Journal of Manufacturing Technology and Research (An International Journal)| Volume 11 | Issue 1-2 | Month Jan-Dec(2018) ISSN: 0973-0281

A life-cycle Assessment of Household Semi-automatic Washing Machine in India

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Abstract

Washing machine is a regularly used device and an integral part of most households all over the world. Increase in the world's population coupled with rapid economic development has resulted in the increased use of washing machines among households for laundry instead of hand washing practices**.** Washing machines account for 14% of total water consumption by households globally and have the second larger share after toilets **(**Application, Data, Saly, & Sheelo, 2010), also it is highly energy intensive device that results in many negative impacts on the environment. Its performance is influenced by various parameters such as water temperature, washing load, frequency of use, and the detergent used, which depend mainly on consumer preferences as well as the specifications of every washing machine. The study's primary objective is to quantify the environmental impacts of the current range of 5 kg semi-automatic 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 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 reduce the overall environmental impact of the washing machine. The results of the LCA have 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. The hotspots in the life cycle of a washing machine have been identified as electricity consumption in the usage phase and the consumption of material resources (such as steel & plastics) in the assembly phase. This quantitative life cycle assessment helps decision-makers to understand the life-cycle environmental impacts of Indian refrigerators and improve its sustainability.

Keywords: Life Cycle Assessment; GaBi; Washing machine; sustainability; ISO 14040/44.

1. Introduction

A washing machine is a regularly used device and an integral part of most households all over the world. Also Laundromat is approximately 50% more expensive than using the domestic washer due to machine utilization vending charges (Garcilaso, Jordan, Kumar, Hutchins, & Sutherland, 2007). This has resulted in the increased use of washing machines among households for laundry instead of hand washing practices. According to a DuPont report published in 2013, "Indian Consumer Laundry Study," only 8.8% of all Indian households owned a washing machine (DuPont, 2013). In India growth of washing machine purchase grew 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 stood at 16.5 million units; out of which rural and urban India contribute 2.2 and 14.3 million units respectively (The World Bank, 2008). Therefore there is a need of practices of various waste management initiatives in India and there is a bigger scope for enhancement in the waste management (Agarwal, Chaudhary, & Singh, 2015).

Further through various studies, it has been found that the use phase of a washing machine has the highest environmental impact with a major contribution from water usage (~92%), GWP

(~73%), Fossil fuel depletion (~62%) and energy use (~60%) of the life cycle impact (McNamara, 2013). WRAP (Waste and Resources Action Programme, 2010) suggests that machine refurbishment is the most environmentally beneficial option because it has a very small contribution to global warming, resource depletion, acidification and photochemical oxidation. Integration of a recovery system able to recover approximately 40% of usable surfactants would cut by half the environmental impacts of current industrial washing machines (Giagnorio, Amelio, & Tiraferri, 2017). Besides, e-wastes generated by the end of life washing machines also hits the environment (Kumar, 2013). Hence, Recycling and eco-design are the best priorities of the washing machine (Park, Tahara, Jeong, & Lee, 2006). The cold washing has the lowest environmental impact due to the fact that extra energy is required to heat the water for the hot cycle but excessive use of detergent or fabric conditioner by even 1% increases the overall impact (Arup, 2010). The impeller machines are less energy intensive than drum washing machines. On the other hand, drum washing machines are more water efficient than impeller ones (Bao et al., 2017). According to Mathews & Beemkumar (2015), front-loading washing machine is superior to a conventional washing machine in every aspect of use phase.
When consumer behavior changes towards waiting until enough laundry is accumulated so that the rated capacity of the washing machine is employed, sustainable use of washing machines with a higher rated capacity could be done (Lasic, 2014).
Based on the above studies a suggestion regarding the provision of proper training and education about the environment to the Indian residents is given based on similar practice adopted in China by Yuan, Zhang, & Liu (2016) for the optimization of consumers' washing habits.

The main objective is to evaluate the environmental impacts associated with the value chain of manufacturing of a low capacity washing machine. As it is found that small capacity washing machines have a slightly more environmental footprint (Rüdenauer, 2005). This will be achieved through conducting the 'Life Cycle Assessment' as per ISO 14040/44 standard for washing machine from cradle to grave in the Indian scenario. Life Cycle Assessment approach is one of the key tools for evaluating and assessing the environmental burdens associated with resource consumption, energy consumption, emissions, effluent, and solid waste generation during the lifespan of the product. To conduct a credible LCA, it is critical to use good quality, current data on all raw materials, energy, and processing aids used as well as the environmental outputs associated with producing a product because this information becomes the platform for performing the life cycle inventories (LCIs) which are the basis for the LCA. The effect of washing machine effect and reverse washing machine effect as suggested by Cullen & Allwood (2009) is taken care in this study.

2. Methods

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. This study was conducted in accordance with the principles of the International Organization for Standardization's (ISO) 14040:2006 series of standards for LCA. LCA is usually carried out in four steps: (1) goal and scope definition, (2) life cycle inventory (LCI) analysis, (3) life cycle impact assessment (LCIA) and (4) life cycle improvement analysis and interpretation. These steps are described in detail below.

2.1 Goal and Scope Definition

The goal of the study is to provide the solution of specific questions which have been raised by the target audience while considering the potential uses of the study's results and quantification of environmental impacts of the semi-automatic washing machine product over cradle-to-grave life cycle stages. The scope of the study defines the system's boundary regarding geographical, technological, and temporal coverage of the LCA study.

2.2 System Boundary

The study is a cradle-to-grave LCI study of the washing machine product. That is, it covers all the production steps from raw materials in the earth (i.e. the cradle) to the production of washing machine product, downstream transport, use phase and end of life in 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. The material production includes the raw material extraction, production of the raw materials and auxiliary material production. The production process contains the in-house manufacturing processes and the transport from supplier to the site. The typical life cycle of washing machine product system can be modeled using a system of different process steps in accordance with the system boundary shown in figure 1.

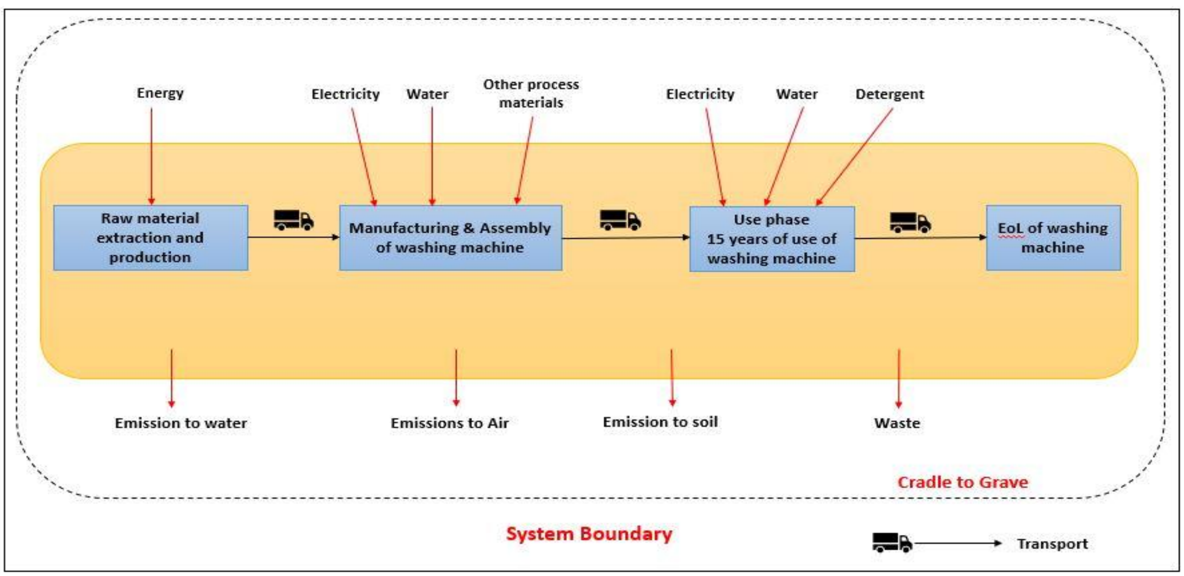


Figure 1. System Boundary for the Selected Products

Table 1: Details of System Boundary Included in the Study

Life Cycle stages	Life Cycle sub-stages	Definitions
Materials	Primary raw materials production	Extraction, production of the raw materials such as plastic tub, sheet metal etc.
Upstream Transport	-	Transport of the raw materials
Manufacturing	Parts production, assembly and packaging	Manufacturing of washing machine products through process
Downstream Transport	-	Transport of the final product i.e. semi-automatic washing machine
Use phase	15 years of use of product	

End-of-Life (EoL)	Reuse/ recycle or disposal	Recycling and/or final disposal in landfill after useful life of product

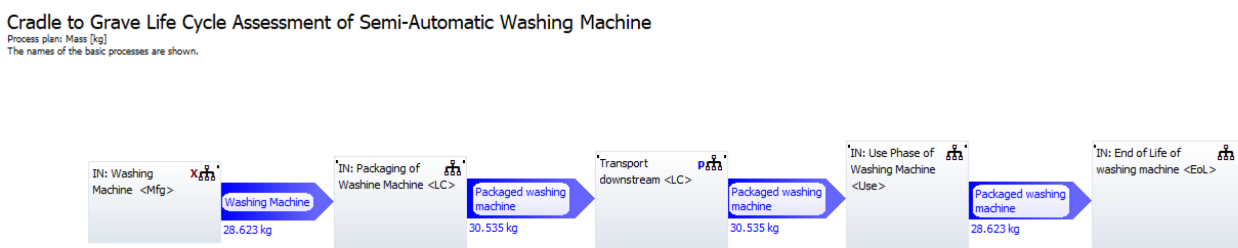
2.3 Functional Unit

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 main reason for choosing the particular load capacity is that 5kg is the maximum load for most of the washing machines available in the Indian market.

2.4 Data Collection

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

Figure 2. LCA model of Semi-automatic washing machine product in GaBi software



questionnaire was prepared and filled by teardown process. During the teardown process, the components of the washing machine were divided into material fractions trying to be as detailed as possible to determine the total weight of the washing machine, subparts, and each child parts.After that bill of materials (can be found in Table no.) was prepared and it is used as an input for the modeling of the inventory part of the LCA. 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). A Compilation of inventory of all the materials that are used for the manufacturing of the machines study. The secondary source of data was GaBi database 2018 and some of the data used were from average data obtained from the literature.

2.5 Life Cycle Inventory

The life cycle inventory (LCI) stage documents qualitatively and quantitatively analyze the materials and energy used (inputs) as well as the products and by-products generated and the environmental releases regarding non-retained emissions to the environmental compartments and the wastes to be treated (outputs) for the studied product system.

The LCI data are useful for: to understand wastes, total emissions, and resource use associated with the material or the studied product; improve production or product performance; or be further analyzed and interpreted to provide insights into the potential environmental impacts from the system (life cycle impact assessment and interpretation, LCIA)

A bill of materials is a list of the raw materials, sub-assemblies, sub-components, and the quantities of each part needed to manufacture a product. The selected semi-automatic washing machine was dismantled to collect different materials information that constitutes the clothes washer.

Table 2 Bill of material of washing machine

S. No.	Material	Material classification	Components	No. of pieces	Unit	Weight	Manufacturing process
0			Washing Machine	1	Kg	28.623	
1	Plastic	HDPE PE	Bottom Body Trolley	1	g	1650	Extrusion
1	Plastic	HDPE PE	(Washing & Spinning) Body	1	g	6014	Moulding
1	Plastic	EPDM	Wire & Plug (electric)	1	g	55	
1	Plastic	HDPE PE	Switch Panel	1	g	150	Extrusion
1	Aluminium	Aluminium	Shell (Capacitor) Combined	1	g	188	Extrusion
1	Steel	Steel	Side Body Cover	1	g	7000	Sheet Metal
1			Wheel Assembly	4	g	72	
2	Plastic	ABS	Wheel	4	g	32	Extrusion
2	Steel	Steel	Wheel Shaft	4	g	40	Extrusion
Washing Tub							
1			Gearbox & Pulley	1	g	750	Machining, Drilling, Casting
2	Plastic	ABS	Pulley	1	g	75	Extrusion
2	Plastic	Elastomers	Seal	1	g	10	Extrusion
2	Steel	Steel	Gearbox	1	g	665	Forging
1			Wash Motor	1	g	3600	
2	Plastic	EPDM	Insulation & Harness	1	g	18	
2	Copper	Copper	Wire	1	g	450	Drawing
2	Aluminium	Aluminium	Wash Motor Pulley	1	g	200	Casting, Machining
2	Steel	Steel	Nuts & Bolts	4	g	32	Extrusion
2	Steel	Steel	Cover Body	1	g	2900	Casting
1	Plastic	EPDM	Belt	1	g	36	
1			Wash Timer	1	g	112	
2	Plastic	POM	Gear	4	g	8	Extrusion
2	Plastic	ABS	Cover Body	1	g	29	Extrusion
2	Steel	Steel	Nuts & Bolts	8	g	24	Extrusion
2	Aluminium	Aluminium	Shaft	1	g	8	Drawing
2	Plastic	Elastomers	Washer	1	g	3	Thermoforming
2	Plastic	Phenol	Knob	2	g	20	Extrusion

		Formaldehyde Resin					
2	Copper	Copper	Wiring	1	g	15	Drawing
2	Steel	Steel	Shaft	1	g	5	Drawing
1	Plastic	ABS	Pulsator	1	g	450	Extrusion
1	Steel	Steel	Nuts & Bolts	1	g	8	Extrusion
1	Plastic	PVC	Button NET	1	g	20	Thermoforming
1	Plastic	PVC	Over Flow Pipe	1	g	30	Extrusion
1	Plastic	ABS	Wash Door	1	g	508	Thermoforming
1	Plastic	Phenol Formaldehyde Resin	Drain Switch	1	g	25	Extrusion
1	Plastic	Phenol Formaldehyde Resin	Water Selector	1	g	35	Extrusion
1	Plastic	Phenol Formaldehyde Resin	Water Level	1	g	50	Extrusion
1			Buzzer	1	g	80	Extrusion
2	Copper	Copper	Wire	1	g	35	Drawing
2	Steel	Steel	Body	1	g	40	Sheet Metal
2	Plastic	Phenol Formaldehyde Resin	Knob	1	g	5	Extrusion
Spin (Dryer)							
1			Drum Assembly	1	g	3100	
2	Steel	Steel	Shaft	1	g	150	Drawing
2	Steel	Steel	Drum	1	g	2850	Casting
2	Plastic	Elastomers	Seal	1	g	80	Thermoforming
2	Copper	Copper	Sleeve	1	g	20	Casting
1			Spin Motor	1	g	3300	
2	Steel	Steel	Cover body	1	g	2064	Sheet Metal
2	Copper	Copper	Wiring	1	g	400	Drawing
2	Steel	Steel	Pulley	1	g	250	Casting
2	Steel	Steel	Nuts & Bolts	6	g	48	Extrusion
2	Steel	Steel	Brake Plate	1	g	150	Casting
2	Steel	Steel	Spring	1	g	10	Drawing
2			Shocker	3	g	378	
3	Plastic	HDPE PE	PART1	3	g	9	Extrusion
3	Plastic	Elastomers	PART2	3	g	30	Thermoforming
3	Steel	Steel	PART3	3	g	339	Casting
1			Hydraulic Assembly	1	g	370	
2	Plastic	PVC	Drain System	1	g	154	Extrusion
2	Plastic	PVC	Drain Pipe	1	g	132	Extrusion

2	Plastic	PVC	Over Flow Pipe	1	g	32	Extrusion
2			Washer Assembly	1	g	52	
3	Steel	Steel	Spring	1	g	2	Wire Drawing
3	Plastic	Elastomers	Washer	1	g	25	Thermoforming
3	Plastic	HDPE PE	Lid	1	g	25	Thermoforming
1			Spin Timer	1	g	60	
2	Plastic	POM	Gear	4	g	8	Injection Moulding, Cutting
2	Steel	Steel	strip	1	g	8	Sheet Metal, Metal Cutting
2	Steel	Steel	Nuts & Bolts	3	g	6	Cold Extrusion
2	Aluminium	Aluminium	Shaft	1	g	8	Extrusion
2	Plastic	ABS	Cover Body	1	g	15	Extrusion
2	Plastic	Phenol Formaldehyde Resin	Knob	1	g	10	Extrusion
2	Copper	Copper	Wiring	1	g	5	Wire Drawing
1	Plastic	Phenol Formaldehyde Resin	Door Switch	1	g	10	Injection Moulding
1	Plastic	ABS	Spin Door	1	g	420	Injection Moulding
1	Plastic	ABS	Safety Door	1	g	280	Injection Moulding
1	Plastic	ABS	Safety Net	1	g	150	Injection Moulding
1	Steel	Steel	Brake Wire	1	g	100	Wire Drawing

Table 3: Process data for the manufacturing and assembly

S. No.	**Input data for manufacturing & Assembly**	**Unit**	**Quantity**
1	Compressed air	m^3	1.41
2	Steam	kg	0.52
3	Water	kg	4.39
4	Electricity	kWh	47.91
5	Epoxy resin	kg	6.37E-02
6	Phosphating agent	kg	3.82E-03
7	Degreaser	kg	3.97E-03
8	Surface conditioning agent	g	0.19
9	Heavy Fuel Oil	kg	0.18
S. No.	**Output data for manufacturing & Assembly**	**Unit**	**Quantity**
1	Non-methane hydrocarbon	g	0.13
2	waste water	kg	3.82
3	suspended solids (SS)	kg	1.91E-03
4	Chemical oxygen demand (COD)	kg	2.29E-03
5	Phosphate sludge	g	6.49E-03
S. No.	**Packaging data**	**Unit**	**Quantity**

1	Kraft liner	kg	1.10
2	Nylon	kg	8.50E-02
3	Paper	kg	0.13
4	Polyethylene (PE)	kg	0.17
5	Polystyrene (PS)	kg	0.42

Table 4: Use phase data of washing machine

	Energy	Water	Detergent
Main customer segment	Household laundry purpose		
Typical use intensity: Annual amount of cleaned laundry (Kg/year) for a 5kg capacity semi-automatic washing machine	1585		
Specific consumption in use phase (Acc. to BEE Report) maximum value for 2-star rating	0.0157 kWh/Kg	120 litres/wash cycle	55 g/wash cycle
Annual consumption in use phase	24.8845 kWh	38040 litres	17435 g
Annual wash cycle (Acc. to BEE report)	317 wash cycle/machine/year		
Average Life span of semi-automatic washing machine	15 years		
Average cold-water temperature	27° C		
Average Hot water temperature	48° C		

Table 5: End-of-Life details for washing machine

	Base case (%)
Recycle steel	85 (as per world steel LCA report)
Landfill steel	15
Recycle Copper	100
Landfill copper	-
Recycled Aluminium	100
Landfill Aluminium	-
Recycled Plastic	-
Landfill Plastic	100

2.6 LCIA Methods

The LCA of washing machine model was created using the GaBi version 8.0 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.

The LCIA phase includes the following mandatory elements:

• Selection of impact categories, category indicators, and characterization models

• Assignment of LCI results to the selected impact categories (classification)

• Calculation of category indicator results (characterization)

Classification: a mapping of items in the inventory to known environmental effects or impacts (e.g., global warming, acidification, resource depletion, etc.).

Characterization: a calculation of scientifically-based indices; each index being an estimation of the potential impact of the inventory items contributing to a given environmental effect (e.g.,

global warming potential, acidification potential, resource depletion, etc.).
The fourth step, Interpretation, consists of the interpretation of LCI and LCIA results which is used to reduce environmental impact.

Table 6 Methodology of Impact Calculation

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

3. Result Analysis and Hotspot Identification

3.1 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 7: Process-wise Environmental 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)	P, PO_4	0.06	1.94E-03	6.32E-06	4.33E-01	-8.01E-03	0.48

[kg Phosphate-Equiv.]							
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

Impact Profile	Lowest	Highest

3.2 Source wise environmental impacts

Table below shows the environmental impacts for 5kg semi-automatic household washing machine with an expected lifespan of 15 years over the cradle to grave system boundary where impacts are classified on the basis of source of impact generation i.e. Raw Materials, Process Emissions (Impact from manufacturing & Assembly and Use phase of washing machine), Energy (Impact from Electricity consumption), Transport (Transport of Raw Materials), and End of life (credit for the recycled of the metals and plastics).

Table 8: 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	Heavy metals, toxic	-13.41	0.03	165.17	0.00	78.03	0.03	229.85

inf.) [kg DCB-Equiv.]	compound							
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

Impact Profile	Lowest										Highest

3.3 Scenarios wise comparative environmental impacts

The scenario technique aims to show possible futures based on a scientific process. It is the goal of scenarios to spread out possible ways and consequences of development, thus giving support to decision makers. In addition, one or two other (or even more) scenarios are defined giving a clue how major changes would form other futures with different impacts and consequences.

Table 9: Scenarios wise LCA Impacts for 15 years life span of one unit of washing machine

Environmental Indicator	**Source of Impact**	**Base Case**	**Scenario -1**	**Scenario -2**	**Scenario -3**	**Scenario -4**	**Scenario -5**
Abiotic Depletion (ADP elements) [kg Sb-Equiv.]	Depletion of fossil elements (metals, non-metals etc.)	3.72E-03	4.89E-03	3.71E-03	3.73E-03	1.09E-02	3.72E-03
Acidification Potential (AP) [kg SO_2-Equiv.]	SO_2, NOx, NH_4	7.66	2.33	6.28	10.37	7.81	7.68
Eutrophication Potential (EP) [kg Phosphate-Equiv.]	P, PO_4	0.48	0.26	0.43	0.60	0.50	0.49
Global Warming Potential (GWP 100 years) [kg CO_2-Equiv.]	CO_2, CH_4, N_2O	1066.31	644.66	953.36	1287.69	1097.75	1071.25
Human Toxicity Potential (HTP inf.) [kg DCB-Equiv.]	Heavy metals, toxic compound	2.30E+02	9.91E+01	1.93E+02	3.03E+02	2.43E+02	2.31E+02

Ozone Layer Depletion Potential (ODP, steady state) [kg R11-Equiv.]	ODS i.e. CFC etc.	3.98E-08	2.96E-08	3.71E-08	4.52E-08	4.01E-08	3.98E-08
Photochemical Ozone Creation Potential (POCP) [kg Ethene-Equiv.]	Non-methyl VOC	3.96E-01	1.51E-01	3.32E-01	5.23E-01	4.13E-01	3.99E-01
Primary energy demand net cal. value) [MJ]	Non-renewable and renewable energy	1.64E+04	2.16E+04	1.51E+04	1.90E+04	1.67E+04	1.64E+04
Blue water consumption [kg]	Ground and surface water	5.78E+05	5.75E+05	5.77E+05	5.79E+05	5.78E+05	5.78E+05

Impact Profile	Lowest → Highest

The scenario analysis aims to evaluate possible ways and consequences of development, thus giving support to decision makers. The five scenarios were identified to evaluate how significant changes would form other futures with different impacts and consequences. Scenario wise % contribution to LCIA is shown in table 10.

Scenario 1 - Energy substitution

In the base case, energy is used for grid electricity in use phase, but in scenario one energy is substituted from grid to photovoltaic cell, i.e., solar energy.

Scenario 2 – Technology enhancement

In this scenario, five-star rating washing machine is used, and data collected from the BEE report. In the base case, the two-star rating washing machine is used.

Maximum (kWh/kg)	Minimum (kWh/kg)	Star Band	Electricity required in 1 cycle (kWh)
0.0157 ≥	≥ 0.0143	2 Star	0.0785
< 0.0117		5 Star	0.0585

Scenario 3 – Hot water in use phase

In base case of this study, room temperature of water (~27° C) is used in the use phase of washing in all wash cycles. In this scenario, hot water is used in 20% of the wash cycle in a year, i.e., 63 wash cycles are considered as hot water wash cycles in rainy season only. Maximum hot water temperature is 48° C is used according to the BEE report in Indian usage. To achieve the temperature of hot water from the cold water by the direct heating concept is applied.

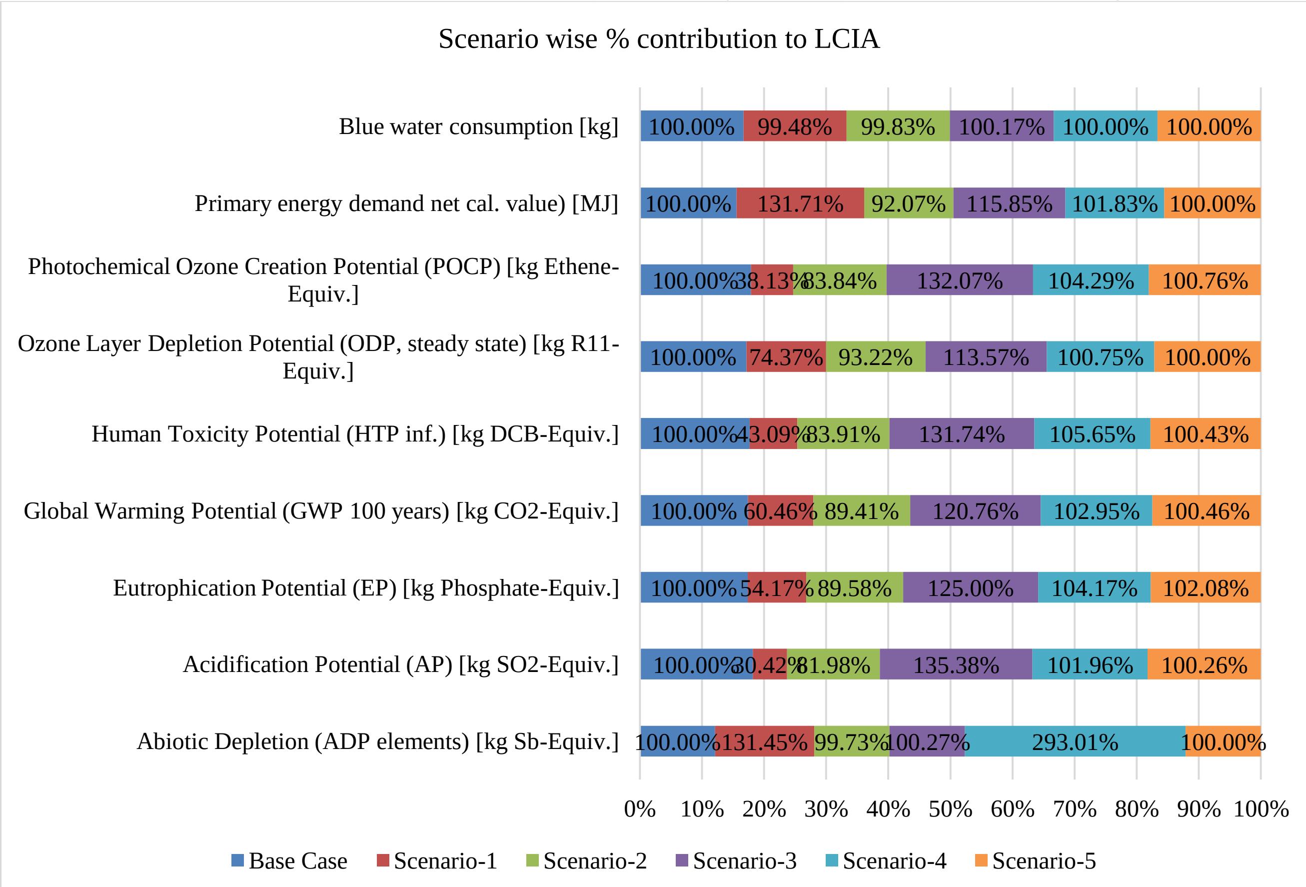
Scenario 4 – No recycling of materials

In this scenario, it is considered that all material components are disposed of in the landfill. With the comparison of base case in this scenario steel, aluminum, copper, plastic completely goes into landfill.

Scenario 5 – Steel and Plastic variation

In scenario-5, it is considered that plastic materials replace steel materials. For that weight of the steel is reduced by 20% from the base case and 15.74% increases plastic weight by assuming that on average mass of the steel components have six-time more massive than of the plastic parts.

Table 10: Scenario Wise % contribution to LCIA Impacts for 15 years life span of one unit of washing machine



5. Conclusions

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, water temperature scenarios. Through these scenarios, the best-case scenario, practically applicable to Indian situation were applied, studied and inferences were 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 the overall high-quality data and represents the actual scenario.

Some of the environmental impact categories showed the highest value out of the 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, packaging 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 accounts for 4.09% and spin dryer assembly for 2.62% of the total impact, and packaging accounts for 0.81% and end of life accounts for -1.65% of the total life-cycle impacts.
Blue Water Consumption is 5.78 E+05 kg with the major contribution from Use phase of the washing machine for ~99.871% of the total impact.
The outcome of this study can be directly used in the vendor qualification process leading to a business proposition of this study.

6. Future scope:

As a next step extension to the study, a fully automatic machine can be compared with the semi-automated washing machine. This was not the objective of the current study; however, as another goal was to identify hotspots, I am presuming that a fully automated machine will have better savings and lesser impacts which can be recognized as an extension of the study. Future research includes expanding the system boundary to cover cradle to cradle, i.e., recycling benefits. Internal and external benchmarking for the value chain can be initiated. Further product wise LCA can be performed for application of new generation domestic appliances products.
The results obtained, show that an environmentally aware society along with national regulation on energy and water consumption can help decrease the environmental impact significantly. However, the most significant change required is awareness among the consumers and an initiative among individuals to reduce their environmental impact. So, the effect of a washing machine on the environment relies heavily on consumers' behaviour.
Consumer choice and behaviour can be highly variable and a major contributor to the environmental impact of typical household activities such as washing, cleaning etc. Interactions between consumers and products may have a large effect on the overall results of life cycle assessment (LCA) studies. However, the variability in consumer behaviour is often not included in LCAs because these are generally aimed at quantifying the average impact of a process or a product rather than the full extent of possible outcomes like in environmental risk assessment methods.

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