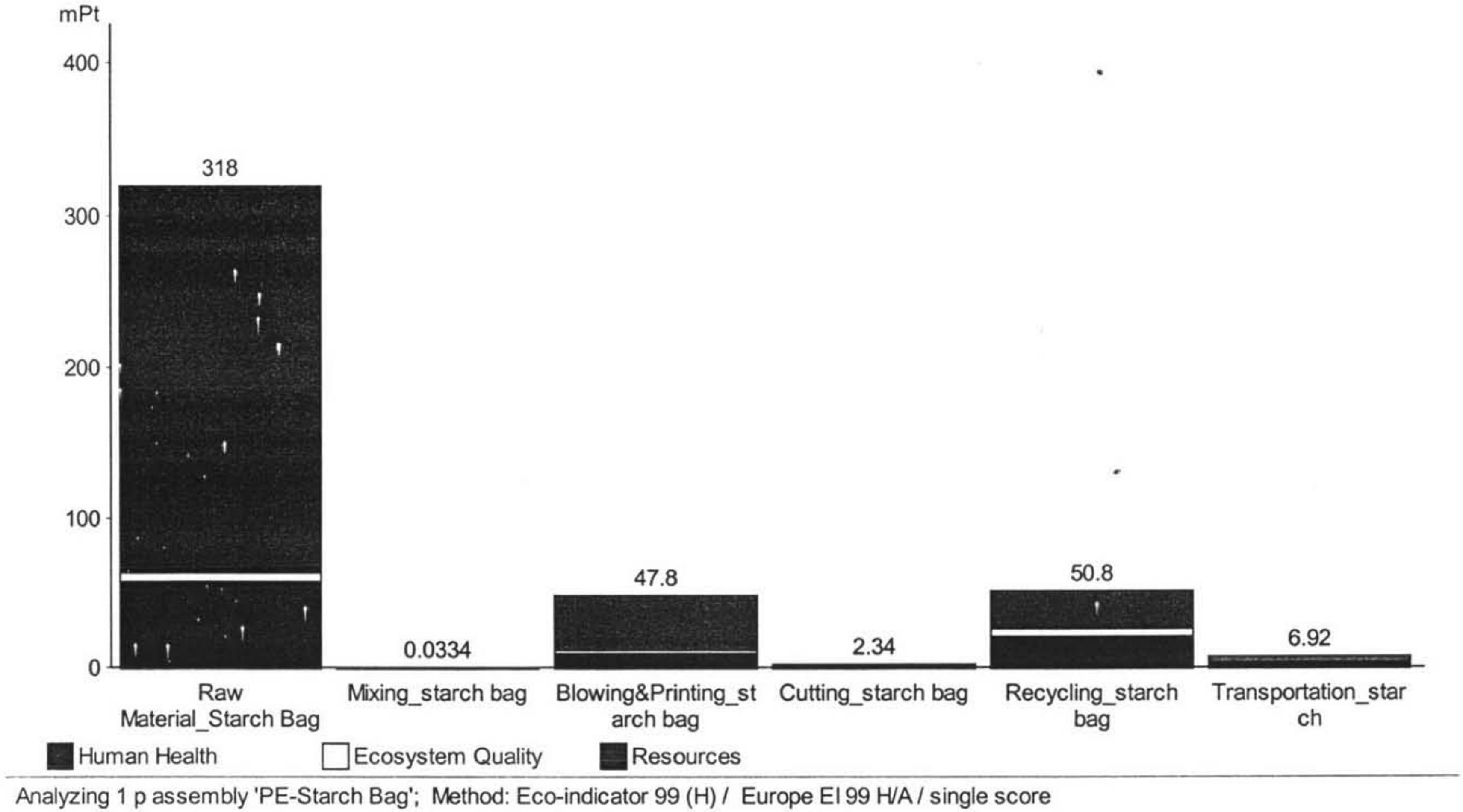

Figure 4.31 The final weight score of PE-starch bag by Eco-indicator 99.

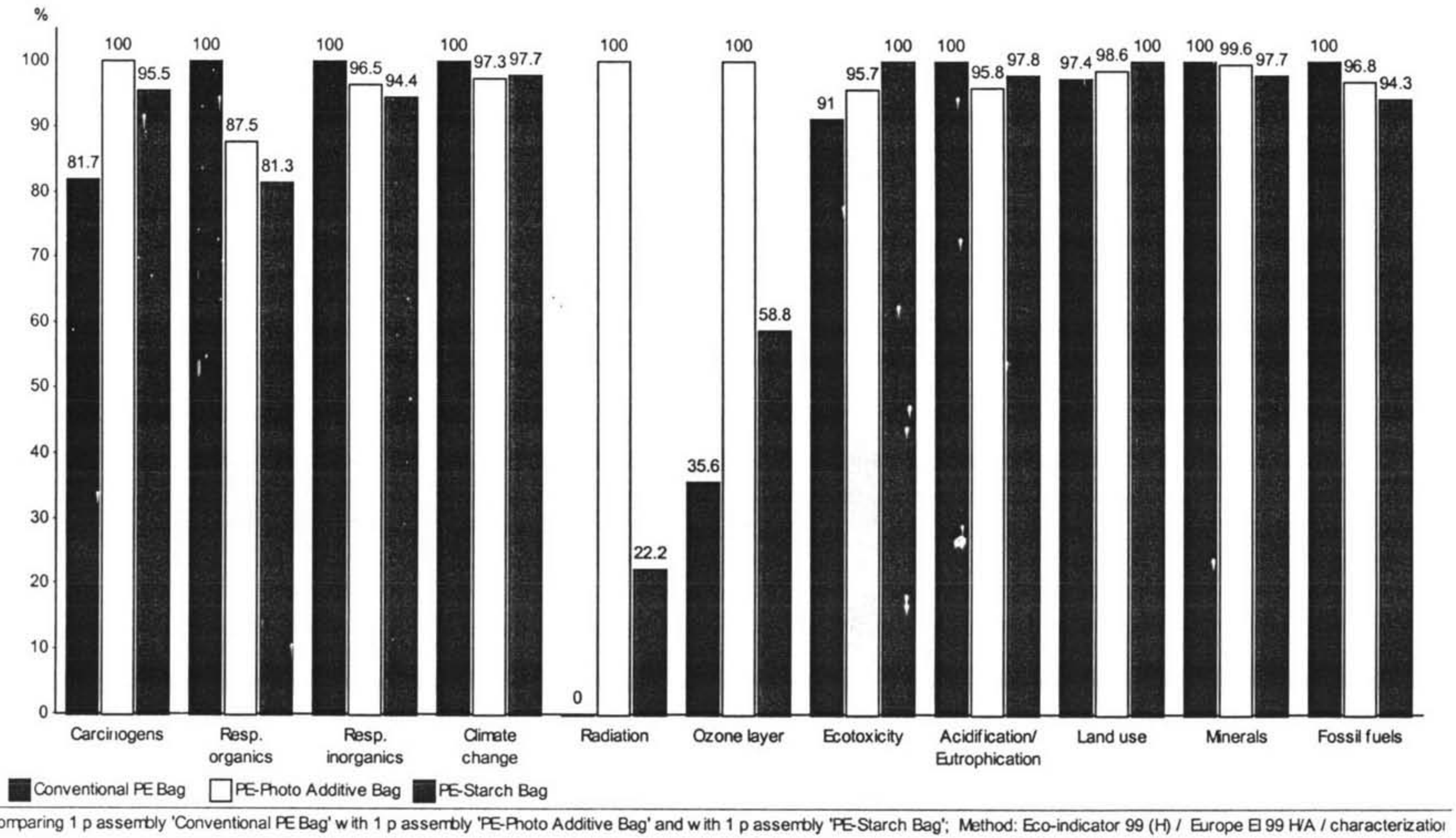

Figure 4.32 The comparisons of the total amount of each impact categories among three types of bag by Eco-indicator 99.

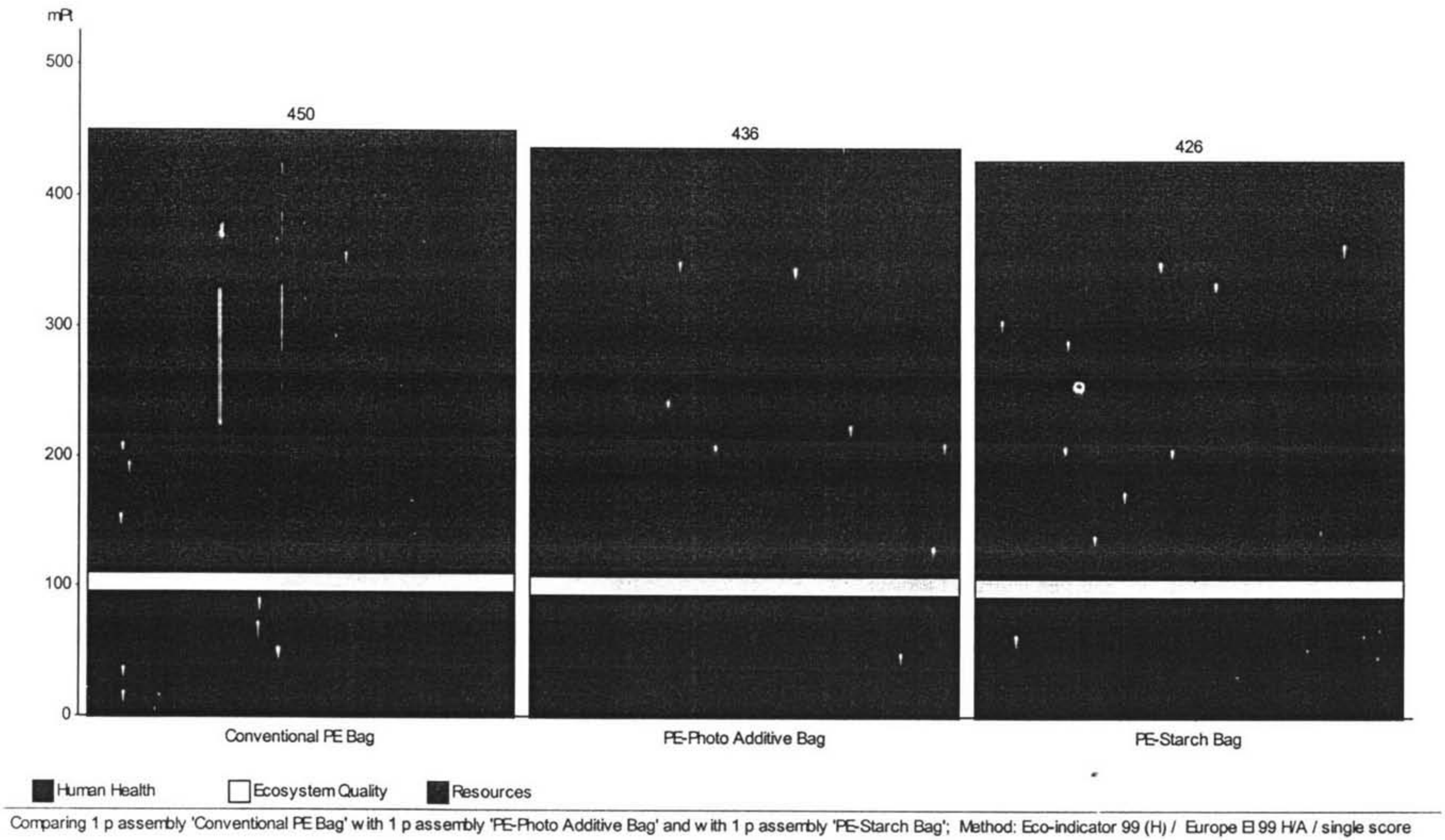

Figure 4.33 The comparisons of the final weight score among three types of bag by Eco-indicator 99.