Life Cycle Analysis of Semi Automatic Washing Machine

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Abstract : The household device most widely used in almost every house in entire world on regular basis is Washing machine. Increased world population and rapid economic development results in more use of washing machine over washing clothes by hand. Using washing machine on regular basis is highly water and energy intensive process which has many negative impacts on the surrounding and environment. There are several influencing factors of its performance like the load of washing, water temperature, uses frequency, detergent and shop used. The impact of these factors depends on the preferences of the customer and the specific washing machine and its working parameters and specifications.

The study's primary objective is to quantify the environmental effects of the current range of 5 kg semi-automatic washing machine. This will be done by conducting the 'Life Cycle Assessment' as per ISO 14040/44 standard for washing machine from cradle to grave in Indian scenario to evaluate the various environmental performance indicators such as primary energy demand, global warming potential, blue water consumption, human toxicity, air emissions in a holistic manner using the GaBi version 8.0 software. The study's secondary objective is to suggest and analyze different future scenarios that would minimize the overall environmental impact of the washing machine. The outcomes of the LCA have been indicated that global warming potential, human toxicity potential, primary energy demand and blue water consumption showed the highest burden on the environment compared to other categories. The use stage of the washing machines is the dominant stage in most of the selected categories. Hence, the effect of a clothes washer on the environment relies heavily on consumers' behavior.

***Index Terms* - Washing Machine, Cradle to Grave, GaBi, Life Cycle Assessment, Global Warming Potential.**

1. INTRODUCTION

The washing machine is a regularly used electronic domestic appliance in most households all over the world. Increase in the world's population along with rapid economic development has resulted in the increased use of washing machines among households for laundry instead of hand washing practices. If we talk about the market scenario of the washing machine in India increased from 1.4 million units in 2005-06 to almost between 2.0 to 2.3 million units in 2007-08. For the 5-year span between 2006-07 and 2011-12, the market for washing machines was estimated to rise at 9.3% ("Indiastat," n.d.). The stock of all washing machines in India in 2011 was 16.5 million units, out of which rural and urban India shared 2.2 and 14.3 million units respectively (The World Bank, 2008).

The main objective is to evaluate environmental impacts associated with the value chain of manufacturing of washing machine. This will be achieved through conducting the 'Life Cycle Assessment' as per ISO 14040/44 standard for washing machine from cradle to grave in Indian scenario to evaluate the various environmental performance indicators such as primary energy demand, global warming potential, blue water consumption, human toxicity, air emissions, effluent discharge and waste generation in a holistic manner using the GaBi version 8.0 software("thinkstep," n.d.). The primary objective of this study is to identify the environmental factors related to the given washing machine throughout the life cycle, i.e., from the production of the raw materials that constitute the machine, manufacturing, distribution, use phase and the end of life. Moreover, the stages where the most significant environmental impacts occur need to be highlighted and discussed. The secondary objective is to suggest and analyse different future scenarios that would reduce the overall environmental impact of the washing machine. The regular domestic washing machine has considered in this study.

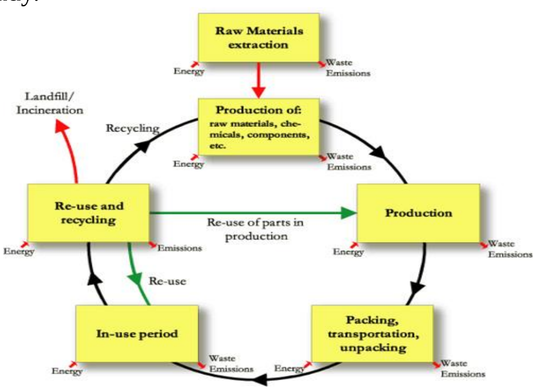


Fig. 1.1. Life cycle of the product value chain

2. Business Value of this Study

This study aims to help us better understand the metal's full effects on the environment from extraction and processing of raw materials through manufacturing, distribution, use, and recycling as well as the significant benefits that the product provides to customers and downstream users. LCA will help in evaluating the environmental benefits in comparison to reference situation in future. LCA and design for the environment are one of the important tools which are used to conceive, develop, and bring sustainable products to the end markets. This study will also help in providing an indication of the current status of environmental performance of the product being analyzed and enables optimization potentials to be identified and a comprehensive platform for communication with authorities, environmental organizations as well as with society (environmental report).

3. Research Method

To carry out the Life Cycle Assessment for the semi-automatic washing machine household product as per the ISO 14040/44 with the help of mid-point CML methodology (PE International AG, 2012). The functional unit, which provides the reference for inputs and outputs throughout the system, in this study functional unit is one piece of a washing machine with an expected lifespan of 15 years. The study covers all the production steps from raw materials in the earth (i.e., the cradle) to the production of washing machine products and delivery at the factory gate. The system boundary is considered from the cradle to the grave and study is focused in the Indian context. The washing machine was dismantled to collect information about the different materials that constitute the washing machine and prepared the bill of materials (i.e., BOM). The outcome of the disassembly process is used as an input for the modeling of the inventory part of the life cycle assessment.

Water, energy and other materials consumption data of the machine during their manufacturing and utilization stage were collected from the literature and Bureau of Energy Efficiency (BEE) respectively ("SCHEDULE – 12 Washing Machines," 2016). Compile an inventory of all the materials that are used for the manufacturing of the machines. Completeness and consistency checks were performed. The LCA of washing machine model was created using the GaBi version 8.0 software system for life cycle assessment, developed by thinkstep AG ("thinkstep," n.d.). Environmental impact indicators viz. Global warming potential (GWP), Acidification potential (AP), Primary energy demand (PED), Photochemical ozone creation potential (POCP), Abiotic resource depletion (ADP) and Ozone depletion potential (ODP) were evaluated. A set of environmental impact indicators considered to be of high relevance with the potential sources of impact are shown in the tables below.

Table 1.1 Environment Impact Indicators (pe international ag, 2012)

Impact Category	Units (equivalents)	Source of Impact	Methodology of Impact Calculation
Abiotic Depletion of Fossil elements	kg Sb eq.	Depletion of fossil elements (metals, non-metals etc.)	CML 2016
Acidification Potential (AP)	kg SO_2 eq.	Emission of SO_2, NO_x, NH_4	CML 2016
Eutrophication Potential (EP)	kg Phosphate eq.	Emission of P, PO_4	CML 2016
Global Warming Potential (GWP)	kg CO_2 eq.	Emission of CO_2, N_2O, CH_4 etc.	CML 2016
Human Toxicity Potential (HTP)	kg DCB eq.	Emission of Heavy metals, toxic compounds etc.	CML 2016
Ozone Layer Depletion Potential (ODP)	kg R-11 eq.	Emission of Ozone depleting substances i.e. CFC	CML 2016
Photochemical Ozone Creation Potential (POCP)	kg ethane eq.	Emission of Non-methane volatile organic compounds	CML 2016
Primary Energy Demand	MJ	Energy demand from non-renewable and renewable sources	CML 2016
Blue Water Consumption	m^3	Ground and surface water consumption	CML 2016

4. LCA Approach and Framework

Life cycle assessment (LCA) is a standardized scientific methodology for systematic analysis of flows (e.g., mass and energy) related with the life cycle of a studied product, a technology, a service or manufacturing process systems (ISO, 2006a). The approach in principle aims at a holistic and comprehensive analysis of the above items including raw material acquisition, manufacturing as well as use and End-of-life (EoL) management. The International Standard: ISO 14040:2006 (Iso, 2006) describes the principal and framework for life cycle assessment and ISO 14044:2006 (Figure 3.1) provides requirement and guidelines for conducting LCA studies. As per guidelines of the International Organization for Standardization (ISO), 14040/44 standards/ a Life cycle assessment study consists of four phases:

- Goal & scope definition (framework and objective of the study)
- Life cycle inventory (input/output analysis of mass and energy flows from operations along the washing machine value chain)
- Life cycle impact assessment (evaluation of environmental relevance, e.g., global warming potential)
- Interpretation (e.g. optimization potential)

5. FUNCTIONAL UNIT

The functional unit is a reference for the product whose lifecycle impact is being assessed. The functional unit allows quantification of the environmental impacts of the domestic semi-automatic washing machine product over cradle-to-grave life cycle stages. These environmental impacts are calculated based on functional unit wherein each flow related to material consumption, energy consumption, emissions, effluent, and waste is scaled to the reference flow. For this study, the functional unit was selected based on an analysis of the current trends of the industry as well as in consumer behavior, particularly in the Indian scenario. "The functional unit, which provides reference for inputs and outputs throughout the system, is one unit of 5kg capacity semi-automatic household washing machine with an expected life of 15 years." The main reason for choosing the particular load capacity is that 5kg is the maximum load for most of washing machines available in the Indian market.

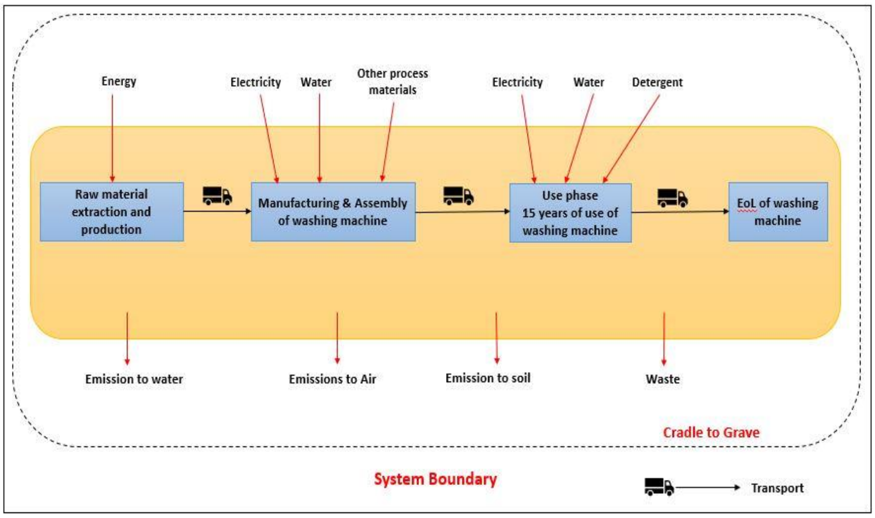


Fig. 1.2. System Boundary for the Selected Products

6. LIFE CYCLE INVENTORY AND SCENARIO ANALYSIS

Life Cycle Inventory is the list of input and output flow which documents the qualitative and quantitative value of material and energy used (as input) and products, by-products and environmental releases (as output) for the product system being studied. LCI is used to understand total emission, waste, and resources associated with input and output, which were further analysed using GaBi version 8.0 Software. A semi-automatic clothes washer comprises of parts like the washtub, dryer tub, and agitator, plastic tubes to feed the water, electric drive motor, and hose. Inside the wash tub, the perforated steel made agitator is used to handle the wastewater out from the washtub. An electrically driven motor powers the rotation of wash tub. The rotation induces current, and the clothes are made to rub against one another. It results in the removal of dirt from the clothes. Specifications of the studied washing machine are given below:

TABLE 1.2 TECHNICAL SPECIFICATIONS OF THE SEMI-AUTOMATIC WASHING MACHINE

Washing Machine (Semi-Automatic)		
Parameters	**Unit**	**Quantity**
Length (L)	mm	712
Width (B)	mm	617
Height (H)	mm	864
Washing drum depth	Inch	19
Net Weight	Kg	28.6
Washing Capacity	Kg	5
Agitation Rate	Strokes/min	12
Water Level Maximum	Litres	50
Machine Speed Control		
Wash Motor	rpm	1440
Spin Motor	rpm	1440
Rated Power Consumption		
Wash	watt	240
Spin	watt	180
Wash	Min.	15
Spin	Min.	5
Power Supply		

Voltage supply	Volt	240
AC Frequency	HZ	50

7. TEAR-DOWN OF SEMI-AUTOMATIC WASHING MACHINE

All data were collected and provided for a semi-automatic washing machine for Indian context by visiting the domestic appliances repair shop in the market. Product specific data collection questionnaire was prepared and filled by teardown process. Teardown is the process of disassembling a product, such that it helps to identify its parts, system functionality, and component weights.

8. MATERIALS COMPOSITION

TABLE 1.3 MATERIAL COMPOSITION OF WASHING MACHINE

Material Composition	Weight	Unit	% Breakup
Steel	16.691	Kg	58.31%
Plastic	10.603	Kg	37.04%
Aluminium	0.404	kg	1.41%
Copper	0.925	kg	3.23%
Total Weight	28.623	kg	100%

9. MODEL DEVELOPMENT AND LIMITATIONS

The data were collected through disassembly of the old washing machine, i.e., used as Bill of material and for the process data literature are considered. With continuing measures to improve the environmental performance of domestic appliances, it should be noted that improvements will occur over the coming years and these will need to be incorporated into the life cycle assessment of washing machine.

a) Site Specific emission factor for electricity is computed based on the contribution of electricity supplied from a power plant.
b) GaBi version 8: 2015 specific database is used for evaluating environmental emissions.
c) Transport of materials through trucks are analysed by using GaBi datasets.
d) The inherent assumption is underlying that households use their washing machines until the maximum lifespan, i.e. 15 years of lifespan.
e) The study is based on average data. In case of individual purchase decisions, the parameters influencing the results might differ from the assumed average data.
f) The results are only valid for the geographical scope of this study (India). Different parameters strongly depend on the country or climatic conditions. Examples of those parameters are: electricity supply and consumer behaviour (washing habits)
g) During the 15 years of the life cycle, we assume a total number of 4755 washing cycles, i.e. 317 washing cycle per year, based on information collected by the literature.
h) For rail transport, country-specific electricity consumption for goods is considered.
i) The variation in consumer use of washing machines was not addressed in this study.

9.1. CUT-OFF CRITERIA

Input and output data have been collected through detailed questionnaires which have been developed and refined. In practice, this means that, at least, all material flows going into the washing machine processes (inputs) higher than 1% of the total mass flow (t) or higher than 1% of the total primary energy input (MJ) is part of the system and model in order to calculate elementary flows. All material flows leaving the product system (outputs) accounting for more than 1% of the total mass flow of the system. For hazardous and toxic materials and substances, the cut-off rules do not apply (PE International AG, 2012).

9.2. DATA QUALITY REQUIREMENTS

It is important that data quality as per the requirements of the study‘s goal and scope. It is essential to the reliability of the study and achievement of the intended application. The quality of the LCI data for modelling the life cycle stages of washing machine has been assessed according to ISO 14044 (ISO, 2006b). The datasets have been used in LCA-models worldwide for several years in industrial and scientific applications for internal as well as critically reviewed studies. For all other data, primary data were used where possible, and finally upstream LCA data from the GaBi version 8 professional database.

9.3. TECHNOLOGY COVERAGE

The exact technological configuration was used for the various processes of operation of its plant for efficient performance in production and minimizing environmental impacts. It was assumed that secondary data from databases that were used for this assessment, were temporally and technologically comparable to that of primary data and within the temporal coverage already addressed.

9.4 GEOGRAPHIC COVERAGE

The geographical coverage of this study covers the production washing machine products in India. Indian boundaries wherever possible have been adapted and others dataset were chosen from EU if no Indian datasets were available. Also, raw materials imported from other geographies are applied in this study.

9.5 TIME COVERAGE

The chosen washing machine was manufactured in 2002 and disposed of in 2018.

9.6 ALLOCATION PRINCIPLES

As much as possible, the allocation has been avoided by expanding the system boundaries. In the study at hand, no general allocation rules have to be applied explicitly. Only the credits for recycling of materials are considered.

9.7 SELECTION OF APPLICATION OF LCIA CATEGORIES

This phase aims to evaluate the amount and significance of potential environmental impacts, arising from the set of results of the previous phase of inventory analysis (ISO, 2006a). The elements of this phase are the selection of impact categories, classification, characterization, and normalization (optional).

9.7.1. SELECTION OF IMPACT CATEGORIES

The choice of impact categories depends on the environmental effects and issues of the assessed product system and should be justified and reflect the goal and scope of the LCA. To facilitate the collection, assignment and characterization modeling of LCI results, necessary components of life cycle inventory analysis (LCIA), for each category, are (ISO, 2006b):

a) Identification of category endpoints
b) For category endpoints, the definition of category indicator
c) Identification of appropriate LCI result for each impact category
d) Identification of characterization model and characterization factors

The relevant impact categories are defined and associated with the inventory data; this is termed classification. Various environmental impacts and emissions are associated with each stage of washing machine production, use phase and end-of-life.

9.7.2. CHARACTERIZATION

Characterization involves the quantification of indicator results and conversion of inventory data to common reference units using characterization factors.
Once LCI results have been assigned to impact categories, characterization factors are applied to the relevant quantities, converting the results to reference units. For example, for the impact category Global Warming Potential, the LCI results would give an amount of a greenhouse gas per functional unit. Relative to its contribution to its contribution to the category, each greenhouse gas has an assigned global warming potential (GWP100) characterization factor, which converts the LCI results to the reference unit, kilograms of CO2 equivalents per functional unit (ISO, 2006b). Figure 4.3 represents the characterization approach for calculating the life cycle impacts from the life cycle inventory.

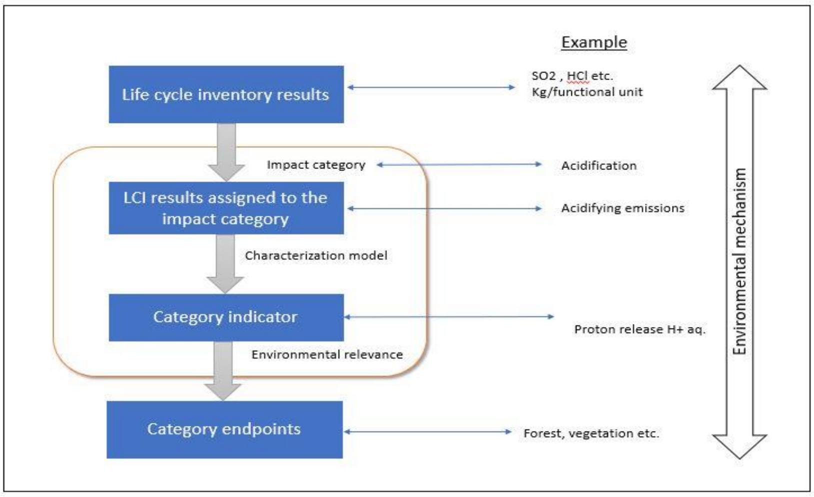


Fig. 5.1. LCI to LCIA Characterization Approach (Gabi, 2012)

10. SOFTWARE AND DATABASE

The LCA model of the washing machine was created using the GaBi version 8.0 Software system for life cycle engineering, developed by thinkstep AG (“thinkstep,” n.d.). The GaBi database provides the life cycle inventory data for several of the raw and process materials obtained from the upstream system.

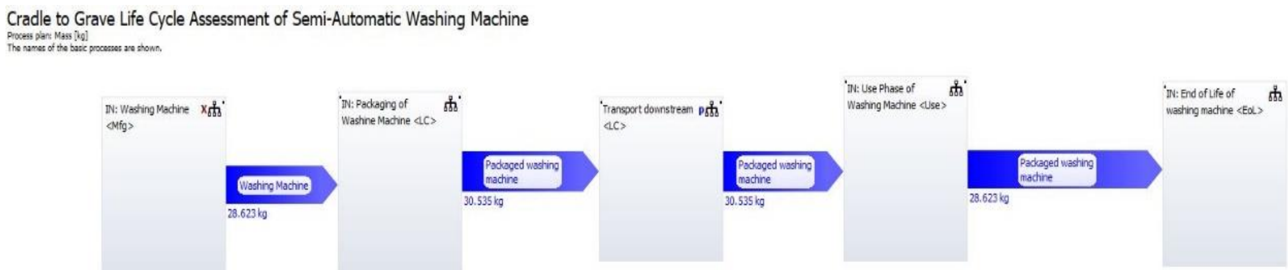


Fig. 5.2. Cradle to Gate LCA model of semi-automatic washing machine

11. Result Analysis And Hotspot Identification

11.1 Cradle to Grave LCIA results for Functional Unit

11.1.1 Process-wise Environmental Impacts

The table below shows the process wise life-cycle environmental impacts for production, packaging, usage, and end of life of 5kg semi-automatic household washing machine with an expected lifespan of 15 years. Washing machine Process includes impact for the raw materials consumed, transport of raw material, manufacturing and assembly, use phase, end of life and process emissions. Electricity & Steam includes the impact of fuel combustion. Packaging includes the impact of packaging materials used and its transport.

Table 6.1 Process Wise Lca Impacts For 15 Years Life Span Of One Unit Of Washing Machine

Environmental Indicator	Source of Impact	Manufacturing & Assembly	Packaging	Downstream-Transport	Use Phase	End - of - Life	Total
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	Depletion of fossil elements (metals, non-metals etc.)	9.97E-03	1.36E-06	1.20E-10	9.12E-04	-7.17E-03	3.72E-03
Acidification Potential (AP) [kg SO_2-Equiv.]	SO_2, NOx, NH_4	1.14	1.54E-02	3.98E-05	6.65	-1.42E-01	7.66
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	P, PO_4	0.06	1.94E-03	6.32E-06	4.33E-01	-8.01E-03	0.48
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	CO_2, CH_4, N_2O	1.40E+02	1.92	5.52E-03	9.54E+02	-29.82	1066.31
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	Heavy metals, toxic compound	68.20	0.39	4.81E-04	1.75E+02	-13.38	229.85
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	ODS i.e. CFC etc.	9.46E-09	4.90E-11	2.79E-14	3.05E-08	-2.49E-10	3.98E-08
Photochemical Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	Non-methyl VOC	0.06	1.24E-03	-9.22E-06	0.35159	-1.59E-02	0.40
Primary energy demand net cal. value) [MJ]	Non-renewable and renewable energy	2.23E+03	132.70	7.33E-02	1.43E+04	-2.71E+02	1.64E+04
Blue water consumption [kg]	Ground and surface water	7.96E+02	19.21	8.30E-03	5.77E+05	-67.01	5.78E+05

11.1.2. Hotspot Identification

The hotspots in the cradle to grave life cycle environmental impacts for 5kg semi-automatic household washing machine with an expected lifespan of 15 years are explained below:

a) Abiotic Depletion Potential (ADP elements) is 3.72 E-03 kg Sb-Equiv. Which is primarily contributed by washing machine production and assembly process (~268.31%). In the washing machine production and assembly process spin dryer accounts for 142.75%, washing assembly accounts for 114.33%, Use phase accounts for 24.53%. In the use phase detergent for 20.09% and tap water accounts for 3.62%, and end of life accounts for -192.89% of the total life-cycle impacts.

b) Acidification Potential (AP) is 7.66-gram SO2-Equiv. With the major contribution from Use phase of the washing machine (~86.75%) and washing machine production and assembly process (~12%). In Use phase electricity accounts for 48.29%, tap water accounts for 29.18% and detergent accounts for 11.69% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 9.1% of the total impact, and packaging alone accounts for 0.20% of the total life-cycle impacts.

c) Eutrophication Potential is 0.48-gram Phosphate – Equiv. With the major contribution from Use phase of the washing machine (~89.25%) and washing machine production and assembly process (~14.90%). In Use phase electricity accounts for 70.73%, and detergent accounts for 9.68% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 6.21% of the total impact, and packaging alone accounts for 0.40% of the total life-cycle impacts.

d) Global Warming Potential is 1066.31 kg CO2-Equiv. With the major contribution from Use phase of the washing machine (~89.46%) and washing machine production and assembly process (~13.15%).

In Use phase electricity accounts for 41.57%, tap water accounts for 30.61% and detergent accounts for 17.26% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 5.35% and spin dryer assembly for 2.97% of the total impact, and packaging alone accounts for 0.18% and end of life accounts for -2.79% of the total life-cycle impacts.

e) Human Toxicity Potential is 229.85-gram DCB- Equiv., with the major contribution from Use phase of the washing machine (~75.98%) and washing machine production and assembly process (~29.67%) and packaging alone accounts for 0.17%, and end of life accounts for -5.82% of the total life-cycle impacts.

f) Ozone Layer Depletion Potential is 3.98 E-08 kg R11 Equiv. With major contribution Use phase of the washing machine (~76.75%) and washing machine production and assembly process (~23.75%). In the use phase detergent accounts for 47.51% of the total life-cycle impacts.

g) Photochemical Ozone Creation Potential is 0.40-gram Ethene-Equiv. With the major contribution from Use phase of the washing machine (~88.72%) and washing machine production and assembly process (~14.97%) and packaging alone accounts for 0.31% and end of life accounts for -4% of the total life-cycle impacts.

h) Primary Energy Demand is 1.64 E+04 MJ with major contribution Use phase of washing machine (~87.249%) and washing machine production and assembly process (~13.56%).

In Use phase electricity accounts for 31.88%, tap water accounts for 21.72% and detergent accounts for 33.63% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 4.09% and spin dryer assembly for 2.62% of the total impact, and packaging alone accounts for 0.81% and end of life accounts for -1.65% of the total life-cycle impacts.

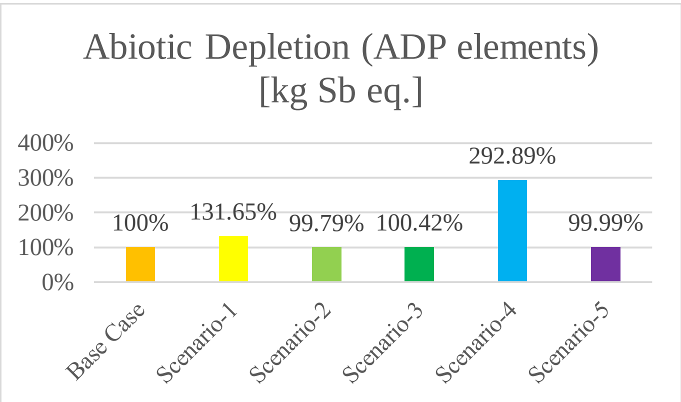
i) Blue Water Consumption is 5.78 E+05 kg with major contribution from Use phase of washing machine for ~99.871% of the total impact.

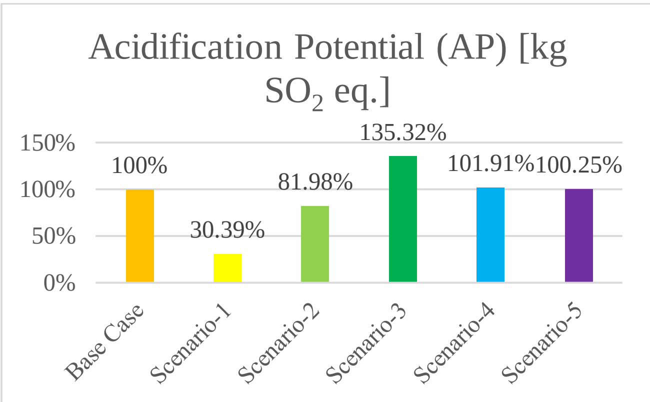
11.1.3. Source wise environmental impacts

Table below shows the environmental impacts for 5kg semi-automatic household washing machine.

Table 6.2 Source Wise LCA Impacts for 15 Years Life Span of One Unit of Washing Machine

Environmental Indicator	Source of Impact	Credit	Disposal	Energy	Process Emissions	Raw Materials	Transport	Total
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	Depletion of fossil elements (metals, non-metals etc.)	-7.17E-03	2.08E-07	3.49E-05	0.00E+00	1.08E-02	9.96E-09	3.72E-03
Acidification Potential (AP) [kg SO_2-Equiv.]	SO_2, NOx, NH_4	-1.44E-01	2.82E-03	6.12E+00	0.00E+00	1.68E+00	5.40E-03	7.66
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	P, PO_4	-1.01E-02	2.50E-03	2.64E-01	5.04E-05	2.27E-01	1.13E-03	0.48
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	CO_2, CH_4, N_2O	-30.72	1.03	5.01E+02	0.00	5.95E+02	0.89	1066.31
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	Heavy metals, toxic compound	-13.41	0.03	165.17	0.00	78.03	0.03	229.85
Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	ODS i.e. CFC etc.	-2.51E-10	2.50E-12	1.21E-08	0.00E+00	2.80E-08	7.45E-13	3.98E-08
Photochemical Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	Non-methyl VOC	-0.02	3.15E-04	2.86E-01	0.00E+00	1.29E-01	-2.00E-03	3.96E-01
Primary energy demand net cal. value) [MJ]	Non-renewable and renewable energy	-2.85E+02	1.63E+01	5.90E+03	0.00E+00	1.07E+04	1.21E+01	1.64E+04
Blue water consumption [kg]	Ground and surface water	-67.04	0.04	3.56E+03	4.39	5.74E+05	0.24	5.78E+05





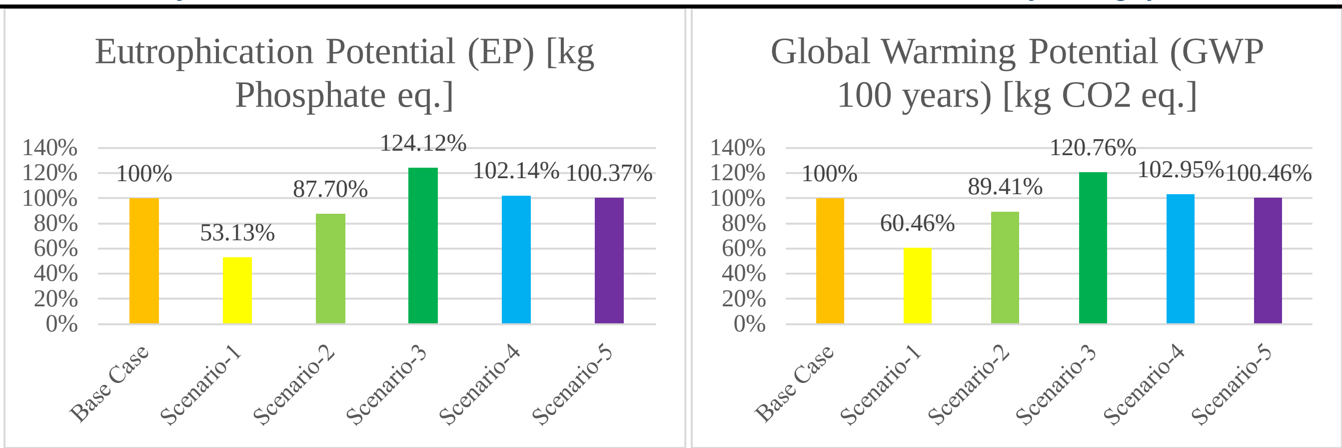


Fig. 6.5. Scenario wise percentage comparison

12. Conclusions and Recommendation

The objective of the study as well as project, i.e., "Quantify environmental impacts of the household 5 kg capacity semi-automatic washing machine product over cradle-to-grave system boundary and identify the hotspots in the value chain of the products for optimization and further reduction of environmental impacts was achieved as an outcome of this study. Various environmental impacts across the identified system boundary were quantified, studied across various life cycle stages and hotspot analysis was carried out. Wherever, the contribution analysis was more than 25%; a scenario analysis was conducted for the best-case scenario in terms of material optimization and substitution with recycled or environmental efficient material, efficiency improvement, energy mix improvements, service life extension of the product, cold water, and hot water temperature scenarios. Through these scenarios, best case scenario, practically applicable to Indian situation were applied, studied and inferences are drawn.

There were certain limitations of the study due to non-availability of part level data or material information which resulted in carrying out the analysis one level higher or considering the closed proxies of the uncertain information. However, appropriate data quality considerations in terms of completeness, timeliness, consistencies, geographical references were closely tracked and ensured that the overall data quality of the study is high and represents the actual scenario. Some of the environmental impact categories showed the highest value out of selected categories. Hotspots have been identified on process and source level in these indicators.

Global Warming Potential is 1066.31 kg CO2-Equiv. With the major contribution from Use phase of the washing machine (~89.46%) and washing machine production and assembly process (~13.15%). In Use phase electricity accounts for 41.57%, tap water accounts for 30.61% and detergent accounts for 17.26% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 5.35% and spin dryer assembly for 2.97% of the total impact, and packaging alone accounts for 0.18% and end of life accounts for -2.79% of the total life-cycle impacts.

Human Toxicity Potential is 229.85-gram DCB- Equiv., with the major contribution from Use phase of the washing machine (~75.98%) and washing machine production and assembly process (~29.67%) and packaging alone accounts for 0.17%, and end of life accounts for -5.82% of the total life-cycle impacts.

Primary Energy Demand is 1.64 E+04 MJ with major contribution Use phase of the washing machine (~87.249%) and washing machine production and assembly process (~13.56%). In Use phase electricity accounts for 31.88%, tap water accounts for 21.72% and detergent accounts for 33.63% of the total impacts. In the washing machine production and assembly process electricity alone accounts for 4.09% and spin dryer assembly for 2.62% of the total impact, and packaging alone accounts for 0.81% and end of life accounts for -1.65% of the total life-cycle impacts.

References

[1]. Agarwal, R., Chaudhary, M., & Singh, J. (2015). Waste Management Initiatives in India for Human Well Being. European Scientific Journal, 7881(June), 1857–7881. Retrieved from http://home.iitk.ac.in/~anubha/H16.pdf

[2]. Application, F., Data, P., Saly, Y., & Sheelo, A. (2010). Washing machine, 1(19).

[3]. Arup. (2010). LCA of Clothes Washing Options for City West Water's Residential Customers. Retrieved from http://www.epa.vic.gov.au/our-work/programs/sustainability-covenants/past-sustainability covenants/~/media/Files/bus/sustainability_covenants/docs/Life-Cycle-Assessment Technical-Report.pdf

[4]. Bao, W., Gong, R. H., Ding, X., Xue, Y., Li, P., & Fan, W. (2017). Optimizing a laundering program for textiles in a front-loading washing machine and saving energy. Journal of Cleaner Production, 148, 415–421. https://doi.org/10.1016/j.jclepro.2017.01.161

[5]. Cullen, J. M., & Allwood, J. M. (2009). The role ofwashing machines in life cycle assessment studies the dangers of using lca for prioritization. Journal of Industrial Ecology, 13(1), 27–37. https://doi.org/10.1111/j.1530-9290.2009.00107.x

[6]. Cutaia, L., & Scialdoni, R. (2011). Life Cycle Assessment , a tool for improving " wash appliances " performances in the framework of the Ecodesign Directive. Life Cycle Management Conference LCM, 7.

[7]. DuPont. (2013). Indian Consumer Laundry Study, (July 2012), 2025.

[8]. Gabi. (2012). GaBi Paper Clip Tutorial. Lca. Retrieved from http://www.gabi-software.com/uploads/media/Paper_Clip_Tutorial_Handbook_Part1.pdf

[9]. Garcilaso, L., Jordan, K. L., Kumar, V., Hutchins, M. J., & Sutherland, J. W. (2007). A life-cycle comparison of clothes washing alternatives. Advances in Life Cycle Engineering for Sustainable Manufacturing Businesses - Proceedings of the 14th CIRP Conference on Life Cycle Engineering, 423–428. https://doi.org/10.1007/978-1-84628-935-4_73

[10]. [10]. Giagnorio, M., Amelio, A., & Tiraferri, A. (2017). SC. https://doi.org/10.1016/j.jclepro.2017.04.012.