

WASHING MACHINE

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Abstract

Washing machines are designed to provide clean clothes while retaining the quality of the material. The use of the washing machine however, is a highly energy and water intense process that results in a number of negative impacts on the environment.

The purpose of this case study is to perform a thorough analysis of the environmental impact of the washing machine. For this reason a life cycle assessment (LCA) is conducted for a state of the art washing machine produced in 2011 as well as an older one, produced in 2005. Comparisons of parameters such as design, energy and overall efficiency of the machines are also considered.

The results of the life cycle assessment indicate that the use phase of the washing machines is the dominant stage where the environmental impact occurs. A comparison among the two models show that the machine produced in 2011 has a better performance during the use phase,

mainly due to higher energy efficiency. However, when it comes to the impact caused by the materials that constitute the machines, the model produced in 2005 has a lower impact than the 2011 model. The increased amount of electronic and plastic parts is responsible for this result. Moreover the formative scenario analysis (FSA) method is implemented in order to develop possible future scenarios and evaluate their influence on the environment.

The results obtained, indicate that an environmentally aware society along with governmental regulation on energy and water consumption can help reduce the environmental impact significantly. However, the most important change required is awareness among the consumers and an initiative among individuals to reduce their environmental impact.

Acknowledgements

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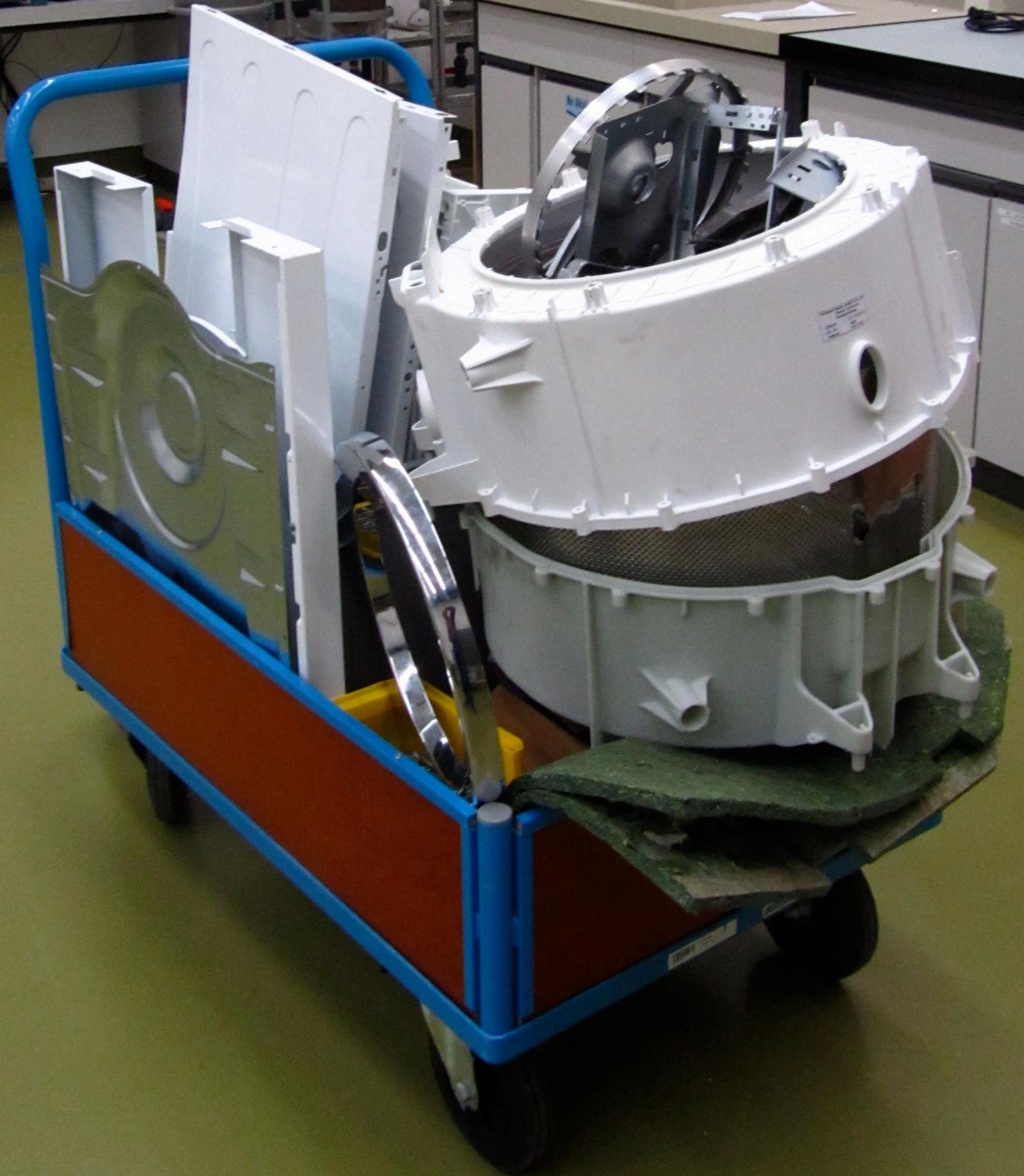
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INTRODUCTION

FRAMEWORK, EXPERIMENTS AND INVENTORY

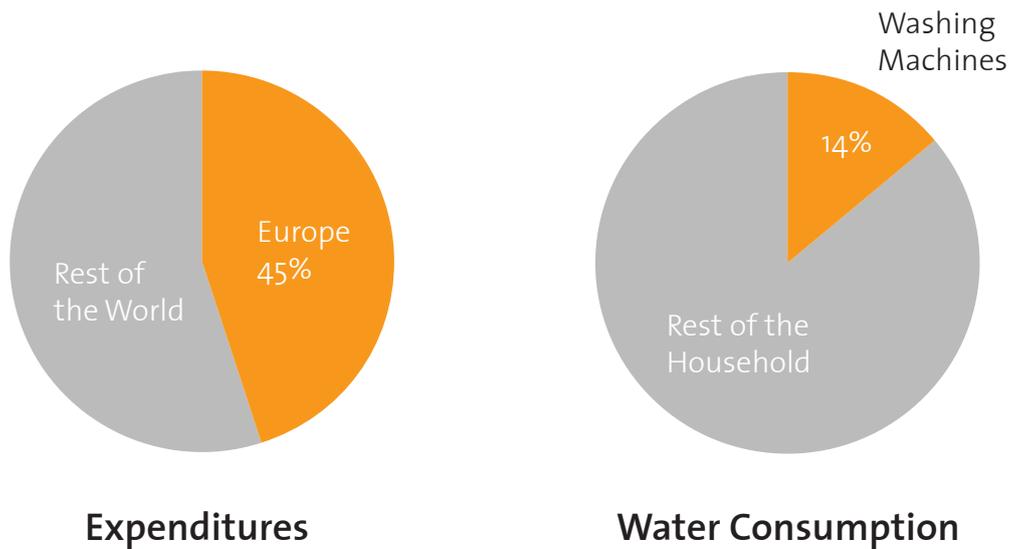


Figure 1: Washing Machines Today.

Framework

Motivations

The washing machine is a commonly 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 to the increased use of washing machines among households for laundry instead of hand washing. Around 17.8 million washing machines are estimated to be sold in Europe every year [1]. Moreover, European countries account for 45% of the global expenditure on washing machines and other laundry products which is around \$41 billion per year [2].

Washing machines are designed to provide clean clothes while retaining the quality of the material. However, its usage is a highly energy and water intense process that result to a number of negative impacts on the environment. Moreover, the product itself consists of a large variety of materials mainly metals and plastics that can lead to significant impacts in regards to resource consumption. Previous studies that examined the life cycle impact of washing machines showed that 95% of the impact is associated to the use phase [3]. Hence, the effect of a washing machine on the environment relies heavily on consumers' behavior. According to industry trends, increase in the load capacity resulted to an increase of the frequency of usage as well.

Washing machines, today, account for 14% of total water consumption by households globally and have the second

larger share after toilets [4]. Technological advancements in the past 20 years have resulted to a decrease of the water consumption during washing to less than 50L per wash [5].

Purpose

This case study performs a thorough analysis of the environmental impact of the washing machine focusing also on parameters such as design, energy and overall efficiency of the machines.

Objectives

The primary objective of this study is to identify the environmental impacts connected to the given washing machines throughout their life cycle i.e. from the production of the raw materials that constitute the machines until the end of life. Moreover, the stages where the most significant environmental impacts occur need to be highlighted and discussed.

The next objective is to discuss a number of improvements as well as to suggest and analyze different future scenarios that would reduce the overall ecological impact of the washing machine including the washing process.

Finally the last objective of this study is to discuss the role of designers, manufacturers and users, and their respective contribution to the overall ecological impact of washing machines.

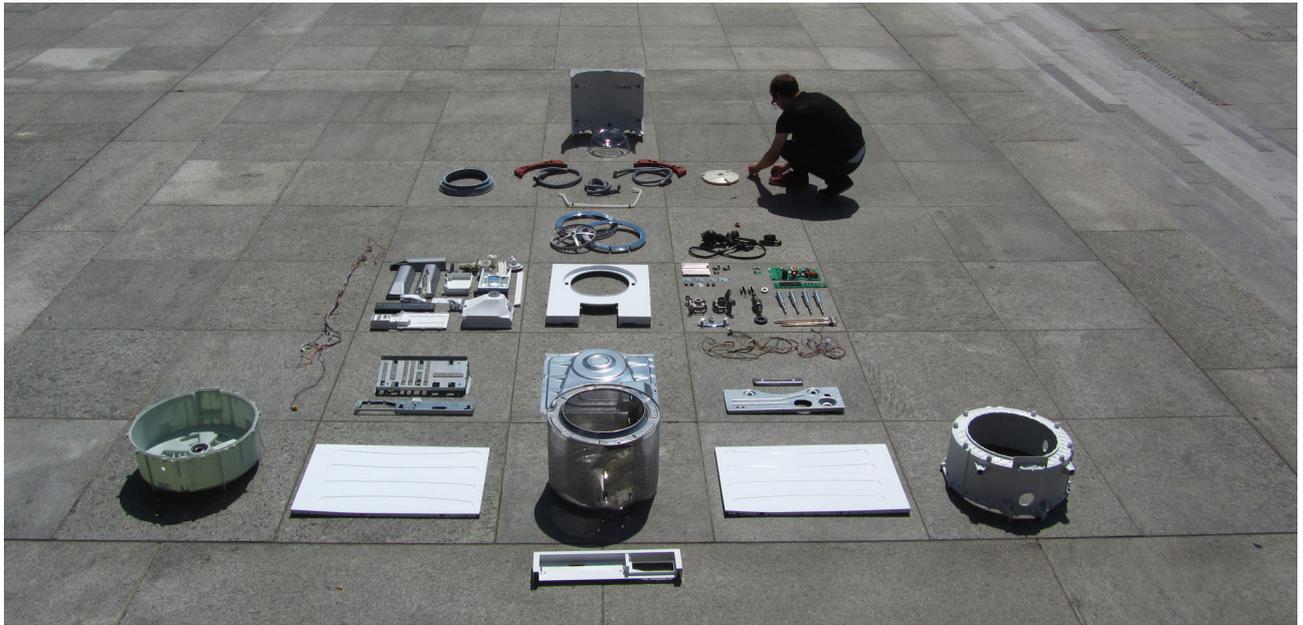


Figure 2: The Washing Machine - sorted.

Life Cycle Assessment

In order to determine the relative impact that washing machines and washing processes have on the environment, we use the life cycle assessment (LCA) methodology. LCA is a tool that examines and evaluates the environmental performance of all different stages that can be identified during the life cycle of a product, starting from material acquisition until the end-of-life processes [6]. All inputs and outputs need to be estimated in order to evaluate the type and significance of the impact that they may cause on the environment.

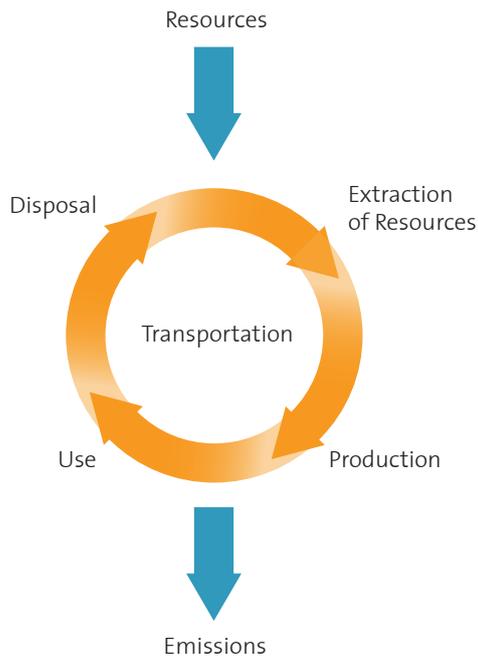


Figure 3: Life Cycle Flows.

Washing Machines

Two washing machines are used for comparison and analysis during this case study, a state of the art V-ZUG ADORA SLQ produced in 2011, hereafter referred to with ADORA, as well as an older model, a NOVAMATIC WA 1656 produced in 2005, hereafter referred to with NOVAMATIC.

The new ADORA machine has been directly provided by the manufacturer V-ZUG AG. The NOVAMATIC machine is an end-of-life machine provided by IMMARMARK, a major recycling company for electronic devices in Switzerland.

In order to be able to perform a thorough and detailed assessment the following tasks need to be completed.

- Collect data about the water and energy consumption of the machines during their utilization stage.
- Compile an inventory about all the materials that are used for the manufacturing of the machines.

The washing machine is a complex unit and its performance is affected by a various parameters such as water temperature, washing load, frequency of use, detergent used, which depend mainly on consumer preferences as well as the specifications of every washing machine.

The washing machines considered in this case study refer to regular washing machines used in private households. Professional washing machines that are used in industries or companies are out of the scope of this work.

The inventory data is analyzed using the Sima-Pro Software (Version 7.1).

Experiments and Results

Water and Energy Consumption

The NOVAMATIC has reached the end of life state and is out of order. Therefore the experimental process regarding the use phase of the washing machines was conducted only for the ADORA.

A number of measurements are performed even though this information can be also found in the printed manual of the machine. However a cross checking and a comparison is made in order to examine the robustness of the manual recommendations.

Three washing cycles are performed that assumed to represent average consumer behavior of a 3 persons household in Europe. The different temperatures examined are: 40°C, 60°C and 95°C while the setting for the load (amount of clothes in every washing cycle) is kept constant at a full load of 7kg. These setting were discussed and decided by the performers of this study based on the literature research and information collected by the manufacturers of the ADORA.

The weight of the washing machine as well as of the clothes was determined before starting the washing program and after the wash. The used water was transferred into buckets in order to measure the total amount of water required per wash. A power and energy meter (emu) was connected to the washing machine to measure its energy consumption.

Material Inventory

Both the ADORA and the NOVAMATIC machines were dismantled in order to collect information about the different materials that constitute the machines.

The different components that were obtained after the dismantling of the two machines were separated into material fractions or component fractions, when further dismantling was not possible. In order to determine the total amount of each material fraction their weight was determined as well as the share of each fraction to the total weight of the washing machine.

The outcome of the disassembly process is used as an input for the modeling of the inventory part of the life cycle assessment.

An additional objective is to compare the materials that constitute the new ADORA (2011) to the older NOVAMATIC (2005) and identify the differences in regards to their composition and the environmental loads related to that.



Model	V-ZUG ADORA SLQ
Type	WA-ASLQ
Dimensions	85cm x 59.5cm x 60cm
Weight of Machine	69.91 kg
Weight of Packaging	3.23 kg

Figure 4: The V-ZUG ADORA SQL

	Experimental Data	Data from Manual
Experiment 1 : 40 °C		
Weight of Clothes	7 kg	1-8 kg
Time Taken for a Wash	1 h 23	1 h 05 - 1 h 14
Water Consumption	69.76 L	70 L
Energy Consumption	0.47 kWh	0.80 kWh
Experiment 2: 60 °C		
Weight of Clothes	7.66 kg (wet)	1 - 8 kg
Time Taken for a Wash	1 h 40	1 h 15 - 1 h 32
Water Consumption	67.6 L	65 L
Energy Consumption	1.08 kWh	1.30 kWh
Experiment 3 : 95 °C		
Weight of Clothes	7 kg	1 - 8 kg
Time taken for a Wash	2 h 28	1 h 38 - 2 h 15
Water Consumption	70.6 L	75 L
Energy Consumption	2.14 kWh	2.20 kWh

Table 1: Experimental Results.

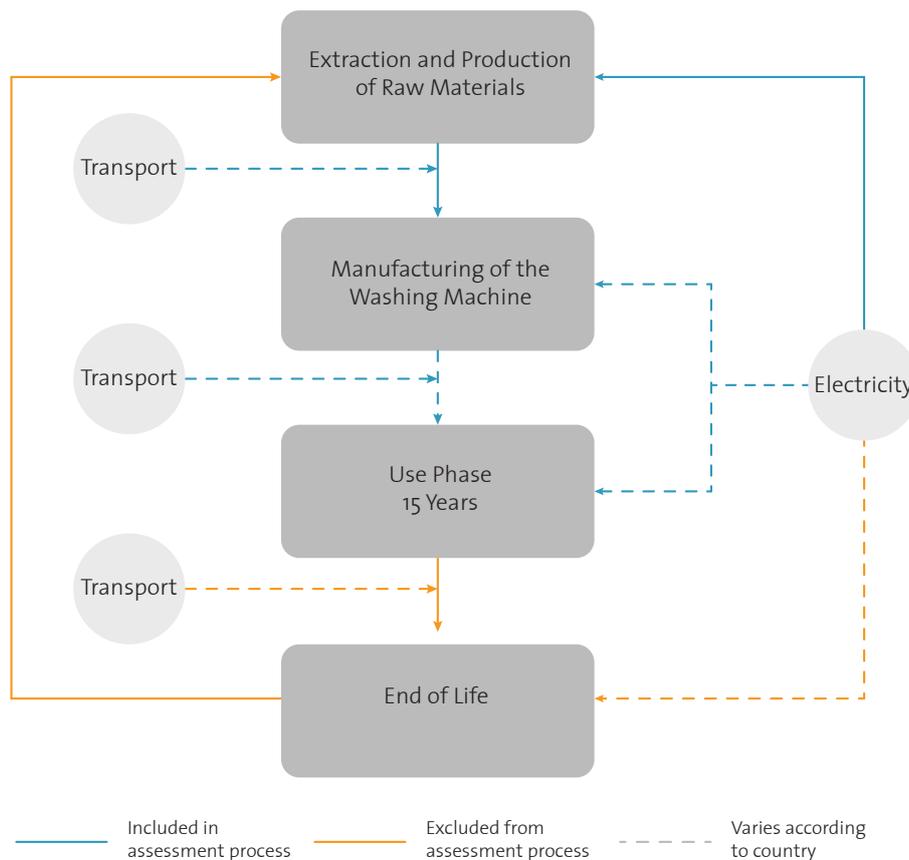


Figure 5: A Representation of the Total Life Cycle of the Machine.

Life Cycle Assessment

We aim to identify and evaluate the environmental impact of two given washing machines, the ADORA and the NOVAMATIC, during their complete life cycle i.e. from cradle to grave. We also aim to highlight the activities and stages that have the biggest contribution to the environmental impact.

More specifically the life cycle stages and activities that are examined in this study include:

- extraction and production of the materials that constitute the washing machines
- manufacturing of the washing machines
- transportation of the product from the producer to the consumer
- utilization

The assessment of the end-of-life processes for the two machines (i.e. recycling processes, incineration etc.) is not included in this case study due to information and time constraints. Maintenance and repair activities of the machines are also excluded.

A reference case is used for the estimation of the environmental impact of the two machines (data for Switzerland) and then scenarios for different countries (Germany, Belgium, Greece, Italy and Australia) are also modeled in order to evaluate the influence of the electricity mix on the final impact.

For the environmental impact assessment the IPCC Global Warming Potential Indicator for 20 years is used as well as the Eco Indicator 99 (HA) method.

Functional Unit

For the purpose of this case study the functional unit was selected based on an analysis of the current trends of the industry as well as trends in consumer behavior, particularly in Europe. As a result the functional unit is defined as a machine having a capacity of 7kg of clothes per wash, washing 175 times per year, at a mix of 40°C, 60°C and 90°C over a life cycle of 15 years.

The reason for assuming these particular values is that 7kg is the maximum load for the majority of washing machines available in the market today. Moreover the trend for the washing temperatures as well as the selection of the life time is based on discussion with V-ZUG.

Assumptions, Limitations and System Boundaries

During the 15 years of the life cycle, we assume a total number of 2625 washing cycles i.e. 175 washing cycle per year, based on information collected by the literature.

We assumed a temperature mix according to data collected by the manufacturer and in the literature about user habits.

In regards to the electricity mix during the use phase several cases are examined for different countries during the analysis. However, the reference case is assumed to be the Swiss mix, as in Figure 7.

Due to inability of getting access to the suppliers, the information was limited to that gathered from the manufacturers. Thus the materials are assumed to be produced in Europe and transported to Switzerland. The transportation of the product from the producer to the consumer is assumed to be 150km for the case of Switzerland and the 2011 washing machine model and 250km for the 2005 since it is produced in Germany. In case

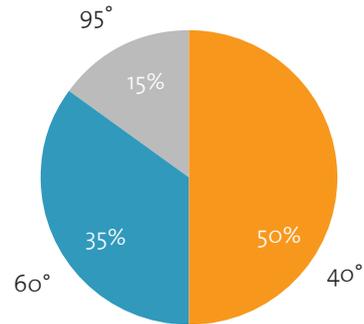


Figure 7: The Swiss temperature Mix.

of further variations this will be indicated to the respective part of the report.

During the modeling process, the default information provided by the databases included in the Sima-Pro software is used. These datasets are assumed for the production of the materials of both machines, ADORA and NOVAMATIC.

Detailed information on the material composition was not available due to the company’s policy. During the disassembly process the components of the two washing machines were divided into material fractions trying to be as detailed as possible. However, for the material composition of a number of parts assumptions were needed when further separation was not possible. Among others rough estimations about their compositions are made for the motor, the cables and other components.

The composition of the detergent is assumed to be as in Figure 6. For every wash 65gr of detergent are assumed according to [8].

Data Collection

This LCA is based on quantitative data which were collected from various sources. Average as well as site specific data are used during the inventory process.

The majority of data in regards to the material composition of the studied washing machine as well as data for the utilization stage were obtained from our own measurements.

Data regarding the production of the raw materials were directly added in the inventory using the Ecoinvent database provided by the Sima-Pro software.

Moreover, during literature research a number of publications related to the topic of the study were reviewed.

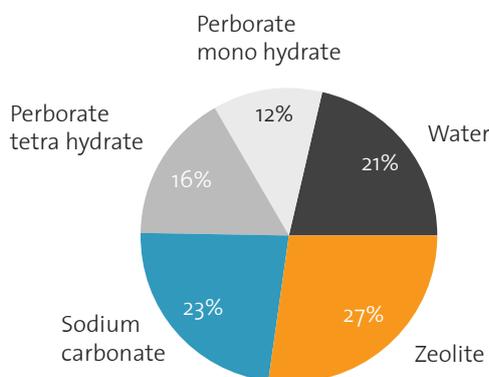


Figure 6: Composition of the Washing Detergent.

Inventory Results

Material Composition

The total weight of the newer ADORA is 70.10 kg while the older NOVAMATIC weights 76.60 kg. In regards to the weight of the different material fractions the two machines have many similarities as well as significant differences as shown in Figure 9.

The metallic parts of the two machines (i.e. steel, aluminum) as well as the plastic (i.e. PP, PE) weight almost the same for both cases.

The most important difference between the two models concerns the stabilization system where the 18.51 kg concrete component in the older machine has been replaced by two cast iron parts weighting 9.3 kg in total, in the new one. Furthermore the weight of glass, copper, MDF, EPDM is slightly increased in the new washing machine. In addition to these, it is noted that the weight of the printed board (i.e. electronics), though small in either case, is more than four times for the new machine compared to the older one. This indicates that the new machine was capable of performing more functions than the older machine.

Use Phase

The comparison of the energy and water usage during the use phase of the machines is shown in Figure 8. While the ADORA consumes slightly more water than the NOVAMATIC, the ADORA is more energy efficient for all temperatures.

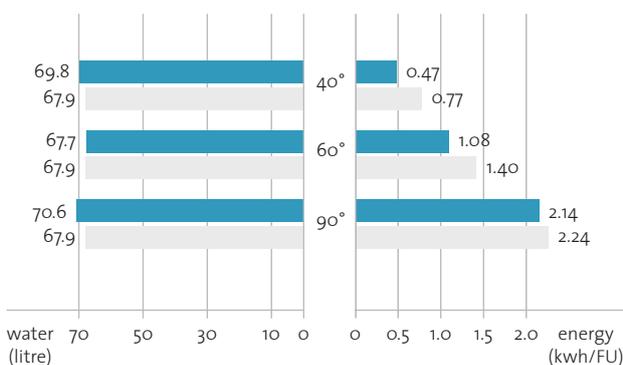


Figure 8: Energy Usage vs. Water Consumption.

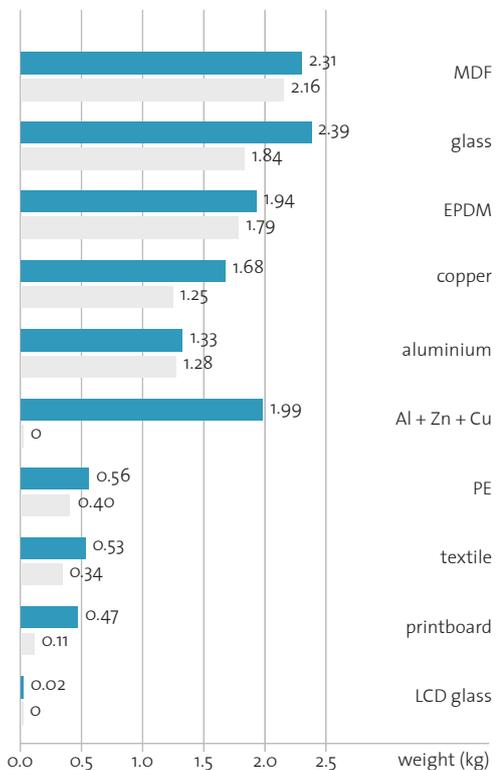
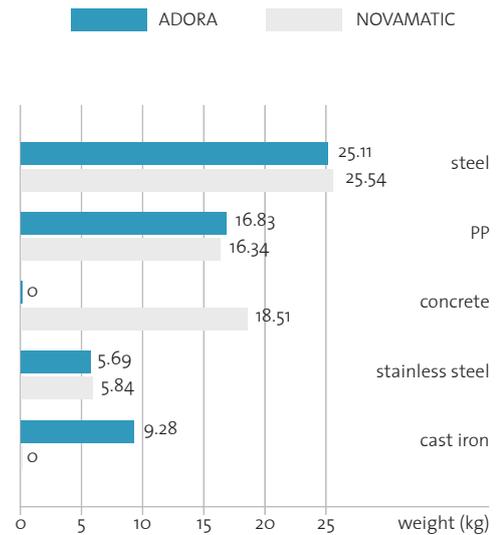


Figure 9: Material Composition.



The Washing Machine, hard at Work during the Use Phase Experiments.

IMPACT ASSESSMENT

PRODUCTION, USE PHASE AND TOTAL LIFE CYCLE

Material Composition

Even though the two washing machines have many similarities in terms of materials, we have identified a number of variations. Some new materials were introduced and some compositions were changed.

IPCC, Global Warming Potential Indicator (GWP)

The ADORA seems to have a greater impact in regards to the GWP indicator compared to the NOVAMATIC, as indicated in Figure 10.

Figure 11 shows the detailed results for the ADORA. We observe that polypropylene (PP) contributes with 37% to the total GWP which is the highest share in this case. In addition, the impact rates on GWP for the printed wiring board and steel are 17% and 14% respectively while the impact of aluminium, copper and Zamak (Al+Zn+Cu) is relatively lower. It can be noted that we observed during the disassembly process that the amount of plastics and copper were slightly higher for the newer ADORA.

Similarly, Figure 11 also shows the details for the NOVAMATIC in comparison with the ADORA, with polypropylene being the highest contributor with 40% to the GWP. The next major contributors are the printed wiring board and steel with 18.5% and 16% respectively. In addition to that aluminium and copper give a relatively smaller impact on GWP.

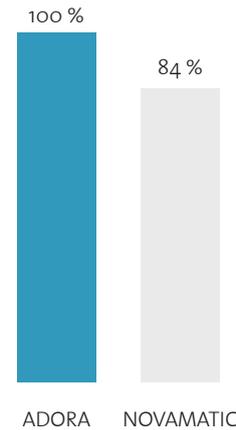


Figure 10: Comparing 1 kg ADORA with 1 kg NOVAMATIC using the IPCC 2007 GWP 20a characterisation Method.

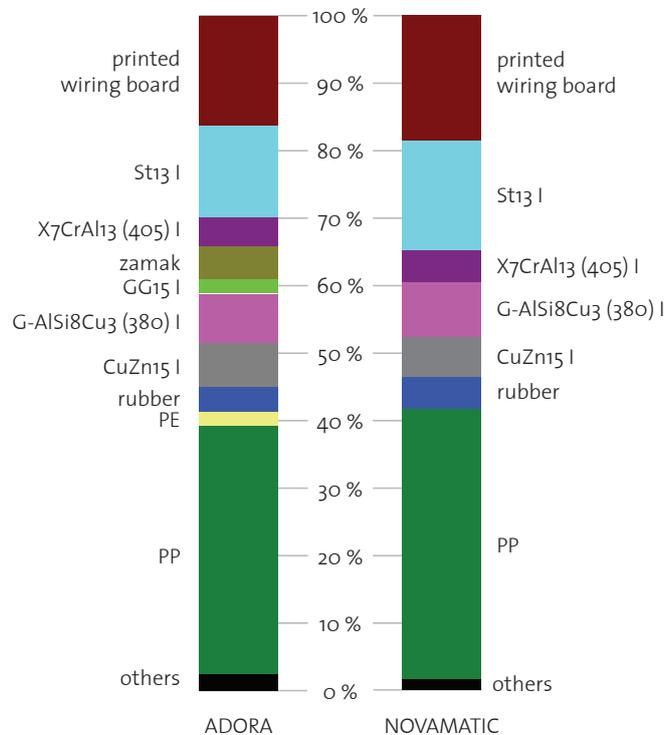


Figure 11: The detailed GWP Indicator.

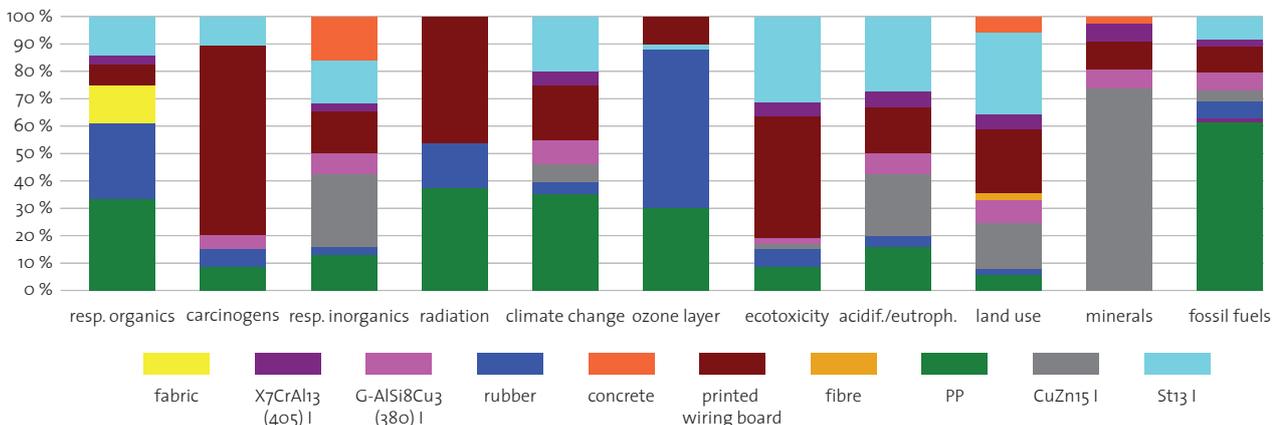


Figure 12: Analyzing the Impact of 1 kg NOVAMATIC on human health, the ecosystem quality and resources by materials using the Eco 99 Single Score Indicator.

Eco Indicator 99 (HA)

The Eco-Indicator 99 is a life-cycle impact assessment method to evaluate the damage in 3 main categories, namely, human health, ecosystem quality and resources [11].

The results obtained by the Eco Indicator 99 method show again that the total impact of the new machine is higher than the older one, see Figure 13. Among the different impact categories for both studied machines, human health is affected the most by the effect from respiratory inorganic substances. The different impact categories included in the method and attributed to the studied products are also indicated.

In Figure 14, the impact of each of the materials is analysed in detail. It can be observed that the printed wiring board and copper fraction have a significant contribution to the categories of carcinogenic and respiratory inorganic substances respectively. In general, printed wiring board, copper, polypropylene and rubber influence human health at the highest rate. Polypropylene gives also a considerable contribution to all three impact categories of climate change, ionizing radiation and ozone layer depletion. However, the highest influence on ozone layer depletion is caused by rubber. The quality of the ecosystem is mainly influenced by the increased amount of printed board, steel and copper that is found in the ADORA. In addition to that the impact of polypropylene and copper on the resources (i.e. fossil fuels and minerals) is also significant.

Again, the results for the NOVAMATIC are very similar, see Figure 9. The biggest influence of the old machine on human health comes from the printed wiring board (mainly by carcinogenic substances), the amount of polypropylene, copper and rubber. Polypropylene has the biggest contribution on global warming potential. The printed wiring board is a major contributor to ionizing radiation while rubber contributes most to the ozone layer depletion. The ecosystem quality is mainly influenced by the printed wiring board, steel and copper. Dominant materials for the depletion of resources are steel (land use), copper (minerals), and polypropylene (fossil fuels).

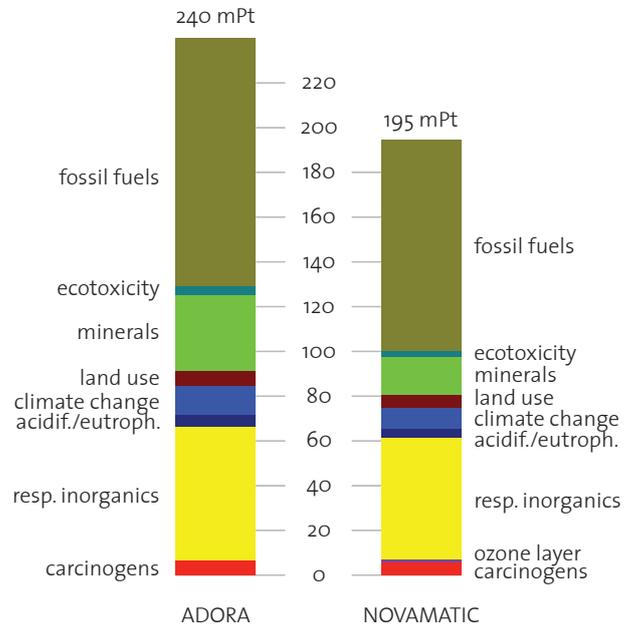


Figure 13: Comparing the ADORA to the NOVAMATIC using the Single Score Eco Indicator 99

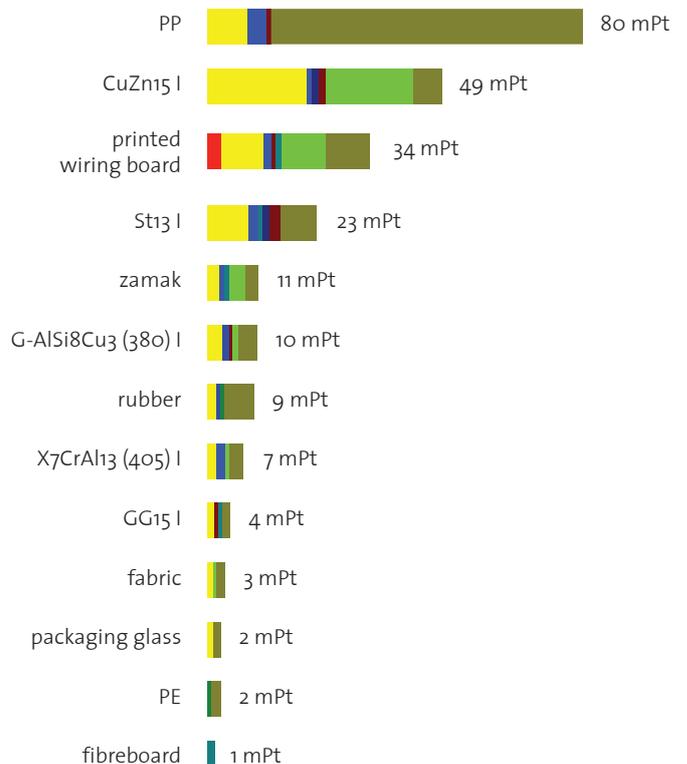


Figure 14: Analyzing the impact of each material of the ADORA using the Eco 99 Single Score Indicator.

Total Life Cycle

Use Phase

The use phase of the two machines has also been evaluated using the GWP and the Eco Indicator 99. During the modeling process the functional unit (life time, temperature mix, etc.) as well as the assumption for the electricity mix were kept constant for the two machines while the amount of energy and water required varied according to the machine (Figure 8).

Figure 15 presents the result obtained for the GWP indicator during the use phase. The ADORA seemed to have a lower impact compared to the NOVAMATIC.

A lower total impact is also assigned to the ADORA using the Eco 99 Indicator. Among the different impact categories the depletion of resources and especially fossil fuels is influenced the most during the use phase of the washing machine mainly due to the life time energy requirements and the electricity mix assumed (in this case the electricity mix of Switzerland). Indicatively the use of fossil fuels accounts for almost 41% for of the total impact to the environment for both washing machines. The next most affected impact category is human health, caused by respiratory inorganic substances.

Total Life Cycle

The use phase is obviously the dominant contributor to the total impact for both washing machines.

Looking deeper into this phase we observe that more than 80% of the impact comes from the 40°C and 60°C washing cycles while the remaining 20% come from the 95°C cycles because the frequency of washing in this temperature is lower as assumed during the inventory.

In lower temperatures the impact of the detergent becomes higher than that of the electricity. For the ADORA, 21% of the impact on GWP during the use phase is due to the detergent with only 9% for electricity at 40°C. While at 95°C, 6.5% comes from the detergent and 12% from the electricity.

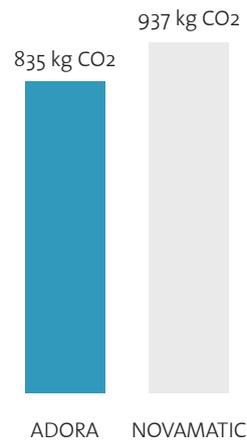


Figure 15: Comparing the Use Phase (40°, 60°C, 95°C) of the ADORA with the NOVAMATIC using the GWP Indicator.

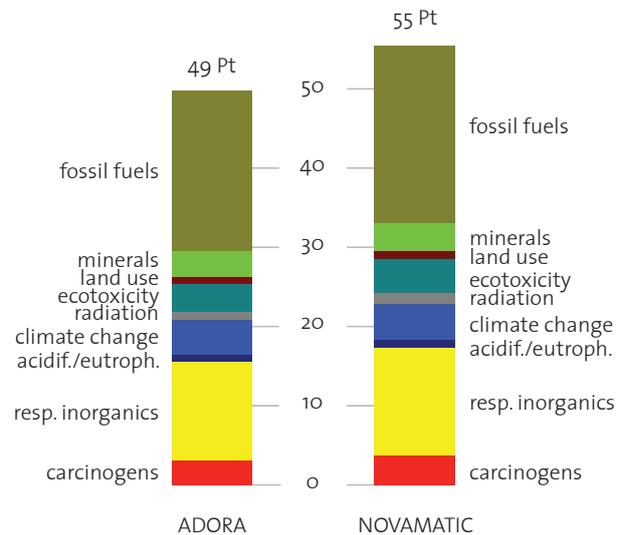


Figure 16: Comparing the detailed Impact of the Use Phase of the ADORA and the NOVAMATIC using the Eco 99 Indicator.

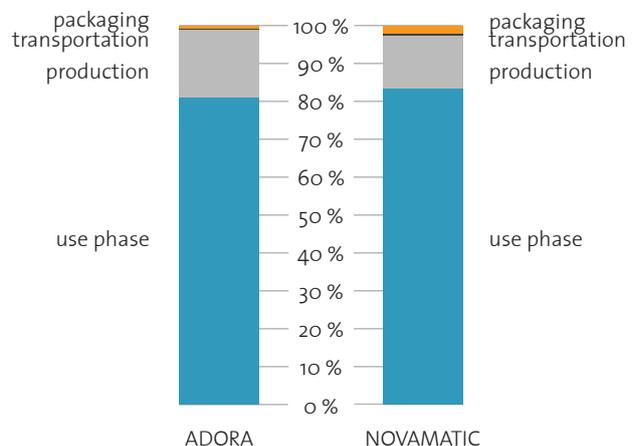


Figure 17: Total Life Cycle Impact using the GWP Indicator.

Different Countries

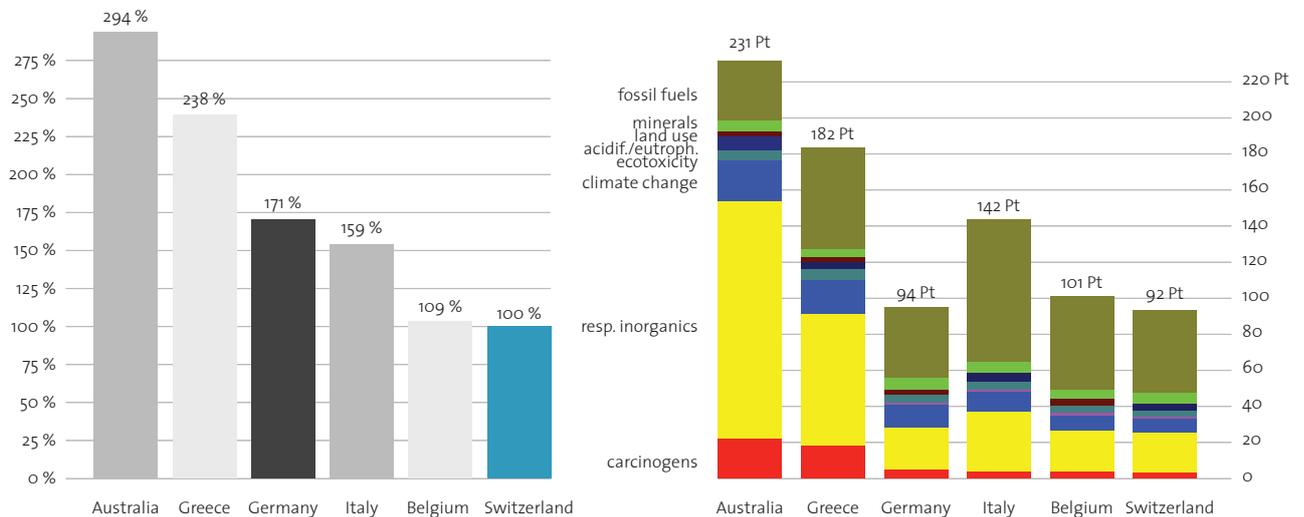


Figure 18: The ADORA in different countries using the GWP Indicator (left) and Eco 99 Indicator (right). The environmental impact depends heavily on the use phase. Therefore the energy mix of the country determines the environmental impact.

In order to analyze the environmental impact of washing machines in different countries, we used the baseline inventory results described above, changing only the electricity mix according to the respective country. Moreover, the appropriate distance from the producer (Switzerland) to the respective end user needs to be estimated. The selected countries are Switzerland (reference case), Italy, Belgium, Greece and Australia.

The following assumptions were made to analyze the impact in transportation phase:

- Zurich, Switzerland – 150 km, Lorry 3,5 ton.
- Florence, Italy – Lorry 7,5 ton.
- Leuven, Belgium – Lorry 7,5 ton.
- Hamburg, Germany – Lorry 7,5 ton.
- Thessaloniki, Greece – Lorry 7,5 ton from Zurich to Ancona and from Patra to Thessaloniki. Container cargo from Ancona to Patra.
- Canberra, Australia – Lorry 7,5 ton from Zurich to Genova and transoceanic freight from Genova to Sydney.

For the use phase different cases for the electricity mix are examined based on the data provided by the Ecoinvent database. Only for the case of Australia an assumption has to be made since no data is included in the Ecoinvent

database. For this reason the energy mix for Australia is assumed to be: 76% coal, 15% gas and 7% renewable (based on a combination of MK (Macedonia) (50%) + PL (Poland) (50%) that seemed to be similar.

In turn the environmental impact for every country is estimated according to the IPCC GWP and the Eco Indicator 99 method similarly to the previous cases. The results presented in Figure 8 show that the Australia gives the highest contribution to GWP due to the relatively long distance of transportation. The next biggest contributor is Greece, followed by Germany, Italy and Belgium. Apart from transportation, the respective energy mix of the country is also a key driver for the GWP of washing machines.

According to the Eco Indicator 99 analysis, Australia gives the highest impact on human health especially in terms of respiratory inorganics and carcinogens. The natural resources like minerals and fossil fuels are influenced by production, transportation and usage of washing machines in all selected countries significantly. Australia and Greece give the biggest contribution to climate change while the other three countries are contributing relatively less. These differences could mainly be due to the transportation distance and use of different energy mixes.



The Washies at V-ZUG, looking into the crystal bowl.

FUTURE SCENARIOS

FORMATIVE SCENARIO ANALYSIS AND RECOMMENDATIONS

Impact Variables

Scenarios for the washing machine were developed in order to gain further insights and analyze the potential for future improvements. The main goal was to develop the most sustainable one.

The scenario technique was developed by Herman Kahn and it depicts the system, in this case, the washing machine at a future time and how it reached that state [10]. In the present case study, a systematic approach was taken to develop 3 scenarios but the probabilities of these scenarios are not important and have, therefore, not been considered. The approach taken was similar to the method described in [10].

Impact variables

In order to predict how the washing machine will look in the future, and which developments are needed, the important factors influencing the machine need to be taken into account.

Consumer Habits

The lifestyle and washing habits of the consumers is a major factor in determining the machine's ecological impact. The following are the main consumer habits taken into consideration:

- Wash load: The amount of clothes per cycle.
- Frequency: The number of times a machine is used.
- Soap used: The amount and type of detergent used has an impact on the lifetime and the quality.
- Maintenance of the machine: Affected by the washing habits of the consumers.
- The program used for washing: The program used affects the machine's overall impact.
- Sharing of machine: Whether one person uses the machine or if it is shared among several parties.

Technology

Advancements in technology would lead to better washing quality per wash as well as more sustainable production of the machines. New technologies could significantly reduce the machine's ecological impact.

- Wash quality and cleanliness of the clothes
- Material usage in production of a washing machine
- Washing machine lifetime

Energy consumption

The energy depends particularly on the temperature. Using lower temperatures would result in minimal energy usage.

Water consumption

A considerable amount of water is used per wash and is a big factor in determining the machine's overall impact.

Price of energy (Yes/No)

Currently, there is no price placed on energy. However, in the future, if a price is placed on energy, it would affect the consumers' washing habits as they would endeavor to use less energy in order to save money. This would have an impact on the usage of washing machines.

Regulations (Yes/No)

At present, there are no regulations regarding the use of washing machines and detergents. In the future, however, if they are implemented it can considerably help consumers check their washing habits and reduce their impact on the environment. In the absence of any regulations, the impact would remain the same.

- Eco labels for the machines: Shows the energy rating of the machine.
- Energy mix: The source of energy used to power the washing machine
- Pre heating: Pre heating the water so that the thermostat in the machine recognizes the incoming hot water and extra energy isn't wasted in heating the water to the desired temperature
- Post heat extraction: Technology to extract heat from the machine after its use, in order to reuse the heat.
- Laws for bio-degradable detergents: Laws in the future which will encourage the use of environmental friendly detergents
- Taxes for using more energy efficient machines: Imposing taxes on the use of machine with a low energy rating.

The impact factors were categorized as quantitative and qualitative. The quantitative factors were those for which numerical values were available for the current scenario. These were then changed (either increased or decreased) to develop the scenarios.

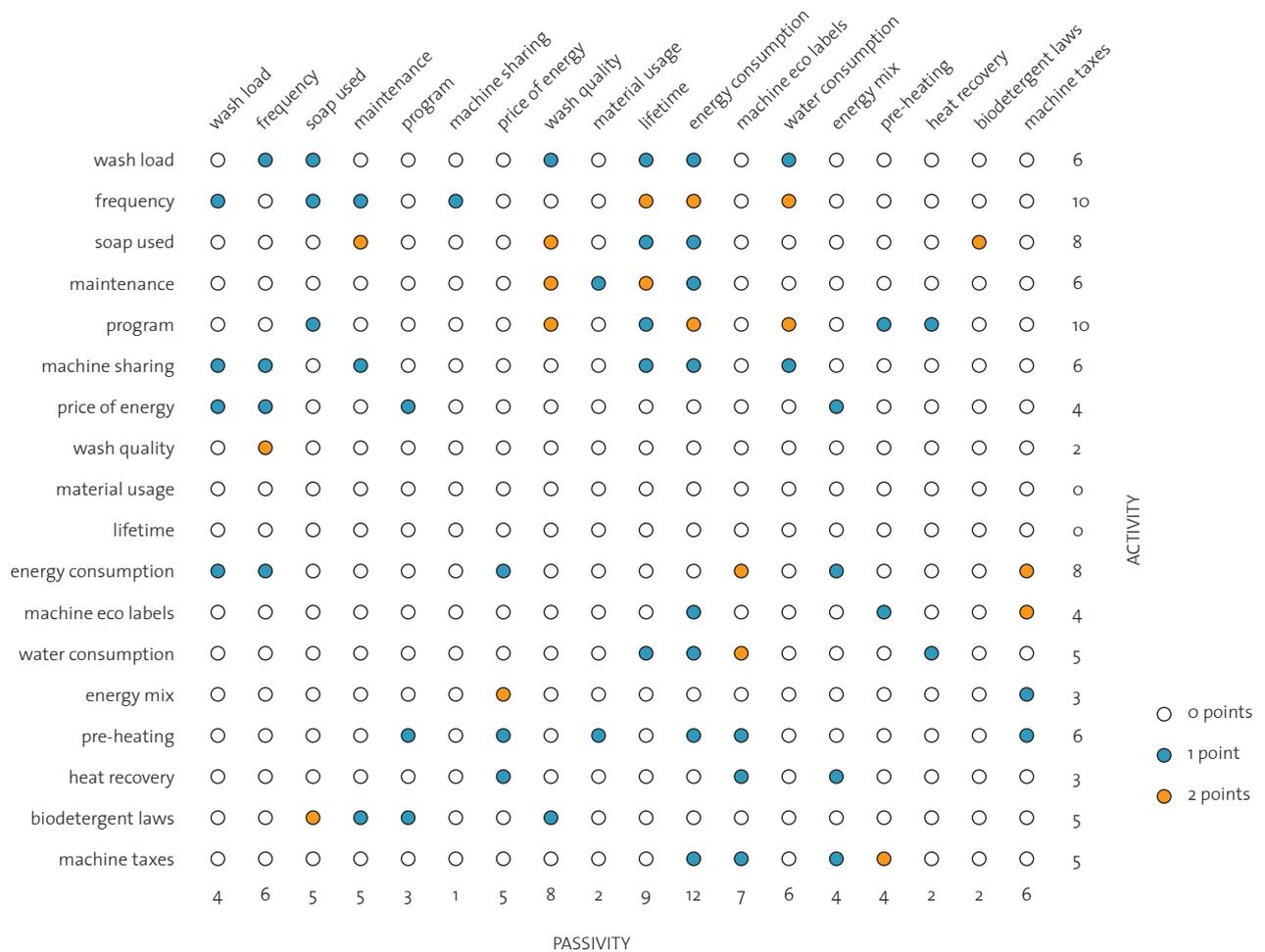


Figure 20: The relation of the different variables and their activity and passivity as defined below.

Impact Matrix

An impact matrix was developed to assess the direct and mutual impact of each of the impact variables. In order to rate the variables, a **scale** ranging from 0-2 was developed where a rating of 0 implies that the variable has very little or no impact, 1 implies that the variable has a medium impact and a rating of 2 is given where the variable has a high impact. The ratings were decided by the case study team after extensive discussion of all the variables and their impact, followed by a group vote. This method, however, is subjective and based on the team’s expertise

in the area, knowledge and opinions.

The row sum was taken for each of the impacts to determine its **activity**. Here, activity refers to the impact of the particular variable on all other variables. The **passivity** was determined by the column sum for each variable and indicates the extent to which the variable is influenced by the other variables. These results were used to generate graphs which have been attached in the next section.



Figure 21: The Impact Variables arranged by activity and passivity and classified accordingly.

Graphical representation

After the assessment of the impact variables (IV), a system grid was introduced in order to visualize the various impacts and their characteristics. The activity and passivity ratings for each variable was plotted to obtain the graph. With the average activity and passivity of 5.1, the sketch can be divided into four areas: The ambivalent IV, active IV, passive IV and the buffer variables.

- Ambivalent impacts have above average passivity and activity and are therefore, the key drivers of the environmental impact.
- Active impacts are directly responsible for environmental impacts. A reduction of these impacts directly contributes to a lower environmental impact.
- Passive impacts are influenced by other impacts and are indirectly responsible for environmental impact.
- Buffer variables are below average in respect to activity and passivity. They are not the main contributors to the environmental impact.

Interpretation

From the graph obtained it can be observed that the factors which have the highest impact are those of frequency, soap used, the lifetime, and water and energy consumption.

High energy consumption is one of the major impacts of washing towards the environment. By the amount of energy consumed, the environment is influenced, over the lifetime of a washing machine. Improving the consumers' behavior is, therefore, the most important and effective way to reduce the overall environmental impact. The use of materials, on the other hand, has a far less significant influence on the environment.

Scenario Development

	Clean and Green	Business as Usual	Worst Case	
Wash Load	12.25	7.00	3.36	kg/wash
Frequency	100	175	365	nb of washes/year
Soap Used	3.3	12	47	kg/year
Sharing of Machine	0.08	0.23	1.20	mio machines/household/year
Lifetime	25	15	5	years
Energy Consumption	35	82	172	kWh/year
Water Consumption	700	12250	25550	L/year

Figure 22: The 3 Scenarios in Numbers.

From the impact matrix the most important factors were determined to be those of wash load, frequency of washing, the amount and type of soap used, habit of sharing of machines, the lifetime of the machine and the energy and water consumption during washes. These are all quantitative factors and were used to develop the scenarios.

The functional unit for the present case scenario is defined as follows: The washing habits of a 3 person household in the year 2020, where the average wash load is 7kgs and washing is done 175 times per year. For each wash, 67 grams of detergent is used and the total number of machines used in Switzerland is 3.5 million units.

Clean and Green (Best Case Scenario)

The 'Clean and Green' scenario assumes that the people are increasingly becoming aware of climate change issues such as global warming and their impact on the environment. As a result, the environmentally concerned people have adapted habits and lifestyles aimed at reducing their carbon footprint and impact on the environment. The government has also introduced laws insisting on the use of bio-degradable detergents. Besides that, the government is regulating the machines in the market to ensure that each comes with an eco-label indicating its energy efficiency. Moreover, consumers buying machines with an energy rating less than A+ will be required to pay an additional tax to offset their ecological impact. In such a scenario, the consumers are conscious about their washing habits and machine usage. Thus, under this scenario, the machines have good eco ratings, and are used on the most energy and water efficient program settings, along with ecological detergents. It is also assumed, that the water is preheated which further reduces the energy consumption of the

machine and the heat generated is extracted for re-use.

Business as usual (Current Scenario)

In the 'Business as Usual' scenario, the global concern about climate change and the environment is increasing and people are becoming more aware of the impact of their daily activities on the environment. However, the population as well as demand and use of household appliances have also increased in conjunction. In this case, the total amounts of washing machines, as well as other habits, have remained the same as they were in 2011. Thus, this scenario assumes that business will be carried on as usual. In this scenario, the water and energy consumption remains the same, since the average population continues to wash their clothes at 40°C. Any regulations, taxes or prices relating to energy and water use have not been implemented. Hence, it is the same as the present day scenario.

We couldn't care less (Worst case scenario)

In this scenario, the people are not well aware of the drastic effects their daily activities can have on climate change and the environment. As a result, the increasing advancement in technology and high economic development, along with increasing global population has resulted in washing machines being used much more frequently. The increase in single-person households has also resulted in a higher number of machines being produced and consumed. Consequently, the water and energy consumption has increased and the washing machine lifetime has decreased drastically. Washing machine technology has advanced, but the worsening of consumer habits outweighs the positive impact of technology. In this case, due to the absence of any laws or taxes, the maintenance of the washing machines is poor due to their excessive usage.

Scenario Results

Once the scenarios were fully developed and values or conditions for the different impact variables were assigned, they were analyzed for their overall environmental impact using the software Sima-Pro. This was done by using the data for each of the scenarios in Sima-Pro to calculate its impact using Eco-Indicator 99. The setting for IPCC (20 years) was used in order to determine the global warming potential (GWP) for each of the scenarios. The results obtained have been given below along with the graphs.

The Eco-Indicator scores obtained from the LCA show that for Scenario 1, the impact can be divided by 3 in comparison to the business as usual Scenario 2. On the other side, the worst case scenario yields a 5 times higher impact.

As for the GWP, it can be observed that Scenario 1 has only 4% of the global warming potential of Scenario 3.

From the results and graphs obtained above, it is clear that the realization of Scenario 1 would significantly reduce the environmental impact as indicated by the Eco-Indicator. Its contribution to global warming is also negligible. Scenario 3, on the other hand, would be detrimental to the environment due to its high level of damage to the environment as well as its huge contribution to global warming.

It can hence be concluded that effort should be made to implement Scenario 1. With the enactment of laws and regulations on energy and water consumption, along with encouraging the use of environmental friendly detergents, an energy efficient and green environment can be achieved. However, the biggest change required is a change in consumer behavior. This can be achieved by creating ecological awareness and making individuals realize the impact of their daily activities on the environment. An environmentally conscious society would use washing machines judiciously and only when required which would greatly reduce their overall impact.

The results also indicate that if society was to remain the same, the total damage to the environment is given a score of 4.3 by eco-Indicator 99 while the GWP is 58.4 kg CO₂ equivalents.

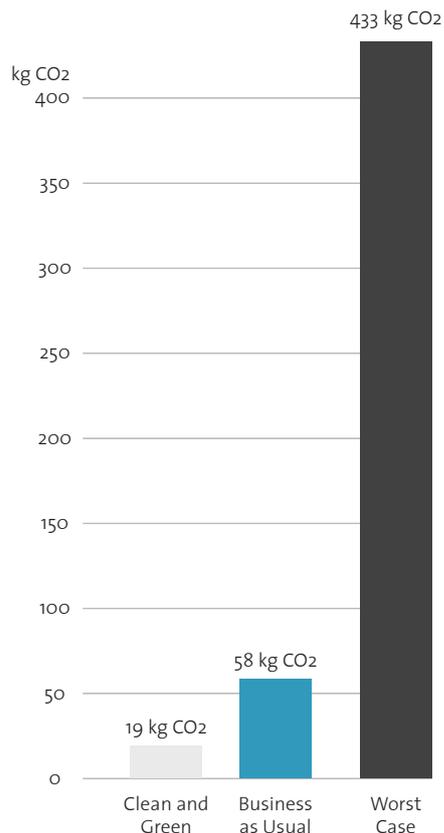


Figure 23: GWP Indicator for the 3 Scenarios.

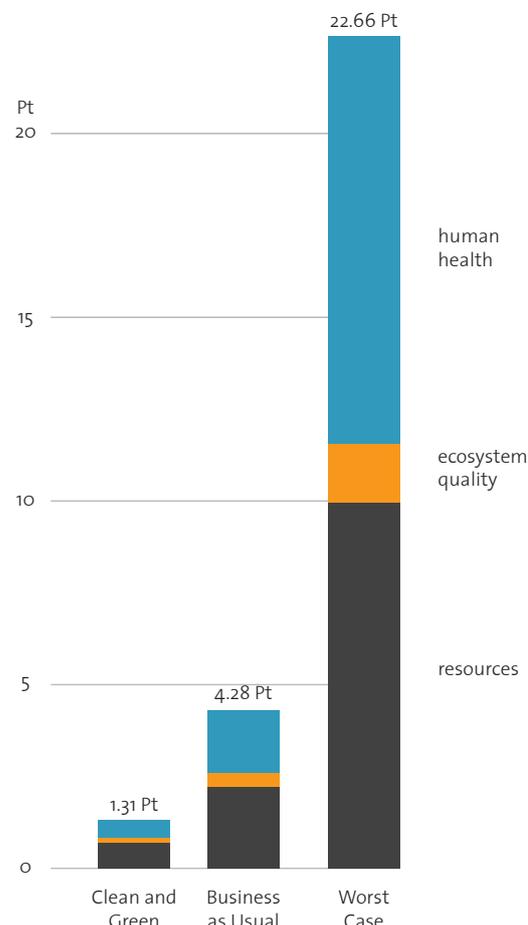


Figure 24: The Eco 99 Indicator for the 3 Scenarios.

Governments	Producers	Consumers
<ul style="list-style-type: none"> • Enforce further improvement of Ecolabels • Taxation of inefficient machines (less than A) • Teach global citizenship in school • Enforce smart grid: less base demand for electricity 	<ul style="list-style-type: none"> • Substitute metal and plastic with biodegradable plastic • Further efficiency in water and electricity • New technologies, i.e. UV instead of soap, plastic granulate instead of water • Reduction of program complexity (printboard) • Use hot water supply 	<ul style="list-style-type: none"> • Less washing, higher washload • Share washing machines • Less soap / better soap • Buy Cradle-to-Cradle machines

Figure 25: Recommendations for a Clean and Green Future.

Recommendations

During the case study a thorough LCA of the two washing machines was conducted successfully, to determine the areas with the biggest impact on the environment followed by a Scenario Analysis to suggest future scenarios which could help reduce the impact significantly.

The LCA results indicate that the use phase is the main contributor to the environment in the case of both machines with an approximate contribution of around 80% to the total environmental impact. The production phase on the other hand accounts for less than 20% of the total contribution. Another interesting result that was observed was that in the use phase, the biggest contributors were electricity and the soap used. For Switzerland, the impact of the soap used is higher at washing temperatures of 40°C, while at 95°C the impact of electricity is higher.

Moreover, a LCA was also conducted for the respective countries of the team members and it was observed that the same washing machine produces 208% more emissions in Australia as compared to Switzerland. Most of Australia's energy is from coal fired power plants whereas in Switzerland the energy derived from coal is almost negligible as most of their energy is from renewable sources such as hydro power and nuclear. It can hence, be concluded that the energy mix of the country makes a significant difference on the environmental impact of appliances such as the washing machine.

The final step in the case study was development of future

scenarios to predict the trends in washing machine usage and how it would affect the environment. A formative scenario analysis was performed and it can be concluded that an environmentally aware society along with governmental regulation on energy and water consumption could help reduce the environmental impact significantly. However, the most important change required is awareness among the consumers and an initiative among individuals to reduce their environmental impact.

Recommendations for a 'Clean and Green' Scenario

At a national level, the government should enforce regulations to make eco-labels mandatory on all washing machines. This would help the consumers decide on a more energy efficient machine while increasing their environmental awareness at the same time. Besides, imposing taxes on inefficient machines would also discourage consumers from buying them. Furthermore, global citizenship should be taught at schools to raise a generation of environmentally conscious individuals. The producers of the machine should introduce more sustainable materials in the production phase along with new technologies for more efficient and ecological machines. One such technology could be the use of UV light to clean clothes or plastic granules. These technologies - if developed - would completely eliminate the use of water and thereby, reduce the impact significantly. Finally, the consumers can make a significant impact by using machines judiciously while keeping the environment in mind.

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