Bachelor Thesis

Faculty of Science and Engineering

Sustainability of drinking cup usage at the University of Groningen

T.H.R. (Rik) Klement

Industrial Engineering and Management

Supervisors:
dr. ir. J. Vos
dr. A. Bosch
drs. C.M. (Karin) Ree
Group 15

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Abstract

Summary of the report

Worldwide, up to 500 billion disposable drinking cups are disposed of every year. Because, on many locations, as the University of Groningen, disposable cups are the norm. Here, The Green Office sees opportunity for sustainable improvement. Throughout the product life cycle of cups, relevant elements of usage are assessed and valuated in terms of pollution and energy requirement. Production, reusable washing and end of life are the most relevant. In the end, the findings are interrelated and made interactive in an advisory model. Driven by a user configurator, and database containing valued sustainability assessment elements. The model provides user specific information and advice on cup usage behavior, predominantly after how many uses of a reusable cup would beat usage of disposable cups. Concluded is that, the majority of cup users on the University of Groningen should switch to reusable cup usage, to improve the sustainability of the drinking cup usage system.

Contents

Abbreviations - frequent usage in report

TGO - The Green Office
UoG - University of Groningen
DE - Douwe Egberts
CO2eq - CO2 equivalent
UoW - University of Wageningen
kWh - Kilo Watt Hour
GHG - Green gouse gas
kJ - Kilo Joule

1 Introduction

1.1 Drinking cup usage on the UoG

Worldwide, over 500 billion disposable drinking cups are disposed of every year [Laura and Bakshi, 2014]. Most disposable cups are land filled or incinerated and not recycled. Either because recycling is not possible or not worth the effort, environmentally or financially. Still, on many locations disposable cups are the go-to option, because of the ease of usage. The University of Groningen is one of such locations.

The environmental impact of drinking cup usage on the University of Groningen can be reduced. The UoG outsources catering activities throughout its facilities. Douwe Egberts and Beijk are the main players in hot beverage services. Vending machines from DE are widely available, on many location throughout the buildings. Beijk vending machines are located in canteens. Both vending options include a disposable cup in the offered beverage. Disposable cups are the easy choice for a organisation as the UoG [Potting and van der Harst, 2015], where users walk their beverage and no widespread washing facilities are available for reusable cup usage. Moreover, the vending machines from DE are operated completely unmanned. Whereas Beijk vending machines require payment with a staff member. The latter enabled for the now offered €0,10 discount per beverage, to users that vend with their own cup. Only, this measure is very low key and not automatically applied. The discount offered is a measure to boost reusable cup usage. As conventional wisdom suggests that multiple uses of a reusable cup produce a lower overall environmental impact per use than a single use of a disposable cup [Hocking, 2018]. Additionally, policy or advice to boost sustainable cup behavior on the UoG, has not yet been implemented widely [Maltagliati, 2020]. Resulting, the norm is still usage of disposable cups. Although, initiative towards reusable cups is on the rise.

1.2 Drinking cup sustainability

The Green Office (TGO) is a department of the UoG, coordinating and initiating projects related to sustainability [UoG, 2020a]. TGO sees opportunities in sustainable improvement of the drinking cup system on the UoG and seeks for insights. Currently, it is unknown what cup is most sustainable in which situation on the UoG [Maltagliati, 2020]. Therefore, policy or advice to boost sustainability has not yet been implemented widely. The environmental impact of the system is relevant, as many cups are used on the UoG. An example of magnitude; on the University of Wageningen (UoW), which is approximately 3 times smaller based on amount of students [UoW, 2020] [UoG, 2020b], around 2.5 million disposable cups are used yearly [Potting, 2013].

Furthermore, no shortcut to simply introducing the 'most sustainable cup' is possible, as such a cup does not exist in a general sense. The situation and setting of usage sets standards for sustainability, as well as measurements to determine to what extent a cup is sustainable. One of the key points of interest here is the *usage iterations* - the number of times one beverage is consumed from one cup. Arising from, the initial environmental impact of producing cups versus using cups. Where generally, per use, a reusable cup becomes more sustainable opposed to, a disposable cup that does not change per use.

This report aims at indicating what the most sustainable drinking cup choice is and boost the usage of it, for drinking cup users on the UoG. Considering both the users' situation at hand and the specifics of the cups available. Providing the first step towards a fitting and sustainable cup usage advice policy on the UoG. By means of a advisory model that indicates the most sustainable cup behavior for a user, according to the users' input. The model is based on sustainability assessment elements, established throughout the life cycle of cups used on the UoG. After which, the sustainability assessment elements are valued in terms of energy requirement and pollution. Both elements of cup usage and cup characteristics are considered. Finally, measures to boost compliance with the advice are proposed, to support sustainable cup usage on the UoG.

2 Problem analysis and conceptualization

2.1 System description - describing the flow of cups for the UoG

This research is set up around the University of Groningen (UoG). More specifically, on the usage of cups - disposable and reusable - at the UoG. Therefore, the system is described by the flow of cups, for the situation of the UoG in Figure 1. The system is described as such, because sustainable assessment is conducted on the different stages of this system.

Cup usage at the UoG starts from cup production where the initial environmental impact of a cup is set, by means of material usage and production method. Following the chain towards the UoG, with transportation. After users select their cup and consume their beverage, one of three possibilities happens with a dirty cup; disposing, rinsing or cleaning. Disposal on the UoG is handled by Renewi at first, the remainder trash is redirected to Attero [Kranenburg, 2020]. Moreover, after disposing, it depends on the cup type and manner of disposal what happens to it [Foteinis, 2020]. Either the cup is recycled or burned as trash. On the other hand, before reuse a cup is rinsed or cleaning. Cleaning facilities are not widely available on the UoG, some research groups or offices have their own kitchen included dishwasher. However, for students no public washing facilities besides toilet sinks is available. After cleaning or rinsing, a reusable cup is ready for reuse.

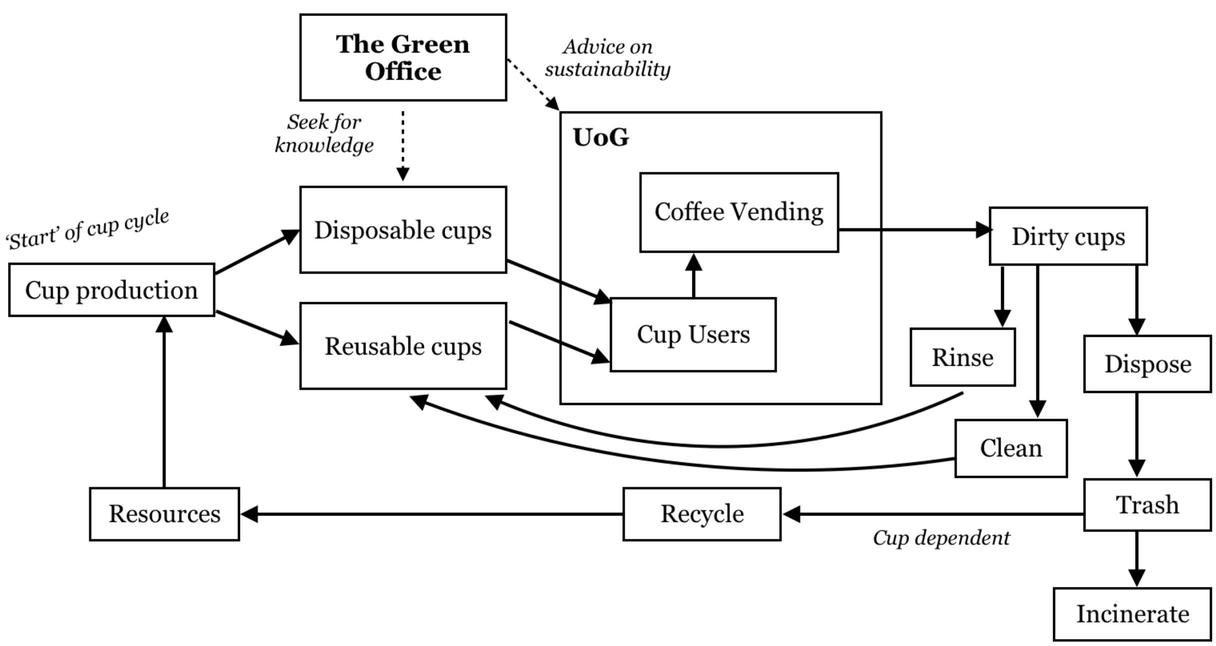

Figure 1: *System described by the flow of drinking cups, in situation of the UoG*

2.2 Stakeholder analysis - stakeholders in the cup usage system at UoG

The system is specified by identification of stakeholders. Identified based on, interest in, and power to influence the outcome of the project. The Mendelow diagram in Figure 2. visualizes stakeholders' power and interest [Ackermann and Eden, 2011].

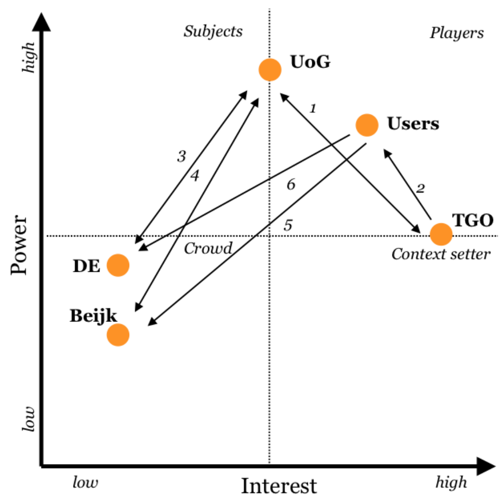

Figure 2: *Mendelow diagram, indicating stakeholders' power, interest in the project outcome*

- **Green Office - Problem Owner**: TGO aims at a sustainable UoG [UoG, 2020a]. Consequently, TGO seeks to get insights into drinking cup usage at the UoG, as room for sustainable improvement is expected. Therefore, TGO has high interest in the outcome of this project, as a first step to sustainable improvement of the drinking cup system on the UoG [Maltagliati, 2020]. As problem owner TGO is regularly updated on project progress and findings, to match the proposed goal and outcome. TGO provides advice to users and the UoG *(connection 1/2 in Figure 2)* giving them only moderate power, as advice is dependent of acceptance and implementation.

- **Cup users UoG**: The outcome of the project eventually aims at cup users on the UoG. Because, sustainability of the cup usage system is dependent of user behavior. When users do not comply with the proposed advice, implementation has no effect. Therefore, users have high power in the final outcome of the project. Consequently, the last subject aims at measures to boost compliance of cup users on the UoG. Moreover, high interest because the hot beverage vending experience is possible changed. Users interact with the system by beverage vending from DE or Beijk, *(connection 5/6 in Figure 2).*

- **University of Groningen (UoG)**: Holds high power as the UoG regulates actions from TGO (connection 1 in Figure 2. On the other hand the interest in the outcome is moderate. Although sustainability is a goal from the UoG, cup sustainability is specific without priority. The UoG regulates both DE and Beijk as service relations *(connection 3/4 in Figure 2).*

- **Douwe Egberts**: DE is providing the majority of coffee services on the UoG. DE could induce some power in the final outcome of the project, by not cooperating with possible cup usage changes that DE is involved in. On the other hand, low interest as the coffee services are provided anyways as the contract with UoG is there. DE is considered crowd, therefore not considered as active stakeholder.

- **Beijk**: Beijk is providing high-end coffee services on the UoG. Beijk coffee is served in disposable cups from Ecotainer. Relative low power compared to DE as there appearance on the UoG is lower. Similar interest to DE. Like DE, Beijk is not considered as active stakeholder.

2.3 Scope - project context defined

The scope of this report is split into: research scope, cup selection and design scope. From the complete system data is gathered in order to design more specific, zooming in on the system. The research scope of this report is limited to sustainability analysis on cups selected within the system of the UoG, cups are defined in section 2.3.1. This analysis is conducted throughout the life cycle of cups. Therefore, the research scope is visualized as the system description in Figure 1. Additionally, the design scope is elaborated in Section 4.

2.3.1 Cup selection

Stakeholders Beijk and DE interact with the system as they provide the gross of hot beverage vending on the UoG. Ecotainer cups are used for beverage vending from Beijk machines and DE cups for beverage vending from DE machines. On the other hand, the not yet widely used reusable cups, could be used for all types of beverage vending as users bring reusable cups themselves. A 'standard' ceramic mug is taken here, that most people already own. The ceramic cup is most likely used by people with regular a work space, like offices or labs. On the other hand, students make up for a large part of drinking cup users on the UoG, students often carry their cup in a bag on a daily basis. Therefore, a 'to-go' cup is taken here. Selected is the *Let's connect* reusable cup from the UoG's I-Shop [I-Shop, 2020], reusable cup selection is further elaborated in section 3.3. The selection of cups within the scope of this study is listed below and depicted in Figure 3.

(a) Ecotainer **(b)** Douwe Egberts **(c)** I-Shop *Let's connect* **(d)** Ceramic mug

Figure 3: The selection of cups considered in this study

2.3.2 Design Scope

The design scope is different from the research scope as focus is on the application of system-wide knowledge gathered through research, in a narrower context. In the end, enabling for advice on sustainable cup behavior on the UoG. Final design is focused on adjusting the system, within the boundaries of the design scope, as indicated in Figure 4. In other words, stimulating a cup user to select the cup that is most sustainable. Additionally, steer towards an efficient cleaning and rinsing procedure. Moreover, how the system could be adjusted to support and boost compliance with the proposed advises. As behavioral change of users in the end ensures a more sustainable drinking cup system.

Focus is not to alter contracts, both for suppliers or waste companies. The UoG is bound to established contracts and contract negotiations are ongoing. Additionally, no cup will be redesigned or waste collection chain is created. In short, to improve sustainability of the drinking cup system, within system boundaries. Therefore the design aims at, sections of the system that a cup user can directly influence or at measures that directly influence users, visualised in Figure 1. Advice on sustainability, is directed towards the cup users and the coffee vending system as a whole. Analysis of cup sustainability per scenario combined with stimulating measures. Where both the user advice and stimulating measures are focused on the following aspects of the cup usage system.

1. Selection of the most sustainable cup
2. Usage of the cup in sustainable manner

Disposing of the cup is excluded here, as the waste stream infrastructure on the UoG is yet insufficient for cup users' behavior to be of relevance, this is elaborated later in section 3.5. Similarly, resources used and production method for cups have no priority to be changed. The zoomed in scope for design is visualized in Figure 4.

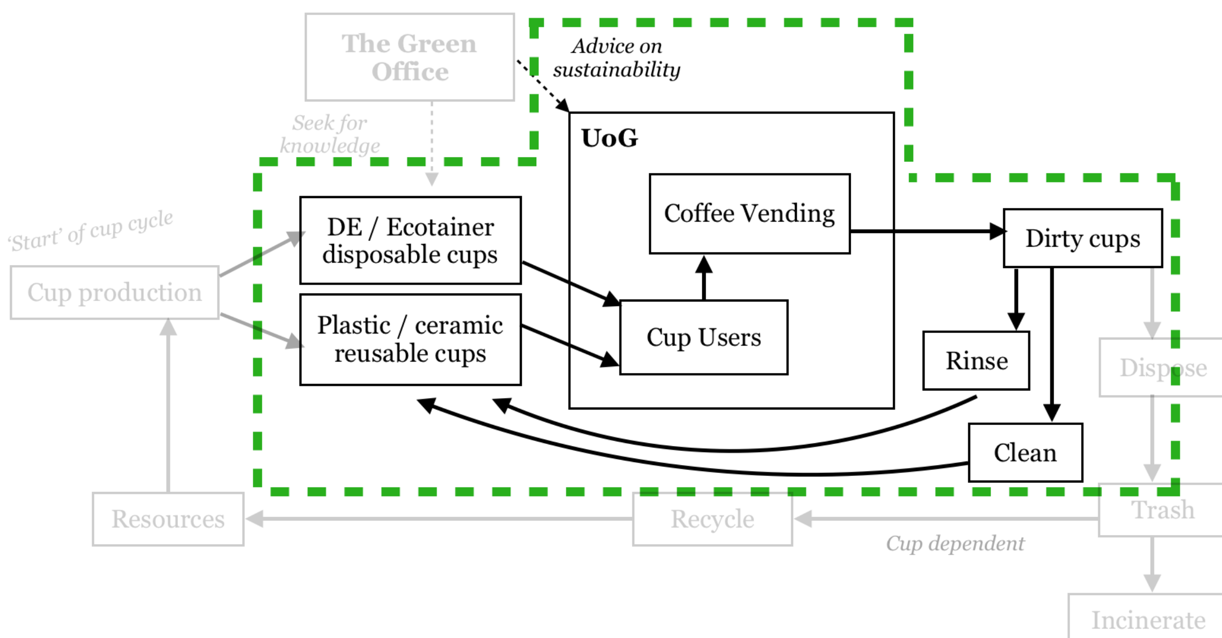

Figure 4: *Design scope, zooming in on the complete system*

2.4 Problem statement - knowledge on cups required for sustainable advice

TGO seeks to adequately advise cup users on sustainable cup usage on the UoG, for that purpose additional case specific knowledge on cup sustainability is required [Maltagliati, 2020]. Furthermore, the magnitude of cup usage on the UoG indicates relevance for possible sustainable improvement. Initiating advice requires case specific research at first [Laura and Bakshi, 2014]. The problem from broad to narrow is visualized and summarized in the why-what model in Figure 5. Where the blue box is the original problem from TGO. The problem statement is formulated as follows:

The Green Office desires a more sustainable UoG and sees opportunity for sustainable improvement in drinking cup usage at the UoG. However, to make the drinking cup usage more sustainable The Green Office needs situation specific knowledge on drinking cup sustainability and directions to apply this knowledge at the UoG.

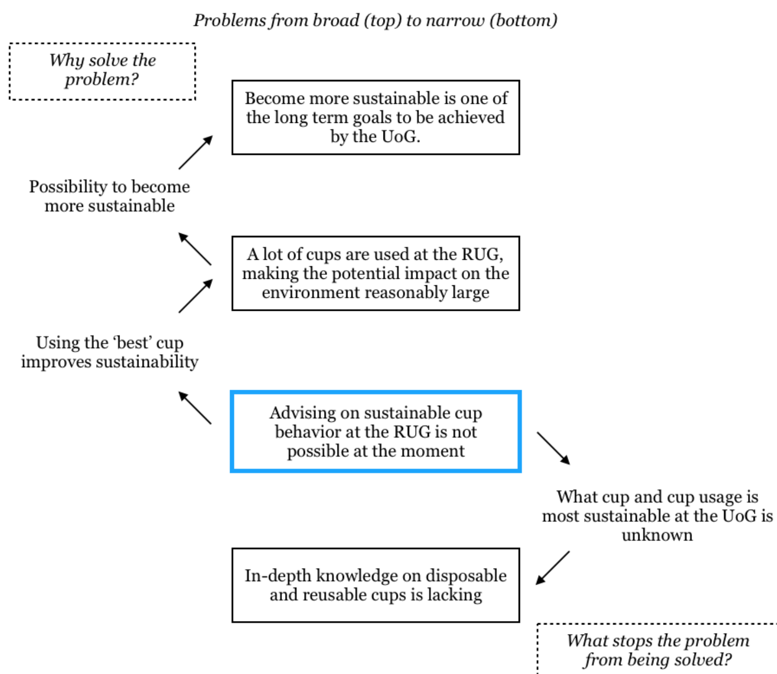

Figure 5: *Why-What model indicating the problem on different levels*

2.5 Goal statement - indicate most sustainable cup usage behavior

The desired goal from the problem owner is adapted based on the problem conceptualization, the position of stakeholders and scope. Resulting in a research goal as formulated below.

Enable The Green Office to improve the sustainability of cup usage on the UoG, by providing an advisory model that indicates the most sustainable cup choice according to the users' situation. Based on, cup characteristics and elements of usage, evaluated on environmental impact. Accompanied with, measures to boost compliance with the advice."

This project is conducted within time-span of three months, chosen such that TGO has time between receiving the deliverable and the start of the new academic year. In order to, fine tune the proposed model and implement a new advice policy for sustainable cup usage.

2.6 Research Framework and Research Questions - from cup characteristics and user interaction to model

The research framework in Figure 6 schematically represents the appropriate steps to achieve the objective [Verschuren et al., 2010]. Initial research is on evaluating or measuring the 'sustainability' of something. More specifically, disposable and reusable cups and user interaction to cup usage *(step a)*. Establishing relevant assessment elements for sustainability per cup type and user interaction scenario *(step b)*. After which, the assessment elements on both cups and user dependent elements are scored and interrelated *(step c)*. Resulting from this analysis, a model that indicates the most sustainable cup according to the user's situation *(step d)*

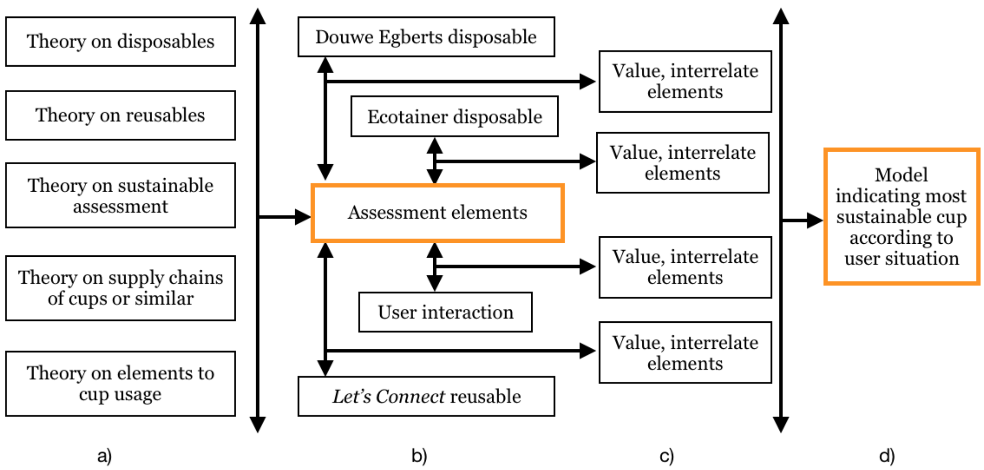

Figure 6: *Research Framework, four steps of the project are indicated with a, b, c, d. Arrows indicate interconnections*

Two central research Questions 1. and 2. are formulated, the answers to the central questions provide the knowledge to satisfy the objective of the project. In other words, the answers provide the knowledge required to enable for design of the model. Formulation of research questions is based on 'subdividing the research framework' method from [Verschuren et al., 2010]. From the research framework in Figure 6 Question 1. corresponds with *part a* and *part b* and Question 2. with *part c* and *part d*. The answers to the sub-questions steer towards an answer to the central questions

1. What cup characteristics and usage dependant elements are relevant for assessing the sustainability of reusable and disposable cups on the UoG?
   (a) In literature, how is determined to what extent a cup is sustainable?
   (b) What elements of the life cycle affect the environmental impact of a cup?
   (c) What are usage specific elements that influence sustainability of cup usage?
2. What is the value of, and interrelation between, the cup usage elements relevant for the different cup types used on the UoG ?
   (a) What methods are useful to value the cups within the scope, based on set elements and user parameters?
   (b) What does literature say about sustainability values of found assessment elements on cups used at the UoG or similar cups?
   (c) What does literature say about the influence of user specific elements on the sustainability of cup usage?

3 Body of knowledge - theory on drinking cup sustainability

3.1 Sustainability determination

What cup is most sustainable, depends on several situation specific elements, often interdependent. Moreover, every step in the life cycle of a cup comes with several elements of influence. Therefore, no general 'most sustainable cup' exists [Laura and Bakshi, 2014]. Hence, the situation in which the determination of cup sustainability is performed, sets the framework of determination and outcome. Characteristics that describe the sustainability are case specific, analyzing the life cycle (LCA) of the cup helps to find the characteristics that are relevant to establish sustainability figures for the case [Blanca-Alcubilla et al., 2020]. The LCA method in general quantifies the environmental impact of a product throughout its life cycle [van der Harst Eugenie et al., 2014]. Moreover, life cycle thinking enables for assessment on cups and cup usage elements in a specific situation. Provided that, the assessment elements selected can be valuated [Nuria and Alvarez del Castillo, 2007]. Throughout the life cycle several key elements for sustainable assessment are indicated. Starting the life cycle from where the cup is 'born', manufacturing. After which the cup is transported, used, cleaned or disposed. This full life cycle is depicted for the UoG in Figure 1 and later on simplified to Figure 10.

3.1.1 Key points of interest

The elements established to be relevant for sustainability assessment for the cup usage system on the UoG are to be valued or scored relative to each other. The key points of interest here are:

- Pollution (CO2 - CO2eq)
- Energy usage (kWh - kJ)
- Usage iterations

Pollution and energy usage are used to compare cups to each other. Whereas usage iterations is a results from the comparison, that makes the comparison tangible. CO2eq or CO2 equivalent is a measurement figure where environmental impact is normalized to CO2 pollution. For example, methane pollution is expressed in terms of CO2eq to enable for equal comparison. Moreover, Global Warming Potential (GWP) is a generalized figure that is expressed in terms of CO2eq and implies a certain potential a process has on the effect of global warming. Energy usage is often normalized to kJ.

3.2 Usage iterations

One usage iteration is defined as: *The consumption of one beverage with one cup*

Distinguishing between usage of a disposable cup or reusable cup has usage iterations as foundation. Because, generally the initial environmental impact of a disposable cup is several times lower than that of a reusable cup [Hocking, 2018]. Where the initial environmental impact is determined by manufacturing related elements. So, usage of disposable cups incurs this initial environmental impact every usage iteration. On the other hand, with a reusable cup it is spread over all uses. The more a reusable is used, the more dispersed the initial environmental impact. Whereas the more often a disposable is used, the environmental impact per usage stays equal. Therefore, the number of usage iterations a user expects to conduct steers towards usage of a disposable or reusable cup.

In the end, for a certain usage iteration figure where the environmental impact of x disposables equals that of x reusable uses. [Hocking, 2018] provides several equations to investigate a break even usage iteration figure. From section 5 production energy requirement of the *Let's connect* reusable cup and DE disposable cup are considered. Energy requirement per usage of the DE cup is plotted with the energy requirement per usage of the *Let's connect* cup, in Figure 7. Hand washing after each iteration is considered for the reusable.

This scenario is visualized to establish the principle of break-even iterations. Washing makes up for a large portion of energy per use for reusable cups, therefore included here, further elaborated in section 3.4.

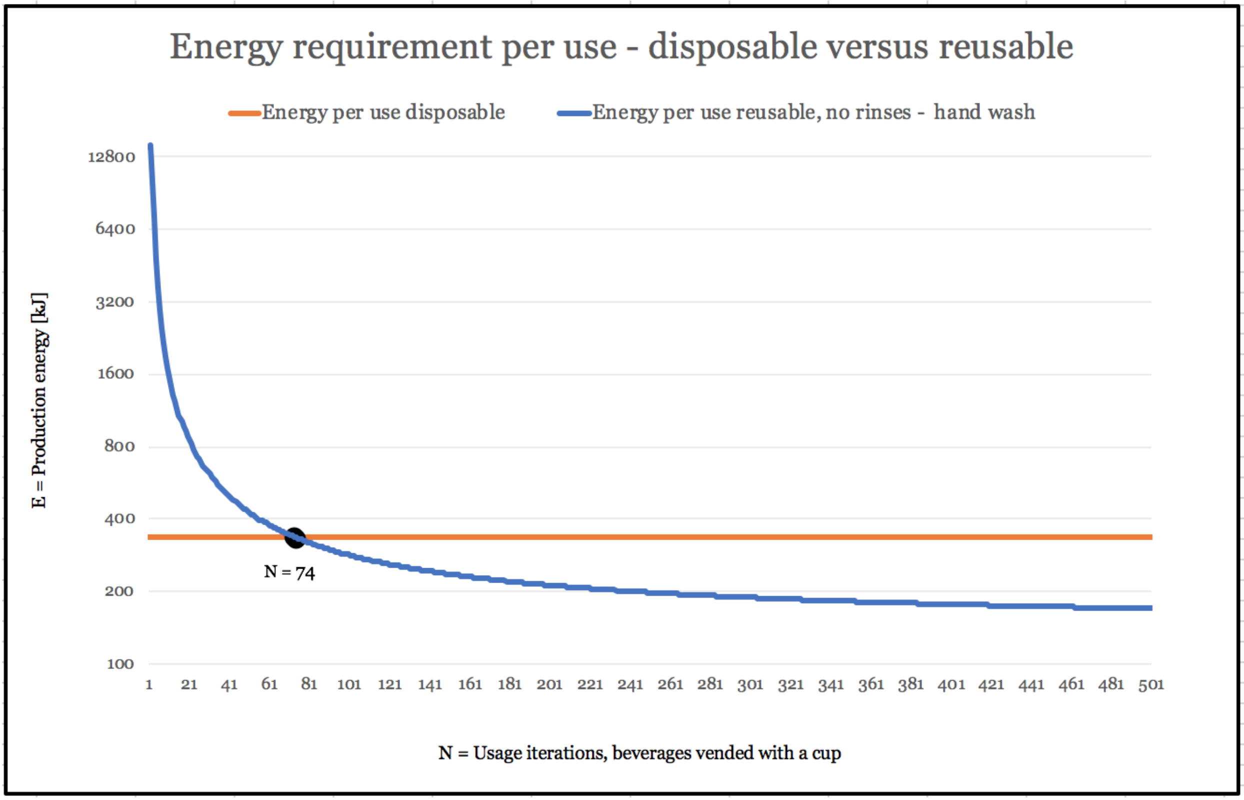

Figure 7: *Energy requirement per usage, DE against Let's connect reusable included hand washing*

Visible is that; after 74 usage iterations the energy per use of a reusable cup intersect with the energy per use of a disposable cup. Formula (1) is the foundation for broader formulas, used for model valuation, therefore marked. The plotted lines are from the the formulas:

$$E_{per-use-disposable} = E_d$$

$$E_{per-use-reusable} = E_r/N + E_w$$

$$N_{break-even} = E_r/(E_d - E_w) \tag{1}$$

Where:

- E_d= Production related energy requirement of a disposable
- E_r= Production related energy requirement for a reusable
- E_w= Energy requirement for washing one cup by hand
- N = Number of uses, usage iterations
- $N_{break-even}$ = Break-even iterations, where energy per use is equal for disposable and reusable

3.3 Reusable cup selection for the UoG

TGO is a key stakeholder in this project, being a organisation from the UoG. Moreover, the research is conducted with the UoG as subject. Therefore, the reusable cup to be advised to cup users on the UoG, is preferably one that an UoG related organ sells. Resulting, the cups from the I-Shop were indicated candidate for selection, listed below [I-Shop, 2020].

- Plastic + metal cup *Let's connect*
- Ceramic mug
- Plastic foldable cup *Stojo*
- Bamboo coffee mug

Selection criteria between the cups, with elaboration is listed below. The selection criteria are compared amongst the cup offering in the I-shop. In that way selecting one cup, for further usage in the report.

- Price: high price could create reluctance amongst users to buy the cup.
- Portability: many cup users on the UoG do not have a regular work space. Therefore, new reusable users are likely to prefer a closable lid.
- Durability: the cup is likely carried every day, a solid, impact proof and so durable cup is a plus.
- Safety: the cup should not impose health risks or dangers in usage.

The cup selected is not necessarily the 'best' cup. However, for the purpose of this study using one cup is most convenient. Therefore, selection based on considered reusable selection criteria is taken sufficient. In Figure 8. the findings on reusable selection criteria per cup offered in the I-Shop are displayed. Prices and portability characteristics are taken from [I-Shop, 2020]. As already introduced in section 2.3 the *Let's connect* reusable is considered in this research. By cancellation of the others; the bamboo cup is not considered because of possible imposed health risks, tested by [Stiftung Warentest, 2019] that discovered possible leakage of melanin and formaldehyde into drinks. However, it should be noted that this test was not conducted on the exact bamboo cup sold by the I-Shop. The ceramic cup is not considered because it is not portable. Lastly the Stojo cup was not considered because, the rubbery material is questionable less solid for carrying purposes and it is more expensive than the *Let's connect* cup.

Criteria / Cups	Metal + Plastic	Bamboo	Ceramic	Plastic
Price	€ 9,95	€ 4,95	€ 9,95	€ 14,95
Portability	Closable	Hole in lid	Not portable	Closable + fold
Durability	Solid	Solid	Solid	Elastic
Safety	Safe	Questionable	Safe	Safe

Figure 8: Selection of one reusable from the I-Shop offering

Moreover, the *Let's connect* cup from the I-Shop can be separated into parts that are separately recyclable [Cazemier, 2020]. Individual parts consist of uniform material and are therefore easily separated into the corresponding waste stream. Visualized in Figure 19 in Appendix 8.5.

3.4 Cleaning a cup

Usage of a reusable cup includes cleaning. Often, a reusable cup is either cleaned or rinsed after each usage, to retain a fresh cup. In a similar case study on the comparison between disposable and reusable cups; [Foteinis, 2020] a reusable with 500 usage iterations is considered: "From the reusable cup carbon foot-print, 9.5% is attributed to the manufacturing processes and 90.5% to washing." Meaning that washing contributes to a large portion of the environmental impact. When spread over 500 uses the initial manufacturing impact is relatively low, compared to the washing after each usage iteration. What should be noted is that the portion of the environmental impact caused by cleaning increases with the number of usage iterations. Therefore cleaning a cup is considered relevant for this project. Most of the electrical energy requirement for dish washing is for heating the water [Hocking, 2018].

3.5 Cup end of life - waste

Waste is a headliner in the disposable versus reusable issue. Because, a disposable cup becomes waste after one use, generally. However, the end of life scenario for the disposed cup depends on the waste handling. Moreover, it depends on the whether a cup is actually recyclable or worth recycling. In [Häkkinen and Vares, 2010] the end of life (waste) options for disposable cups are investigated thoroughly, distinguishing mainly in the environmental impact of the different options. Resulting, cups with a PE waterproof lining, like the DE cups used on the UoG, can not be recycled with regular paper. Because, the waterproof lining can only be removed with a specialised process, as the lining is strongly bonded to the paper. Conventional paper recycling stations would be contaminated by the lining and therefore the PE lined cups are mostly not recycled [Foteinis, 2020]. On the other hand, the PLA lined disposable cups from Ecotainer. Ecotainer cups are 'a fully compostable package in commercial composting facilities' [International Paper, 2016]. However, in [Häkkinen and Vares, 2010] established is that such processes require specific composting conditions. These conditions are not met on Dutch land-filling/composting sites. Moreover, The Benelux Disposables Organisation [SDB, 2011] states: *'Not one Dutch company is currently willing to invest in plants to compost biodegradable cups. The related costs are disproportional high.'*. Even though possible, DE cups are not recycled and Ecotainer are not decomposed. Resulting, for recycling the disposable cups, the UoG would have to collect disposable cups separately and redirect to companies specialized in offering full life cycle cup service. Resulting from, the cup characteristics and the available waste infrastructure for cup usage on the UoG, the end of life scenario for disposable cups is incineration [Kranenburg, 2020].

4 Methods

Throughout the stages of the report, different methods are used to obtain knowledge and tools that enable to provide answers to the research questions and fulfill the objective. The methods are explained according to the stages of the report, referring to Figure 6. where the stages are visualized accordingly. The stages are divided into the following:

1. Indicating and establishing sustainable assessment elements
2. Valuating and interrelating the established assessment elements
3. Interactive values and interrelations into the model
4. Proposing measures to boost the user compliance with sustainable cup behavior

4.1 Indicating and establishing sustainable assessment elements

By executing literature search on projects with a similar focus, sustainable assessment elements are established. The focus is to investigate what extent a cup is sustainable in a certain situation. Identified executed subjects are; aviation [Blanca-Alcubilla et al., 2020], healthcare [McPherson et al., 2019] or a large event [Nuria and Alvarez del Castillo, 2007]. In addition, [Potting and van der Harst, 2015] investigates facility management on organisations similar to Universities. From studies - amongst which the mentioned above - elements that have impact on sustainability for cup usage on the UoG are derived. Resulting, the sustainability assessment elements are adjusted to the specific setting at the UoG.

Life cycle analysis (LCA) enables case specific adjusting of sustainability assessment elements. Whereas, LCA indicates stages of the product throughout the life cycle. Moreover, enables to distinguish between relevant and less relevant sustainability elements. Not to confuse with software supported LCA method, that requires data sets on inventory and software support [Laura and Bakshi, 2014]. The life cycle of cups used on the UoG, includes both elements related to cup characteristics and elements of cup usage.

4.2 Valuating and interrelating assessment elements

Secondly, the established assessment elements are valued to enable for comparison with one another. Evaluation is in terms of in terms of energy requirement or pollution. Where energy is measured in kWh and Joules and normalized to kWh and pollution is measured in grams of $CO2/CO2eq$ or when applicable other green house gasses. Values for energy requirement or pollution of a process are based predominantly on literature. Where values of process energy, material specific energy are derived from.

Furthermore, in order to establish the weight, cups are weighed. Because, especially production related sustainability elements are sensitive on weight [Hocking, 2018].

- Weight of the DE disposable cup is determined with a 0.01 gram accuracy digital scale from *KERN*. Weight for calculations for the DE cup is rounded to 0.1 accuracy
- Weight of the *Let's connect* reusable is determined with a 1.0 gram accuracy digital scale from *SOEHNLE*. Weight for calculations for the *Let's connect* cup is rounded to 1.0 accuracy.

The difference in scale accuracy is caused by unavailability of a high accurate scale to establish the weight of the *Let's connect* cup. Where the weight of the DE cup is lower, the accuracy of the weight is more important. Therefore it was decided to still round the DE cup to 0.1 gram accuracy rather than level both weights to 1.0 gram accuracy.

Interrelating established elements is based on decision tree theory. The elements are outcomes to situation related questions or scenarios. Where the outcome is one or the other, the outcome directly steers to preference for a cup or influences the scored elements. Moreover, scoring and interrelating of sustainable assessment elements is supported by questioning or searching websites from TGO, Douwe Egberts, Ecotainer, UoG services, I-Shop. From literature, often ranges of values and options are provided. Therefore, the holders of information and stakeholders can function as a confirmation method.

4.2.1 Questioning and searching sources, subjects

Questioning or searching demands specific terms that steer towards a desired and useful answer. Therefore, searching and questioning is only performed after thorough literature search on the subject, and functions as confirmation method. Transcripts of the personal communication with information holders are provided in Appendix 8.4.

1. Search: Douwe Egberts / Ecotainer
   (a) Confirmation materials used
      i. Douwe Egberts: Paper + Polyethylene (PE) [Jacobs Douwe Egberts, 2020]
      ii. Ecotainer: Paper + Poly lactic acid (PLA) [Biomass Packaging, 2020]
2. Question: University Services (waste streams) [Kranenburg, 2020]
   (a) Post-University waste handling
   (b) Waste handling company policy: incineration / composting / land filling
3. Question: The Green Office [Maltagliati, 2020]
   (a) Proposed goal of the project
4. Question: UoG's I-Shop [Cazemier, 2020]
   (a) I-Shop reusable cup characteristics
   (b) Argumentation behind sustainable cup claim

4.3 Advisory model

After analysis and valuation of both assessment elements of usage and cup characteristics, the findings are combined into a model that forwards advice on cup (usage). The model consists of four elements, elaborated in the sub-sections below.

4.3.1 Database

The database of the model consists of all valued assessment elements. The values categorized per cup or usage manner and put in an Excel table, to enable for quick selection in formulas used. Basically, the numerical data input for the used formulas in the model.

4.3.2 User configurator

As introduced before, how sustainable a drinking cup is, depends on the scenario and manner of usage. Elements as; how and how often a cup is washed and how often a cup is used create preference for usage of one cup or another. Included in the model are elements of usage, therefore the elements of usage must be retrieved from a user. By means of the user configurator, that is a list of questions to a cup user on the UoG. Functions as, scenario dependent input for the model, steers the decision tree.

'Any time a selection must be made among alternatives, a decision is being made, and it is the role of the analyst to assist in the decision- making process" [Alemi and Gustafson, 2007]. Here, the component parts are the elements of usage, that steer towards the usage of one cup. Defining the situation creates the decision. Cup users provide required information to drive the decision tree model, by means of the users configurator. Eventually, the selected answers by a user steer via a pathway in the decision tree, towards sustainable preference for a cup. Whereas, pathways are based on the established assessment elements and interrelations. Therefore, the provided scenario analysis from the user configurator is the input for the model that uses the input to 'make the decision'. After which, the numerical figures on usage iterations and washing are based on that cup.

4.3.3 Engine

The engine is the working principle of the model. Where the valued assessment elements of the database are interconnected with the user configurator. Enabling for input dependant results and proposed advice. The engine is, as the other elements, created in excel and works predominantly with conditional statements. Especially for the cup selection part, the decision tree.

1. =IF(TEST;IF-TRUE;IF-FALSE)
2. =IF.CONDITIONS(TEST1;IF-TRUE1;TEST2;IF-TRUE2..)

Additionally, energy usage/requirement formulas are used to calculate how many uses are required for a cup user to be better of with a reusable than disposable cup, in iterations and days. The energy requirement formulas are presented in Section 5.6, in Formulas (2) and (3).

4.3.4 Outcome

Where the engine is the back-end, enables for calculations and decisions on cup usage. The outcomes are solely front-end, displays the outcome. In Figure 9. the description of possible outcomes the model proposes are provided.

Description
Cup type to use
Number of **days** in order to be more sustainable with a mug or the *Let's connect* reusable cup than the DE or Ecotainer disposable cup
Number of **beverages** to vend to be more sustainable with a mug or the *Let's connect* reusable cup than the DE or Ecotainer disposable cup
Cup usage elements
Cup type
Washing
Rinsing

Figure 9: *Advisory outcomes the model proposes*

In the end, the model answers the question 'what cup is most sustainable to use and how to use it?'. Based on, the given user scenario as input. Moreover, the valued assessment elements and conditional relations as working principle. Eventually, the options on cup to use the model provides are:

1. DE disposable
2. Reusable you use already
3. Reusable that you could already use
4. Buy a reusable

4.4 Proposed measures to boost sustainable behavior

From the advisory model, cup users are proposed the most sustainable cup behaviour, within the boundaries of this study. As stated before, the standard on the UoG tends to disposable cups. Therefore, in several scenarios the user are proposed to change from current habit. When the model proposes change in behavior, it is uncertain whether the user is actually triggered to change and complies with the advice. Only when users comply, the sustainability of the system is actually improved on, creating uncertainty. Because, people show resistance to a directive - are reluctant to change, especially when this change requires effort [Knowles and Linn, 2003].

Therefore, the last section of the report discusses several measure to assists in enforcing the change in cup usage behavior. These measures go beyond quotes as: 'think of the environment' and aim at easing the change and financial compensation. This section is based on literature search.

Relating financial interest with the interest of the environment is one measure to stimulating people to comply with advice. Currently, on hot beverage from Beijk machines a 10 cent discount is offered when an own cup is used. Nevertheless, this cup need not necessarily be a 'sustainable' - reusable cup. On the other hand, beverage vending from DE machines has no regulation on the cup that is used. In other words, no active stimulus for users on the UoG to bring their own cup for the beverage. Additionally, ensuring that facilities are sufficient to support the proposed measures.

5 Results

The results section start with established relevant cup usage elements for assessing cup sustainability, within the scope. After which, the established elements are valued in terms of energy requirement or pollution. Where, energy is normalized to kJ and pollution to grams of CO2/CO2eq or when applicable other green house gasses. Eventually, the valuated elements are put to use in the model, to interactively indicate sustainable cup behavior for users on the UoG.

5.1 Relevant cup characteristics and user interaction elements for assessing cup sustainability

Here, the considered relevant assessment elements, both user and cup related, are elaborated. Throughout the life cycle of the cups, where the case specific and simplified life cycle displayed in 1, several elements affect or determine sustainability. Three stages of the product life cycle consider most elements:

1. Production
2. Usage
3. End of life

Order and relation is visualised in Figure 10. derived from [Meskers et al., 2008]. Moreover, sections are connected and related by movement. On the other hand, what is not described in Figure 10. is the stage before production, that is the gathering/transportation of raw materials. That is minimally considered as this element is often generalized to material related figures, and not analyzed for the specific case. For example, the specific location of woods for paper production used for the batch of cups analyzed must than be known. Therefore, life cycle stages before production are considered within the production block.

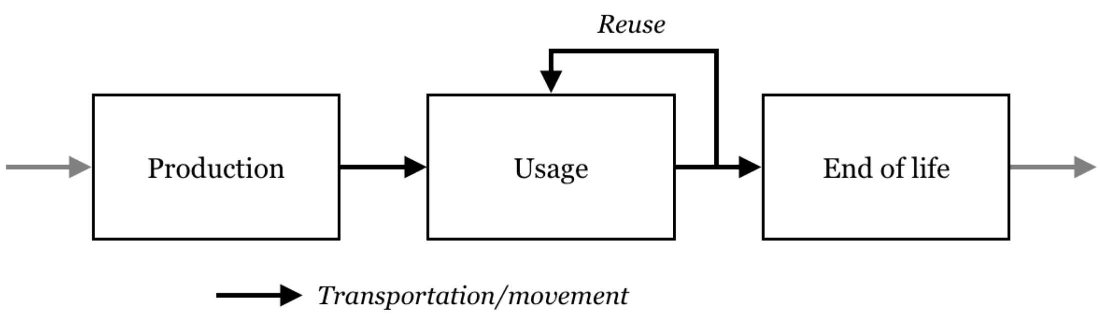

Figure 10: *Drinking cup life cycle stages, simplified*

5.1.1 Production related elements

Location of production
Geographic location of production could affect the environmental impact of the product, by means of transportation from production site to usage location. Where especially the difference between cup production location is relevant. Cross border production and shipping for example is trivially more environmental pressuring than local production. However, difficulty was experienced in attempts to contact manufacturers with unknown production location. DE does not intend to share any information for educational or research purposes [Douwe Egberts, 2020]. Moreover, difficulty was experienced in retrieving the manufacturer behind the *Let's connect* cup. *International Paper* the company behind Ecotainer did share this information [International Paper, 2016]. Resulting, it was decided to not consider the location of production and related elements for pollution and energy requirement figures.

Production related elements are considered from generalized figures. Often included or based on averages from:

1. **Material used**
2. **Production method**
3. **Raw material extraction / Recyled materials**

5.1.2 Cup usage

Washing
When using a reusable cup the cup is cleaned after usage. How the cup is cleaned affects the environmental impact of cup usage. In [Foteinis, 2020], a reusable used 500 iterations is considered: "From the reusable cup carbon footprint, 9.5% is attributed to the manufacturing processes and 90.5% to washing." Washing contributes to a large portion of the environmental impact of reusable cups. Because, spread over 500 uses the initial manufacturing impact is relatively low, compared to the washing that is done over again. Individual reusable cup usage proposes opportunity for environmental improvement, during washing. Thorough cleaning, is generally best done by dishwasher. Although dependant on the program selected or dishwasher used and on alternative washing manner by hand. In [Stamminger et al., 2007], it was concluded that dishwashers reach at least the same cleaning performance as almost any test person, but need considerably less water and energy. Moreover, sometimes washing by hand is required, if the cup requires so or because of non availability of a dishwasher. It should be noted that, washing up under running water takes more than three time as much water as washing up in a sink or bowl [Stamminger, 2008].

Rinsing
Additionally, no washing, either by hand of machine is even better. From coffee brewing theory known is that the beverage of coffee is made because of the partial solubility of solid coffee in water. Around 28% of solid coffee beans are water solvable, these coffee solids are extracted during coffee brewing. Because, during water-coffee contact several part of the solid coffee are dissolved in water, like tea extraction [West et al., 2015]. Similarly for the instant coffee from DE machines, where literally dehydrated brewed coffee is put into solution with water again [Goodman, 2012]. Therefore, when left over coffee eventually dries up in a cup, the remaining is mostly solid, but soluble coffee. The solubility characteristic works backwards, enabling for relatively easy rinsing of the used or dirty cup. During rinsing the dirt in the coffee cup is put in solution again and can be flushed away. Therefore, if a reusable cup is used by one consumer, a rinse in between usage iterations is sufficient to fresh up the cup. Individual usage, because sanitation of the cup is necessary otherwise, that is not achieved with rinsing. On the other hand, after a some uses the cup is best thoroughly cleaned, for freshness of smell and flavor. *KeepCup*, a large Australian based company, having sold more than 5 million reusable cup globally, recommend their users to just rinse their reusable cup after each usage and wash thoroughly every week [KeepCup, 2020].

5.1.3 End of life

Reuse
Using a cup more than once allows for spreading of the environmental impact over the number of reuses. Where the environmental impact here is that associated with the first stage of the product life cycle, 'production' in Figure 10. Generally, disposable cups have single usage purpose. Although theoretically a disposable cup could be used a few times rather than 1 this is not considered in this report. Because of, impracticality of carriage and structural integrity of the cup. Therefore, a disposable cup is disposed of after one usage, handled as waste that is discussed in the next section. Reusable cups after using once are washed and reused in every case. In the end, focus will be on the reuse of reusable cups versus the repetitive disposable of disposable cups.

Waste
For the largest part, waste in the Netherlands is either incinerated or recycled [CBS, 2014]. For disposable cups especially the method of waste handling plays a role in the end of life environmental impact. The waste at the UoG, although separated on the spot, all ends up in the same 'big bag' of trash. Whereas the disposable cups were already to be disposed in 'general trash', indicating the non-paper recyclability. Due to the policy from the municipality and the handling of the waste separation company [Kranenburg, 2020]. Only at the waste separation site machine-wise separation takes place, to split waste into several recyclable streams and end of life waste. As established before 3.5, the disposable cups used on the UoG are not recycled. Therefore, either incinerated or land-filled . Both options resulting in a different outcome on sustainability score.

5.2 Values of cup characteristics related assessment elements

Elements relevant for the sustainability of cup usage were established in the previous section. Here, the established elements are valued in respect to each other and interrelated when applicable. Based on compared scores and interrelations, the results can be comprised into the model.

5.2.1 Production energy and pollution

Disposable - pollution
Materials used for Ecotainer disposable cups are: paper, Ingenio PLA lining. [International Paper, 2016]. Materials used for DE disposable cups are: paper, PE lining. Between the two disposable cups considered the lining is the difference in materials used. In [Häkkinen and Vares, 2010] cups with PE and PLA linings are compared on environmental impact throughout the life cycle, in terms of CO2eq. However, end of life is excluded as it requires separate attention, as PE and PLA behave different here. For a batch of 100.000 disposable cups the manufacturing related global warming potential of the cups is:

1. PLA lined cup: 1090 kg CO2eq
2. PE lined cup: 1030 kg CO2eq

Recalculated to values per cup with formula 8.2 in Appendix B.

1. Ecotainer cup: 10,9 gr CO2eq per cup
2. DE cup: 10,3 gr CO2eq per cup

The difference here comes from the fact that PLA lined cups require more energy to manufacture. Moreover, the difference in the case for the UoG, between DE and Ecotainer, is larger, more favorable for DE cups. The Ecotainer cups are heavier, so more material is used, extending the global warming potential figure. Ecotainer cups might be favorable for usage if the waste infrastructure would enable for decomposition of the cups, the end of life purpose of Ecotainer cups. However, as established before, both cup types are incinerated end of life. Therefore, DE cups are selected for sustainable comparison with reusable cups.

Disposable - production energy
From [Hocking, 2018], 66,2 MJ/kg of energy is required for production of non-coated paper cups. The DE cup is used for the break-even iteration figure, as established before. The DE cup weighs in at an average of 5.2 grams, based on the average weight of 10 cups, provided in Figure 16. in Appendix A. Resulting, 344,2 kJ of energy is required for production of a DE cup, from calculation 8.2 in Appendix B.

Reusable - production energy
Cup users that currently use (mainly) disposable cups and could improve on their environmental impact of usage, are advised the *Let's connect* cup from the I-Shop as a reusable. The cup consists of several hard plastic parts and an inner 304 stainless steel cup. This stainless steel part contains the liquid contents and the plastic parts function as isolation or lid. Based on [Hocking, 2018], a commonly used heat proof plastic for reusable cups requires 106.6 MJ/kg to produce. For the *Let's connect* that weights in at 110 grams this results in 11.7 MJ to the plastic part of the reusable cup, from calculation 8.2 in Appendix B. Additionally, the 304 stainless steel inner cup is accounted for. About 53 GJ of electricity are required to produce 1 tonne of stainless steel, based on global averages [Johnson et al., 2007]. That is 53 MJ/kg, with inner cup weight of 46 grams this results in 2,44 MJ energy requirement, from calculation 8.2 in Appendix B. Resulting, the *Let's connect* reusable cup requires 14,14 MJ of energy to produce. This figure is used to calculate for break-even usage iterations when compared to disposables.

Reusable - pollution
Production of 1 kg stainless steel releases around 3.6 kg of CO2 [Johnson et al., 2007]. Based on the stainless steel weight this results in 0,162 kg or 162 grams of CO2 per for the stainless steel part of one cup. Additionally, several figures exist for plastic manufacturing. From [Dormer et al., 2013], 1.538 kg CO2eq is found to be the carbon footprint of 1 kg hard plastic (PE) production. Whereas other sources suggest higher values [Andreoni et al., 2015], 2kg CO2 pollution per kg of plastic is considered for this project. With a plastic weight count of 110 grams this results in 220 grams of CO2 for the plastic part of the cup. Totally, the production of one *Let's connect* reusable cup generates around 382 grams of CO2.

Cup users that currently use a reusable cup already most likely use the 'widely known ceramic mug'. Based on [Hocking, 2018] such a ceramic mug requires 14 MJ of energy to produce, per cup based on a weight of around 300 grams. The energy required to produce a typical ceramic mug is around equal to that of the *Let's connect* cup.

5.3 Values of cup usage related assessment elements

Washing
The article [Berkholz, 2014] combines several state of the art research paper on dish washing performance, as: [Stamminger et al., 2007] and [Berkholz, 2013]. Combined to unify results on machine washing and hand washing efficiency. Results from the studies conducted are all based on EU standards for dish wash tests (IEC 60436:2004+A1:2009 (E)). The focus for this project is on machine washing and hand washing energy consumption. Energy consumption in dish washing arises mainly from the heating of water. It should be noted that the values are averages and are sensitive to extreme user behavior or non-average machine washers.

For one cycle of machine washing, on a normal program setting, rather than quick or intensive, in Europe on average 1.1 kwh of energy is used. Resulting, on average 9.0 Wh of energy is used to machine wash a single item. For one cycle of hand washing, with the same amount of dishes that are used in the dishwasher, around 1.6 kWh of energy is used. Mainly from heating the water. Resulting, on average 21,6 Wh of energy is used to hand wash a single item. Consequently, on average the values states below are used washing one reusable cup from Formula 8.2 in Appendix B.

1. 77,76 kJ of energy to hand wash one cup

2. 32,40 kJ of energy to dish wash one cup

The current energy production efficiency in the Netherlands is around 55%. Moreover, around 0,45 kg/CO2 is polluted per kWh of energy production. These figures are based on the most recent publications on the energy mix efficiency in the Netherlands, from [CBS, 2017]. As [Hocking, 2018] suggests the energy efficiency is to be accounted for to recalculate to primary energy usage, as is included in production energy figures. Therefore, based on Formula 8.2 in Appendix B, the following energy requirements are used to include washing in the model.

1. 141,4 kJ of energy to hand wash one cup

2. 58,9 kJ of energy to dish wash one cup

It could be that, the environmental impact of washing is far off the average values established, possible the energy used even surpasses the impact of disposable production. Caused by, generous washing behavior from the user. In that scenario, using a disposable cup would theoretically be better. However, improving washing behavior is aimed at. For example with intermediate rinsing of the cup, spreading the generous washing behavior. The alternative proposed of rinsing the cup between iterations before washing thoroughly is performed with cold water. As the energy requirement for washing with machine or by hand comes mainly from heating the water, the relative energy consumption of quick rinsing is taken to be zero.

5.3.1 End of life

Waste

Most waste generated by the UoG, that is not separated for recycling by waste handling company Attero, is incinerated [Kranenburg, 2020]. As established before, disposed cups on the UoG are not recyclable in regular waste handling streams. Therefore, disposable cups used on the UoG are incinerated. Moreover, for both disposable cups considered the product life cycle is equal starting from usage. Meaning that the excluding the end of life environmental impact does not affect further into the analysis. Although the environmental impact of incineration of the cups is different.

Similarly, the end of life of reusable cups also influence the full life cycle environmental impact. Still, this is not considered for the project. As the end of life is only after many iterations, or in the rare occurrence of product failure.

5.4 User Configurator - interactive model input

The user configurator is a questionnaire for cup users. Where, the user provides input on elements of cup usage, specific to their situation. Consequently, the provided information is used by the model to indicate, break even number of iterations, what cup to use when improvement is possible and advice for washing. All aiming at the most sustainable cup usage on the UoG. The configurator is excel based, by clicking the answer box, a list is displayed from which the most applicable answer is selected. The provided answers are redirected to the engine, where it either feeds the decision making element or the break even iterations formula. The configurator is displayed in in Figure 11, as an example. It should be noted that, the filled in answers are randomly chosen and the configurator does not function interactively in the report. The options that can be selected are displayed in Figure 18 in Appendix 8.3.

User situation questions	Options	Index
Do you use a reusable drinking cup on the UoG?	yes	
Do you regularly attend the UoG? (student, employee)	no	
Are you a one time visitor or short term stay?	no	
Do you **already** have a reusable cup that is convenient for usage on the UoG, or could you already use a reusable cup from your office/canteen/lab?	no	
On average, how many hot beverage do you consume on the UoG per day?	5	[B]
How do you currently wash your cup thoroughly?	By hand	→ [Ew]
After how many uses do you clean your reusable cup thoroughly?	10	[R]

Figure 11: *Configurator; questionnaire for cup users*

5.5 Database - static model input

The database contains all data or information required for calculating the user specific break even iterations. Whereas, the user specific information is interactive, the values here are static as database. The database contains the values from comparison between the DE and *Let's connect* cup. Taken from, energy and pollution figures established and calculated before in Section 5.2. Basically, the back-end of the model where all information is retrieved from. In Figure 12 this tabular form database is displayed. The values in the database are used to determine a certain break-even point on cup usage activity in which it becomes more sustainable to use a reusable instead of disposable. In the bottom halve of Figure 12, some extreme and static break-even iterations figures are already provided.

Assessment elements / Cup type	**Douwe Egberts**	***Let's Connect* I-Shop**
	disposable	reusable
Production related elements		
[E_d, Er] Energy (kJ/cup)	334,2	14.140
Pollution (gr CO2/cup)	10,3	382
Washing energy requirement		
[E_w] Hand wash (kJ/cup)	-	141,4
[E_w] Machine wash (kJ/cup)	-	58,9
Intermediate rinsing	-	+/- 0
	Break-even iterations - extremes	
Disposable - reusable comparison	Elaboration	Usage iterations - break even
Energy comparison	Just production-related	43
Pollution comparison	Just production-related	38
Energy + hand wash	No intermediate rinses	74
Energy + machine wash	No intermediate rinses	52
Energy + hand wash	10 intermediate rinses	45
Energy + machine wash	10 intermediate rinses	44

Figure 12: *Database; energy and pollution values of cup types*

5.6 Advisory model - elaboration and build-up

Readers of this report are granted access to the actual model, as complementary Excel document.

This section elaborates on the working principle of the model. The engine is explained based on the formulas used and decision making logic.

5.6.1 Formulas

Achieved from the formulas is awareness on the break-even iterations. The cup that is advised to use is not directly dependent on the figures the formulas produce. However, the figures do indicate after how many uses a reusable beats the disposable on environmental impact of usage. Therefore, the effect of the formulas is to boost usage of a reusable when this is advised based on the decision tree logic.
Parameters used:

E_d = Energy required to produce a **disposable** cup
E_r = Energy required to produce a **reusable** cup
E_w = Energy used for thorough **washing**
R = Number of intermediate **rinses** between thorough washes
B = Average number of beverages consumed per **day**
N = Usage iterations

Formulas used:

$$N_{break-even-iterations} = E_r/(E_d - (E_w/R) \tag{2}$$

$$N_{break-even-days} = N_{break-even-iterations}/B \tag{3}$$

Formulas (2) and (3) are inspired by break even usage formulas from [Hocking, 2018]. Corresponding parameter values are retrieved from the database and user configurator. Parameter indexes are mentioned at the corresponding values. In the specific case of E_w two values are possible. From the user configurator selection is made between cup washing by hand or machine, the corresponding energy required for washing is allocated in the formula.

Description	**Cup to use or time period**
Cup type to use	Reusable you use already
Number of **days** in order to be more sustainable with a mug or the *Let's connect* reusable cup than the DE or Ecotainer disposable cup	9
Number of **beverages** to vend to be more sustainable with a mug or the *Let's connect* reusable cup than the DE or Ecotainer disposable cup	45
Cup usage elements	**Advice to improve cup usage sustainability**
Cup type	Reusable, good
Washing	When possible, switch to thorough cleaning with a dishwasher. When filled properly, with use of regular programs, machine washing is better than hand-washing
Rinsing	Every time the reusable is rinsed, rather than washed thoroughly. This saves on average 60 kilo Joules of energy for machine washing and 140 kilo Joules of energy for washing by hand.

Figure 13: *Static representation of one advisory model outcome*

The formulas that are interactively used in the Excel advisory model, are provided in Appendix 8.5. Formulas are indicated included the description as stated in Figure 13.

5.6.2 Decision making

The model outcome elements "cup type to use" as in Figure 13, is determined based on decision making logic. Whenever a user already uses a reusable cup, it is always advised to keep using it. Because, the initial high environmental impact has already been established. Therefore, the environmental impact from usage of disposable cups would only build upon the already established production related environmental impact of reusable cup production. Thus, the manufacturing related environmental impact, although lower, is not relevant. Similarly, for users that could already conveniently use a reusable cup on the UoG. For example, PhD students that have access to reusable cups in the research group's canteen or students that own a leak-proof travel cup for carriage in their backpack.

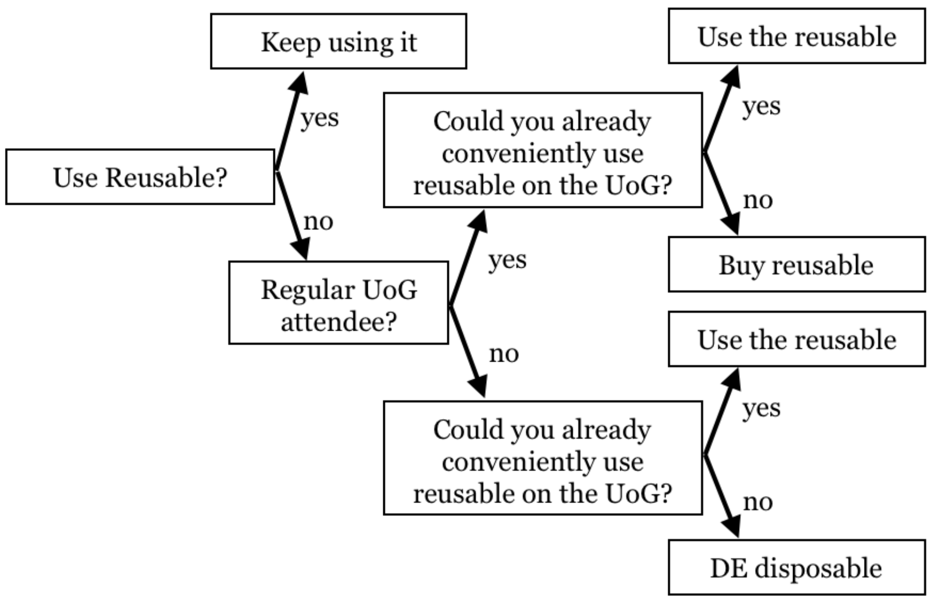

Figure 14: *Decision making logic for the cup to be advised*

The decision making logic as visualized in Figure 14, is translated to Excel code for the model. The excel code, by means of conditional statements, is provided in Appendix 8.5.

5.7 Measures to boost cup usage sustainability

The provided decision tree model in figure .... suggests sustainable cup usage behavior for users on the UoG. In order to boost compliance with the proposed changes several measures are proposed. Infrastructural changes that simplify sustainable behavior for users. As well as, measures to encourage users for sustainable usage.

5.7.1 Stations for cup rinsing

Cleaning sets a relevant portion of the environmental impact of reusable cup usage. Established is a beneficial washing pattern of frequent rinsing with thorough cleaning every now and then. Placing of cup-rinsers throughout the university enables quick and efficient cup rinsing. These cup-rinsers should be allocated close to beverage vending machines, for easy and widespread access. Moreover, preventing toilet sinks from getting crowded and dirty. Additionally, widely available and easily usable cup-rinsers lower effort for users to rinse their cup. Again, the lower the effort related to change the more likely users will comply with the proposed change [Knowles and Linn, 2003]. Two examples of a cup rinsers is displayed in Figure 15. included a reservoir sink to catch the water used for rinsing.

(a) Cup rinser with sink **(b)** Cup rinser with sink

Figure 15: Two similar rinsers with sink [Faucet, 2020]

5.7.2 Monetary discount

One of the hold backs of switching from disposable cup usage to a reusable cup, is the associated monetary costs. One of the possibilities for a cup user on the UoG is: not using a reusable cup and also not in possession of a convenient to use reusable cup. Meaning that, switching to a reusable requires one to purchase it. The *Let's connect* taken as a reference in this project, has a cost price of 10 euro [I-Shop, 2020]. Aiming at. the cup users in the scenario of, not using and not owning a reusable cup, convenient for hot beverage vending on the UoG. The provided monetary discount should aim to financially compensate for using a reusable cup. Not earlier than, at the point where the user would also be more sustainable with usage of the reusable. As established, the worst case $N_{break-even-iterations} = 74$, so only after at least 74 iterations a user should financially benefit from the usage of the reusable cup. Considering 10 euros as retail price, this boils down to around 0,10 cents per usage iteration. Therefore, the current proposed discount is actually appropriate but not enforced on enough. Moreover, not available for DE vending machines. Rather than providing discount for reusable usage, raising the price for a beverage included disposable cup is also an option. Increasing the total price of the beverage creates reluctance.

6 Discussion

This section discusses several aspects of the study that may effect the final results or can be improved upon. Generally, in life cycle analysis based studies options that could be considered for analysis are endless. Therefore, not every element that influences the sustainability of the assessed cups is included. Per project, processes are identified to be included in the product system [Rebitzer et al., 2004]. Although the assumptions are supported, results can differ when the product system is set differently with other assessment elements included.

Environmental impact for reusable cups is expected to decrease further as the electricity mix becomes less CO2-intensive with replacement of coal-fired generators by natural gas, wind, and solar and as less efficient dishwashers are replaced with new units compliant to current laws [Laura and Bakshi, 2014]. Because, the environmental impact of reusable cup usage is greatly dependent of energy consumed by washing.

Possible environmental impact that arises from end of life scenarios is not considered, for both cup types. This effect could alter the full life cycle environmental impact that comes with cup usage. In the form of GHG pollution from incineration of the disposable paper cups. Conversely, energy consumption from recycling metal parts from the *Let's connect* reusable cup. Additionally, the environmental impact between DE cups and Ecotainer cups might be even more different. Because, transportation from manufacturer to the UoG was not considered. From Ecotainer it is known that the cups are produced in the USA [International Paper, 2016]. However, DE neither shares information on cups, nor responded to the request for insights on DE disposable cups. Confirmed by the statement from [Douwe Egberts, 2020]: ”It is not possible for DE to share information for study/research purposes, beyond that can be found on the website.” If the transportation element was considered, local production could favorably affect the environmental of DE cups respective to Ecotainer cups or vice verse.

Both the averaged energy requirement and pollution related to stainless steel manufacturing are highly reduced when recycling of the material is ensured. Because, the figures are related to production from virgin material, requiring refinement from iron ore [Johnson et al., 2007]. However, discovering whether or not this characteristic is applicable for this project, requires deeper understanding of the supply chain of cup production. Therefore, the Let's connect reusable cup is possibly less energy demanding to produce.

Only in the last stages of the project, it was discovered that it is not recommended for the *Let's connect* reusable cup to be washed in the dishwasher. Whereas, washing by machine is advised, when possible, to be more sustainable. The late discovery was caused by slow communication due to closure of the I-Shop as result of the ongoing pandemic. Eventually, the *Let's connect* cup was received physically by mail, for such investigations, only in the week before the proposed end of the project.

6.1 Further research

Selection for the reusable cup was conducted based on the current drinking cup offer by the UoG's I-Shop. Meaning that, there may be cups available that share the same price, durability and portability characteristics with better sustainability figures. Similar results would be found when conducting the same study with the cup, only the break-even iterations figure would be lower. Therefore, such a cup would ensure sustainable cup usage on the UoG within a shorter time-span. Additionally, as mentioned in Section 6. the *Let's connect* cup chosen for this study, is actually not recommended to wash by hand. Therefore, future research should focus on the identification of the 'perfect reusable for the UoG'. Rather than, the best from the current offering.

Measures to boost compliance with the proposed advice are not very elaborated yet. Further research could dive into effective measures to cheer on compliance with the cup usage advice proposed by the model. As introduced before, the adequate advice is one, but user compliance is necessary to eventually improve the system of drinking cup usage on the UoG. The model itself includes some motivating load, by the visualization of the possible achieved reduction in energy usage per iteration, when switching to a reusable cup. However, the stimulus can be further improved upon.

7 Conclusion

The gross of cup users on the UoG should switch to, or keep using reusable drinking cups, to improve the sustainability of the drinking cup usage system at the UoG.

At first, elements to assess sustainability were established. Both elements of user interaction and cup characteristics were considered, throughout the life cycle of cups, as displayed in Figure 10. Consequently, per life cycle stage relevant elements, are identified as follows. The production process taken as a whole, included material handling, production method and material extraction. Furthermore, in the life cycle stage of usage, washing is relevant. The different options of washing by hand, machine or quick rinsing have different effect on the total environmental impact. Washing enables for reuse, which is key in usage of reusable cups. The life cycle of disposable cups on the UoG ends with disposal followed by incineration. Resulting, established assessment elements enable for sustainable valuation of the drinking cup usage system on the UoG.

Secondly, the established assessment elements were valued in terms of KPI's: required energy for the process [kJ] or pollution caused by the process [CO2eq]. Where the energy KPI was further used for comparison between disposable and reusable cup usage. Valuation was performed on the DE disposable cup, because of its lightweight and the end of life scenario for disposable cups, DE is the more sustainable choice over the Ecotainer disposable cup. The Let's connect sold by the UoG's I-Shop is taken as reusable counterpart. Disposable cup production energy set at 344 kJ versus 14140 kJ for the reusable cup. Production energy is the main element of comparison. Additionally, washing a reusable cup by hand takes 141 kJ of energy, compared to 59 kJ with a machine wash, arising mainly from heating water. Whereas a quick rinse with cold water, in between uses, takes close to 0 kJ of energy. For both cups, the end of life scenario was not considered in KPI valuation.

Lastly, all findings are comprised into an advisory model. Where, the user specific input from the users configurator is combined with the valued sustainability assessment elements. Database values, energy-requirement comparison formulas and decision making logic provide advice to cup users. Including, advice on cup to use and washing, also an indication on break even iterations. Standalone the advisory model function as knowledge base for cup users and TGO. Because, it is easily visible what cup is used best in what scenario. Additionally, it is a motivating tool for cup users to actually comprehend and comply with the proposed advice. To further boost compliance with the proposed advice, stations to rinse reusable cups should be placed. Furthermore, monetary benefits of switching to reusable cups when this is more sustainable for the cup user, provides extra stimulus for users.

After how many uses a reusable cup is more sustainable than usage of disposable cups - break-even usage iterations - was the main sustainability KPI. Break-even iterations are predominantly based on cup production and washing energy requirement. For the worst case scenario within the study scope $N_{break-even-iterations} = 74$. Even for a regular UoG attendee that does not consume hot beverages very often, this figure is still achievable on the short term. Only exemption is, visitors of or short terms stays on the UoG, who do not already have the possibility to use a reusable cup. Thus, for the gross of cup users on the UoG the switch to a reusable drinking cup is more sustainable. *"The best reusable is the one you use"* [KeepCup, 2020]. Or better phrased: **the most sustainable cup is a reusable cup that you use.**

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8 Appendix

8.1 Appendix A - cup weight

(a) Weight of 1 DE disposable cup (5,2 gr) **(b)** Weight of 10 DE disposable cups (52 gr)

Figure 16: Weight of DE disposable cups

(a) Weight of plastic part (110 gr) **(b)** Weight of stainless steel part (46 gr)

Figure 17: Weight of *Let's Connect* reusable cup

8.2 Appendix B - energy requirement formulas

Energy conversion formulas
1 kWh = 3.600.000 Joules
1 Wh = 3.600 Joules
1 kJ = 1000 Joules
1 MJ = 1000 kJ

Primary energy usage = Energy usage * (1/ efficiency of energy production)

Production energy of disposable cups:
PLA:
1090 kg CO2eq * 1000 / = 1.090.000 grams of CO2eq
1.090.000 / 100.000 = 10,9 gr CO2eq / cup.

PE:
1030 kg CO2eq * 1000 / = 1.030.000 grams of CO2eq
1.030.000 / 100.000 = 10,3 gr CO2eq / cup.

Production energy calculations on the different cups and parts of cups.
Formula: Material specific energy [MJ/kg] / (1000 / cup weight [grams])

Calculation 1: energy requirement DE cup:
66,2 / (1000/5,2) = 0,34424 MJ/cup = 344,2 kJ/cup
Calculation 2: energy requirement stainless steel part *Let's connect*:
53 / (1000/46) = 0,00244 MJ/cup = 2,44kJ/cup
Calculation 3: energy requirement stainless steel part *Let's connect*:
106.6 / 1000/110 = 0,0117 MJ/cup 11.7 kJ/cup

8.3 Appendix C - user configurator options

Options that can be selected by cup users, to be filled in to the user configurator.

Uses before thorough clean	Options	Washing method	Number of hot beverages per day
1	yes	By hand	0,25
2	no	Machine	0,5
3	-		1
4			2
..			..
50			20

Figure 18: *Options for user configurator*

8.4 Appendix D - personal communication transcripts

Appendix D displays transcripts from e-mail communication with holders of information, introduced as method in section 4.2.1. Transcripts are build up with questions asked to the holder of information (Q). Followed up with, answer from the information holder (A).
Personal communication by e-mail with Y. Klein Kranenburg (UoG services department - waste streams) - this transcript is translated from Dutch to English.

- Q: How are disposable cups handled as waste?
  A: Disposable cups end up in the bag with remainder waste. However, for new contractual terms waste coffee cup recycling will be considered.
- Q: Is remainder waste from the UoG incinerated, land filled or recycled?
  A: After separation on site by Atero, the remainder trash is incinerated.

Personal communication by e-mail with F. Cazemier (Coordinator of the UoG's I-Shop) - this transcript is translated from Dutch to English.

- Q: As all products the I-Shop sells are sustainable, why is the *Let's connect* reusable cup sustainable?
  A: The *Let's connect* reusable cup can be completely disassembled into metal and plastic parts, which can be recycled separately, visualized in attached Figure **??**.
- Q: What is the weight and Material of the *Let's connect* reusable cup sold by the I-Shop?
  A: Plastic and aluminium. No scale available, I can ship you one.

Comments: The cup was indeed shipped and received well, for weighing purposes. Aluminium turned out to be RVS on receipt.

Figure 19: *Let's connect cup disassembled into parts*

8.5 Appendix E - back-end model

Appendix E contains the filled in formulas as used in the Excel model. Due to language settings of the computer used for this project the formulas are in Dutch. Shortlisted are the basic translations from the Dutch. At the start of each formulas, indicated is the corresponding outcome description, as displayed in Figure 13.

"Cup type to use"
=ALS.VOORWAARDEN(EN('User configurator'!D5="no";'User configurator'!D6="no";'User configurator'!D8="no");"DE disposable";'User configurator'!D5="yes";"Reusable you use already";EN('User configurator'!D6="yes";'User configurator'!D7="yes");"Reusable that you could already use";EN('User configurator'!D8="no";'User configurator'!D6="yes");"Buy a reusable";EN('User configurator'!D6="no";'User configurator'!D8="yes");"Reusable that you could already use";EN('User configurator'!D6="yes";'User configurator'!D8="yes");"Reusable that you could already use")

"Number of days in order to be more sustainable with a mug or the Let's connect reusable cup than the DE or Ecotainer disposable cup"
=ALS.VOORWAARDEN('User configurator'!D11="By hand";Table!D23;'User configurator'!D11="Machine";Table!D26)

"Number of iterations in order to be more sustainable with a mug or the Let's connect reusable cup than the DE or Ecotainer disposable cup"
=ALS.VOORWAARDEN('User configurator'!D11="By hand";AFRONDEN.NAAR.BOVEN(Table!B23;);'User configurator'!D11="Machine";AFRONDEN.NAAR.BOVEN(Table!B26;))

"Cup type"
=ALS(M18="Use DE disposable";"Try using the disposable more than once";"Reusable, good")

"Washing"
=ALS('User configurator'!D11="By hand";"When possible, switch to thorough cleaning with a dishwasher. When filled properly, with use of regular programs, machine washing is better than hand-washing";"Good. When filled properly, with use of regular programs, machine washing is better than hand-washing")

"Rinsing"
="Every time the reusable is rinsed, rather than washed thoroughly. This saves on average 60 kilo Joules of energy for machine washing and 140 kilo Joules of energy for washing by hand."