# Lifecycle Management Methodology using Lifecycle Cost Benefit Analysis for Washing Machines


Hiroshi YAMAGUCHI*[1)], Norihiro ITSUBO[1)], Sang-Yong LEE[1)], Masaharu MOTOSHITA[1)], Atsushi INABA[1)],, Masayuki ICHINOHE[2)], Noriaki YAMAMOTO[2)], Yuzuru MIYANO[3)]

[1)]Research Center for Life Cycle Assessment
National Institute of Advanced Industrial Science and Technology
16-1 Onogawa, Tsukuba, 305-8569 Japan
[2)] Hitachi, Ltd [3)], Hitachi Appliances, Inc.
*E-mail: yamaguchi-h@aist.go.jp



**Keywords:** CBA, LCC, LCIA, Electric and Electronic Products, RoHS



## ABSTRACT

To cope with the environmental restrictions for electric and electronic equipments such as on chemical substances, development of environmental risk evaluation method has started for the electric and electronic equipment products. It aims to develop the technique to evaluate the health risk from hazardous chemicals and the social economic risk by consumption of rare metal as peculiar environmental risks for the electric and the electronic equipments, and to construct the decision support system able to perform Life Cycle Cost Benefit Analysis (LCCBA) that comprises these environmental impacts. For an example case of washing machine, LCC and LCA are performed in screening level to clarify the high impact parts and identify the tasks to solve. Then dewater-by-circulation scenario, lead-free scenario are settled to solve the tasks. The actual stages of product development, manufacturing, distributing, marketing, using and recycling are surveyed. LCA and LCC are performed before and after the environmental options in these scenarios. The results are compared and the LCCBA are performed for the options. Through these processes the basic methodology of LCCBA for LCM is established, its effectiveness is confirmed and the future tasks are clarified.

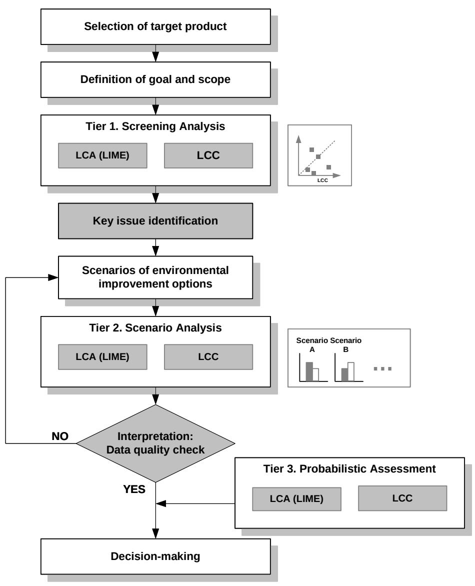

## 1. Problems and Research Target

Life Cycle Management (LCM) is an important concept and method for organization, groups, and society to build the sustainable society. LCA including LCIA and LCC are important tools for evaluation. The environmental control for electric and electronic equipments such as on chemical substances are becoming stronger and stricter by the EuP directive, the RoHS restrictions, and the REACH regulations, etc. However, to cope with these restrictions and directives the existing tools for environmental evaluation do not correspond to the requirements. For the electric and electronic equipment industry, environment acts can not find incentives from the result of the environmental evaluation.

Thus it started the development of environmental risk evaluation method for the electric and electronic equipment products. It aims to develop the technique to evaluate the health risk from hazardous chemicals and the social economic risk by the consumption of the rare metal as peculiar environmental risks for the electric and the electronic equipments, and to construct the decision support system able to perform Life Cycle Cost Benefit Analysis (LCCBA) that comprises these environmental impacts[1][2].

This method constructs the evaluation technique for various environmental measure ideas such as the alternative effect for the RoHS restriction materials and the environmental preservation effect of the recycling system construction for the WEEE directive. In this method, for plural environmental risk decreasing plans for electric and electronic equipment, their benefit and effect are compared so that the method can be used to choose the most effective plan from the view point of cost vs. benefit analysis (CBA).

**Fig.1 Flow of LCCBA Method**




## 2. Method,

Figure 1 shows the flow chart of this method.

First, the target product is selected. Screening analysis is performed, using general data. From the results important key issues for cost and environment are extracted. Then scenarios of environmental option are made and evaluated. LCC and LCA are performed for the cases before and after the improvemental options. The results are confirmed if the important tasks are extracted, the measures are effective and the data quality are enough high. If not so, again the scenario analysis is performed until it is satisfied. Then probabilistic assessment will be performed from the view point of uncertainty and reliability.

With all these results, decision making for the environmental options will be performed. Here the results of screening analysis and scenario analysis are shown. Then the effectiveness and the tasks for development of the life cycle cost-benefit analysis are clarified［2］.

## 3. Results

### 3.1 Selection of Target Products

A home appliance washing machine is selected as a target product, in which the clothes are put in the washing drum, and washed in the water current with detergent by rotational wing. To achieve these functions, the washing machine is composed of a casing unit, a washing drum unit, a driving unit, a water circulation unit, a dryer unit, a controller unit, and so on.

### 3.2 Phase1（Screening LCA, LCC）

The life cycle of an average domestic large-scale washing machine was evaluated in a screening analysis from the material, production to transportation, use, and processing. Screening LCC and LCA were performed simply by using average data by the Japan Electrical Manufacturer's Association and the Energy Conservation Center, Japan, etc［3］.

#### 3.2.1 LCA

LCA caluculation was performed with SimaPro ver. 5.1 using Japanese data for use stage and European data for other stages. LIME ver.1 was used for the integrated impact assessment. The results shows global warming, air pollution, and eutrophication occupy the highest rank in impact category. Manufarcturing stage occupies 3,670 yen and maximum and use stage (water, the detergent, and the electricity) occupys 3,297 yen in total.

#### 3.2.2 LCC

LCC is a method for thinking the burden of the total life cycle cost, to decrease the entire cost by improving the process where the life cycle cost is large. The price, transportation electricity amount used and the water use period recycling processing cost are surveyed from the literature, reports , input-output tables to perform LCC for the averaged life cycle of washing machine.

Thus the life cycle cost was calculated and the results are shown in Figure 2. The cost in use is the highest, the cost until manufacturing the product is high, and the cost of the collection and abandonment is comparatively small.

#### 3.2.3 Key Issue Identification

From the result of screening analysis each stage of manufacturing, transportation, use (electricity, water, and detergent) of the washing machine were plotted as shown in Figure 2. For each stage, the key issue for the cost and the environmental task were made visible from the plots.

1) For both of LCC and LCIA, transportation, processing, and use (electricity) are small, so that there are no important tasks.
2) Manufacturing stage has large LCIA results and decreasing of its environmental burden has high priority.
3) In use stage (water ) LCC and LCIA is large and the reduction of them has top priority.

Moreover, in use stage(detergent), decreasing of LCC has priority .

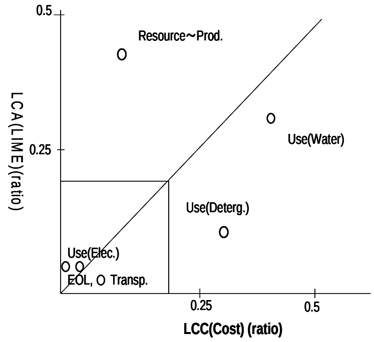



Figure 2 LCC-LCA Relation of Life Cycle Stages

### 3.3 Phase 2: Detailed LCA

#### 3.3.1 Detailed Data

LCA was achieved for the detailed data. from the production factory of Washing Machine and precise survey for use stage. As an LCA software SimaPro7.0, Ecoinvent, LIME ver.1 was used.

**(1) Production**

<u>(a) Input</u>

(ⅰ) <u>Material</u> : Material used were found from part lists of designing. Few thousand of parts were divided into eleven units, e.g. driver unit, housing unit, controller unit, etc. The weight of parts are summed up for each material.

(ⅱ)<u>Process–material</u>: For process-material, paints, solvents, machining oil, etc. were included.

(ⅲ)<u>Utility:</u> Electricity, water, compressed air used in the factory were counted for utility. The amount of compressed air is changed into electricity consumption by the compressor, and added to the electricity consumption. Utility (electricity, water, compressed air) was allocated to each unit by the man power for the unit manufacturing.

(b) Output:

Emission to air: Outputs of PRTR (Pollutant Release and Transfer Register) was used. It was allocated to a unit by manpower of unit manufacturing in the same way as utility.

Emission to Water: Wastes water from the factory was processed in the waste-water-treatment facility. The regulated materials such as harmful chemicals, heavy metal are measured regularly. After confirming that these are under the regulated value, the water is discharged into rivers. The maximum measured values are used for LCA calculation.

Emission to soil: There was no emission to soil.

Industrial waste: Valuable thing to be recycled such as waste metal, waste plastic, cardboard, EPS together with invaluable things not recycled were investigated and allocated into each unit by manpower of the unit manufacturing.

**(2) Transportation**

Whole Japan were divided into eight areas, and the transportation data from a factory to the center of each area and data from a each the center to stores in an area are investigated.

**(3) Use**

The use period was assumed in the same way as Phase 1 with 11.5 year [3]. Average frequency of washing is 1.63 times/day, 6.3day/week by investigation, which corresponds to 535.426 times/year [4].

A quantity of use in a life cycle was found from average use electricity and average use quantity of water by a standard by the Energy Conservation Center, Japan. It was assumed that a quantity of sewage water was the same as supplied water and that the amount of detergent use was the same as Phase 1.

Table 1 LCA Data for Phase1 and Phase 2

| Stage | | Phase1 | Phase2 | Comments |
|---|---|---|---|---|
| Material to Production | Material Production | Steel, Copper, Aluminum, PP, ABS, Others | More than 35 LCI databases | Factory data |
| | Parts Production | Production in supplier not include | Production in supplier not included (PCB included as an inventory data) | |
| | Packaging Material Prod Assembly | EPS, Cardboar, others included not included | unit assembly, Whole assembly included | |
| Use | Electricity Consumption | 32.8kWh/yr( JEMA average data) | 91kWh/yr (JEMA average data) | JSDA survey of Washing Frequency |
| | Detergent Use | 15.2kg/yr Database: IO | 23.6kg/yr Database:Ecoinvent | JSDA survey of Washing Frequency |
| | Water Use | $46.9m^3$/yr Database: AIST | $47.1m^3$/yr Database: Ecoinvent | |
| Transportation | Transportation | To Consumer: 85.1tkm To Recycler : 85.1tkm | To Consumer: 254.6tkm To Recycler : 85.1tkm | Actual Trasp. Data Truck, Ferry, Trailer |
| EOL | EOL scenario | Recycle for Home Appliance:100% | Recycle for Home Appliance:98.6% Illegal Damping: 1.4% (to Soil) | |
| | Recycle | Metal, plastics: 100% recycled Opened recycle not considered | Metal, plastics: 100% recycled Opened recycle considered | |
| | Landfill | Other material | Other material | |

JEMA : Japan Electric Manufacturer's Association JSDA : Japan Soap and Dtergent Association

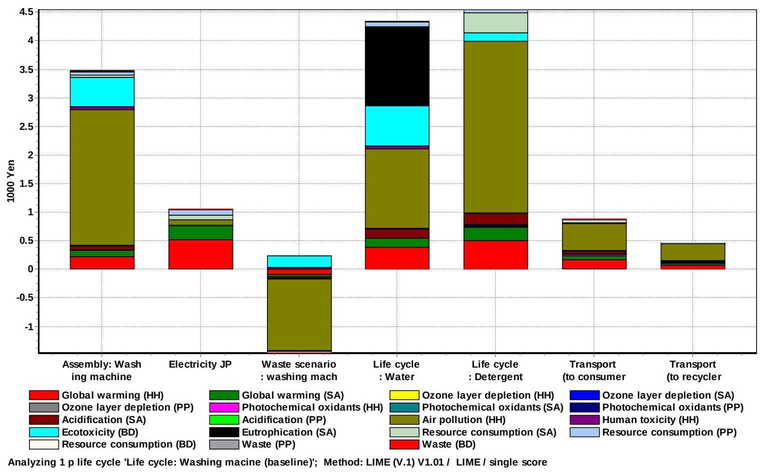



Figure 3 LCIA Results for Activities

**(4) End of Life**

Used washing machines are collected in a designated place, and recycled in household appliances recycling factory. Overseas exportation as used goods is settled out of the scope of LCA here. The ratio of the household electric appliances recycling was assumed as 98.60% the same as collected amount of a designated place. The administration collection including illegal abandonment collection (1.40%) were assumed to be fully illegality abandonment as the worst case, in which all the component material were assumed to emit into soil［5］.

It was assumed that the collection transportation was the same as transportation data from a local center to stores in an area

A recycling process percentage of household electric appliances are opened [6]. Therefore using the recycling ratio of each material, the environmental load was calculated using SimaPro.

### 3.3.2 LCA result

SimaPro7.0, Ecoinvent, and LIME are used. for LCA. LIME calculation results for each activity are shown in Figure 3. A social cost of a life cycle of washing machine is 13,540 yen by LIME. Social costs are 4,500 yen for detergent, 4,300 yen for water, 3,500 yen for production respectively. Social costs for production process and use stage (water, electricity, detergent ) are large. Negative value appears by the avoided effect of new material production at the waste and recycling stage and as a whole, total social cost is decreased.

The impact categories of each stage are shown in Figure 3. Influence of air pollution is big in detergent, and production.

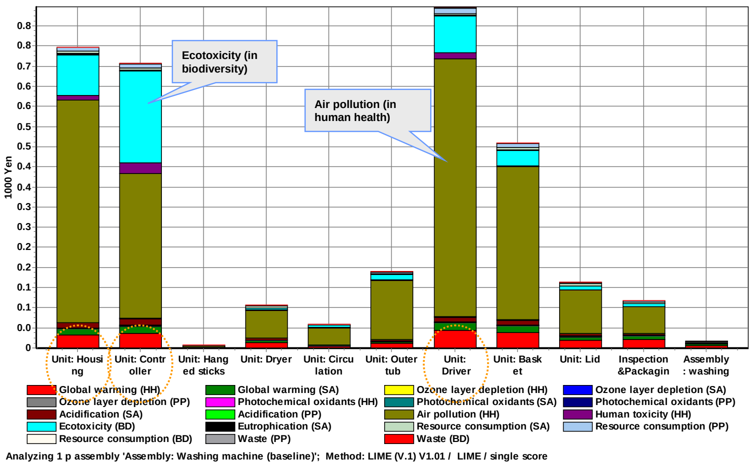



Figure 4 LCIA Results for Unit Production

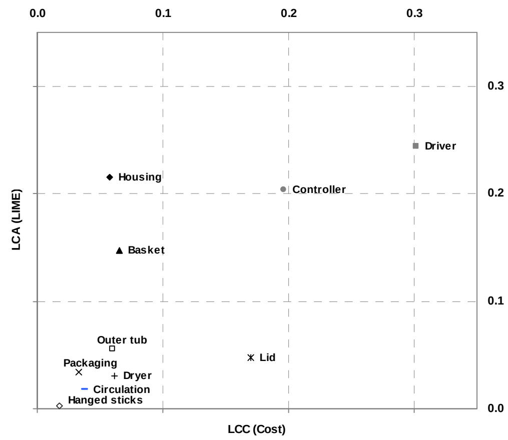



Figure 5 LCC-LCA Relation of Unit Production

In addition, impacts of eutrophication, ecotoxicity and airpollution are large in a life cycle of water. Production of water supplies and a sewage system of waste water causes a large factor of eutrophication, ecotoxicity, and air pollution.

In addition, as for the avoided effect by recycling of a disposal scenario, avoided effect to airpollution is large.

Figure 4 shows the environmental influence for each unit. Environmental impact is high for driving unit, housing unit, controller unit, and basket unit. Air pollution comes from the production of steel and PP and other materials. For the Controller unit ecotoxicity is large because so many kinds of chemicals are used in the controller circuit boards.

As for LCC (Cost) in production stage, cost of materials, process materials, utility are calculated for each unit.

LCA – LCC (Cost) relation for units are shown in figure 5. The units are divided into 4 groups: (1) Driving unit and controller unit shows the high cost and high environmental load, (2) housing unit and basket unit shows the high environmental load with small costs, (3) lid unit shows high cost and low environmental load and (4) other units shows both low. Each group has different task for cost and environmental load.

## 3.4 Scenario Analysis for Environmental Measures

Scenario evaluation are performed for lead-free scenario and circulation-type dewater scenario. In this Washing Machine, dewater and lead-free are already adopted (after the measure). Therefore in the scenario analysis the cases before dewater and lead-free (before) are assumed. Then the LCA results of before and after the measures are compared.

### 3.4.1 Circulation-Type Dewater Scenario

LCA evaluation items of measures before and after the water saving measure are shown in table 3.

This model of washing machine is different from a conventional one. With a little water circulated by water-circulating mechanism, the laundry is pushed up by turn of a wing of special shape with up-and-down motion and forward-back motion,

then the laundry is washed by pushing, swatting and rubbing. Therefore, it is thought that washing method with a new wash wing and the control method in itself show a water saving effect.
However, here simplified scenario evaluation was performed that saving water gets possible simply by adding the circulation unit.

Table 2 LCA Data before and after Dewater

| Stage | | Unit | Before | After | Difference | Comments |
|---|---|---|---|---|---|---|
| Production | materials | | No circl. Unit | With circl. Unit | circl. unit | electricity for circl. unit production |
| | Electricity | kWh/P | 54.37 | 54.63 | 0.26 | |
| | Other Items | | | | non | |
| Transportation | | | | | non | |
| Use | | | | | | |
| Electricity | for washing | Wh/Washing | 157.81 | 170.00 | 12.18 | electricity for circl. unit use |
| | for a year | kWh/year | 84.50 | 91.03 | 6.52 | |
| | for LC | kWh | 971.77 | 1046.81 | 75.02 | |
| Water | for washing | L/Washing | 196.00 | 88.00 | −106.00 | by dewater |
| | for a year | kL/year | 104.95 | 47.12 | −56.76 | |
| | for LC | kL | 1206.92 | 541.88 | −652.72 | |
| Detergent | for washing | g/Washing | 47.40 | 47.40 | 0.00 | |
| End of Life | | | EOL Scenario | EOL Scenario | little | EOL of circl.unit |

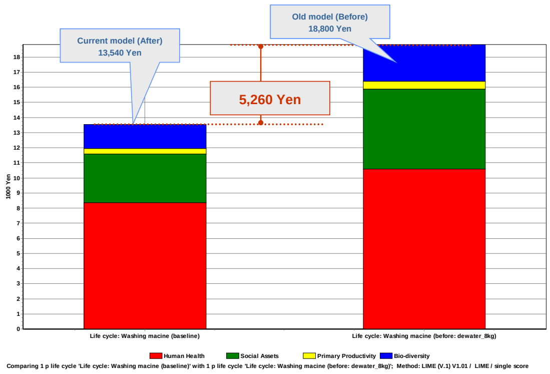



Figure 6 LCIA Results before and after Dewater

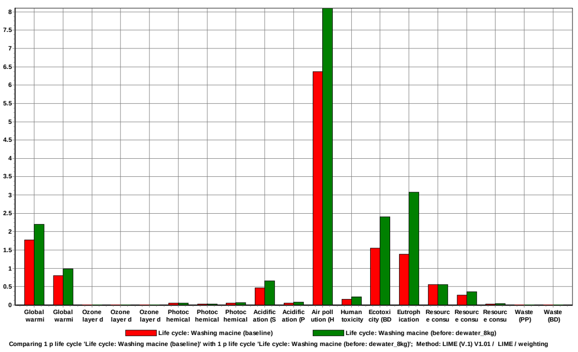


Figure 7 LCIA Results for Impact Categories

The evaluation items before and after the water saving measure are shown in Table 2. Materials and production electricity for circulation unit increase. Use electricity increases for driving the circulation unit Water use quantity for 8kg laundry by a model before dewater is 196L and after dewater it is 88L. In a life cycle water of 652.7L is saved.

LCIA results of the saving water measures before and after are shown in figure 6. A social cost is 13,540 yen before, and 18,800 yen after. The reduction of hazards to human health and social assets are large. after the water saving measures, thus social cost reduces by 5,260 yen (28.0%).

(b) Impact Category

The results of evaluation before and after the saving water with impact categories are shown in figure 7. Global warming, air pollution, ecotoxicity, and eutrophication increase by the increase of water before the dewater measure.

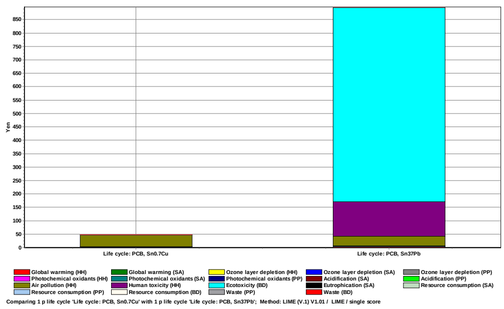


Figure 8 LCIA Results before and after Lead-free Soldering

### 3.4.2 Lead-free Scenario

Lead-free scenario was evaluated to change solders used for printed circuit board from Sn37Pb into Sn0.7Cu. The amount of solder material and the electricity consumption of reflow furnace are considered. Figure 8 shows the results of evaluation in the case the circuit board infiltrates into the soil, and component lead is emitted fully into soil. A social cost per a circuit board reduces by 842 yen (94.4%) from 892 yen to 50 yen through the adoption of lead-free solder. This depends mainly on the impact reduction of ecotoxicity and the human toxicity.

## 4. Conclusion and Future Task

Environmental risk evaluation method for the electric and electronic equipment products is in development. As phase1 LCA and LCC general washing machine is evaluated with literature based data and as phases 2 detailed LCA is achieved with a detailed production data and precise use data for washing machine. LCC for precise production data for unit are carried out. Following conclusion are resulted.

### 4.1 Conclusion

1) Important items are extracted from the results of LCC and LCA of Phase1 about environment and cost. For water and detergent in use, production of a washing machine, both of the cost and environmental load are large. It is understood that these measures for them are important.

2) As Phase 2, production detailed data for each unit are investigated, and the environmental loads are clarified. It is made clear that environmental impact of driving unit, housing unit control unit are large.

3) From the results of LCA and LCC for production, the units are divided into four groups having, (1) high environmental load and high cost, (2) high environmental load and low cost, (3) low environmental load and high cost, (4) low environmental load and low cost. Each group has their tasks for environmental load and cost. This can be regarded as an indicator of environment-conscious designing.

4) Circulation-type dewater scenario and lead free scenario were taken for environment measures scenarios, and environmental influence of measures before and after were clarified.

ⅰ) Water circulation is highly effective in reduction of air pollution, eutrophication, ecotoxicity by reducing the water use. The social cost of a washing machine is reduced by 29%.

ⅱ) Lead-free scenario of a circuit board is much effective for the reduction of human toxicity and ecotoxicity. Reduction of a social cost of a circuit board is 94% when lead included is emitted fully nto the soil.

### 4.2 Future Task

1) Detailed LCC data will be investigated for production including the costs of detailed planning, development, production, delivery and sales of the products, so that detailed LCCBA will be carried out.

2) Chemicals included in the products will be evaluated, emission from them in end of life stage will be estimated and the environmental load will be evaluated［7］.

3) Uncertainty analysis, sensitivity analysis will be performed so that the LCCBA technique will be developed with high precision and high reliability able to use for decision making and external communication［8］［9］.

**Acknowledgement**

The authors are grateful to New Energy and Industrial Technology Development Organization for their financial support.

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