Life cycle comparison of reusable and non-reusable crockery for mass catering in the USA

Study commissioned by MEIKO Maschinenbau GmbH & Co. KG, Offenburg, Germany

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Final Report

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Abbreviations

ALOP	Agricultural land occupation potential
BAT	Best available technology
Carc.	Carcinogenic
CED	Cumulative Energy Demand
CH	Switzerland
Cp	Thermal capacity
Eds.	Editors
EN	Standard developed by the European Committee for Standardization
EPS	Extruded polystyrene
EU	European Union
EURO4	EURO4; vehicle emission class
EoL	End of Life
e.g.	exempli gratia
eq.	equivalent
FDP	Fossil depletion potential
FU	Functional Unit
GLO	Global
GWP	Global warming potential
ISO	International Organization for Standardization
HF	Hydrogen Fluoride
Km	Kilometer
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LDPE	Low density polyethylene
MA	Massachusetts
MJ	Mega joule
MSWI	Municipal solid waste incineration
NLTP	Natural land transformation potential
NPCC	Northeast Power Coordinating Council
NY	New York
PA	Pennsylvania
PE	Polyethylene
PLA	Polylactide acid
PP	Polypropylene
PS	Polystyrene
ReCiPe	Set of Life Cycle Impact assessment category indicators
Resp. eff.	Respiratory effects
RoW	Rest of world
SERC	South East Reliability Corporation
SO_2	Sulfur dioxide
SPP	Southwest Power Pool
TAP	Terrestrial acidification potential
TRACI	Tool for the Reduction and Assessment of Chemical and other Environmental Impacts
USA	United States of America
USETox	The UNEP-SETAC toxicity model
WDP	Water depletion potential

Summary of the study

"Life cycle comparison of reusable and non-reusable crockery for mass catering in the USA"

Background and objectives

In facilities of stationary operation in many areas of the world, multi-use crockery[1] is predominantly used. Single-use crockery is typically used only for special areas of application (open-air events without water or electric utilities and facilities without sufficient space for a dishwashing area). With regard to the US-specific conditions, the commissioner of this study, MEIKO Maschinenbau AG (followed named MEIKO) assumes that single-use crockery is used in areas of application where the use of multi-use crockery would also be appropriate – particularly under environmental considerations.

MEIKO is interested to increase the share of reusable systems in the US catering facility market, among others, on the basis of arguments based on environmental aspects. Against the background that disposable systems and reusable systems differ from each other throughout their life cycle, the method of Life Cycle Assessment (LCA) is the preferred method for confirming the environmental approach.

MEIKO has commissioned Oeko-Institut e.V. to compare the environmental performance of reusable crockery systems with the environmental performance of single-use crockery systems in selected scenarios of stationary out-of-home catering facilities in the United States.

For the purpose of this study, and based on place setting components that have been collected in respective facilities, generic place settings have been defined. Place settings are therefore as realistic as possible, but nonetheless generic and may vary according to considered pieces and material.

The study results refer solely to the analyzed and defined systems. The results are not intended for application in other than the US market (e.g. Europe, Asia) nor in relation to non-stationary or temporarily installed catering facilities.

Assessed scenarios and methodological approach

Against this background, Oeko-Institut e.V. has carried out a Life Cycle Assessment (LCA) study according to the ISO 14040 series of standards. For the comparison of the two different systems, three selected scenarios were taken into consideration:

- Serving non-patient meals in a hospital cafeteria
- Serving lunch to students in a school cafeteria
- Serving breakfast to guests in a hotel

[1] "Crockery" in this study includes all items directly used by the end diner including dishware: plates, bowls, cups, drinking glasses; cutlery: knife, fork, spoon; and tray. At the same time crockery does not include preparation or serving containers or utensils, so called black-ware which is assumed as being the same for both systems.

With regard to the systems functions, both reusable and disposable systems have been evaluated to be functionally equivalent with regard to the functional unit[2], defined as “Provision of dishes for the hygienic delivery of a scenario specific number of portions of food a day within a year in a stationary out-of-home cafeteria in the USA”. For each of the scenarios, the following functional unit was specified.

	Scenario 1: hospital[3]	**Scenario 2: school**	**Scenario 3: hotel**
Catering meals per day	400	500	105
Breakdown to breakfast / lunch / supper	56 / 240 / 104	0 / 500 / 0	105 / 0 / 0
Days of operation per year	365	180	365
Meals per year	146,000	90,000	38,325

The basic assumptions on the assessed crockery items are described in detail within the course of the description of the scenario-specific life cycle inventories. Non-stationary or only temporarily installed catering facilities were not part of the comparison.

The system boundary includes the entire life cycle (“cradle to grave”) of both, reusable and disposable crockery items. With regard to the multi-use system the production or manufacturing of the dishwashing machines has not been taken into account in this study. However, it could be shown that the omission of the production phase of the dishwashing machines does not impair a well-balanced comparison of the two system alternatives. With regard to the End-of-life treatment US-specific waste treatment procedures have been taken into account.

With respect to the technological coverage it should be noted that this study aims at showing the transition of the U.S. market from the commonly used disposable systems towards an increased use of reusable solutions. Therefore, the base case scenarios in the multi-use systems take into account dishwashing with machines, representing currently best available technology (BAT), because this should be the case if a facility comes to the decision to switch to a reusable system. As shown in a sensitivity analysis, the consideration of BAT machines compared to machines with an 10% increase in energy usage machines leads to lower environmental impacts. The energy and water usage in stock machines ranges by far more than 10 % (energy usage by 361% and water usage by 663%, according to a recently published report by the consumer advocacy Group Fischer-Nickel). This highlights the importance of choosing the best available technology when ordering dishwashing machines.

The focus of this study is an equitable comparison of two system alternatives, noting, however, that the investigation does not aim at comparing different cafeterias or crockery items from different manufacturers within the two systems. In concrete terms, it is not the purpose of this study to conduct a benchmark comparison between cafeterias or crockery producers. The underlying data basis and especially the modelling approach of this study are suitable for the comparison of single-use and multi-use systems, however, they are not suitable for benchmarking within one of the systems.

2 According to DIN EN ISO 14040:2009-11 the functional unit (FU) is defined as the quantified performance of a product system for use as a reference unit.

3 Hospital stationary catering for staff and visitors (not patients).

Conformance and critical review

MEIKO intends to use the results of the study to inform planning experts in the field of commercial kitchens, responsible persons or decision-makers in US commercial kitchens; as well as competent authorities on environmental impacts of crockery used to serve meals in stationary out-of-home facilities. This means that the LCA results are intended to support comparative assertions to the public, thus, according to the ISO14040 series of standards, a critical review has to be carried out.

In each of the three scenarios, the whole life cycle of the two systems under investigation was taken into account: from raw material acquisition to crockery production and use of the crockery up to final disposal. In contrast to the disposable crockery, and based on information from commercial cafeterias, the reusable crockery can be used 1,000 times when washed in between until they end up as waste.

In order to obtain data to the extent necessary to ensure the validity of the data basis, specific data relating to the relevant life cycle stages has been gathered for both systems.

In the LCA, all potential environmental impacts considered to be relevant for the compared systems have been analyzed. Life Cycle Impact Assessment[4] was performed using the following impact categories:

- ozone depletion
- global warming
- fossil depletion
- acidification and terrestrial acidification
- eutrophication
- photochemical oxidation
- agricultural land occupation
- natural land transformation

In addition to these impact categories, the results of relevant life cycle inventory (LCI) indicators are also presented. These indicators comprise the following input parameters, which were regarded as characteristic for the systems under investigation:

- cumulative energy demand
- water depletion

With regard to the toxicity-related impact indicators, a comparison should be undertaken only with due caution. Besides the ongoing scientific discussion on the best way to handle complexity and uncertainty in building toxicity equivalents, the toxicity-related input parameters in currently available LCI databases raised concerns whether a data consistency beyond the datasets in these databases can be ensured. Due to the modelling approach chosen in this study (e.g. taking into account aggregated market datasets for the provision of raw materials) it has not been possible to exhaustively trace back every toxicity-related input parameter. Likewise, it cannot be established with sufficient certainty that the toxicity-related impact indicator results are based on adequate data

[4] According to DIN EN ISO 14040:2009-11 the life cycle impact assessment (LCIA) is defined as a phase of life cycle assessment, aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product

symmetry. Accordingly, it was decided not to draw definite conclusions on the comparison of single-use and multi-use crockery systems with respect to the toxicity-related environmental impacts.

According to requirements defined in ISO 14040/14044, the environmental impact indicators haven't been weighted and aggregated to one individual environmental indicator.

Results

In the base case scenarios, the reusable systems show lower values[5] for all or at least for the majority of impact assessment indicators than the respective disposable systems and can therefore be seen as environmentally favorable. Only the water demand of the reusable system is 1.2 (scenario school) to 2.9 (scenario hotel) times higher in the standard scenarios than the corresponding values of the disposable system. Only regarding the hotel scenario, and only concerning the acidification-related indicators, the disposable system shows results comparable to that of the reusable system.

Based on the results of the impact assessment the relevant stages in the life cycle of single-use and multi-use systems could be determined as follows:

Single-use system: With regard to the three single-use scenarios, the production of the required crockery items and their end-of-life treatment (disposal processes) contribute most to the overall environmental impacts along the product life cycle.

Multi-use system: With regard to the multi-use systems, in all three scenarios, the use phase and, more specifically, the dishwashing process, contributes the most to the overall results whereas the other life cycle stages are only of secondary importance.

Based on the findings of the contribution analyses, key driving factors for both systems have been identified and selected for further evaluation within the scope of the sensitivity analyses that have been conducted. With respect to parameters significantly influencing the results of the analyzed systems, the results from the most important sensitivity analyses shall be interpreted in the following.

For the disposable systems the main environmental impact is derived from material production and, to a lesser extent, from end-of-life treatment of crockery items for all or at least the majority of impact indicators. In contrast, for the reusable system, the main impact is caused by the dishwashing process in the use phase, and here especially by the demand for electric energy which is used to operate the dishwashing machines.

Conclusions on the hospital scenario

For the hospital base case scenario, a hospital cafeteria serving meals to non-patients has been assessed. The non-patient meals served in the hospital's cafeterias are assumed to be currently served with single-use crockery. By taking into account a hypothetical multi-use place setting in the hospital's cafeterias, the potential environmental impacts of a transition to a multi-use crockery system have been assessed. Overall, in the hospital scenario, there is the highest number of catering participants per functional unit (146,000), which is why in the multi-use scenario a medium-size band transport dishwashing machine has been considered. As such a band machine usually already exists to handle the reusable patient crockery this yields synergy effects.

[5] Lower values are environmentally better representing a lower negative impact on the environment or/and direct on persons.

Under these conditions and under the general conditions of the comparison in this study, the results can be specified as follows: The reusable system – as compared to the respective disposable system – proved to be particularly advantageous for all of the assessed impact indicators. Unlike in the other scenarios, in the hospital scenario this also applies to the water depletion potential (WDP), which is mainly due to the high water demand for the provision of PLA-based crockery items assumed to be used in this scenario for the disposable system. In summary, the overall results can be explained by the fact that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase (dishwashing process) of the reusable system.

With regard to the general decision-making situation in the hospital scenario, it can be established that a transition from single-use to multi-use crockery systems in hospitals' cafeterias would lead to lower environmental burdens.

Conclusions on the school scenario

Regarding the school scenario cafeteria, both single-use and multi-use systems appear to be very common in US facilities. In this study it has been assumed that meals in schools' cafeterias are typically served on compartment trays with a set of cutlery. With regard to the single-use system, it has been assumed that some meal components (e.g. dessert) are additionally pre-packed when served to students. Overall, in the hospital scenario, an average number of 90,000 catering participants per functional unit has been considered, which is why, in the multi-use scenario, use has been made of a hood type dishwashing machine.

In consideration of the prevailing conditions and also the general conditions of the comparison here too, the reusable systems offers significant benefits for all impact indicators that have been assessed, with the only exception being that of the impact indicator water depletion potential (WDP). With regard to this indicator, it has to be noted that the water demand of the reusable system (dishwashing) in the standard scenario exceeds the water demand of the disposable system by a factor of 1.2. For the other impact indicators, the overall results can also be explained (as in the Hospital scenario) by the fact that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase (dishwashing process) of the reusable system.

Also with regard to the general decision-making situation in the school scenario, it can be established that the use of multi-use crockery systems leads to lower environmental burdens, with the exception of the WDP.

Conclusions on the hotel scenario

Within the hotel scenario, the serving of breakfast to hotel guests has been taken into consideration. In this scenario, the self-serving of breakfast from a buffet on single-use and multi-use crockery items and the related environmental burdens have been compared. The place setting has been defined to meet the specific situation of a self-serving buffet. In general it should be noted that, in practice, the variation of the place setting per catering participant is comparably high, as the catering participants themselves freely choose from a selection of crockery items to use for their breakfast. However, every effort has been made to ensure an adequate and fair comparison. An overall number of about 40,000 catering participants per year was assumed for the hotel scenario. To meet the requirements in terms of the dishwashing capacity needed, based on both the scenario-specific place setting and the number of hotel guests, a hood-type dishwashing machine has also been selected for the multi-use system. The hood-type machine selected from MEIKO's product portfolio is the same as for the school scenario.

Regarding the hotel scenario, the comparison of the disposable and the reusable systems yields results broadly similar to those obtained in the other two scenarios. However, it should be noted that the differences between the two systems in the hotel scenario are less pronounced, but even though still significant, than in the other two scenarios. As in the school scenario, the multi-use system proved to be advantageous in environmental terms, with the exemption of the water depletion potential (WDP). In this scenario again, the water demand for the dishwashing process in the reusable system exceeds the water demand caused by the production processes of the disposable crockery items by a factor of 2.9. With regard to the acidification, related impact indicators TRACI environmental impact, acidification (TRACI acidification) and ReCiPe, Terrestrial acidification (ReCiPe TAP) lie more or less within the same range.

Nonetheless, and with the exemption of WDP and acidification, the multi-use systems have shown to have lower overall environmental impacts. With regard to the general decision-making situation, it can therefore be concluded that, from an environmental perspective, the use of multi-use crockery systems is advantageous for the hotel scenario as well.

Conclusions on sensitivity analyses

Based on the findings of the contribution analyses, key driving factors for both systems have been identified and selected for further evaluation within the scope of a set of nine sensitivity analyses, in order to test the base case results and underlying assumptions for sensitivity and consistency. With respect to parameters significantly influencing the results of the analyzed systems, the results from the most important sensitivity analyses show that

- the material weight of disposable crockery items is a significant parameter for the description of the disposable system, and taking into account a higher material weight confirms the results of the standard scenarios.
- taking into account shorter and longer distribution distances in the disposable system is of minor importance, or in other terms, has no effect on the overall results;
- taking into account a cooling of waste disposable crockery is also of minor importance;
- taking into account dishwashing machines in stock (with even a 10% increase in electricity consumption) instead of BAT machines for the dishwashing process, the reusable system remains the clear winner over the single-use system. From recently published data covering a selection of BAT and stock machines, it can be seen that energy usage ranges by an astounding 361% and water usage by a phenomenal 663%., This large span highlights the importance of choosing the best available technology when ordering dishwashing machines.
- a change in the emissions profile of the electricity dataset, as applied for the energy demand of the dishwashing process, leads to significant variations of the reusable system's impact indicator results. While this does not affect the general conclusions for the hospital and school scenarios, it turned out that the results from the comparison of systems in the hotel scenario, depending on the applied electricity dataset, in few cases leads to an impact indicator result that differs from the base case scenario insofar that results of both systems lie within the same range, or are even higher for the multi-use system.
- taking into account either a higher or lower average service life of reusable crockery has no effects on the overall results;

- taking into account possible and realistic variants of the disposable system in the hotel scenario may change the comparison results significantly in favor of the reusable system;
- taking into account a 100:0 instead of a 50:50 allocation rule has no effect on the overall results.

Recommendations

The recommendations are based solely on the evaluation of environmental aspects. As some aspects (e.g. economic aspects) are out of the scope of this study, the recommendations are not based on any other than environmental considerations.

Commonly there is no scientific-based system commonly acknowledged which provides the weighing and aggregating of the different impact indicators to one single environmental indicator. Against this background recommendations necessarily have a subjective character. Taking this into account, from the perspective of the Oeko-Institut, it is justified to claim that the higher water demand in the reusable systems is less relevant in comparison with the advantages of the reusable system in the other impact indicators. Under this condition, and based on conclusions on findings in the study at hand, and with regard to the intended audience, it may be recommended for environmental reasons:

- to implement reusable crockery systems instead of disposable crockery systems;
- to examine whether the implementation of a reusable crockery system is possible where a disposable system is currently implemented and where space requirements and building services (e.g. electrical connections) for dishwashing machines are well suited.
- to examine whether the implementation of a reusable crockery system is possible, if there is a need to decide which system should be implemented (e.g. in the course of renovation or in new facilities);
- not to change from reusable crockery systems to disposable crockery systems if a reusable system is already implemented.

1. Introduction

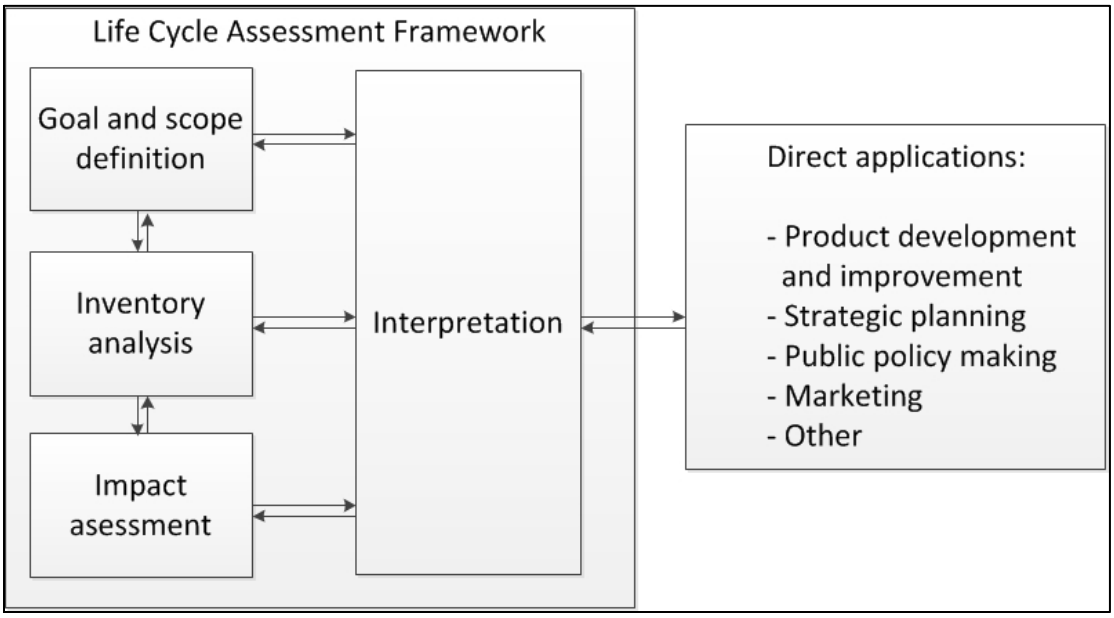
This study will address the use of different types of crockery used in catering facilities in the USA. In general it is possible to serve meals to customers with single-use or with multi-use crockery.

In facilities of stationary operation in Germany, multi-use crockery is predominantly used, not least in order to avoid waste resulting from the user of single-use crockery. Single-use crockery is typically used only for special areas of application (open-air events, facilities without sufficient space available for a dishwashing area). With regard to the US-specific conditions, MEIKO Maschinenbau AG (below named MEIKO) assumes that single-use crockery is used in areas of application where the use of multi-use crockery would also be appropriate.

MEIKO is interested to increase the share of reusable systems in the US catering facility market among others on the basis of arguments based on environmental aspects. Against the background that disposable systems and reusable systems differ from each other throughout the life cycle, the method of Life Cycle Assessment (LCA) is the method of choice for confirming the environmental approach.

Against this background, MEIKO commissioned Oeko-Institut e.V. in May 2014 to conduct a study aimed at analyzing and comparing the potential environmental impacts of a returnable and of a disposable system for serving meals in typical cafeterias in the USA. The LCA study at hand should meet the requirements set out in ISO 14040:2006 and ISO 14044:2006, and is therefore structured in accordance with the predefined structure of typical stages of an LCA (Figure 1-1).

Figure 1-1: Stages of a Life Cycle Assessment



Source: DIN EN ISO 14040:2009 © Beuth Verlag, Berlin 2009

In section 2, the goal and scope of the study are described. Section 3 gives an overview of the modelling and the data basis used; section 4 presents and explains the results. Based on the discussion of the results during life cycle interpretation (section 5) conclusions are drawn in section 6. Finally in section 7 there are given recommendations.

The final report at hand includes:

- the documentation of the methodological approach,
- characterization of the three scenarios and description of the data set,
- the results, including contribution and sensitivity analysis,
- the interpretation of results and findings, and
- the conclusions and recommendations derived.

2. Goal and scope

2.1. Goal of the study, intended audience, intended and not intended applications of the study

Kitchen planners and manufacturers of dish washing equipment – in which group MEIKO and MEIKO US fall – as well as to a lesser extent those in charge of kitchens are repeatedly confronted with questions as to the environmental performance of reusable systems compared to the environmental performance of single-use systems (also known as disposable systems). **The main goal and intended application** of the project is an evaluation and comparison of the potential ecological impacts of two types of crockery systems, namely reusable and disposable ones, which are used in stationary catering facilities, throughout the whole life cycle of the crockery items. Against the background described in the introduction this study, the focus is on the U.S. market.

The **reason for carrying out this LCA study** is to communicate the environmental performance of reusable crockery in distinct catering facility markets in relation to the alternative usage of disposable dishes and cutlery (which are assumed to be more commonly used at present). In accordance with MEIKO, three different scenarios have been selected from various use-patterns in order to cover three typical, and as far as possible representative application areas. Key criteria for the selection were the market relevance for the US out-of-home food market as well as the relevance to MEIKO as a manufacturer of professional dishwashing machines.

Regarding the **audience,** the results of the study are intended to be communicated to:

- Planning experts in the field of commercial kitchens;
- responsible persons or decision-makers in US commercial kitchens; and
- if relevant, competent authorities.

The study results refer solely to the analyzed and defined systems. The results are not intended for application in relation to other than the US market (e.g. Europe, Asia) nor in relation to non-stationary or temporarily installed catering facilities.

Due to the fact that the results of the LCA at hand are intended to be used in comparative assertions intended to be disclosed to the public, in accordance with DIN EN ISO 14040:2009-11 and DIN EN ISO 14044:2006-10 some additional requirements have to be taken into account. Especially the equivalence of the systems being compared shall be evaluated before interpreting the results. This applies to the comparison of performance, system boundaries, data quality, allocation procedures and impact assessment of both investigated product systems. Further details on this issue will be discussed in the following sections 2.2–2.9.

In the framework of this study, in particular the transition from single-use to reusable systems, which are assumed to be equipped with dishwashing machines produced by MEIKO, will be investigated. Accordingly, the new acquisition of dishwashing machines with the currently best available technology (BAT) has been assessed. The definition of BAT in this respect is expected to significantly affect the results of the reusable system. Therefore the use of a dishwashing machine with an average level of technology, typical for the average installation, has also been calculated (see sensitivity analyses, section 4.3.4).

The recommendations (given in section 7) are based solely on the evaluation of environmental aspects. As some aspects (e.g. economic aspects) are out of the scope of this study, the recommendations are not based on any other than environmental considerations.

2.2. Short description of investigated systems

There are principally two different ways of serving meals to consumers: using reusable dishes and using disposable dishes. Both alternatives are enabled through a number of processes using different materials of various origins. In this LCA, the following two systems of serving meals to consumers in stationary out-of-home catering facilities will be analyzed.

- **Disposable crockery system** (also referred to as single-use crockery system): The disposable crockery system uses single-use disposable crockery items, which can be used for serving meals to customers in stationary out-of-home catering facilities. The disposable crockery items are produced and manufactured from raw materials such as different types of plastics (e.g. polypropylene (PP), foamed and solid polystyrene (PS), polylactic acid (PLA)) and different types of paper products (e.g. solid unbleached board, kraft paper). The composition of place settings strongly depends on the application. Therefore, three model scenarios have been assessed (see also section 2.3). From the production sites' factory gate, the disposable crockery items are packaged, distributed to a wholesaler, and finally delivered to the catering facilities by truck transport. In this study, disposable crockery items do not cause any environmental burdens during the use phase. After their use by catering facility clients, the disposable crockery items are collected in waste containers at the facilities. Thereafter, items are collected by a refuse truck and transferred to waste treatment facilities, where they are finally treated and incinerated or disposed of in accordance with the waste disposal routes typical for the USA. As described in section 3.1.4, it is assumed that, in practice, there is no material recycling of used disposable dishes both due to technical and economic reasons. Regarding the waste treatment in municipal solid waste incineration plants (MSWI), combustion with energy recovery has been considered.
- **Reusable crockery system** (also multi-use crockery system): The reusable crockery system uses multiple-use crockery items which can be repeatedly used for serving meals to customers in stationary out-of-home catering facilities. The reusable crockery items are produced and manufactured of porcelain, stainless steel, glass and reusable plastics (e.g. PP, thermosetting resins). From the production sites, the multi-use crockery items are delivered to a wholesaler and, from there, distributed to the catering facility. After each use by catering facility clients, the reusable crockery items are collected and re-processed in the on-site dishwashing area by washing them in a dishwashing machine with detergents and rinse aid chemicals, especially formulated for industrial dish washing machines. Besides detergents and chemicals, energy and water are required for the washing process. Thereafter, the reusable crockery is used again. In this study, an average of 1,000 washing cycles (for detailed information on re-processing cycles see also section 3) has been set as product lifetime for the base case scenarios described in further detail below. When the re-usable crockery items have reached the end of their product lifetime, they are also collected by a refuse truck and afterwards treated and incinerated or disposed of in accordance with the waste disposal routes typical for the respective materials in the USA.

Exclusions from the scope of this study: Since it can be assumed that there are no differences between the two compared systems regarding the storage of food waste (e.g. leftovers) or waste from the preparation of food, these aspects are excluded from the scope of this study.

- Nonetheless, there may be differences between the two systems, for example in the working time for handling used dishes as well as labor costs arising for manpower or the demand for sufficient and trained staff to load and unload the dishwashing machines. However, these aspects are not expected to affect the environmental comparison of the two product systems.
- A detailed description of typical place settings for both, reusable and disposable crockery is given in section 3. All results in the study will be given according to the respective functional unit set out in the standard scenario described in the following section, unless it is stated differently.

2.3. Functional unit and function of the product systems – reference flows

Within this study, two product systems – serving meals on multi-use and serving meals on single-use crockery – are investigated. The comparison is made by examining three different application scenarios, followed by nine sensitivity analyses in order to identify the significant parameters of the systems and scenarios under consideration. Regarding the fact that both systems have been successfully applied in practice throughout decades, this may serve as justification for setting the functionality of both systems as “to serve a meal in a hygienically safe condition”. With regard to the defined functionality, both systems are regarded to be basically functionally equivalent. The following functional unit[6] has been defined in order to compare the existing disposable system to the hypothetical reusable system.

“Provision of dishes for the hygienic delivery of X portions of food a day within a year[7] in a stationary out-of-home cafeteria in the USA.”

The comparison of the two systems will be substantiated in relation to three typical scenarios representing model out-of-home markets. The markets addressed as scenarios in this LCA are given in Table 2-1. In addition to the different absolute numbers of catering participants, there is also a difference in the composition of required / used crockery items in the different catering facility markets. The scenario specific place setting components and properties are given in the respective reference flow tables in section 3.

Table 2-1: Reference flows for each of the two systems

	Scenario 1: hospital[8]	Scenario 2: school	Scenario 3: hotel
Catering meals per day	400	500	105
Breakdown to breakfast / lunch / supper	56 / 240 / 104	0 / 500 / 0	105 / 0 / 0
Days of operation per year	365	180	365
Meals per year	146,000	90,000	38,325
Scenario specific place setting components and properties	See sections 3.1.3.1 (Table 3-1) and 3.2.3.1 (Table 3-17)	See sections 3.1.3.2 (Table 3-5) and 3.2.3.2 (Table 3-25)	See sections 3.1.3.3 (Table 3-9) and 3.2.3.3 (Table 3-30)

Source: Own compilation

6 The functional unit (FU) is defined as the quantified performance of a product system for use as a reference unit.

7 One year defined here as scenario specific days of operation per year.

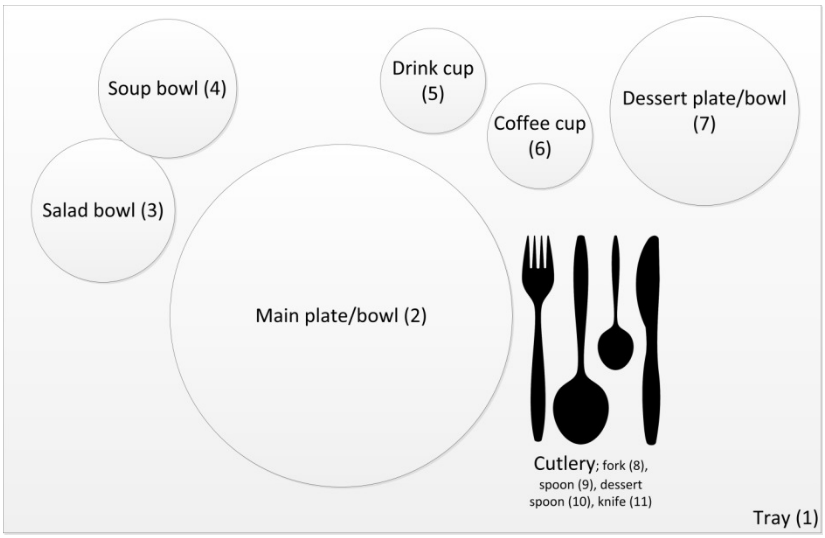
8 Hospital stationary catering for staff and visitors (not patients).

Due to the differences between the scenarios, the functional unit as well as the corresponding reference flows differ analogously, and are defined specifically for each scenario. In order to define functional units for the respective catering facility markets in the scope of this study, a typical average place setting was specified for each scenario. Details will be discussed in the sections below.

2.3.1. Scenario 1: US hospital market

The composition of a typical place setting for serving non-patient meals in a hospital cafeteria is given in Figure 2-1, thereby providing a basis for the evaluation of the environmental performance of using single-use and multi-use crockery items.

Figure 2-1: Composition of a typical place setting[9] for serving non-patient meals in a hospital cafeteria



Source: Own schematic illustration, Oeko-Institut e.V.

The data basis covering the hospital cafeterias scenario has been retrieved by MEIKO from three different hospitals in the US.

- The **Cooley Dickinson Hospital**, 30 Locust St. Northampton, MA. The private hospital has 140 beds. Its cafeteria currently serves approximately 400 portions of non-patient meals every day.
- The **Thomas Jefferson University Hospital,** 111 South 11th St., Philadelphia, PA. The university hospital has 957 beds. Its cafeteria currently serves approximately 1700 portions of non-patient meals every day.
- The **St. John's Riverside Hospital,** 967 North Broadway, Yonkers, NY 10701. The private hospital has 273 beds. Its cafeteria currently serves approximately 475 non-patient meals.

The hospitals have catering facilities for patients and for non-patients, which have been used to define the typical meal place setting. All three hospitals serve about 97% of the patient meals on reusable place settings (only 3% of the patients receive single-use trays and crockery due to their

[9] The term “typical place setting” in this context means that this represents a typical full place setting serving for non-patient meals in a hospital cafeteria. The composition of individual trays for each meal period will differ. Furthermore, it should be noted that this place setting is used for breakfast, lunch and supper. The calculation of the reference flow in chapter 3 (Table 3-3) considers the different variations for the three variants of meals.

highly infectious diseases or as the patients are in the intensive care unit). Respectively, the hospital kitchens in all three cases are already equipped with a dishwashing area and a medium-size band transport dishwashing machine for washing crockery used for the patient's meals. In contrast, the non-patient meals served in the hospital's cafeterias are currently served with single-use crockery in each of the three hospitals. Data along with the single-use items of each cafeteria have been collected by a MEIKO US product manager, who has a wide base of first-hand experience stemming from visits to a large number of hospitals over a period of more than 10 years. Unfortunately, none of the collected data-sets has been 100% complete. The best available database could be established for the Thomas Jefferson University Hospital. Accordingly this hospital was primarily used to define the crockery of a typical place setting. The composition of the single-use place setting for serving non-patient meals in the hospital cafeteria is given in section 3.1.1.

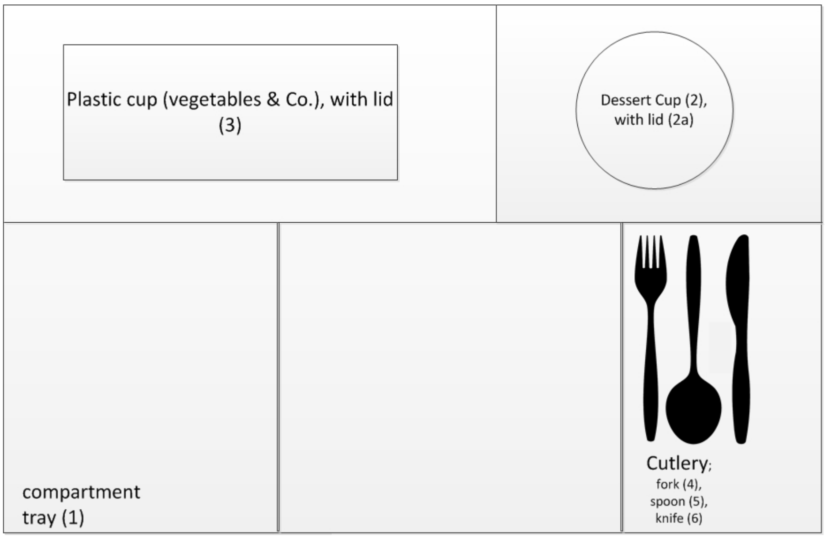
In order to be able to make a comparison, a hypothetical composition of a multi-use place setting has been derived from the data discussed above, assuming that the meals that are served in the cafeteria with single-use crockery items could be replaced by serving the meals with multi-use crockery items that can be washed in the hospital's already existing dishwashing area.

In two of the three hospitals the sculleries are currently equipped with a Hobart FT 822 5 8 9 BD, a machine which represents typical stocks in terms of age and state of technology. For this study the best available technology representing the state of the art is to be used. As MEIKO machine specific data (e.g. energy consumption, water and detergents demand) shall be used within the LCA regarding the dishwashing process in the reusable crockery system, a dishwashing machine that best fits the scenario-specific operational requirements was selected out of the MEIKO product portfolio. This selection was undertaken by MEIKO experts. In the current case a medium band transport machine of the MEIKO M-iQ series with one dryer has been selected. For this application the machine washes with a NSF approved band speed, water usage and temperatures and represents current best available technology (BAT).

2.3.2. Scenario 2: US market for school cafeterias

The base crockery component in school cafeterias is the divided tray. The composition of a typical place setting for serving lunch on disposable crockery in a school cafeteria is given in Figure 2-2.

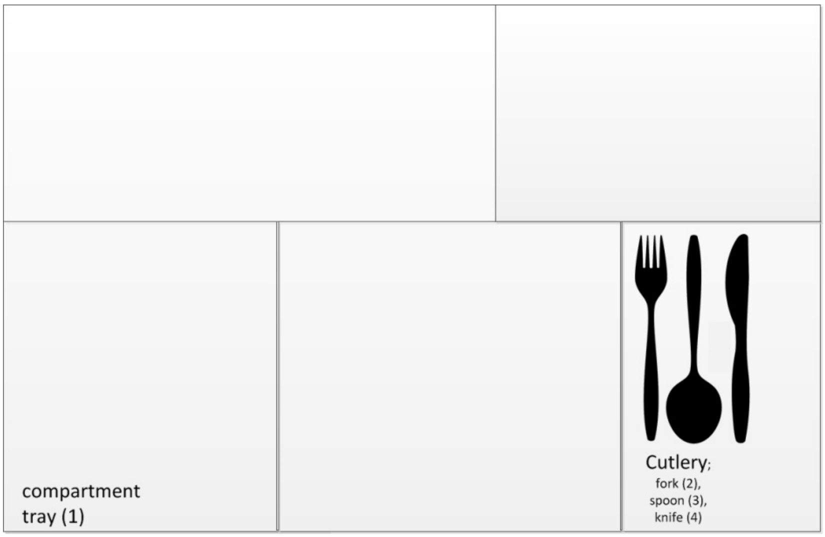
Figure 2-2: Composition of a typical place setting for serving lunch with disposable crockery items in a school cafeteria



Source: Own schematic illustration, Oeko-Institut e.V.

In contrast to the multi-use system shown in Figure 2-3 below, the single-use system uses two additional crockery items. This involves a disposable dessert cup (with lid) and a plastic container (with lid) for pre-packaged foodstuff, as typically used for vegetables. Within the multi-use system it has been assumed that these two items are not a typical place setting component.

Figure 2-3: Composition of a typical place setting for serving lunch with reusable crockery items in a school cafeteria



Source: Own schematic illustration, Oeko-Institut e.V.

The data basis covering the scenario "school cafeterias" has been retrieved by MEIKO from five different schools in the USA, including three elementary schools, one middle school and one high school. Typical for the USA an average amount of 180 school days per year has been assumed for all schools.

- The **Bancroft Elementary School**, 15 Bancroft Rd. Andover, MA. The public school (Grades 1-5) currently serves approximately 200 lunches every school day.
- The **Osage Elementary,** 110 Summerale Rd., Voorhees, NJ. The public school (Grades 1-5) currently serves approximately 650 lunches every school day.
- The **G.H. Robertson Elementary School,** Cross Street, Coventry, CT. (Grades 3-5) currently serves approximately 340 lunches every school day.
- The **Upper Middle School**, 1000 Hollyoak Dr., Vorhees, NJ. (Grades 5-8) currently serves approximately 1200 lunches every school day.
- The **Andover High School**, 80 Shawsheen Rd., Andover, MA. (Grades 9-12) currently serves approximately 1100 lunches every school day.

Currently all schools serve lunch meals in compartment trays with cutlery, e.g. without extra plates. Two out of five schools serve meals on single-use foamed polystyrene trays and offer single-use cutlery, one school uses multi-use trays and cutlery, while the other two schools use multi-use trays mixed with single-use cutlery.

Items of each cafeteria have been collected by a US product manager of MEIKO. The composition of the single-use place setting for serving lunch in the school cafeteria is given in section 3.1.3.2.

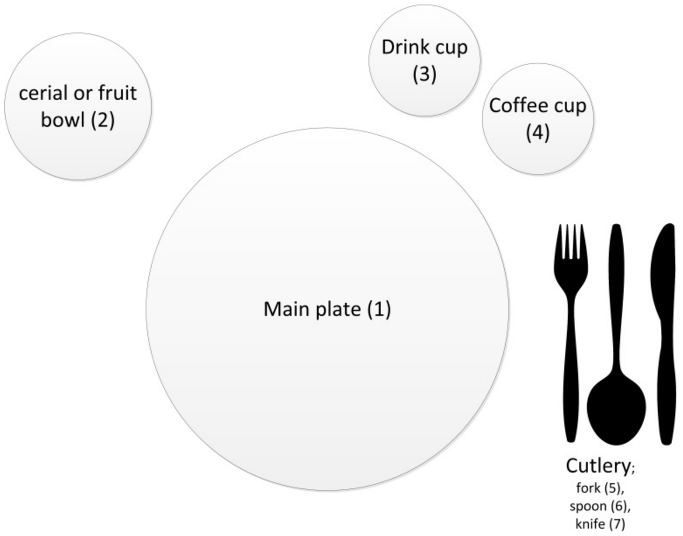
Regarding the dishwashing process of multi-use compartment trays, the sculleries are currently equipped with machines which represent typical stocks in terms of age and state of technology. As MEIKO specific data (e.g. energy and detergent consumption as well as water use) shall be used within the LCA, a "MEIKO equivalent" was selected out of the MEIKO product portfolio. This selection was undertaken by MEIKO experts. In the current case, the MEIKO M-iClean H, a hood machine, representing current best available technology (BAT), was selected.

2.3.3. Scenario 3: US market for hotels serving breakfast

Offering breakfast to guests in hotels is not as widespread in the USA as it is for example in Germany. Nevertheless, the number of hotels offering breakfast to guests is increasing. Out of numerous different types of place setting items available on the market, one reference place setting for serving breakfast in hotels has been put together for modelling the base case scenario (Figure 2-4).

Due to the wide variation of possible alternatives in the scenario "US market for hotels serving breakfast", a set of variants has been evaluated in order to supplement the base case scenario (described in detail in section 3.1.3.3). Documentation of variants can be found in section 4.3.

Figure 2-4: Composition of a reference place setting for hotels serving breakfast with both disposable and reusable crockery



Source: Own schematic illustration, Oeko-Institut e.V.

The data basis covering this scenario has been retrieved by MEIKO from three different hotels (Marriott / Hilton / Best Western Plus):

- Hotel #1[10] has about 100 rooms and is serving about 80 breakfasts every week day and 80 breakfast every weekend day;
- Hotel #2 has 60 rooms and is serving about 50 breakfasts every week day and 100 breakfasts every weekend day;
- Hotel #3 has about 175 rooms and serves about 150 breakfasts every week day and about 250 breakfasts every weekend day.

The composition of the single-use place setting for serving breakfast in the reference hotel is given in section 3.1.3.3.

In order to be able to make a comparison of disposable and reusable crockery, a multi-use place setting has been defined, using items with typical material and dimensions. Regarding the dishwashing process the same dishwasher as for the scenario school, the MEIKO M-iClean H, a hood machine, representing current best available technology (BAT), has been selected.

2.4. System boundaries of the product systems

Life cycles of reusable and disposable dishes differ depending on the used materials. Life cycle stages that they have in common are the production of the materials for reusable and disposable dishes and the serving of meals in the use phase. Differing life cycle aspects are the materials used, and therefore the production processes of the materials with their specific possibilities of being reused. The following figure (Figure 2-5) shows the two systems investigated in this study:

- System 1: System using single-use crockery (made from various raw materials)
- System 2: System using multi-use crockery (made from various raw materials)

10 Names removed and order changed to provide anonymity for the hotel owners.

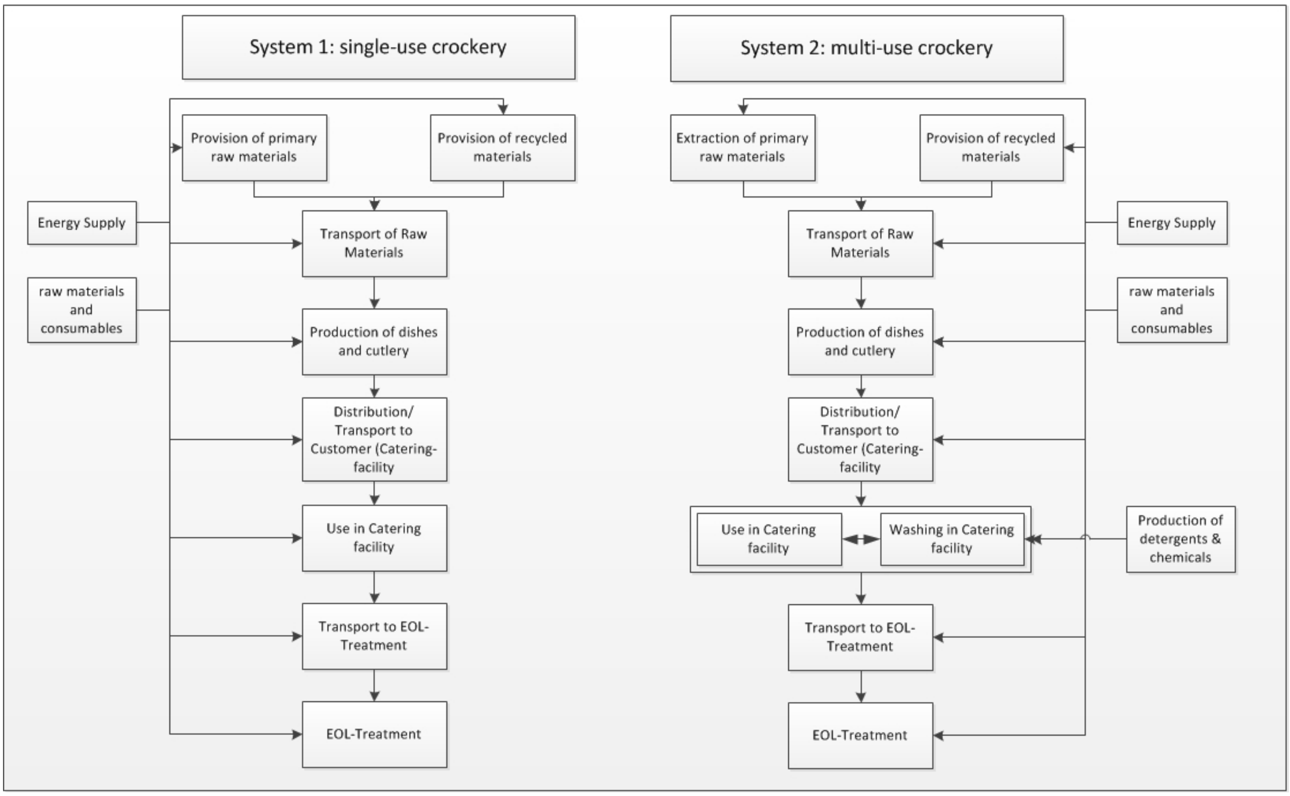
The investigated options or respectively systems will be described in detail in section 3.

For the single-use crockery system, the following life cycle stages will be included within this study.

- production and provision of dishes and cutlery,
- distribution of dishes and cutlery to the customer;
- the use phase in the respective facility;
- the end-of-life treatment of dishes and cutlery (including required transport services).

In this study, the provision of kitchen infrastructure (provision of storage, production of dishwashing machine and accessories have been excluded from the scope of this study. The storage of crockery before use and the storage of used disposable crockery are excluded from the study's scope. The storage demand might be a reasonable point in discussing the differences of using single- and multi-use crockery e.g. for planning purposes. In this study and with regard to the disposable system, however, no activities causing environmental burdens have been considered for the base case scenarios. From an environmental point of view of this study – storage is only important if energy for heating or cooling is required. Although this is usually not the case, the possible cooling demand in the storage of used disposable crockery as part of the waste management will be taken into consideration with the help of sensitivity analysis 4.3.3.

Figure 2-5: Life cycles of both investigated systems, as applied in all three scenarios (market case studies)



Source: Own schematic illustration, Oeko-Institut e.V.

For the multi-use crockery system, the following life cycle stages will be included within this study:

- production and provision of dishes and cutlery;
- distribution of dishes and cutlery to the customer;
- the use phase in the respective facility;
- the washing (reprocessing) of the crockery in the catering facility (including production of detergents and chemicals as well as required transport services); and
- the end-of-life treatment of dishes and cutlery (including required transport services).

Furthermore, the production of detergents and rinse chemicals (only relevant for the multi-use crockery system) will be included as well as the energy and water demand and the waste water treatment demand for the washing process in the catering facility. The production of the dishwashing machine, however, will not be taken into account for the reason that the impacts are very limited. This has been proved in a preparatory study in the course of the EU eco-design process (Rüdenauer et al. 2011). Likewise, the packaging for detergents has been excluded from the scope of this study. Regarding the packaging for single-use crockery items, it was decided to estimate the packaging demand for the disposable crockery, in order to get an indication for the relevance of the packaging demand. The analysis of the contributions revealed that packaging demand contributes to the results of the disposable system (section 4.2.1.1).

It is assumed that there is no difference between the two compared systems as far as the process of meal preparation and the process of washing the cookware is concerned. The same applies to the storage of kitchen waste and leftovers. On the assumption that there is no difference between the two compared systems, the treatment of leftovers and kitchen waste is excluded from the scope of this study.

2.5. Data quality requirements

According to ISO 14044:2006 (section 4.2.3.5) data quality requirements have to be included for the following categories:

- Time-related coverage: Only data not older than 10 years can be used for this LCA study. Only data not older than 5 years can be used for those processes which contribute significantly to the overall result. This applies to the datasets used for modelling the provision of raw materials for single-use crockery and to all datasets used for modelling the dishwashing process within the reusable system. Due to data availability, it was necessary for some unit processes to make an exception to this requirement, e.g. for some detergent ingredients and the production of porcelain. However, it is assumed that these processes will not change significantly in regard to their environmental performance and / or will only have a minor impact on the total results, as will be further specified in section 3.
- Geographical coverage: Concerning supply chain processes (e.g. porcelain production, paper production, polystyrene production) the geographical coverage should correspond to the assumed supply chain (world market for production of mineral oil based plastics, paper and biogenic plastics and porcelain). Concerning processes of importance for the overall result, as well as for the EoL treatment processes, the collected data refers to US-specific conditions. The same applies to the electricity supply used within the use phase of the reusable crockery system. For details concerning the specific situation of the electricity supply in the USA, see also section 3.
- Technological coverage (i.e. technological standard of production, transport, use and disposal processes): For processes which contribute significantly to the overall result (so-called “key

processes"; e.g. the dishwashing process for the multi-use system and production and end-of-life treatment for the single-use system) all data used for this study refers to status quo processes used in the US or where applicable, representing the current situation on the global raw material markets. Regarding the provision and handling of raw materials and production of the reusable dishes, the data analogously refers to the status quo in the respective country / region or represents a situation on the global market in kind of a volume-based share of the different regions to the specific global market. Regarding the dishwashing processes of the re-usable dishes and in line with the goal definition, all data in this study refers to best available dishwashing technology (BAT). Currently, single-use ware has a remarkably high share in the US markets. It is assumed that it is possible to replace the single-use ware by multi-use ware. In the framework of this study, the transition from single to reusable systems which are equipped with dishwashing machines by MEIKO will be investigated. Accordingly, the new acquisition of dishwashing machines with best available technology (BAT) has been assessed. Since this definition is significant in relation to the results, the impact of a 10% higher energy demand for the dishwashing process representing existing machines in stock has been checked with the help of scenario analyses (see also section 4.3.4).

- Precision: With regard to the precision of the used data, the variability of the data values for each data expressed (e.g. variance) have been assessed with respect to the requirements in the ISO 14040 series. With regard to remaining uncertainties, especially concerning necessary assumptions, a broad set of sensitivity analyses have been carried out, in order to ensure to fulfil data precision requirements.
- Completeness: Within the iterative process of data collection, the data basis has been developed step by step. As mentioned above, and with regard to remaining uncertainties, especially concerning necessary assumptions, a broad set of sensitivity analyses have been carried out, in order to ensure to fulfil data completeness requirements.
- Representativeness: The degree to which the data reflects the actual existing (market) situation has been qualitatively assessed with respect to the transferability of the model plants (for example the three different hospitals). With regard to this assessment, those factors have been identified which are relevant in terms of their impact on transferability. As a decisive factor, the type of machine which is assumed in the scenario models has been identified. Therefore, the different types of dishwashing machines are to be described for the three different scenarios, but within one scenario, the same machine type has been regarded in the different model facilities. In the case of the hospital market this means that the fact that in all three hospitals of different size (140 beds to 957 beds) a medium band transport dishwashing machine is currently installed has been evaluated.
- Consistency: It has been assured that the study methodology is applied uniformly to both systems and related sub-systems under consideration. Particular importance was placed on ensuring a comparable detailed analysis of both, the single- and the reusable systems, in all of the three markets under consideration.
- Reproducibility: Assured through a thorough documentation, the LCA at hand aims to present all relevant information about the methodology and the input data that would allow an independent practitioner to reproduce the results reported in the study in the framework of typical model preciseness.
- Uncertainty of information: As already mentioned above, sensitivity analyses have been carried out in order to assess the extent to which changes of input data or assumptions influence the indicator results. Within this study, sensitivity analyses have been carried out for all relevant input data as well as for parameters where it has been necessary to cope with lacking data by

making assumptions. The data basis is described in detail in section 3. The sensitivity analyses that have been carried out are discussed and described in section 4.2.3.

2.6. Impact assessment methodology

In general terms, life cycle impact assessment (LCIA) involves assessing the results of the life cycle inventory in relation to their relevance to the environment.

According to the requirements of ISO 14040 / 14044, the life cycle impact assessment phase includes the following mandatory elements:

- Selection of impact categories, category indicators and characterization models;
- assignment of LCI results to the selected impact categories (classification); and
- calculation of category indicator results (characterization).

Additionally to the mandatory elements, also a normalization, according to ISO 14040 series an optional part of the LCIA, has been carried out.

It should be kept in mind that LCA has some inherent limitations; the study-specific limitations are given in section 2.8.

Furthermore, and due to the fact that the impact indicators are intended to be used in comparative assertions intended to be disclosed to the public, a high value has been assigned to the assurance that all impact indicators are scientifically described, technically valid, and environmentally relevant.

As required by ISO 14044:2006 (section 4.4.5), LCIA intended to be used in comparative assertions intended to be disclosed to the public shall employ a sufficiently comprehensive set of category indicators and the comparison shall be conducted category indicator by category indicator. Last, but not least, it has been ensured that all category indicators evaluated and reported in this study (respectively more precisely the characterization models used to derive the impact indicators) are internationally accepted. From the authors' point of view, this selection ensures a sufficient set of impact categories in order to reflect the systems under consideration.

In accordance with the goals and scope (section 2), the impact assessment of this study focusses on such characterization methods and impact categories which are particularly acknowledged for being the state of science and methodology in the USA. It is for this reason, that the complete list of impact categories of the TRACI-Model, as implemented in the ecoinvent database, has been selected for the impact assessment in this study.

In order to also address environmental impacts that are not covered by the TRACI-Model, but considered to be relevant for the fair comparison of the two compared systems (e.g. fossil and water depletion potential, agricultural land occupation and natural land transformation), additionally impact categories provided by the ReCiPe-Model have also been taken into account.

Regarding acidification, it has been decided to additionally evaluate the terrestrial acidification potential (TAP100a) as implemented in ReCiPe.

Impact assessment of toxicity aspects is not entirely uncontroversial, mainly due to uncertainties concerning data availability or data symmetry in background datasets at the level of the inventory. Therefore, it has been decided to additionally evaluate the impact indicators of the UseTox-Model, which is referred to as state-of-the-art scientific consensus model, in order to harmonize the assessment of toxicity aspects in LCA. Nonetheless, evaluation of UseTox indicator results needs to be carefully reviewed. For this reason, the toxicity-related impact indicator results have been analyzed in the course of the life cycle interpretation (see section 5.4).

The impact assessment methods and categories, which were applied against the principles discussed above, are summarized in Table 2-2.

Table 2-2: Overview of impact categories used in the course of the impact assessment

Method	Impact category [unit]	Short name (as used in chapter 4)	Source & comment
Cumulative Energy Demand	CED_{total} [MJ]	CED, total	Hischier, R., Weidema B. Eds. (2010), pp. 33-40
TRACI[11]	Ozone depletion [kg CFC-11-eq.]	TRACI, ozone depletion	Bare et al (2003); for implementation in ecoinvent see also Hischier, R., Weidema B. Eds. (2010), pp. 149-155
	Global Warming (100a) [kg CO_2-eq.]	TRACI, global warming	
	Acidification [moles H^+-eq.]	TRACI, acidification	
	Eutrophication [kg N]	TRACI, eutrophication	
	Photochemical oxidation [kg NOx-eq.]	TRACI, photochemical oxidation	
	Ecotoxicity [kg 2,4-D-eq.]	TRACI, ecotoxicity	
	Human health (air pollutants) carcinogens [kg benzene-eq.]	TRACI, human health, carc.	
	Human health (air pollutants) non-carcinogens [kg toluene-eq.]	TRACI, human health, non-carc.	
	Human health (air pollutants) respiratory effects average [kg PM2.5-eq.]	TRACI, human health, resp. eff.	
ReCiPe Midpoint (H) w/0 LT	Terrestrial acidification w/o LT, TAP 100 w/o LT [kg SO_2-eq.]	TAP_{100a}	Goedkoop et al 2009);for implementation in ecoinvent see also: Hischier, R., Weidema B. Eds. (2010), pp. 143-148
	Agricultural land occupation w/o LT, [m²*a]	ALOP	
	Natural land transformation w/o LT [m²]	NLTP	
	Fossil Depletion w/o LT, FDP w/o LT [kg Oil-eq.]	FDP	
	Water depletion w/o LT, WDP w/o LT [m³]	WDP	
USE_{TOX}	USE_{tox} human toxicity, total [CTU_h]	USEtox, human toxicity, total	Huijbregts et al (2009); for implementation in ecoinvent see also: Hischier, B; Weidema, B. (Eds.): ecoinvent report No.3 (2010), pp. 156-160
	USE_{tox} ecotoxicity, total [CTU-eq.]	USEtox, ecotxicity, total	

Source: Own compilation

[11] Concerning the TRACI characterization factors and according to the ecoinvent report no 3, site specificity is available for many of the impact categories, but for all indicators, a US average value exists. These US average values were entered into the ecoinvent data base and have been applied in the present study.

2.7. Allocation

In the context of LCA, allocation implies partitioning the input or output flows of a process or a product system between the system under consideration and one or more other product systems. Allocation procedures are necessary when more than one product is generated within the investigated processes (e.g. various bulk chemicals including different types of plastics out of naphtha). Another pre-requisite for allocation are so-called multi-input processes (e.g. waste incineration) where the resulting emissions have to be assigned to the different inputs. Within the scope of this study, allocation procedures are necessary for a number of processes. Implicit allocation procedures at process level are described in section 2.7.1. Allocation procedures at the system level are discussed in section 2.7.2.

2.7.1. Implicit allocation at process level

Implicit allocations are all allocations that are already taken into account in background datasets taken from databases (i.e. ecoinvent). At this point, only datasets of the system ecoinvent allocation default have been used for modelling the two product systems in the course of this study. The implicit allocation of the applied datasets is reported within the documentation of such datasets and ecoinvent datasets. The documentation can be found on the ecoinvent website after login (https://ecoquery.ecoinvent.org/Account/LogOn?ReturnUrl=%2f).

2.7.2. Allocation on system level

An allocation on system level has been carried out with regard to the end-of-life treatment of both systems. Taking into account credits for thermal and material recycling, for example, can be of relevance with regard to the overall results of the comparison. This is particularly true for the case of the disposable system. The procedure on handling the end-of-life treatment in this study has been documented for the single-use system in section 3.1.4 and for the reusable system in section 3.2.4.

According to requirements defined in ISO 14040/14044, in case of comparative assertion at least two variants of the allocation of credits resulting from thermal or, if applicable, material recycling have to be considered. Within the course of this study, the so-called 50:50-rule has been applied for the base case scenario, meaning that 50% of the credits from recycling shall be credited to the system delivering the recycled material and 50% of the credits credited to the system that takes up the recycled material. As an alternative representing a best case assumption for the single-use system, a 100:0-rule has been applied within the framework of the sensitivity analysis (see section 4.3).

2.8. Limitations

This study compares the environmental impacts of two systems for the provision of dishes and the hygienic serving of food in this context. The following limitations to the study's results have to be taken into consideration:

- In principle, it must be borne in mind that LCIA results are relative expressions and are unable to predict any potential impacts on category endpoints, the exceeding of thresholds, safety margins or risks.
- In respect to the impact assessment, it has to be stated that the impact categories used for impact assessment in LCA cannot display all environmental effects caused by the analyzed systems (e.g. effects on biodiversity are left out). The knowledge on the de-facto environmental

effects related to the two product systems under investigation is limited. Beyond this, the USEtox potentials as well as the TRACI toxicity potentials have to be discussed with special caution due to a still insufficient set of inventory data (with respect to completeness, quality and especially asymmetric data availability in compared systems, leading to uncertainties for characterization factors for many substances).

- Partly, a real-life system (e.g. disposable dishes in a hospital cafeteria) has been compared to a system with a hypothetical status quo (e.g. reusable dishes in the same hospital cafeterias) based on assumptions. Although specific attention has been paid in order to result in realistic assumptions, it cannot be generally ruled out that real life will vary from these assumptions.
- The data gathered from the reference facilities represents specific applications, but must not necessarily cover the addressed markets in all cases as a whole. Site-specific effects and parameters (e.g. material composition of crockery items) might influence the overall results and have to be taken into account when exporting results and using them in another context (e.g. non-stationary dishwashing appliances, other geographical scopes).

2.9. Description of the critical review process

As defined in the goal and scope section, the results of the LCA at hand are foreseen to be used in comparative assertions intended to be disclosed to the public. According to ISO 14040/14044 series, there is thus a need for a critical review by an external critical review experts panel (in terms of ISO, also called “panel of interested parties”) in order to check and to evaluate whether the LCA study has met the requirements of the international standard concerning methodology, data and reporting. In particular the review process will thereby take into account:

- Consistency of the method used with accepted practice (ISO standards),
- scientific and technical validity of the method used,
- appropriateness and reasonability of the obtained data for fulfilling the study’s goals,
- appropriateness of interpretation and conclusions in respect to the data obtained, the limitations identified and the goal of the study,
- transparency and consistency of the study report.

Another purpose of the Critical Review is to improve both the quality and the credibility of the study.

Prof. Dr. Brigit Grahl (LCA consultant, Germany) was selected as external expert to act as chair of the review panel. In consultation with Prof. Dr. Birgit Grahl, Terri Boguski (LCA consultant, US) and Ed Morano (Canadian based food service consultant & specialist planner of commercial kitchens, who provides consulting services throughout the US and Canada) were selected as further members of the Critical Review Panel by the chairperson. All three experts chosen are familiar with the ISO 14040 series.

The relevance of selected impact categories assessed within LCIA has been discussed with the chair of the review panel at an initial state of the first project phase. The selected impact categories, the overall modelling approach and relevant stipulations on the data that has to be taken into account have been discussed during a tele-meeting with the review panel and were regarded as sufficient with respect to the goal and scope of this study.

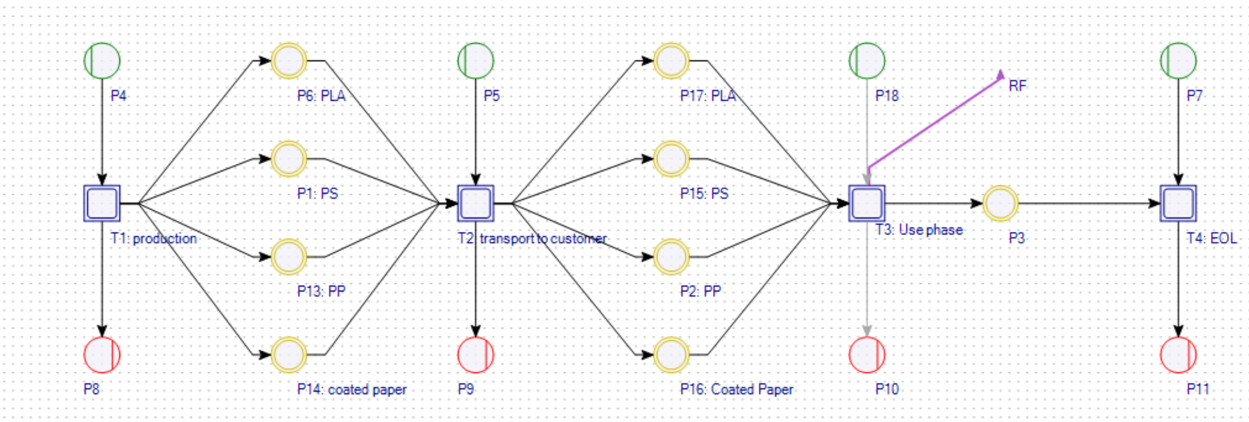
3. Basis of the Life Cycle Inventory (LCI): Modelling and data basis

The data sources used for the LCI section of the study can be distinguished into specific and general data:

- General data are average values representing the average technological standard used for the investigated process within a specified geographical coverage and are often appropriate for up-stream and down-stream processes. Within the scope of this study, general data is used for the provision of raw materials and the production processes of both single-use and multi-use ware. The same applies for transports and transport distances (distribution of the crockery, end-of-life-transport) where average datasets have been used for modelling the respective transport-related environmental impacts. Regarding electricity production, US-specific generic datasets (see section 3.2, several regional grids have also been compared within the scope of the sensitivity analyses set out in section 4.3.5) have been applied for modelling the emissions due to electricity demand in the use phase of the reusable system. The same regional US-specific dataset has been applied (see section 3.2.1) for the energy demand in the production of multi-use crockery.
- Specific data, on the other hand, is used when the respective section of the system shows specific requirements and conditions, which otherwise would be mapped too coarsely, when using generic data. Thus, in this study, especially input data of the dishwashers (demand for electricity, water and detergents) are inventoried with specific data provided by MEIKO. The same applies to the material identity and the specific weight of each crockery item for both single-use and multi-use ware. Last but not least, the number of meals served per day has been derived from the specific data gathered at the respective model facilities.

The calculation of the life cycle assessment was carried out by using the LCA tool "Umberto NXT Universal". In the following sections, the process steps and the unit processes of the life cycle stages will be specified regarding modelling assumptions and data basis. Within Umberto, the unit processes are linked together and thus form a balanced network for the respective life cycle stage, which is then connected with the other life cycle stages in order to establish a network for the whole product system (i.e. the life cycle of disposable dishes).

Figure 3-1: Screenshot of the single-use hospital scenario (main net) from the LCA tool "Umberto NXT Universal"



Source: umberto NXT Universal, ifu Hamburg

On the basis of this data network, the energy and material flows for the functional unit have been calculated.

In the following, the investigated options and the data base will be described in detail:

- System 1: Disposable system, using disposable dishes to serve meals in the three specific markets (section 3.1); and
- System 2: Reusable system, using reusable dishes to serve meals in the three specific markets (section 3.2).

The specific data were collected using a spreadsheet developed in accordance with MEIKO and sent out to MEIKO US' sales managers.

For both systems the following life cycle stages apply:

- production and provision of dishes and cutlery,
- distribution of dishes and cutlery to the customer, and
- the end-of-life treatment of dishes and cutlery (including required transport services).

Accordingly, it can be assumed that significant differences between the three scenarios, respectively between the three specific markets, only exist in regard to the use phase of the two systems. Therefore, the description of the use phase (section 3.1.3 for the disposable system and section 3.2.3 for the reusable system) has been divided in case study-specific sub sections.

3.1. Disposable system

The model of the disposable dishes encompasses the following life cycle stages:

- production of disposable dishes and cutlery, including packaging (section 3.1.1);
- distribution to the customers (section 3.1.2);
- use in… (section 3.1.3):
  - hospital cafeterias
  - school cafeterias
  - hotels serving breakfast
- end-of-life treatment, including the required transport services (section 3.1.4)

3.1.1. Production of disposable dishes and cutlery

The sub-network of the disposable dishes production consists of the following process steps:

- production and provision of raw materials,
- manufacturing of raw materials (i.e. thermoforming of EPS),
- manufacturing of products (i.e. calendaring of EPS), and
- manufacturing of packaging materials for final products & packaging of final products[12]

[12] Regarding the contribution of packaging materials for final single-use products, a rough estimation has been prepared, in order to be able to assess whether such packaging-related efforts are of relevance for the overall results.

Raw materials for disposable dishes may come from a variety of sources, such as PE / PP / PLA EPS / paperboard. Based on information gathered in the model facilities and on assumptions of the market share, within the framework of this study, it is assumed that disposable dishes and cutlery are made of the materials shown in Table 3-1. Likewise, for each of the given materials, the production process and process-specific production losses already considered in the dataset (e.g. 2.3% for the process thermoforming with calendaring), have been taken into account for the crockery item production. Further process and material specific losses occurring during production processes (such as stamping losses for paperboard items), have also been regarded. Losses which have been considered were addressed through a 20% loss during stamping circular pieces out of a rectangle band and a 5% loss during stamping out rectangle pieces out of a rectangle band. With regard to the stamping losses, the material has been assumed to be recycled in quasi-closed loop. Respectively, no burdens have been assumed for reprocessing of stamping losses. With regard to the manufacturing process, the additional production expenses have been regarded.

The actual composition of crockery items is different depending on the specific market scenario. In the hospital cafeteria, for example, other crockery items are used than in a school cafeteria and so on. As already mentioned above in section 2, the composition of crockery items building the market-specific place setting is described for each market scenario in section 3.1.3.

3.1.2. Distribution to the customers

The distribution of disposable dishes to customers was modelled as a truck transport service. A transport distance of 1,500 km (931.5 miles) has been assumed to be the typical average road transport distance in the US.

The truck transport has been modelled by using US-specific data from the NREL US LCI database. The inventory data from the dataset "Transport, light commercial truck, diesel powered" has been adjusted to ecoinvent intermediate flows, in order to be able to perform the LCIA. In concrete terms this includes efforts for truck construction, maintenance and the end of life of the vehicle as well as efforts for road infrastructure; as such efforts are not considered in the US LCI database, but are important for the sake of consistency with all other datasets used in the modelling of this study. The intermediate flows that needed to be supplemented have been considered by adding the respective flows from the ecoinvent dataset "market for transport, freight, lorry 16-32 metric ton, EURO4 [GLO]", which represents a mix of transport services in Europe (share 29%) and Rest-of-World (share 71%) (ecoinvent Centre 2014).

Furthermore, it was examined within a sensitivity test whether the assumed transport distance is of significant influence on the results of the comparison (section 4.3.2).

3.1.3. Use phase

3.1.3.1. Hospital cafeteria

Derived from data gathering in three different US hospitals, the composition of the single-use place setting for serving non patient meals in the hospital cafeteria is given in Table 3-1 and Table 3-2.

Therefore, an assumed packaging demand (100 g packaging film LDPE / 10 kg of product and corrugated board box 1.5 kg / 10 kg product) has been taken into account.

Table 3-1: Reference flow[13] per single-use place setting (hospital scenario, metric)

Item	Quan-tity	Material	Dimen-sions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent v3.1
Tray	1	Solid unbleached cardboard	342 x 250	58.6	58.6	8,556	Market for solid un-bleached board [GLO][14]
Main plate (bowl)	0.8	Styrofoam	246 x 170	5.9	4.72	689	Market for polystyrene, expandable [GLO]
Bowl (salad)	0.6	Styrofoam	225	11.4	6.84	999	Market for polystyrene, expandable [GLO]
Cup – soup	0.6	Compostable	94	8.7	5.22	762	Market for polylactide, granulate [GLO]
Small clam shell	0.2	Woodfree cardboard, coated	152 x 152	23.1	4.62	675	Market for paper, woodfree, coated [RoW] + market for packaging film, low density polyethylene [GLO]
Drink cup	0.9	Waxed paper	90	11.0	9.9	1,445	Market for kraft paper, unbleached [GLO]
Cup lid	0.5	Plastic (not specified)	90	2.3	1.15	168	Market for polypropy-lene, granulate [GLO]
Coffee cup	0.75	Paper	77	7.3	5.5	799	Market for kraft paper, unbleached [GLO]
Coffee cup lid[15]	0.75	Plastic (not specified)	77	2.0	1.5	219	Market for polypropy-lene, granulate [GLO]
Dessert plate	0.6	Woodfree cardboard, coated	153	6.6	4.0	578	Market for paper, woodfree, coated [RoW] + market for packaging film, low density polyethylene [GLO]
Cup – fruit / pudding	0.6	Compostable	94	8.7	5.22	762	Market for polylactide, granulate [GLO]
Fork	1	Plastic (not specified)	165	3.8	3.8	555	Market for polystyrene, general purpose [GLO]

[13] ISO 14040 defines the reference flow as the measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.

[14] Suffix [GLO] in dataset names designates the geographic region or scope of the dataset. In this case "GLO" stands for the global market, meaning that the inventory of the datasets reflects geographical coverage of the respective market. As it is considered that the materials used to produce the disposable crockery are traded globally, the chosen dataset is seen as an appropriate approximation.

[15] With regard to the use of lids in the single-use system it has been assumed, that in any case the coffee cup requires a lid, in order to avoid rapid cooling and spilling of hot content, while for cold drinks situation is not the same and therefore not every catering participant taking a drink cup (90%) takes a lid (50%).

Item	Quantity	Material	Dimensions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent v3.1
Spoon	1	Plastic (not specified)	153	3.4	3.4	496	Market for polystyrene, general purpose [GLO]
Dessert spoon	0.6	Plastic (not specified)	125	1.5	0.9	131	Market for polystyrene, general purpose [GLO]
Knife	1	Plastic (not specified)	177	3.7	3.7	540	Market for polystyrene, general purpose [GLO]
				Sum	119	17,375	

Source: MEIKO

Table 3-2: Reference flow[16] per single-use place setting (hospital scenario, imperial)

Item	Quantity	Material	Dimensions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent v3.1
Tray	1	Solid unbleached cardboard	13.5 x 9.8	2.07	2.07	18,863	Market for solid unbleached board [GLO][17]
Main plate (bowl)	0.8	Styrofoam	9.7 x 6.7	0.21	0.17	1,519	Market for polystyrene, expandable [GLO]
Bowl (salad)	0.6	Styrofoam	8.9	0.40	0.24	2,202	Market for polystyrene, expandable [GLO]
Cup – soup	0.6	Compostable	3.7	0.31	0.18	1,680	Market for polylactide, granulate [GLO]
Small clam shell	0.2	Woodfree cardboard, coated	6.0 x 6.0	0.81	0.16	1,488	Market for paper, woodfree, coated [RoW] + market for packaging film, low density polyethylene [GLO]
Drink cup	0.9	Waxed paper	3.5	0.39	0.35	3,186	Market for kraft paper, unbleached [GLO]
Cup lid	0.5	Plastic (not specified)	3.5	0.08	0.04	370	Market for polypropylene, granulate [GLO]
Coffee cup	0.75	Paper	3.0	0.26	0.19	1,761	Market for kraft paper, unbleached [GLO]

16 ISO 14040 defines the reference flow as the measure of the outputs from processes in a given product system required to fulfil the function expressed by the functional unit.

17 Suffix [GLO] in dataset names designates the geographic region or scope of the dataset. In this case “GLO” stands for the global market, meaning that the inventory of the datasets reflects geographical coverage of the respective market. As it is considered that the materials used to produce the disposable crockery are traded globally, the chosen dataset is seen as an appropriate approximation.

Item	Quan-tity	Material	Dimen-sions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent v3.1
Coffee cup lid[18]	0.75	Plastic (not specified)	3.0	0.07	0.05	483	Market for polypropy-lene, granulate [GLO]
Dessert plate	0.6	Woodfree cardboard, coated	6.0	0.23	0.14	1,274	Market for paper, woodfree, coated [RoW] + market for packaging film, low density polyethylene [GLO]
Cup – fruit / pudding	0.6	Compostable	3.7	0.31	0.18	1,680	Market for polylactide, granulate [GLO]
Fork	1	Plastic (not specified)	6.5	0.13	0.13	1,224	Market for polystyrene, general purpose [GLO]
Spoon	1	Plastic (not specified)	6.0	0.12	0.12	1,093	Market for polystyrene, general purpose [GLO]
Dessert spoon	0.6	Plastic (not specified)	4.9	0.05	0.03	289	Market for polystyrene, general purpose [GLO]
Knife	1	Plastic (not specified)	7.0	0.13	0.13	1,190	Market for polystyrene, general purpose [GLO]
				Sum	4.20	38,305	

Source: MEIKO

The numbers given as “quantity” in the table’s second column take into account, that not all crockery items are part of each meal that is served in the hospital cafeteria. To give an example, it is expected that every meal is served on a tray (quantity 1) but a soup cup is only part of the place setting 60% (quantity 0.6) of the time. On the basis of the data on mass and quantity, an average place setting has been derived. As the production of the crockery items has also been modelled on a material-related mass basis, the single items have been grouped by material (Table 3-3 and Table 3-4).

Table 3-3: Composition of a typical single-use place setting in hospital cafeteria (metric)

Material	Mass (g/place setting[19])	Mass (kg/FU)
Solid unbleached cardboard	58.6	8,556
Polystyrene (foamed)	11.6	1,688
Polystyrene (solid)	11.8	1,723
Polylactide,acid (compostable)	10.4	1,524

[18] With regard to the use of lids in the single-use system it has been assumed, that in any case the coffee cup requires a lid, in order to avoid rapid cooling and spilling of hot content, while for cold drinks situation is not the same and therefore not every catering participant taking a drink cup (90%) takes a lid (50%).

[19] Quantity per placer setting (see table 5) already included

Paper, woodfree, coated	8.6	1,253
Kraft paper, unbleached	15.4	2,245
Polypropylene	2.7	387
Sum	119	17,375

Source: US hospitals; provided by MEIKO, data contains rounding differences

Table 3-4: Composition of a typical single-use place setting in hospital cafeteria (imperial)

Material	Mass (oz./place setting[20])	Mass (lb/FU)
Solid unbleached cardboard	2.07	18,863
Polystyrene (foamed)	0.41	3,721
Polystyrene (solid)	0.42	3,799
Polylactide,acid (compostable)	0.37	3,360
Paper, woodfree, coated	0.30	2,762
Kraft paper, unbleached	0.54	4,949
Polypropylene	0.10	853
Sum	4.20	38,305

Source: US hospitals; provided by MEIKO, data contains rounding differences

Within the framework of this study, it has been decided that initially no pre-warming (or also cooling) of the disposable crockery will be taken into account. For materials from which disposables are typically made of, a pre-warming of disposable dishes can be considered as neither necessary nor relevant.

Meals are served on trays (cardboard trays). Regarding the provision of the required material for tray production, specific data has been gathered in the Cooley Dickinson hospital, were cardboard trays are used to serve the non-patients meals.

3.1.3.2. School cafeterias

Derived from data gathering in five different US schools, the composition of the single-use place setting for serving lunch in the school cafeteria is given in Table 3-5 and Table 3-6.

[20] Quantity per placer setting (see table 5) already included

Table 3-5: Reference flow per single-use place setting (scenario school, metric)

Item	Quantity	Material	Dimensions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent v3.1
Compartment tray	1	Styrofoam	31,7 x 21,4 x 2,8	12.0	12.0	1,079	Market for polystyrene, expandable [GLO]
Dessert cup	1	PP		6.3	6.3	567	Market for polypropylene [GLO]
Dessert cup lid	1	PS		2.9	2.9	261	market for polystyrene, general purpose [GLO]
Packaging cup (vegetables & co)	1	PP		10.8	10.8	972	Market for polypropylene [GLO]
Fork	1	Plastic (not specified)	153	2.4	2.4	212	Market for polypropylene [GLO]
Spoon	1	Plastic (not specified)	146	2.1	2.1	189	Market for polypropylene [GLO]
Knife	1	Plastic (not specified)	138	2.1	2.1	185	Market for polypropylene [GLO]
				Sum	38.5	3,465	

Source: MEIKO

Table 3-6: Reference flow per single-use place setting (scenario school, imperial)

Item	Quantity	Material	Dimensions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent v3.1
Compartment tray	1	Styrofoam	0.7 x 8.4 x 0.8	0.42	0.42	2,379	Market for polystyrene, expandable [GLO]
Dessert cup	1	PP		0.22	0.22	1,250	Market for polypropylene [GLO]
Dessert cup lid	1	PS		0.10	0.10	575	market for polystyrene, general purpose [GLO]
Packaging cup (vegetables & co)	1	PP		0.38	0.38	2,143	Market for polypropylene [GLO]
Fork	1	Plastic (not specified)	6.0	0.08	0.08	467	Market for polypropylene [GLO]
Spoon	1	Plastic (not specified)	5.7	0.07	0.07	417	Market for polypropylene [GLO]
Knife	1	Plastic (not specified)	5.4	0.07	0.07	408	Market for polypropylene [GLO]
				Sum	1.36	7,639	

Source: MEIKO

On the basis of the data on mass and quantity, an average place setting has been established. As the production of the crockery items has also been modelled on a material-related mass basis, the single items have been grouped by material and material demand (Table 3-7 and Table 3-8).

Table 3-7: Composition of a typical single-use place setting in a school cafeteria (metric)

Material	Material in report	Mass per place setting [g] [21]	Mass per FU [kg]
Market for polystyrene, expandable [GLO]	Polystyrene (foamed)	12.0	1,080
market for polystyrene, general purpose [GLO]	Polystyrene (solid)	2.9	261
Market for polypropylene [GLO]	Polypropylene	23.6	2,125
	Sum	38.5	3,465

Source: Own calculation

[21] Quantity per placer setting already included

Table 3-8: Composition of a typical single-use place setting in a school cafeteria (imperial)

Material	Material in report	Mass (oz./place setting)	Mass (lb/FU)
Market for polystyrene, expandable [GLO]	Polystyrene (foamed)	0.42	2,381
market for polystyrene, general purpose [GLO]	Polystyrene (solid)	0.10	575
Market for polypropylene [GLO]	Polypropylene	0.83	4,685
	Sum	1.36	7,639

Source: Own calculation

3.1.3.3. Hotels serving breakfast

Derived from data gathering in a reference US hotel, the composition of the single-use place setting for serving breakfast in a hotel is given in Table 3-9 and Table 3-10.

Table 3-9: Reference flow per single-use place setting (hotel scenario, metric)

Item	Quan-tity	Material	Dimen-sions/ diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent v3.1
Plate	2	Waxed paper	219	12.1	24.2	927	Market for kraft paper, unbleached [GLO]
Bowl (cereal or fruit)	0.9	Waxed paper	152	8.7	7.9	301	Market for kraft paper, unbleached [GLO]
Drink cup	0.3	6 PS translucent	92 h x 70 Ø	3.9	1.2	44	Market for poly-styrene, expandable [GLO]
Coffee cup	0.9	6 PS styrofoam	91 h x 79 Ø	1.7	1.5	59	Market for poly-styrene, expandable [GLO]
Cup lid	0.9	6 PS plastic	84 Ø	1.7	1.6	60	Market for polystyrene, general purpose [GLO
Coffee stirrer	0.9	PP, poly-propylene	92	0.9	0.8	31	Market for poly-propylene [GLO]
Fork	1.1	PP, poly-propylene	150	2.5	2.7	105	Market for poly-propylene [GLO]
Spoon	1.1	PP, poly-propylene	140	2.7	3.0	116	Market for poly-propylene [GLO]
Knife	1.1	PP, poly-propylene	160	2.6	2.9	110	Market for poly-propylene [GLO]
				Sum	45.7	1,752	

Source: MEIKO

Table 3-10: Reference flow per single-use place setting (hotel scenario, imperial)

Item	Quan-tity	Material	Dimen-sions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent v3.1
Plate	2	Waxed paper	8.6	0.43	0.85	2,044	Market for kraft paper, unbleached [GLO]
Bowl (cereal or fruit)	0.9	Waxed paper	6.0	0.31	0.28	664	Market for kraft paper, unbleached [GLO]
Drink cup	0.3	6 PS translucent	3.6 h x 2.8 Ø	0.14	0.04	97	Market for poly-styrene, expandable [GLO]
Coffee cup	0.9	6 PS styrofoam	3.6 h x 3.1 Ø	0.06	0.05	130	Market for poly-styrene, expandable [GLO]
Cup lid	0.9	6 PS plastic	3.3 Ø	0.06	0.06	132	Market for polystyrene, general purpose [GLO
Coffee stirrer	0.9	PP, poly-propylene	3.6	0.03	0.03	68	Market for poly-propylene [GLO]
Fork	1.1	PP, poly-propylene	5.9	0.09	0.10	231	Market for poly-propylene [GLO]
Spoon	1.1	PP, poly-propylene	5.5	0.10	0.11	256	Market for poly-propylene [GLO]
Knife	1.1	PP, poly-propylene	6.3	0.09	0.10	243	Market for poly-propylene [GLO]
				Sum	1.61	3,862	

Source: MEIKO

On the basis of the data on mass and quantity, a reference place setting has been derived. As the production of the crockery items has also been modelled on a material-related mass basis, the single items have been grouped by material and material demand (Table 3-11 and Table 3-12).

Table 3-11: Composition of a typical single-use place setting in a hotel (metric)

Material	Material in report	Mass per place setting [g] [22]	Mass per FU [kg]
Market for kraft paper, unbleached [GLO]	Kraft paper, unbleached	32.0	1,228
Market for polystyrene, expandable [GLO]	Polystyrene	4.3	163
Market for polypropylene, granulate [GLO]	Polypropylene	9.4	361
	Sum	45.7	1,752

Source: Own calculation

Table 3-12: Composition of a typical single-use place setting in a hotel (imperial)

Material	Material in report	Mass (oz./place setting)	Mass (lb/FU)
Market for kraft paper, unbleached [GLO]	Kraft paper, unbleached	1.13	2,707
Market for polystyrene, expandable [GLO]	Polystyrene	0.15	359
Market for polypropylene, granulate [GLO]	Polypropylene	0.33	796
	Sum	1.61	3,862

Source: Own calculation

3.1.4. End-of-life treatment of disposable dishes and cutlery, including required transport services

After use, the participants put their used dishes etc. in the provided collection containers. The trays are collected, together with food leftovers and the used disposable dishes in the same waste bin. For the purpose of this study, no garbage bags have been taken into account. Up until collection by a waste management company, both kitchen waste and leftovers are stored. As defined above (section 2.2), the treatment of leftovers and kitchen waste is excluded from the scope of this study as it is expected, that there is no difference between the two compared systems regarding the storage of kitchen waste and leftovers.

The used disposable dishes are also stored up until collection by a waste management company. None of the visited kitchens acknowledged using cooled storage for their waste. However, as this question was formulated after the start of information gathering, not all visited kitchens were asked. Also it might be dependent on the climatic conditions of the country or where waste collection is less frequent. As it has not been possible to definitely find out whether there is a demand for cooling the used disposable dishes (i.e. in order to avoid spreading of pathogens or unpleasant odors), it has been decided to assess the effect of an additional cooling effort for the storage of the

[22] Quantity per placer setting already included

used disposable dishes by a rough estimate within the framework of a sensitivity analysis (section 4.3.3).

The transportation of disposable dishes to waste treatment facilities has been modelled as a truck transport service. A transport distance of 100 km (62.1 miles) has been assumed to be the typical average transport distance for refuse truck in the US.

The truck transport has been modelled by using US-specific data from the NREL US LCI database. Similar to the distribution (see section 3.1.2), the inventory data from the dataset "Transport, refuse truck, diesel powered" has been adjusted to ecoinvent intermediate flows, in order to be able to perform the LCIA. In concrete terms this includes efforts for truck construction, maintenance and the end of life of the vehicle, as well as efforts for road infrastructure; as such efforts are not considered in the US LCI database, but are important in terms of being consistent with all other datasets used in the modelling of this study. The intermediate flows that needed to be supplemented have been considered by adding the respective flows from the ecoinvent dataset "market for transport, freight, lorry 16-32 metric ton, EURO4 [GLO]".

After the disposable dishes have been picked up by a waste collection and processing company, the used disposable dishes are handed over to the applicable recycling and waste treatment recycling routes. In reality, a large number of potential waste treatment scenarios exist for modelling the EoL treatment of used disposable dishes. The latest published US-specific information from US EPA (2015)[23] has been retrieved for modelling the dispatch of waste streams to respective waste treatment and recycling routes, taking into account a treatment within a municipal solid waste incineration plant (MSWI) and deposing in an inert landfill.

No material recycling has been taken into account for disposable crockery items. In out-of-home-facilities, accumulating waste is nearly always mixed waste with, for example, contaminations with food residues. For process-related and economic reasons it appears unrealistic that material recycling for used disposable crockery is realized in relevant quantities. This applies for crockery items made of plastics as well as for crockery items made of paper and paperboard. The US EPA figures on municipal solid waste flows have been adjusted accordingly, based on the assumption, that shares of waste to material recycling are treated in a waste incineration plant. Relative material-specific shares are given in Table 3-13.

[23] Information has been retrieved from the US EPA Report: "Advancing Sustainable Materials Management; Facts and Figures 2013. Assessing Trends in Material Generation, Recycling and Disposal in the United States", June 2015, US EPA.

Table 3-13: Modelling of EoL treatment of used disposable dishes

Material	Share	Waste disposal route	Data set
Waste dishes (PS & EPS)	20%	Incineration	Treatment of waste polystyrene, municipal incineration [CH][24]
	80%	Sanitary landfill	Treatment of waste polystyrene, sanitary landfill [CH]
Waste dishes (PP)	20%	Incineration	Treatment of waste polypropylene, municipal incineration [CH]
	80%	Sanitary landfill	Treatment of waste polypropylene, sanitary landfill [CH]
Waste dishes (PLA)	20%	Incineration	Treatment of waste polypropylene, municipal incineration [CH]
	80%	Sanitary landfill	Treatment of waste polypropylene, sanitary landfill [CH]
Waste dishes (paper and cardboard)	20%	Incineration	Treatment of waste graphical paper, municipal incineration [RoW][25]
	80%	Sanitary landfill	Treatment of waste graphical paper, sanitary landfill [CH]

Source: Own compilation, based on EPA 2015; datasets retrieved form ecoinvent V3.1

With regard to the treatment of waste disposable dishes in a municipal solid waste incineration plant, it has been assumed that in any case, incineration is conducted in conjunction with energy recovery (or, in other terms, waste to energy (WTE). Regarding the incineration with energy recovery in the disposable scenarios, a credit for the produced electric energy has been applied to the systems. Based on findings by Kaplan et al (2009) and referenced on the US EPA website, each ton of incinerated municipal solid waste yields an average of 550 kWh of electricity. The avoided environmental burden of the provision of 550 kWh has been valued for the crediting of the EoL treatment of disposable crockery items. The environmental burden of the respective amount of electricity provision has been calculated using the dataset "market for electricity, medium voltage [SERC]; ecoinvent 3.1", i.e. the same dataset as within the production and use phase of the re-usable system[26].

[24] Suffix [CH] in dataset names designates the geographic region or scope of the dataset. In this case, "CH" stands for Switzerland, meaning that the inventory of the datasets reflects technological coverage of municipal incineration in Switzerland. As it is considered that there is a comparable current state-of-technology of municipal incineration in Switzerland and in the US, and facing the fact that no US-specific datasets have been available, the chosen dataset is seen as an appropriate approximation.

[25] Suffix [RoW] in dataset names designates the geographic region or scope of the dataset. In this case, "RoW" stands for "Rest of World", and therefore covering an average of all available datasets with national or regional scope (without Switzerland) and representing the share of the respective datasets to the global market, meaning that the inventory of the datasets reflects technological coverage of municipal incineration in the rest of world (without Switzerland).

[26] As an US-wide dataset on the electric energy mix in the US has not been available in the database ecoinvent, it was decided to use one of the ten US specific regional grid datasets and evaluate the other nine datasets within a sensitivity analysis. The selection of the SERC dataset for the base case scenarios has been based on the comparison of the GWP of all ten datasets available in ecoinvent by building the mean GWP per kWh and selecting the one with the least deviation compared to the mean. As it turned out, this was the SERC-dataset.

In all three scenarios, a 50:50 allocation of avoided burdens have been given as credit to the disposable systems as base case. What this means in specific is, that 50% of the avoided burden from electricity provision are credited to the disposable system. As recommended by ISO 14044, a 100:0 allocation rule has been further evaluated within the framework of a sensitivity test (see section 4.3.9).

3.2. Reusable system

The model of the reusable dishes encompasses the following life cycle stages:

- production of reusable dishes and cutlery (section 3.2.1);
- distribution to the customers (section 3.2.2);
- use in…:
  - hospital cafeterias (section 3.2.3.1);
  - school cafeterias (section 3.2.3.2); or
  - hotels serving breakfast (section 3.2.3.3);
- end-of-life treatment, including the required transport services (section 3.2.4).

In the following sections, the process steps and the unit processes of the life cycle stages will be specified regarding their modelling assumptions and data base.

3.2.1. Production of reusable dishes and cutlery

The reusable dishes and cutlery production consists of the following process steps:

- production and provision of raw materials;
- manufacturing of raw materials (i.e. processing of porcelain working compound); and
- manufacturing of products (i.e. shaping, drying and firing of porcelain).

Raw materials for reusable dishes may also come from a variety of different sources: Materials that have been taken into account within the framework of this study regarding the production of reusable crockery are porcelain, melamine, polypropylene (PP) and chromium steel for the cutlery. Another alternative which has not been taken into account for the calculation is the use of crockery made from tempered glass (i.e. Arcopal®). While the specific heat capacity of tempered glass is comparable to that of porcelain, resulting in similar efforts from dishwashing, the latter is less complex and burdensome in production, which can be seen as a slight conservative assumption regarding the modelling of the reusable system.

Within the framework of this study and based on assumptions on the market share, it is assumed that reusable dishes and cutlery are made from the materials shown in Table 3-14.

Table 3-14: Data basis for the provision of raw materials and the production of reusable dishes

Process step	Material	Unit process & reference
Porcelain, Melamine, PP and stainless steel production and provision	Feldspar (22.5%)	Market for feldspar [GLO]; ecoinvent 3.1
	Silica sand (25%)	Market for silica sand [GLO]; ecoinvent 3.1
	Kaolin (52.5%)	Market for kaolin [GLO]; ecoinvent 3.1
	Melamine	Market for melamine formaldehyde resin [GLO]; ecoinvent 3.1
	Polypropylene	Market for polypropylene [GLO;] ecoinvent 3.1
	Cutlery	Market for chromium steel 18%, hot rolled [GLO]; ecoinvent 3.1
Manufacturing of products	Porcelain dishes	Market for heat, district or industrial, natural gas [RoW]; ecoinvent 3.1
		Electricity voltage transformation from high to medium voltage [SERC]; ecoinvent 3.1
	Melamine dishes	Market for thermoforming with calendering [GLO]; ecoinvent 3.1; process specific production losses of 2.3% already considered in dataset
	Polypropylene dishes	Market for thermoforming with calendering [GLO]; ecoinvent 3.1; process specific production losses of 2.3% already considered in dataset
	Stainless steel cutlery	Market for metal working, average for chromium steel product manufacturing [GLO]; additionally 25% of material losses due to stamp losses

Source: Own compilation

Within the framework of this study, the crockery made from porcelain is modelled according to data available in the literature (Fischer 2007, Broca 2008). Fischer 2007 enumerates raw material provision and preparation, forming, drying and the firing process as the major production steps of the industrial production of porcelain. The calculation of the energy demand for the preparation, forming and drying of porcelain is based on data provided by Broca 2008. Consequently, an energy demand of 5.9 MJ (heat, provided by combustion of natural gas) und 4.3 kWh (electricity) has been taken into account for one kilogram of final porcelain product. Regarding the heat energy demand, the dataset “market for heat, district or industrial, natural gas [RoW]; ecoinvent 3.1” has been applied. As regards the demand for electricity, the Southeast Electric Reliability Council (SERC)-specific dataset “electricity voltage transformation from high to medium voltage [SERC]; ecoinvent 3.1” has been applied.

With regard to the firing process, it is assumed that a two-step quick firing is suitable. Based on data derived from Fischer (2007), the resulting energy demands for various firing processes in different types of ovens are given in Table 3-15.

Table 3-15: Two-stage fast firing process of porcelain

Process	Temperature (°C)	Time (h)	Energy (KJ/kg)	Type of oven
Preliminary firing	600-800	1.5–8	2,100–3,900	Tunnel kiln
	1000	0.5–1	1,700–2,500	Bogie hearth furnace
Glost firing	1400-1420	1.5–4	12,500–18,000	Sled kiln
	1400	3–4	7,500–10,500	Roller passage kiln
	1400	4–6	14,700–21,000	Tunnel kiln with table conveyance
On-glaze firing	900-1250	0.75–1.5	2,300–4,700	Roller passage kiln
Totals		2.75–15.5	11,500–29,600	

Source: Fischer (2007); translation by the authors

According to Table 3-15, an overall energy demand of 20.60 MJ per kg (9.35 MJ / lb) final porcelain product (arithmetic average) can be calculated for the firing process. Unfortunately, Fischer does not distinguish between thermal and electrical energy demand. Based on information on the splitting of thermal (82%) and electrical energy (18%) demand by (Broca 2008), the total energy demand is divided into a heat demand of 16.9 MJ / kg (7.67 MJ / lb) final porcelain product and an electricity demand of 3.7 MJ / kg (1.68 MJ / lb) final porcelain product.

During porcelain production, in particular throughout the firing process of the porcelain, process-specific emissions of hydrogen fluoride (HF) and sulfur dioxide (SO_2) occur as result of constituent parts of the raw materials. These have to be taken into account in addition to the energy-related emissions. Rentz et al (2001) give clean gas values for best available technologies in 2000. Accordingly, process-specific clean gas values for HF are 3.5 mg per m^3 of light natural gas and 350 mg SO_2 per m^3 of light natural gas. Also according to Rentz et al 2001, the burning of 1 m^3 of light natural gas leads to a flue gas volume of 50.4 m^3. Taking into account a lower heating value of 31.9 MJ per m^3 of light natural gas energy, the resulting process HF- and SO_2 emissions are given in Table 3-16. No waste heat recovery has been taken into account.

Table 3-16: Process specific emissions of the porcelain burning process

Process specific emission	Quantity	Unit
Hydrogen fluoride (HF)	0.1261	g/kg porcelain
Sulfur dioxide (SO_2)	12.61	g/kg porcelain

Source: Own calculation based on Rentz et al. (2001)

Regarding the production and provision of stainless steel cutlery, it is assumed that reusable cutlery is made of 100% stainless steel. The efforts of cutlery production have been modelled by using the ecoinvent 3.1 dataset “market for steel, chromium steel 18/8, hot rolled [GLO].

The ecoinvent 3.1 process “market for metal working, average for chromium steel product manufacturing [GLO]” has been regarded as a manufacturing process.

With regard to process losses due to cutting cutlery pieces, the metal provision LCI datasets already take account of primary and secondary scrap contents, so these losses (to be seen as primary scrap) can be assumed to be within a quasi-closed-loop recycling system.

3.2.2. Distribution to the customers

The distribution of reusable dishes to customers was modelled as a truck transport service as already described in section 3.1.2 for the disposable cutlery. A transport distance of 1,500 km (931.5 miles) has been assumed to be the typical average road transport distance in the US.

The truck transport has been modelled by using US-specific data from the NREL US LCI database, with the same adaptions described above for the distribution of disposable dishes in section 3.1.2.

3.2.3. Use phase

After distribution to the customer, the reusable crockery also has to be kept in a storage area. It is assumed that no special storage efforts (i.e. energy demand for cooling) are required for the storage of the reusable crockery. Therefore, this storage process was not taken into account in the current study. In the following sections, the definition of the place settings and other relevant parameters relevant for modelling the use phase will be described in detail for the three scenarios.

3.2.3.1. Hospital cafeterias

Derived from data gathering in three different US hospitals (see section 2.3.1), the composition of the multi-use place setting for serving non patient meals in the hospital cafeteria is given in Table 3-17 and Table 3-18. It is assumed that in case of serving non-patient meals on reusable crockery in the future, hospitals would probably decide to use the same items for patient and non-patient meals[27].

[27] Under the multi-use scenario taking into account take-outs (requiring single-use material) is reasonable. Therefore take outs have been taken into account with regard to the scenario specific dishwashing efforts (taking into account machine load, energy and water demand and demand for detergents and rinse aid). With regard to the single-use items required for take-outs, the provision, transport and EoL treatment haven´t been regarded in either the single-use or the multi-use scenarios within this study.

Table 3-17: Hypothetical multi-use place setting in hospital cafeteria (non-patients, metric)

Item	Quantity	Material	Dimensions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU[28] (kg)	Modelled in LCA software as / data source: ecoinvent V3.1
Tray	1	Glass fibre filled melamine	Hex 355 x 455 x 190	527	527	76.9	80% market for melamine formal-dehyde resin [GLO]+ 20% market for glass fibre [GLO]
Main plate	1	Porcelain	225 Ø	656	656	95.8	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Salad bowl	0.6	Melamine	150 Ø	137	82	12.0	Market for melamine formaldehyde resin [GLO]
Soup bowl	0.6	Reusable plastic	110 Ø x 60	92	55	8.1	Market for polypropylene [GLO]
Drink cup	0.9	Reusable plastic	83 Ø x 90	69	62	9.1	Market for polypropylene [GLO]
Coffee cup	0.75	Reusable plastic	87 Ø x 100	103	77	11.3	Market for polypropylene [GLO]
Small plate – dessert	0.6	Porcelain	157 Ø	213	128	18.7	22.5% Market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Small bowl – dessert or fruit	0.6	Reusable plastic	87 Ø x 60	67	40	5.9	Market for polypropylene [GLO]
Fork	1	Stainless steel	178	22.1	22	3.2	Market for chromium steel 18%, hot rolled [GLO]
Spoon	1	Stainless steel	178	26.3	26	3.8	Market for chromium steel 18%, hot rolled [GLO]
Dessert spoon	0.6	Stainless steel		11	7	1.0	Market for chromium steel 18%, hot rolled [GLO]
Knife	1	Stainless steel	205	44.4	44	6.5	Market for chromium steel 18%, hot rolled [GLO]
				Sum	1,727	252.2	

Source: MEIKO GmbH

[28] The numbers per functional unit (FU) are based on the assumption of 1,000 reuses of the multi-use ware. For a detailed description, see section 2.3. For example multiplying the tray mass per place setting of 0.527 kg by 146,000 meals per year (Table 2-1) and dividing by 1000 reuses equals a FU of 76.9 kg of trays.)

Table 3-18: Hypothetical multi-use place setting in hospital cafeteria (non-patients, imperial)

Item	Quantity	Material	Dimensions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent V3.1
Tray	1	Glass fibre filled melamine	Hex 14.0 x 17.9 x 7.5	18.59	18.59	170	80% market for melamine formaldehyde resin [GLO]+ 20% market for glass fibre [GLO]
Main plate	1	Porcelain	8.9	23.14	23.14	211	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Salad bowl	0.6	Melamine	5.9	4.83	2.90	26	Market for melamine formaldehyde resin [GLO]
Soup bowl	0.6	Reusable plastic	4.3 x 2.4	3.25	1.95	18	Market for polypropylene [GLO]
Drink cup	0.9	Reusable plastic	3.3 x 3.5	2.43	2.19	20	Market for polypropylene [GLO]
Coffee cup	0.75	Reusable plastic	3.4 x 3.9	3.63	2.73	25	Market for polypropylene [GLO]
Small plate – dessert	0.6	Porcelain	6.2	7.51	4.51	41	22.5% Market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Small bowl – dessert or fruit	0.6	Reusable plastic	3.4 x 2.4	2.36	1.42	13	Market for polypropylene [GLO]
Fork	1	Stainless steel	7.0	0.78	0.78	7	Market for chromium steel 18%, hot rolled [GLO]
Spoon	1	Stainless steel	7.0	0.93	0.93	8	Market for chromium steel 18%, hot rolled [GLO]
Dessert spoon	0.6	Stainless steel		0.39	0.23	2	Market for chromium steel 18%, hot rolled [GLO]
Knife	1	Stainless steel	8.07	1.57	1.57	14	Market for chromium steel 18%, hot rolled [GLO]
				Sum	60.92	556	

Source: MEIKO GmbH

As already described for disposable crockery, the “quantity” specified in the table’s second column takes account of the fact that not all crockery items are part of each meal. On the basis of the data on mass and quantity, an average place setting was defined. As the production of the crockery items has also been modelled on a material-related mass basis, the single items have been grouped by material and material demand (Table 3-19).

Table 3-19: Material composition of a multi-use place setting in hospital cafeteria

Material	Mass (g/place setting)	Mass (oz./place setting)
Glass fibre filled melamine	527	18.59
Melamine	82	2.89
Porcelain	784	27.65
Polypropylene	235	8.29
Stainless steel	99	3.49
Sum	1,727	60.92

Source: Own calculation

One should note that another alternative material for reusable dishes for hospital cafeterias is tempered glass (i.e. Arcopal®). As it can reasonably be concluded that the production of tempered glass is a less energy-intensive process than porcelain production, this might also cause a reduction of the environmental burden arising from the production process.

Different from that in the single-use scenario, here the required number of crockery might be taken from the storage and kept pre-warmed in a heatable plate dispenser before use. Pre-warming of porcelain plates in a heatable plate dispenser could be seen as providing an added value compared to the single-use ware, where pre-warming does not make sense. Nonetheless, as a conservative assumption (or in other terms a worst case scenario), the effort of an additional pre-warming of the porcelain plates has been taken into account, based on information available online (www.gastro-gigant.de) on the heatable plate dispenser by the German company Bartscher GmbH (https://www.bartscher.de/blobs/Datenblatt/103065.pdf) regarding the assumptions given in Table 3-20.

Table 3-20: Energy demand for pre-warming porcelain plates (multi-use) in a dish warmer

Description	Quantity	Unit
Capacity per item	100	Plates; Ø 30 cm
Capacity demand	200	Plates; Ø 30 cm
Power	2.0	kW
Electricity demand of connected value over time	25	%
Daily operational hours	2	H
Operational days per year	365	D
Annual energy consumption for pre-warming plates	730	kWh/a

Source: Own calculation based on company information[29]

29 Technical data sheet available online URL: https://www.bartscher.de/blobs/Datenblatt/103065.pdf, last access 02.09.2015.

The food preparation takes place in the hospital's large scale kitchen. The cookware needed for the preparation of the meals in both systems has been excluded from the scope of this study (see section 2.4.

Reprocessing (washing) and Reuse

After use, participants either put their trays in the provided collection containers or place them on a conveyer. In the wash room of the hospital cafeteria, the staff separates the trays, food leftovers and the used reusable dishes. As in the case of the disposable system, both kitchen waste and leftovers (or, in other terms, food waste) are stored until they are collected by a waste management company.

Within the context of the reprocessing step, trays, dishes and cutlery are washed and cleaned within a professional dishwasher. The reusable crockery parts are scraped or shaken, in order to be cleaned from coarser dirt particles before they are loaded into the dishwashing machine. Prewashing is not necessary. It is assumed that the crockery for the non-patient meals are washed in the same dishwashing machine as the crockery for the meals served to patients. In other words this means that it is assumed that only one dishwashing machine is installed in the hospital[30]. Due to economies of scale, this allows for earning synergetic effects and leads to lower treatment efforts per place setting.

For the purpose of modeling the dishwashing process, data provided by MEIKO was referred to. The required energy demand for the dishwashing process has been experimentally determined by Dr. Ing. Allen Jakway, engineer in MEIKO's R&D section.

An overview comparison of dishwashing machines taken into account for the multi-use scenarios is given in Table 3-21.

Table 3-21: Comparison of dishwashing machines in the multi-use scenarios

		Hospital	School and Hotel
Machine type		band transport	Hood
Manufacturer		MEIKO	MEIKO
Model		medium band	M-iClean HM
Waste air heat recovery		yes	Yes
Dryer		one	No
Operation		continuous	Batch
cycle times (s)	wash	-	40
	drip	-	4
	rinse	-	8
	dwell	-	7
	total cycle	-	59
band speed ft./min		6	-
band speed m/min		1.83	-
Conveyor width (inches)		29.50	-
Peg Spacing		72 mm	-

30 The assumption that there is only one dishwashing machine in a hospital, washing both the dishes of patients and non-patients is valid for the majority of hospitals. Nonetheless, there probably exist a limited set of facilities, were the installation of a separate dishwashing machine for the non-patient dishes in the hospital cafeteria could be eligible.

		Hospital	School and Hotel
Fill Water	amount (l)	260	15
	times filled during the day	1	1
Rinse Water	amount	213 liters/h	2,8 liters/cycle
Capacity			18 plates/cycle
	NSF Max	7493 plates/h	1008 plates/h

Source:MEIKO

Pictures and schematic drawings of the two dishwashing machines that have been taken into account in the multi-use scenarios are presented in Figure 3-2 and Figure 3-3.

Figure 3-2: M-iQ, Picture and schematic of medium sized band transport machine similar to that used in the hospital scenario

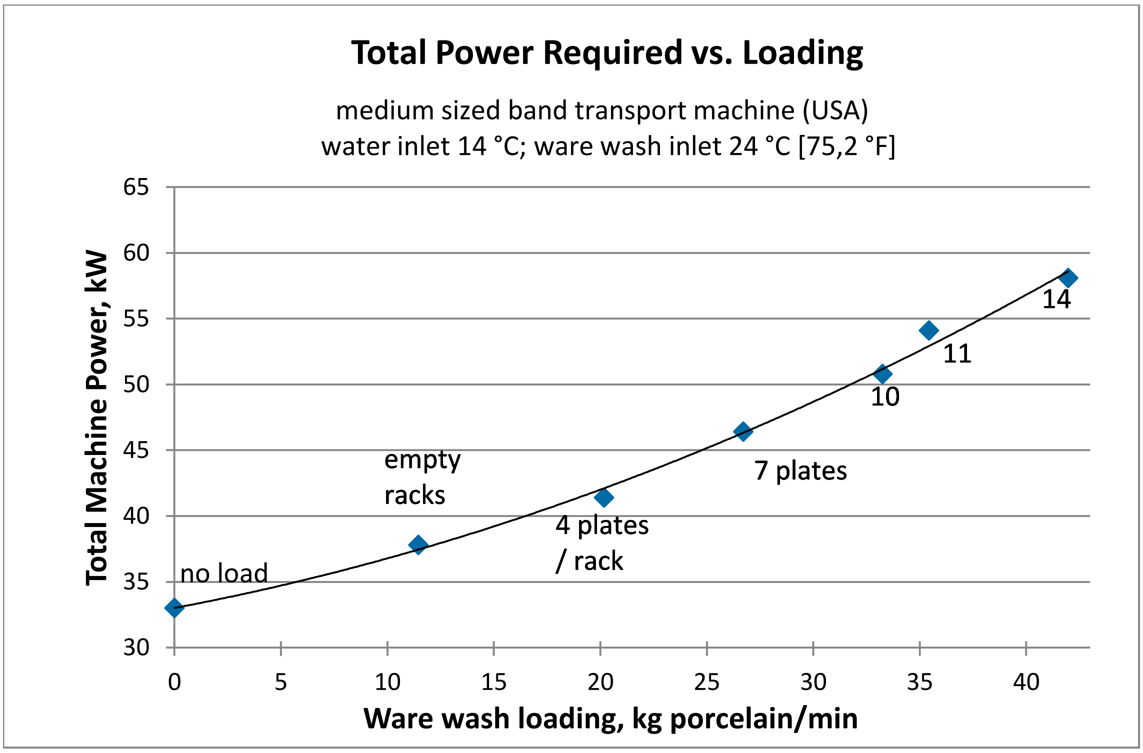
Source: MEIKO

Figure 3-3: M-iClean HM, Picture and schematic of the hood machine taken into account for scenarios school and hotel

Source: MEIKO

The procedures to calculate the relevant process parameters for the dishwashing process in the hospital scenario are the same as described below in section 3.2.3.2. However, instead of a hood dish washing machine, a flight type dishwashing machine with continuous band transport is used. In this scenario a mid-size MEIKO transport dish washing machine of the M-iQ series with one dryer unit representing the state of the art in technology is used as the machine of choice. All wash ware is placed individually on the machine's transport band. Furthermore, a typical realistic loading of the band is then calculated, based on the width of the machine, the speed of the band, and loading factors for the various types of ware wash based on field observations. This realistic loading is transformed into an average value of kilograms per equivalent loading of porcelain, similar to the procedure described in detail in section 3.2.3.2. Tests were run on the band machine where the electrical and water consumption was measured for seven different loadings. The thermal equivalent mass in porcelain has been calculated for each loading. In the next calculation step, the seven data points are plotted on a graph, and the equation for the best fit curve has been determined (Figure 3-4).

Figure 3-4: Experimentally determined total power requirements vs. wash ware loading (porcelain plates)



Source: MEIKO

The calculated mass flow of porcelain equivalent is plugged into the equation to yield the expected average energy consumption of 37 kW. This value has been multiplied by the required total wash time. Dividing by the number of diners, this yields 0.12 kWh per diner per day. Additionally, the idle energy and the energy of filling the dish washing machine have also been measured. Furthermore, the warm and cold water usage is measured for the initial filling as well as for washing. Only the cleaning chemicals usage had to be estimated, as different chemical producers have different usage settings that tend not to be published.

The relevant process parameters for the dishwashing process in the hospital scenario are given in Table 3-22.

Table 3-22: Relevant process parameters for the dishwashing process in hospital cafeterias

Parameter	Quantity	Unit
Fresh water	0.95	litres/place setting
Detergents	1.09	ml/place setting
Rinse aid	0.22	ml/place setting
Elec. usage, kwh/place setting	0.176	kWh/place setting

Source: MEIKO

Regarding the detergent and rinse aid chemicals, no specific data was available from the three model facilities except that the used detergents are all solid detergents while the used rinse aid chemicals are liquid chemicals. Therefore, data given in Rüdenauer et al. (2011) has been used as representative reference for the typical composition of detergents used on the European market (Table 3-23)

Table 3-23: Standard composition of detergents for one-tank dishwashing machines

Component	Amount or proportion (%)	Modelled in UmbertoNXT Universal as…
Potassium tripolyphospate solution, 50% (mass fraction)	20	market for sodium tripolyphosphate [GLO]; ecoinvent V3.1
Potassium hydroxide, 50% (mass fraction)	36	market for potassium hydroxide [GLO] ; ecoinvent V3.1
Sodium silicate (water glass)	23	market for sodium silicate, solid [GLO] ecoinvent V3.1
Oxidizing agent[31]	0–4 (2)	market for sodium perborate, monohydrate, powder [GLO]; ecoinvent V3.1.
Deionised water	ad 100	market for water, deionised, from tap water, at user [GLO]; ecoinvent V3.1

Source: Rüdenauer et al. (2011)

Analogously, a typical rinse agents' formulation is given in Table 3-24.

Table 3-24: Standard composition of rinse agents for one-tank dishwashing machines

Component	Proportion (%)	Modelled in UmbertoNXT Universal as…
Acetic acid	5.5	market for acetic acid, without water, in 98% solution state [GLO]; ecoinvent V3.1
Alcohol	5.5	market for 1-propanol [GLO] ecoinvent V3.1
Ethoxylated alcohol (AE7)	2	market for ethoxylated alcohol (AE7) [GLO] ecoinvent V3.1
Deionised water	ad 100	market for water, deionised, from tap water, at user [GLO]; ecoinvent V3.1

Source: Rüdenauer et al. (2011)

31 Oxidizing agents are not part of the standard test detergent defined in DIN 10512. However, one manufacturer of dishwashing machines described oxidising agents as a typical component in dishwashing detergents.

A parameter, expected to be significant for the description of the reusable system is the derivation of a plausible number of possible re-uses or, respectively, the service life time of the multi-use crockery. Different aspects determine the practical service life, such as chipping, breakage, sorting out of (optical) defective parts, or other reasons for shrinkage of stocks over time, as well as further unknown losses. In line with available and relevant studies and based on expert assessment by MEIKO on multi-use dishes, an average lifetime of 1,000 reuses has been assumed. Based on information provided by the clinic kitchen of the University Hospital Freiburg, Germany, this can be seen as a conservative assumption. In the year 2013 they purchased 600 main plates (or 22% percent of their total stock of 2790 pieces of main plates) to replace those that had been sorted out due to chipping, breakage, or optical defects. Thus the whole stock is changed within a period 4.65 years. As the kitchen has three times the amount of table ware in stock required for one meal, each plate is used once a day or in other terms 365 times every year. Regarding the period of 4.65 years this leads to a lifetime of nearly 1,700 cycles.

3.2.3.2. School cafeterias

Derived from data gathering in five different US schools, the composition of the multi-use place setting for serving lunch in the school cafeteria is given in Table 3-25 and Table 3-26. Regarding the tray, a reusable PP compartment tray from one of the schools has been used as reference item. The same applies for the stainless steel cutlery[32].

Table 3-25: Reference multi-use place setting in a school cafeteria (metric)

Item	Quan-tity	Material	Dimen-sions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent v3.1
Tray	1	Polypro-pylene co-polymer	376 x 222 x 21	325.9	326	29.3	Market for poly-propylene [GLO]
Fork	1	Stainless steel	204.5	22.1	22	2.0	Market for chro-mium steel 18%, hot rolled [GLO]
Spoon	1	Stainless steel	178	26.3	26	2.4	Market for chro-mium steel 18%, hot rolled [GLO]
Knife	1	Stainless steel	178	44.4	44	4.0	Market for chro-mium steel 18%, hot rolled [GLO]
				Sum	419	37.7	

Source: MEIKO

32 As opposed to the reference single-use place setting in a school cafeteria, the reference multi-use place setting doesn´t contain an extra dessert cup, as the compartment tray already contains a compartment for serving the dessert, even though it cannot be ruled out that desserts are served in extra dessert cups.

Table 3-26: Reference multi-use place setting in a school cafeteria (imperial)

Item	Quantity	Material	Dimensions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent v3.1
Tray	1	Polypropylene copolymer	14.8 x 8.7 x 0.8	11.50	11.50	65	Market for polypropylene [GLO]
Fork	1	Stainless steel	8.1	0.78	0.78	4	Market for chromium steel 18%, hot rolled [GLO]
Spoon	1	Stainless steel	7.0	0.93	0.93	5	Market for chromium steel 18%, hot rolled [GLO]
Knife	1	Stainless steel	7.0	1.57	1.57	9	Market for chromium steel 18%, hot rolled [GLO]
				Sum	14.77	83	

Source: MEIKO

On the basis of the data on mass and quantity, an average place setting was defined. As the production of the crockery items has also been modelled on a material-related mass basis, the single items have been grouped by material (Table 3-27).

Table 3-27: Material composition of a multi-use place setting in a school cafeteria

Material	Material in report	Mass per place setting [g]	Mass per FU [kg]	Mass per place setting [oz.]	Mass per FU [lb]
Market for polypropylene [GLO]	Polypropylene	325.9	29.3	11.50	65
Market for chromium steel 18%, hot rolled [GLO]	Stainless steel	92.8	8.3	3.27	19
	Sum	418.7	38	14.77	83

Source: Own calculation

Unlike in the multi-use scenario for serving non-patient meals in a hospital cafeteria on porcelain plates, the lunch in the reference school is served on a PP compartment tray for which a pre-warming would neither make sense nor be possible. Due to this fact, pre-warming has not been taken into account in the modelling of the multi-use scenario school cafeteria. The required number of crockery might be taken from the storage and kept in a tray dispenser before use.

Reprocessing (washing) and reuse

Within the reprocessing step, trays and cutlery are washed and cleaned within a dishwasher. The calculation procedure and the underlying assumptions necessary in this context are described in the following.

It is assumed that one tray is used per each of the 500 daily catering participants. All crockery items, including the trays and the cutlery are washed in the dishwasher. Not that all that comes out of even the best dishwashers is 100% clean. Different factors can lead to the need for a second wash such as persistent residues from e.g. lipsticks, baked on food (due to heat lamps or warming plates) or items from previous days. Hard numbers have not been found. MEIKO observations suggest different rewash frequencies for different types of wash ware. For example trays are generally only lightly soiled and glasses, except for lipstick, are usually easily cleaned. So 1% of rewashes has been assumed for the trays (e.g. resulting in 505 instead of 500 tray washings. The rewash values from Table 3-28 were used in this study.

Table 3-28: Rewash values used in the multi-use scenarios

Material	Rewashes in %
Dishes and bowls	5%
glasses	3%
flatware	10%
trays	1%

Source: MEIKO

For the washing process, trays are filled into dishwashing racks, with a capacity of 16 trays per rack. This makes for a washing demand of 33 racks (rounded up). The same procedure applies to the dishwashing of the cutlery, resulting in a washing demand of another 16 racks. Both washing of trays and washing of cutlery sum up to 49 racks that are to be washed for each lunch.

The multi-use trays from the reference school are made out of 326 grams of PP, with a specific heat capacity of 1.8 J/g K. This allows for calculating the product (586.8 J/tray*K) and multiplying with the 525 trays to be washed per each lunch. The result is then divided by the specific heat capacity of porcelain (0.84 J/g K), resulting in the equivalent mass of trays in terms of porcelain-equivalents to be washed. The same procedure applies to the silverware and the racks. All this adds to the total mass to be washed in terms of porcelain equivalents. The calculation result is then divided by the above-mentioned 49 racks that are to be washed per each lunch in order to get the average mass in kilograms of porcelain (12 kg; 26.5 lb) that enters and leaves the machine for each wash cycle.

One possible solution to carry out the load-specific process parameters would have been to load a dish washer with 12 kg (26.5 lb) of porcelain equivalent and measure the required energy. However, as soon as any of the above-mentioned parameters change, the machine measurements must be repeated. To avoid this, and to get a more robust calculation basis, the method described in the following was chosen.

The same hood, also referred to as door type dishwashing machine, is assumed to be used in both the school scenario and the hotel scenario. Measurements were made on a Meiko M-iClean HM dishwashing machine, washing with settings as are prescribed by NSF. Measurements of water and electricity consumption are made, while the machine washes four different loadings of plates in racks. For each loading, the thermal equivalent mass in porcelain was calculated as described above. Then, the four data points were plotted on a graph and the equation for the best fit curve was determined. In the next calculation step, the 12 kg of porcelain equivalent was put into the equation to produce the expected average energy consumption, resulting in 347 Wh per cycle. This value has been multiplied by the total number of required washing cycles (49) and then divided by the number of catering participants, in order to get the energy consumption of 34 Wh per catering participant.

Measured were also the water and energy consumption during the initial filling and heating as well as during idle phases. Combining with assumed idle time and that the machine is filled once per day, per person values were calculated and added to the wash values to arrive at the total machine usage values on a per person basis. The overall calculation results are presented in Table 3-29.

Table 3-29: Calculation of water, energy and chemical demand per multi-use place setting

Material	Value
Water, liters/place setting	0.32
Electricity usage, wh/place setting	40.33
Detergent, g/place setting	0.61
Rinse-aid, ml/place setting	0.06

Source: MEIKO

3.2.3.3. Hotels serving breakfast

Derived from data gathered in three reference US hotels along with experience with European hotels, the composition of the reusable place setting for serving breakfast in hotels is given in Table 3-30 and Table 3-31. It is assumed that most people going for seconds take fresh dishware. Furthermore, it should be noted, that take-outs have been left out of the analysis for both compared systems, as take-outs are always disposables, regardless of what the seated diners are eating on.

Table 3-30: Reference multi-use place setting in a hotel serving breakfast (metric)

Item	Quantity	Material	Dimen-sions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent V3.1
Plate	2	Porcelain	196	255	510	19.5	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Bowl (cereal or fruit)	0.9	Porcelain	138	195	176	6.7	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market

Item	Quantity	Material	Dimen-sions / diameter (mm)	Mass per item (g)	Mass per place setting (g)	Mass per FU (kg)	Modelled in LCA software as / data source: ecoinvent V3.1
							for kaolin [GLO]
Cold drink glass	0.3	Glass	60	240,8	72	2.8	Market for packaging glass, white [GLO]
Coffee cup	0.9	Porcelain	97	167.1	150	5.8	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Coffee stirrer/ spoon	0.9	Stainless steel	107	13.3	12	0.5	Market for chromium steel 18%, hot rolled [GLO]
Fork	1.1	Stainless steel	178	22.1	24	0.9	Market for chromium steel 18%, hot rolled [GLO]
Spoon	1.1	Stainless steel	178	26.3	29	1.1	Market for chromium steel 18%, hot rolled [GLO]
Knife	1.1	Stainless steel	205	44.4	49	1.9	Market for chromium steel 18%, hot rolled [GLO]
				Sum	1,022	39.2	

Source: MEIKO

Table 3-31: Reference multi-use place setting in a hotel serving breakfast (imperial)

Item	Quantity	Material	Dimen-sions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent V3.1
Plate	2	Porcelain	7.7	8.99	17.99	43	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Bowl (cereal or fruit)	0.9	Porcelain	5.4	6.88	6.19	15	22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]
Cold drink glass	0.3	Glass	2.4	8.49	2.55	6	Market for packaging glass, white [GLO]
Coffee cup	0.9	Porcelain	3.8	5.89	5.31	13	22.5% market for feldspar [GLO] + 25% market for silica sand

Item	Quantity	Material	Dimen-sions / diameter (in.)	Mass per item (oz.)	Mass per place setting (oz.)	Mass per FU (lb)	Modelled in LCA software as / data source: ecoinvent V3.1
							[GLO] + 52.5% market for kaolin [GLO]
Coffee stirrer/ spoon	0.9	Stainless steel	4.2	0.47	0.42	1	Market for chromium steel 18%, hot rolled [GLO]
Fork	1.1	Stainless steel	7.0	0.78	0.86	2	Market for chromium steel 18%, hot rolled [GLO]
Spoon	1.1	Stainless steel	7.0	0.93	1.02	2	Market for chromium steel 18%, hot rolled [GLO]
Knife	1.1	Stainless steel	8.1	1.57	1.72	4	Market for chromium steel 18%, hot rolled [GLO]
				Sum	36.06	86	

Source: MEIKO

On the basis of the data on mass and quantity, an average place setting was defined. As the production of the crockery items has also been modelled on a material-related mass basis, the single items were grouped by material and material demand (Table 3-32).

Table 3-32: Material composition of a multi-use place setting for the hotel scenario

Material	Material in report	Mass per place setting (g)	Mass per FU (kg)	Mass per place setting (oz.)	Mass per FU (lb)
22.5% market for feldspar [GLO] + 25% market for silica sand [GLO] + 52.5% market for kaolin [GLO]	Porcelain	835.9	32	29.49	71
Market for packaging glass, white [GLO]	Glass	72.2	2.8	2.55	6
Market for chromium steel 18%, hot rolled [GLO]	Stainless steel	114.1	4.4	4.02	10
	Sum	1022.2	39	36.06	86

Source: Own calculation

Reprocessing (washing) and reuse

The same machine and machine-specific parameters as for the school cafeteria have been used for the modelling of the dish-washing process in the reference hotels serving breakfast. Figures differ only due to the different place setting components that have to be washed in the machine and the number of meals served per day.

The same applies to the modelling of the detergent and rinse aid. The provision and composition of these chemicals has been modelled analogously to the school scenario (see section 3.1.3.2) but scenario-specific consumption values have been considered.

With regard to hotels that do not cook, these hotels could use smaller under counter industrial dishwasher models. The water use per rack and thereby also the chemical and energy use per rack in these cases would drop around 14% per rack. This under counter scenario is not covered by this report.

3.2.4. End of life treatment (including required transport services)

At the end of the service life (EoL), crockery may be sorted out while it has become chipped, scratched, or broken or due to losses of optical quality. The reusable dishes that have thus been taken out of service will also be picked up by a waste collection and processing company and subsequently handed over to the applicable recycling and waste treatment routes.

The transportation of reusable dishes to waste treatment facilities has been modelled in the same way as for the disposable dishes, as truck transport service with a transport distance of 100 km (62.1 miles).

The truck transport has been modelled in the same manner as for the disposable system (see section 3.1.4)

After the reusable dishes have been picked up by a waste collection and processing company, the crockery items are handed over to the applicable waste treatment and recycling routes. As for the disposable crockery system, the latest published US-specific information from the US EPA (2015)[33] has been retrieved for modelling the dispatch of waste streams to respective waste treatment routes, taking into account the treatment within a municipal solid waste incineration plant (MSWI) and deposing in an inert landfill.

The material-specific data for EoL treatment in the reusable scenario is given in Table 3-33.

Table 3-33: Modelling of EoL treatment of used multi-use dishes

Material	Share	Waste treatment	Source or respectively dataset
porcelain	100%	Sanitary landfill	Treatment of inert waste, sanitary landfill [RoW]
cutlery	100%	Sanitary landfill	Treatment of scrap steel, inert material landfill [CH]

Source: Own assumption based on EPA (2015)

[33] Information has been retrieved from the US EPA Report: “Advancing Sustainable Materials Management; Facts and Figures 2013. Assessing Trends in Material generation, recycling and Disposal in the United States”, June 2015, US EPA.

It has to be noted, that no recycling has been taken into account for the reusable system in all three scenarios. Due to the overall comparatively small material flows in the reusable system, it can be taken for granted, that this modelling assumption does not significantly affect the results of the reusable system. From the perspective of the reusable system, the assumption of 100% landfill of the cutlery can be deemed as worst case assumption.

4. Impact assessment results

In the following section, the impact assessment results will be presented by starting with a comparison of the overall results (section 4.1). In sections 4.2.1–4.2.3, scenario-specific results are discussed within the scope of a more detailed analysis of contributions by life cycle stages, and on processes of great influence. The results of the sensitivity analysis that have been additionally carried out will be given in section 4.3.

ISO 14044 section 4.1 requires LCA studies to include or at least make available the inventory analysis. In order to comply with ISO 14044 the LCI results are available on request via MEIKO.

4.1. Statement on the significance of assessing impact indicator results

According to the ISO 14044, “additional techniques and information may be needed to understand better the significance, uncertainty and sensitivity of the LCIA results, for example in order to help distinguish if significant differences are or are not present. The need for and choice of techniques depend upon the accuracy and detail need to fulfil the goal and scope of the LCA” (ISO 14044). In particular, this applies when the LCA results, as in the case of this study, containing comparative assertions, foreseen to be disclosed to the public.

Proving significance of LCA results by applying classical error calculation and the effect of error propagation is not the general rule in the majority of LCAs. Nonetheless, in order to avoid the over-interpretation of small differences in the indicator results of the two systems, the comparison has been conducted by considering materiality thresholds, even though these materiality thresholds haven’t been derived from mathematical procedures.

Based on long-term experience in conducting LCAs, Oeko-Institut assumes the following materiality thresholds, to be seen as both practicable and expedient.

Differences of 10% or more can be seen as significant for the impact indicators CED and GWP, due to the broad scientific consensus among the scientific society and the comparably good representation of underlying data in the used datasets

Differences of 20% or more can be seen as significant for all other impact indicators

Supplementary, with regard to the toxicity related impact indicators, were underlying data (especially with regard to data symmetry) is still discussed among experts, results have been analyzed with specific attention as far as possible in the context of this study. For the purpose of this study, it has to be concluded that it was not possible to define a decisive criterion on the significance of the toxicity related indicator results. Accordingly, it has been decided to not draw conclusions on the comparison of single-use and multi-use crockery systems with respect to the toxicity related environmental impacts. This applies for the impact indicators TRACI (ecotoxicity, human health carc., human health non-carc, human health, resp. eff.) and USEtox, human toxicity, total and USEtox, ecotoxicity, total.

The described approach has to be considered as a pragmatic procedure, nonetheless, the approach can be seen as established practice in LCA.

4.2. Overall results

The overall LCIA results for all three scenarios are given in Table 4-1.

As mentioned within the description of the impact assessment method (section 2.6), there are some environmental impacts that are represented by more than one indicator. Beside the acidification (addressed as well by the ReCiPe Terrestrial Acidification Potential (TAP) as by the TRACI, acidification), this applies as well to the toxicity-related impact indicators (addressed by the TRACI ecotox and humantox indicators and the respective USEtox indicators). It should therefore be paid attention to avoid double counting of the respective environmental impacts.

Results of the hospitals scenario show a clear advantage for the multi-use system. This applies to all of the impact indicators assessed within the framework of this study. While the results on the non-reusable system are mainly driven by contributions from the production phase and the "End-of-Life" (EoL) treatment, the dishwashing in the use phase and thereby the demand for electricity to run the dishwashing machines dominates by far the overall impact assessment results of the reusable system. The only exception is the WDP of the reusable scenario, as it is mainly driven by the water demand for the dishwashing process. Overall, the hospital scenario shows the highest impact assessment result, compared to the school and hotel scenario. This is mainly due to the comprehensive place setting, and the comparably high number of meal participants per year, that have been defined as functional unit. As a consequence, the hospital scenario reveals a comparably high overall material flow.

Furthermore, the results of the school scenario show a clear advantage of the multi-use system compared to the disposable system. With only one exception, the disposable system results are higher than the corresponding results on the reusable system in the assessed impact indicators. The only exception from the overall arithmetic is the impact indicator on the water depletion potential. The water demand for the dishwashing process in the reusable system exceeds the water demand, which in the disposable system is caused by the production processes of the disposable crockery items. Taking a closer look at the contributions from life cycle stages to the WDP and with regard to the multi-use scenarios, there are only minor differences between the scenarios (98% from the use phase in hospital scenario, 99% from the use phase in scenarios school and hotel). This suggests that the WDP results in the hospital scenario are primarily driven by the contributions to the single-use hospital scenario. Taking a closer look on the contributions from the different life cycle stages, about 75% of the WDP contributions in the single-use hospital scenario are caused by the production of the PLA components, were each kg of PLA (2.204 lb) PLA) production causes a WDP of 377 liters (99.5 gallons) of water. Multiplied with the PLA reference flow of about 1520 kg (3350 lb) PLA per FU the PLA related WDP sums up to about 570 m^3 (150,578 gallons). The documentation of the ecoinvent dataset states that the agricultural input for PLA production is corn. Therefore, it can be assumed that the high WDP for PLA production is caused by irrigation of maize plants serving as input material for PLA provision.

When looking at the impact assessment results for the hotel scenario, also the reusable system shows advantages over the disposable system for all impact indicators but WDP, were the disposable system shows clear advantages, and the acidification impact indicators (ReCiPe TAP and TRACI – acidification) lie more or less within the same range. However, it should be noted that the differences between the two systems in the hotel scenario are less than for the other two scenarios. Here too, the water demand for the dishwashing process in the reusable system exceeds the water demand caused by the production processes of the disposable crockery items. The respective indicator results will be discussed in more detail within the scope of a contribution analysis in section 4.2.3.

Table 4-1: Overall LCIA results for all three scenarios

	LCIA indicator	Unit	Hospital scenario			School scenario			Hotel scenario		
			disposable	reusable	diff. [abs.]	disposable	reusable	diff. [abs.]	disposable	reusable	diff. [abs.]
ReCiPe	ALOP	m²a	86,600	1,290	-85,300	1,580	186	-1,390	9,380	264	-9,120
	FDP	kg Oil-eq.	18,400	5,780	-12,600	7,270	829	-6,440	2,080	1,160	-919
	NLTP	m^2	6.51	1.64	-4.88	0.82	0.24	-0.58	0.69	0.36	-0.33
	TAP100	kg SO_2-eq.	235	127	-109	50	17	-32	24	26	2
	WDP	m³	756	221	-535	35	42	8	23	66	44
TRACI	Acidification	moles-H^+-eq.	13,600	7,070	-6,570	2,890	976	-1,910	1,410	1,450	32
	Ecotoxicity	kg 2,4-D-eq.	78,500	16,700	-61,800	3,200	2,460	-731	8,630	3,640	-4,980
	Eutrophication	kg N	52	7	-45	4.6	1.2	-3.4	5	2	-3
	Global warming	kg CO_2-eq.	63,500	21,200	-42,400	16,100	2,990	-13,100	6,670	4,290	-2,380
	Ozone depletion	kg CFC-11-eq.	3.1E-03	7.3E-04	-2.4E-03	4.4E-04	1.0E-04	-3.4E-04	3.1E-04	1.5E-04	-1.6E-04
	Photochemical oxidation	kg NOx-eq.	155	41	-114	35	6	-29	16	8	-7
	Human health, carc.	kg benzene-eq.	89	36	-54	11	6	-5	9	7	-2
	Human health, non-carc.	kg toluene-eq.	466,000	102,000	-365,000	42,700	16,100	-26,500	48,200	22,600	-25,500
	Human health, resp. eff.	kg PM2.5-eq.	84	29	-55	15	4	-11	9	6	-3
USEtox	Ecotoxicity, total	CTU	34,600	4,180	-30,400	2,970	700	-2,270	2,850	966	-1,890
	Human toxicity, total	CTU	1.5E-02	1.1E-03	-1.4E-02	7.4E-04	2.0E-04	-5.4E-04	1.7E-03	2.7E-04	-1.4E-03
CED total		MJ	1,502,000	369,000	-1,133,000	373,000	52,500	-321,000	166,000	74,000	-91,600

Source: Own calculation

In Table 4-2 for each scenario the share of the results of the disposable system is presented in relation to the amount of the respective reusable system. In this respect the reusable system is presented as 100%, whereas the presentation of the disposable system is always in relation to the respective 100% value in each scenario.

Table 4-2: Relative overall LCIA results for all three scenarios

LCIA indicator		Hospital scenario		School scenario		Hotel scenario	
		disposable	reusable	disposable	reusable	disposable	reusable
ReCiPe	ALOP	6712%	100%	850%	100%	3557%	100%
	FDP	318%	100%	876%	100%	180%	100%
	NLTP	398%	100%	338%	100%	192%	100%
	TAP100	186%	100%	285%	100%	93%	100%
	WDP	343%	100%	82%	100%	34%	100%
TRACI	Acidification	193%	100%	296%	100%	98%	100%
	Ecotoxicity	470%	100%	130%	100%	237%	100%
	Eutrophication	792%	100%	381%	100%	253%	100%
	Global warming	300%	100%	540%	100%	155%	100%
	Ozone depletion	423%	100%	439%	100%	208%	100%
	Photochemical oxidation	381%	100%	599%	100%	187%	100%
	Human health, carc.	251%	100%	194%	100%	127%	100%
	Human health, non-carc.	458%	100%	264%	100%	213%	100%
	Human health, resp. eff.	294%	100%	379%	100%	154%	100%
USEtox	Ecotoxicity, total	829%	100%	424%	100%	295%	100%
	Human toxicity, total	1436%	100%	369%	100%	630%	100%
CED total		407%	100%	711%	100%	224%	100%

Source: Own calculation

4.2.1. Hospital scenario

Table 4-3 shows the contributions by life cycle stages for both systems in absolute and in system-specific relative terms, meaning that the perecentage figures of each table row sum up to 100%. As it has been already mentioned above, it is the use phase that dominates the overall results for the reusable system, while the production of the single-use crockery is the dominant contributor to the results of the disposable dishes system. Impacts from the use phase of the reusable system contribute between 85% and 98% of the overall indicator results. Only three impact indicators (natural land tranformation potential (NLTP), ozone depletion and human health, carc.) show a use phase contribution lower than 90%. The EoL treatment, as well as the distribution phase is of only minor importance for the overall results of the reusable system. The contributions from the production of the reusable crockery items account for 2-15%, with the highest contribution for the impact indicator human health, carc. The respective impact is mainly driven by the provision of raw materials and the production process of the reusable cutlery items.

Regarding the single-use system, the production stage (71%-100%), followed by the EoL treatment (0-25%) contributes substantially to the overall impact indicator results. Whereas the distribution and the EoL treatment is of minor importance for the reusable system, the distribution in the disposbale system contributes, depending on the impact indicator, accounts for between 0-19%. A typical result in this context is derived from the impact indicators NLTP and ozone depletion, where the contribution through the distribution stage sums up to 19% of the overall indicator result.

Overall, it can be stated that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase (dishwashing process) of the reusable system, leading to general benefits of the reusable system compared to the disposable system in the hospital scenario.

Table 4-3: Hospital scenario: absolute and relative contributions by life cycle stages for both systems

LCIA indicator		System	Production		Distribution		Use phase		EoL treatment		EoL-credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
ReCiPe	ALOP	disposable	8.66E+04	100%	4.69E+01	0%	0.00E+00	0%	2.17E+01	0%	-4.78E+01	0%	8.66E+04	100%
		reusable	8.25E+01	6%	5.84E-01	0%	1.21E+03	94%	3.08E-01	0%			1.29E+03	100%
	FDP	disposable	1.70E+04	93%	1.33E+03	7%	0.00E+00	0%	2.23E+02	1%	-2.11E+02	-1%	1.84E+04	100%
		reusable	4.30E+02	7%	1.65E+01	0%	5.34E+03	92%	3.07E+00	0%			5.78E+03	100%
	NLTP	disposable	5.63E+00	86%	1.46E+00	22%	0.00E+00	0%	-5.26E-01	-8%	-5.23E-02	-1%	6.51E+00	100%
		reusable	1.69E-01	10%	1.82E-02	1%	1.46E+00	89%	-7.96E-03	0%			1.64E+00	100%
	TAP100	disposable	2.18E+02	93%	1.66E+01	7%	0.00E+00	0%	5.15E+00	2%	-4.69E+00	-2%	2.35E+02	100%
		reusable	8.66E+00	7%	2.06E-01	0%	1.18E+02	93%	5.81E-02	0%			1.27E+02	100%
	WDP	disposable	7.52E+02	99%	2.84E+00	0%	0.00E+00	0%	3.82E+00	1%	-2.27E+00	0%	7.56E+02	100%
		reusable	3.63E+00	2%	3.54E-02	0%	2.17E+02	98%	3.90E-02	0%			2.21E+02	100%
TRACI	Acidification	disposable	1.25E+04	91%	1.08E+03	8%	0.00E+00	0%	3.43E+02	3%	-2.63E+02	-2%	1.36E+04	100%
		reusable	4.65E+02	7%	1.34E+01	0%	6.59E+03	93%	3.84E+00	0%			7.07E+03	100%
	Ecotoxicity	disposable	7.84E+04	100%	3.35E+02	0%	0.00E+00	0%	3.75E+02	0%	-5.97E+02	-1%	7.85E+04	100%
		reusable	6.27E+02	4%	4.18E+00	0%	1.61E+04	96%	1.39E+00	0%			1.67E+04	100%
	Eutrophication	disposable	2.36E+01	45%	1.94E+00	4%	0.00E+00	0%	2.64E+01	51%	-8.43E-02	0%	5.19E+01	100%
		reusable	2.80E-01	4%	2.42E-02	0%	6.23E+00	95%	1.90E-02	0%			6.56E+00	100%
	Global warming	disposable	4.61E+04	73%	3.47E+03	5%	0.00E+00	0%	1.47E+04	23%	-7.87E+02	-1%	6.35E+04	100%
		reusable	1.24E+03	6%	4.32E+01	0%	1.98E+04	94%	7.10E+01	0%			2.12E+04	100%
	Ozone depletion	disposable	2.33E-03	75%	6.80E-04	22%	0.00E+00	0%	1.08E-04	3%	-2.55E-05	-1%	3.10E-03	100%
		reusable	7.75E-05	11%	8.47E-06	1%	6.45E-04	88%	1.73E-06	0%			7.33E-04	100%
	Photochemical oxidation	disposable	1.29E+02	83%	2.05E+01	13%	0.00E+00	0%	7.60E+00	5%	-1.49E+00	-1%	1.55E+02	100%
		reusable	2.51E+00	6%	2.55E-01	1%	3.79E+01	93%	7.58E-02	0%			4.08E+01	100%
	Human health, carc.	disposable	8.39E+01	94%	1.88E+00	2%	0.00E+00	0%	5.03E+00	6%	-1.66E+00	-2%	8.92E+01	100%
		reusable	7.38E+00	21%	2.33E-02	0%	2.80E+01	79%	7.18E-02	0%			3.55E+01	100%
	Human health, non-carc.	disposable	4.52E+05	97%	8.67E+03	2%	0.00E+00	0%	9.34E+03	2%	-3.72E+03	-1%	4.66E+05	100%
		reusable	1.09E+04	11%	1.08E+02	0%	9.08E+04	89%	1.30E+02	0%			1.02E+05	100%
	Human health, resp. eff.	disposable	8.08E+01	96%	3.00E+00	4%	0.00E+00	0%	1.08E+00	1%	-1.03E+00	-1%	8.39E+01	100%
		reusable	2.38E+00	8%	3.74E-02	0%	2.61E+01	91%	1.25E-02	0%			2.85E+01	100%

LCIA indicator		System	Production		Distribution		Use phase		EoL treatment		EoL-credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
USEtox	Ecotoxicity, total	disposable	3.32E+04	96%	5.93E+02	2%	0.00E+00	0%	1.01E+03	3%	-1.52E+02	0%	3.46E+04	100%
		reusable	6.06E+02	15%	7.38E+00	0%	3.56E+03	85%	8.71E+00	0%			4.18E+03	100%
	Human toxicity, total	disposable	1.47E-02	98%	1.23E-04	1%	0.00E+00	0%	2.68E-04	2%	-3.12E-05	0%	1.50E-02	100%
		reusable	1.39E-04	13%	1.53E-06	0%	9.05E-04	86%	1.58E-06	0%			1.05E-03	100%
CED total		disposable	1.44E+06	96%	6.01E+04	4%	0.00E+00	0%	1.19E+04	1%	-1.37E+04	-1%	1.50E+06	100%
		reusable	2.39E+04	6%	7.49E+02	0%	3.45E+05	93%	1.45E+02	0%			3.69E+05	100%

Source: Own calculation

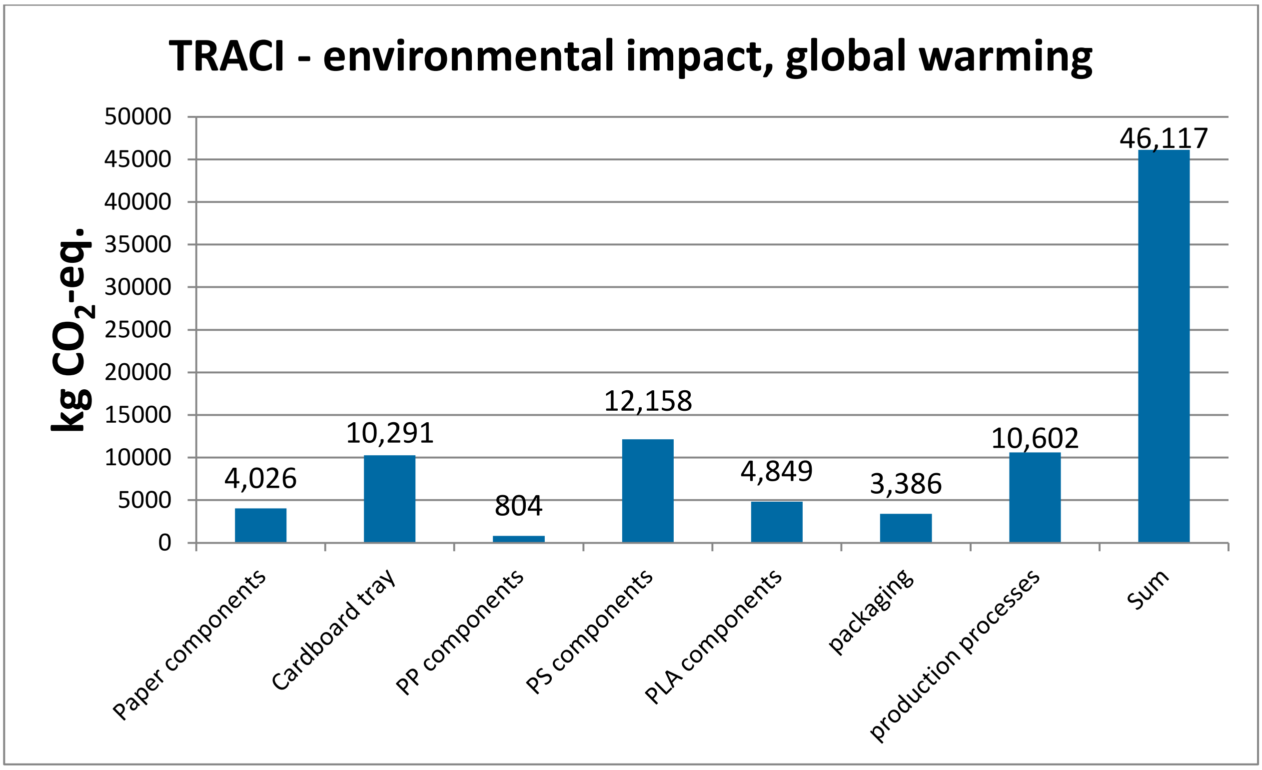
4.2.1.1. Focus on disposable crockery: Contributions from the production stage

In the course of contribution analyses, the processes that contribute most to the overall results for both systems, and have therefore to be seen as significant parameters for the respective system, will be discussed in more detail.

With regard to the disposable crockery, the main contributions, as mentioned above, arise from the production process, while the distribution and use phase and the EoL treatment are of minor importance. With regard to the eutrophication potential, however, the EoL treatment is of great importance, accounting for about 50% of the overall impact indicator result. Even though to lesser extent, the EoL treatment is also of importance for the GWP, summing up to 24% of the overall impact indicator result. Due to this fact, the focus of the contribution analyses focusses on these two processes.

The in-depth analyses in the following sections, for the sake of clarity and ease of comprehension, are only shown for the impact indicator results addressing the global warming potential (GWP) and the cumulative Energy demand (CED, given as CED, total in this study). The absolute CO_2eq.-emissions from the production stage of the disposable system in the hospital scenario sums up to 46,000 kg CO_2-eq. (73% of the overall GWP).

Figure 4-1: Contribution to the GWP of the production stage in disposable "hospital" scenario



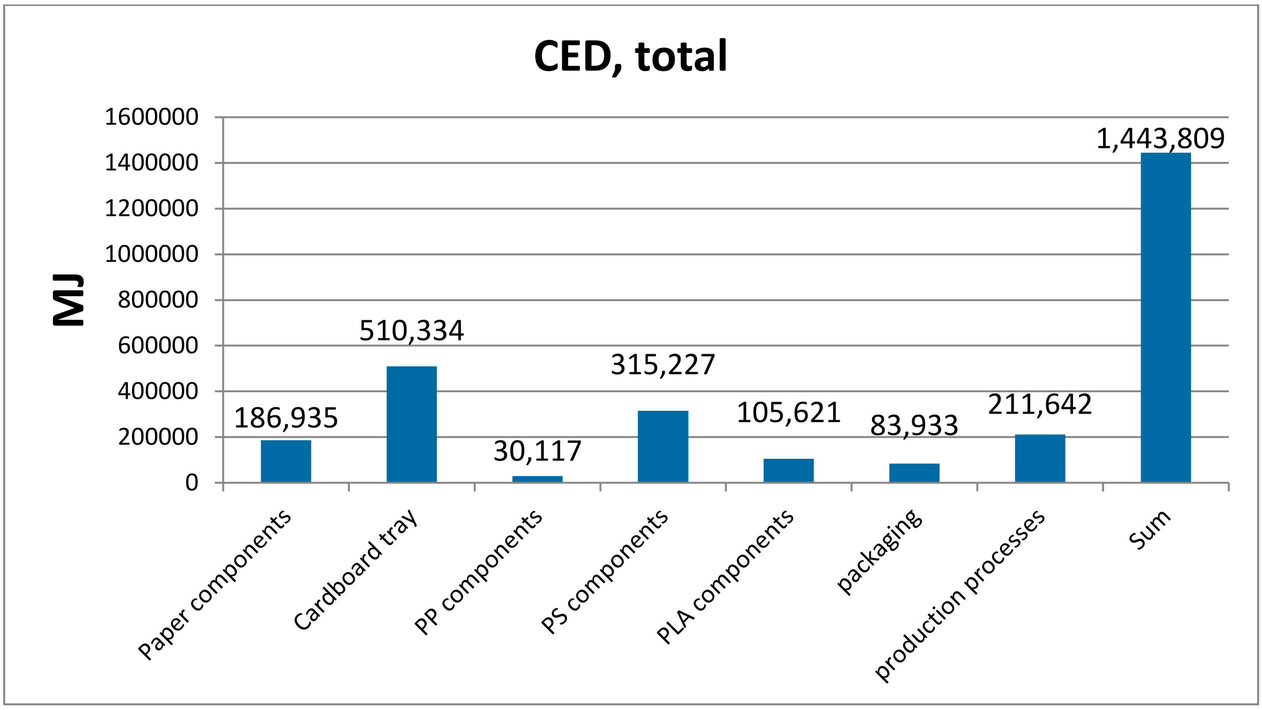
Source: Own calculation

By far, the largest proportion (70%) of the overall results comes from the provision of the required materials for the production of the disposable crockery items. The highest single-item contribution (22%) arises from the cardboard trays, mainly due to the material flow of 8,560 kg (18,866 lb) of paperboard. The highest contribution by a material (26%) arises from the production of the PS components: main plate and salad bowl made of foamed PS and the cutlery items, made of solid PS. With respect to the plastic components (PS, PP and PLA), the contributions are driven by both the material flow and the comparably high specific GWP emissions arising from the material provision.

With regard to the calculation procedure for biogenic carbon (in this study relevant for PLA), it should be noted that the amount of CO_2 taken up in biomass and the equivalent amount of CO_2 emissions from the biomass at the point of complete oxidation results in zero net CO_2 emissions when biomass carbon is not converted into methane, non-methane volatile organic compounds (NMVOC) or other precursor gases (ISO TS 14067). In the context of this study, the biogenic carbon uptake has been taken into account, by using the dataset "Market for polylactide, granulate [GLO]" as implemented in the ecoinvent database. According to the documentation of the dataset in ecoinvent, polylactide acid is a polymer of the monomer $C_3H_4O_2$ with a non-fossil carbon content of 0.5 kg CO_2/kg PLA (0.5kg CO_2/2.204 lb PLA). With regard to the EoL-modelling of PLA-based crockery items, in line with the overall modelling of plastics in this study, it has been assumed that 20% become incinerated in a MSWI, while 80% go to sanitary landfill. As there hasn´t been available a PLA-specific dataset for the specific treatment of PLA in both municipal incineration and sanitary landfill, the respective waste treatment flow has been modelled by using the respective datasets for waste polypropylene (see also Table 3-13). For the 80% of PLA going to sanitary landfill, and taking into account the decomposition behaviour of PLA compared to PP, this has to be seen as best case assumption for the single-use system. Even though this might be seen as an over-simplification, the authors would like to point out that the treatment of PLA-based crockery items contributes only about 2% to the overall CO_2-Emissions from the EoL stage (Figure 4-3) and the simplification can therefore be seen as being of minor relevance to the results.

The production processes, altogether, contribute further 23%, including as well the production of the paperboard tray as the production of the other crockery items. Furthermore, the demand for packaging crockery items for distribution (corrugated board boxes and packaging film), altogether contributes 7% of GWP emissions.

Figure 4-2: Contribution to the CED, total of the production stage in disposable "hospital" scenario



Source: Own calculation

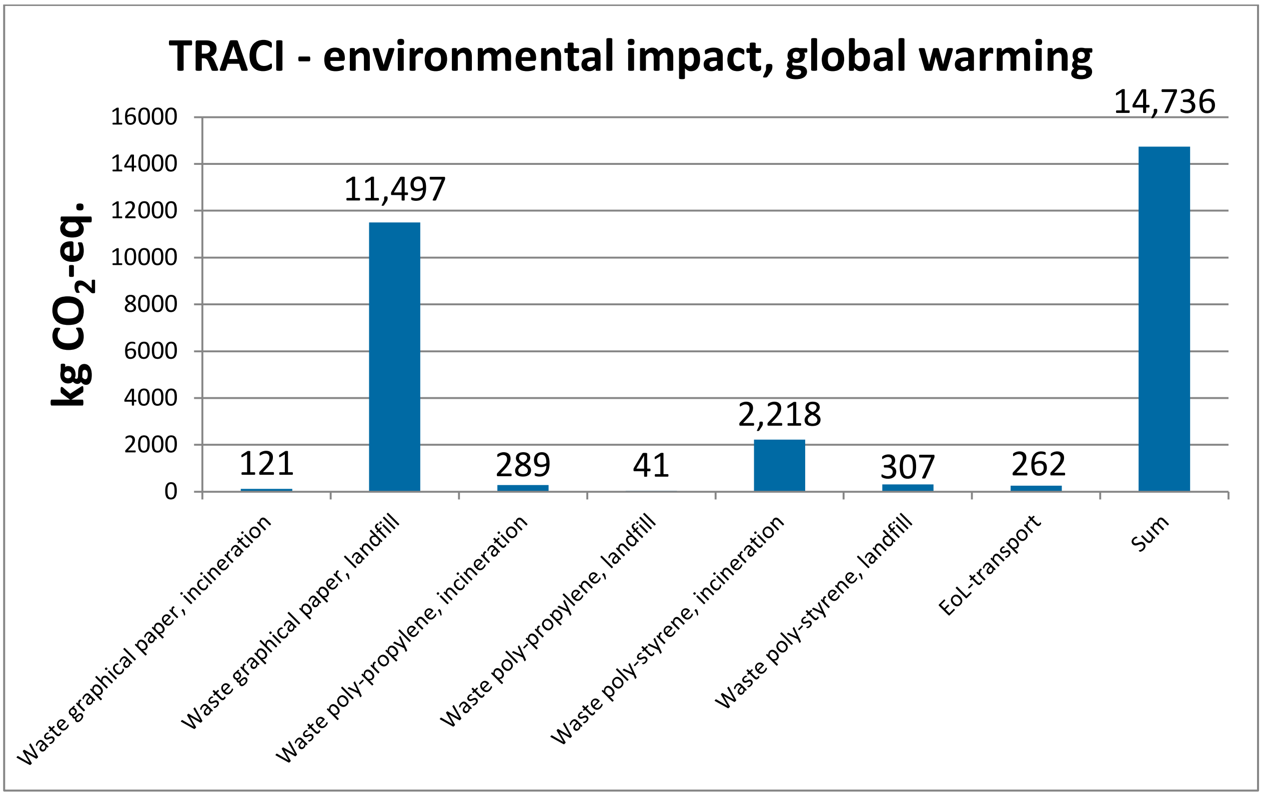
With regard to the CED, total as before the cardboard tray contributes the highest single-item burdens 35%, followed again by the PS components (22%). The contributions from the other materials also follow the logic of the GWP results and reflect the respective material flows. This also applies for the production processes which all together contribute 7% of the overall CED, total of the production stage in the disposable system hospital scenario.

Taking into account the results of the contribution analysis, it may be concluded that the weight of disposable crockery items is a significant parameter. Due to this fact, the parameter of crockery weight has been further assessed within the framework of a sensitivity analysis (section 4.3.1).

4.2.1.2. Focus on disposable crockery: Contributions from the EoL stage

As for the production phase described above, in-depth analyses have also been carried out for the impact indicator results addressing the (GWP). The absolute CO_2-eq. emissions from the EoL stage of the disposable system in the hospital scenario sum up to 14.750 kg CO_2-eq. (23% of the overall GWP).

Figure 4-3: Contribution to the GWP of the end of life stage in disposable “hospital” scenario

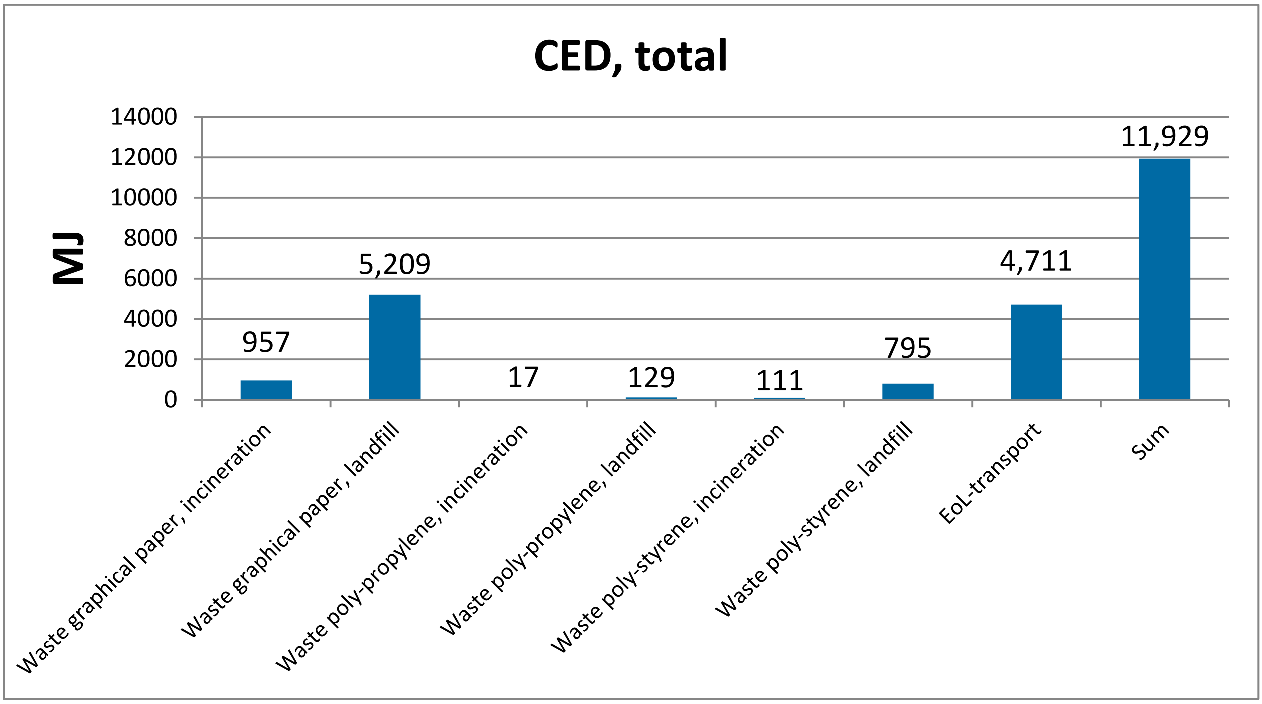


Source: Own calculation

As for production, the treatment of waste paper, modelled as treatment of waste graphical paper[34], also shows the highest contributions for the EoL processes. Main contributions arise from share of paper that will be landfilled, while emissions from incineration are of minor importance. Equally the reverse situation can be seen for the treatment of the fossil-based materials (e.g. waste poly-styrene), where specifically the treatment in an MSWI shows higher impacts. The EoL transport by refuse truck contributes only 2% to the GWP emissions.

[34] “graphical paper” is paper used for writing, printing or other graphic purposes.

Figure 4-4: Contribution to the CED, total of the end of life stage in disposable "hospital" scenario

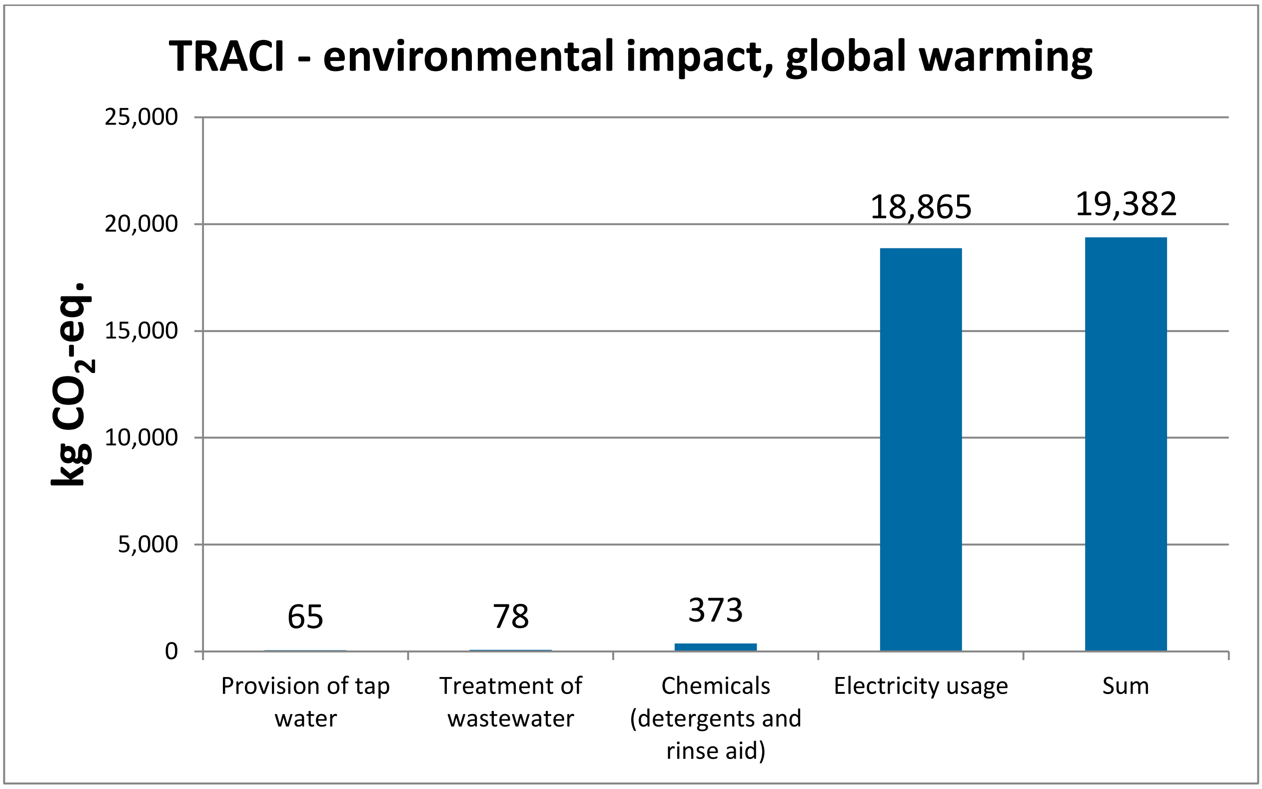


Source: Own calculation

4.2.1.3. Focus on the reusable crockery: Contributions from the dishwashing of reusable dishes

In this study, the impacts from the use phase, and therein the dishwashing process, dominate the overall LCIA results of all three reusable scenarios. All other phases, namely production, distribution, EoL treatment as well as the pre-warming process of plates in the hospital cafeteria are of only secondary importance. Figure 4-5 shows the contributions from the dishwashing process in the hospital scenario with reusable dishes.

Figure 4-5: Contribution to the GWP of the dishwashing process in reusable "hospital" scenario[35]

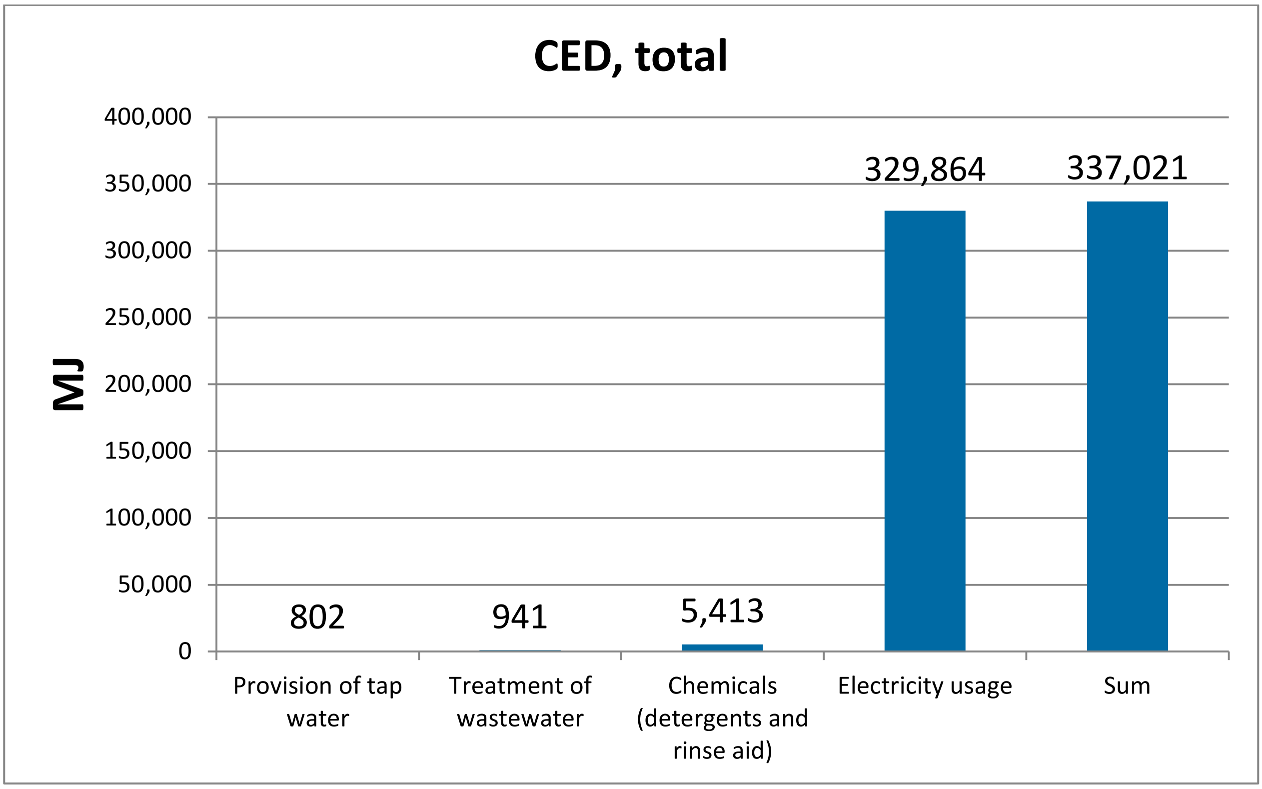


Source: Own calculation

On closer inspection of the dishwashing process, GWP emissions from the electricity usage for running the dishwasher dominate the result with a contribution of 97%. On the other hand, chemicals contribute only 2%, while the emissions from the provision of water and the treatment of wastewater are negligible with regard to the GWP. The emissions from the electricity usage dominate the results in the majority of the impact indicators that have been assessed. An overview of the contributions to the dishwashing process for all impact indicators is given in the technical Annex (section 9.2.1 in Table 9-3. Figure 4-6 shows the contributions from the dishwashing process to the CED, total results in the hospital scenario with reusable dishes.

[35] The numbers in the tables and corresponding figures may not be exactly the same. This is attributed to rounding differences of various software that has been used to calculate the results. The authors assume that this will not have any substantial effect on the overall results as well as on the interpretation of results and the conclusions drawn from the results.

Figure 4-6: Contribution to the CED, total of the dishwashing process in reusable "hospital" scenario



Source: Own calculation

Once more, the electricity usage dominates the impact indicator results. In the case of CED, total the electricity usage during the dishwashing process sums up to 98%.

Taking into account the results of the contribution analysis, it can be concluded that the choice (or respectively the assumption) of a distinct type of dishwashing machine, including machine-specific operation parameters and LCI datasets used for modelling the dishwashing process are parameters of high significance for the description of the reusable system. Due to this fact, the respective parameters have also been assessed within the scope of two additional sensitivity analyses (sections 4.3.4 and 4.3.5).

4.2.2. School scenario

Table 4-4 shows the contributions by life cycle stages for both systems in absolute and in system-specific, relative terms. Here again, it is the use phase that dominates the overall results for the reusable dishes system, while the production and provision of the single-use crockery is the dominant contributor to the results of the disposable dishes system. Impacts from the use phase of the reusable system contribute by more than 90% to the overall indicator results for the majority of impact indicatros assessed within this study. Only four impact indicators (TRACI, human health, carc, TRACI human health non-carc, USEtox ecotox and USEtox humantox) show a use phase contribution lower than 90%. This is due to the fact that the contribution from the production phase is higher for these indicators, which is mainly due to the production of reusable crockery items and here especially due to the contributions of the cutlery production from stainless steel and the production of crockery items made of reusable plastic.

Looking over all impact indicators that have been assessed, the contributions from the production of the reusable crockery items contributes by 1-24% to the overall result. The EoL treatment as well as the distribution phase are of only minor importance for the overall results of the reusable system, which can be explained by the fact that, overall, the material flows in relation to the Functional Unit are fairly low.

Regarding the single-use system, the production stage (65%-100%), followed by the distribution (1-35%) and the EoL treatment (0-24%) contributes significantly to the overall impact indicator results, followed by the contributions from the distribution and the EoL treatment.

With regard to the contributions from the distribution, especially the results for the two impact indicators NLTP (35%, mainly due to natural land transformation for road infrastructure) and TRACI, ozone depletion (31%, mainly due to ozone depleting emissions from combustion of diesel in trucks) are remarkable.

Overall, it can be stated that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase of the reusable system, with the only exception for the water depletion potential, where the water demand for the dishwashing process in the reusable system exceeds the water demand for the production of disposable crockery items. Excluding the WDP, it can be concluded that the reusable system shows benefits overall compared to the disposable system in the schools scenario.

Table 4-4: School scenario: absolute and relative contributions by life cycle stages for both systems

LCIA indicator		System	Production		Distribution		Use phase		EoL treatment		EoL credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
ReCiPe	ALOP	disposable	1.58E+03	100%	9.30E+00	1%	0.00E+00	0%	4.25E+00	0%	-1.02E+01	-1%	1.58E+03	100%
		reusable	1.23E+01	7%	8.71E-02	0%	1.73E+02	93%	4.68E-02	0%		0%	1.86E+02	100%
	FDP	disposable	7.01E+03	96%	2.63E+02	4%	0.00E+00	0%	4.63E+01	1%	-4.53E+01	-1%	7.27E+03	100%
		reusable	7.00E+01	8%	2.47E+00	0%	7.57E+02	91%	4.53E-01	0%		0%	8.29E+02	100%
	NLTP	disposable	6.55E-01	80%	2.90E-01	35%	0.00E+00	0%	-1.11E-01	-13%	-1.12E-02	-1%	8.23E-01	100%
		reusable	1.11E-02	5%	2.72E-03	1%	2.31E-01	95%	-1.07E-03	0%		0%	2.43E-01	100%
	TAP100	disposable	4.63E+01	93%	3.29E+00	7%	0.00E+00	0%	9.57E-01	2%	-1.01E+00	-2%	4.96E+01	100%
		reusable	6.42E-01	4%	3.08E-02	0%	1.67E+01	96%	9.41E-03	0%		0%	1.74E+01	100%
	WDP	disposable	3.35E+01	97%	5.64E-01	2%	0.00E+00	0%	9.81E-01	3%	-4.86E-01	-1%	3.45E+01	100%
		reusable	5.05E-01	1%	5.28E-03	0%	4.16E+01	99%	8.13E-03	0%		0%	4.21E+01	100%
TRACI	Acidification	disposable	2.67E+03	92%	2.14E+02	7%	0.00E+00	0%	6.34E+01	2%	-5.63E+01	-2%	2.89E+03	100%
		reusable	3.71E+01	4%	2.01E+00	0%	9.37E+02	96%	6.24E-01	0%		0%	9.76E+02	100%
	Ecotoxicity	disposable	3.23E+03	101%	6.66E+01	2%	0.00E+00	0%	3.08E+01	1%	-1.28E+02	-4%	3.20E+03	100%
		reusable	8.63E+01	4%	6.24E-01	0%	2.38E+03	96%	2.36E-01	0%		0%	2.46E+03	100%
	Eutrophica-tion	disposable	3.13E+00	68%	3.86E-01	8%	0.00E+00	0%	1.12E+00	24%	-1.81E-02	0%	4.62E+00	100%
		reusable	3.60E-02	3%	3.61E-03	0%	1.17E+00	96%	4.07E-03	0%		0%	1.21E+00	100%
	Global warming	disposable	1.29E+04	80%	6.88E+02	4%	0.00E+00	0%	2.69E+03	17%	-1.69E+02	-1%	1.61E+04	100%
		reusable	1.54E+02	5%	6.45E+00	0%	2.81E+03	94%	1.63E+01	1%		0%	2.99E+03	100%
	Ozone depletion	disposable	2.87E-04	65%	1.35E-04	31%	0.00E+00	0%	2.27E-05	5%	-5.47E-06	-1%	4.39E-04	100%
		reusable	4.17E-06	4%	1.26E-06	1%	9.44E-05	94%	2.80E-07	0%		0%	1.00E-04	100%
	Photo-chemical oxidation	disposable	2.98E+01	85%	4.06E+00	12%	0.00E+00	0%	1.33E+00	4%	-3.20E-01	-1%	3.49E+01	100%
		reusable	3.37E-01	6%	3.80E-02	1%	5.43E+00	93%	1.23E-02	0%		0%	5.82E+00	100%
	Human health, carc.	disposable	8.67E+00	81%	3.72E-01	3%	0.00E+00	0%	2.00E+00	19%	-3.55E-01	-3%	1.07E+01	100%
		reusable	1.30E+00	24%	3.49E-03	0%	4.18E+00	76%	1.66E-02	0%		0%	5.50E+00	100%
	Human health, non-carc.	disposable	3.90E+04	91%	1.72E+03	4%	0.00E+00	0%	2.78E+03	7%	-7.97E+02	-2%	4.27E+04	100%
		reusable	1.87E+03	12%	1.61E+01	0%	1.42E+04	88%	2.78E+01	0%		0%	1.61E+04	100%
	Human health, resp. eff.	disposable	1.49E+01	96%	5.96E-01	4%	0.00E+00	0%	1.94E-01	1%	-2.21E-01	-1%	1.54E+01	100%
		reusable	3.14E-01	8%	5.58E-03	0%	3.75E+00	92%	1.99E-03	0%		0%	4.07E+00	100%

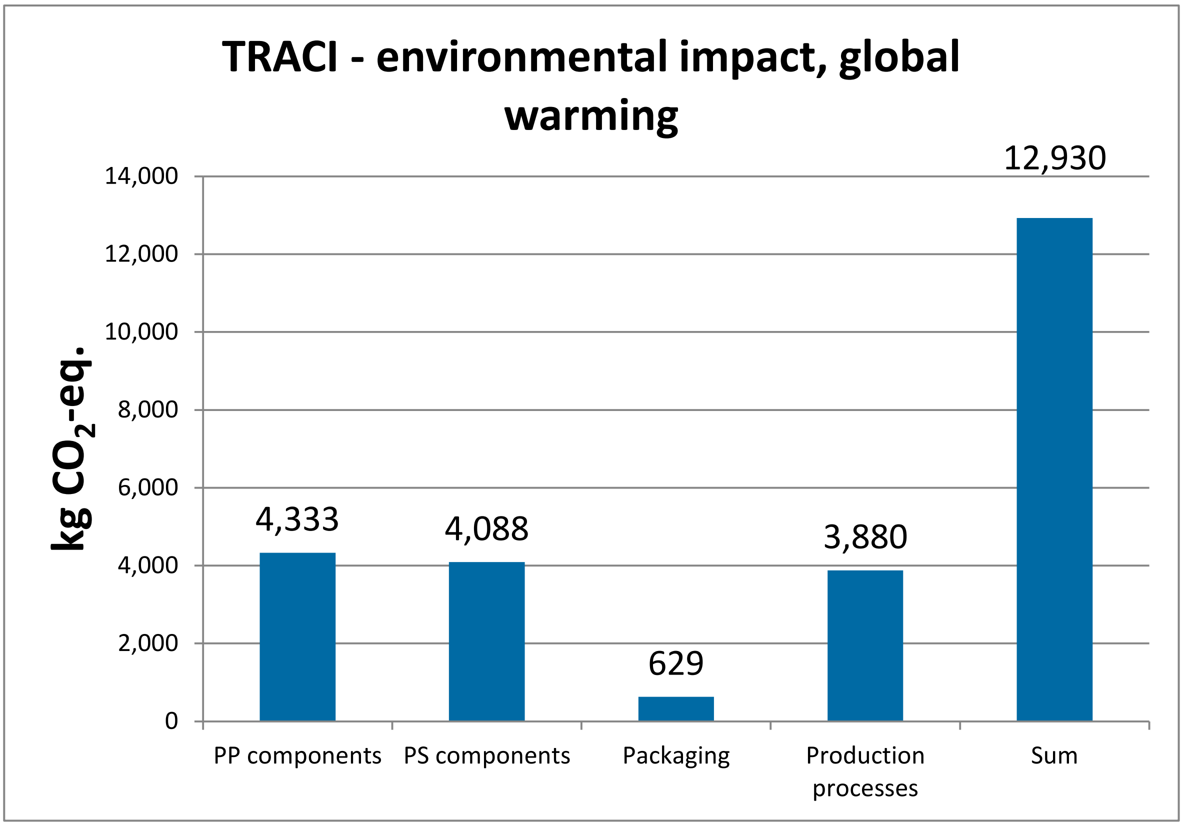
LCIA indicator		System	Production		Distribution		Use phase		EoL treatment		EoL credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
USEtox	Ecotoxicity, total	disposable	2.47E+03	83%	1.18E+02	4%	0.00E+00	0%	4.17E+02	14%	-3.26E+01	-1%	2.97E+03	100%
		reusable	1.09E+02	16%	1.10E+00	0%	5.88E+02	84%	1.92E+00	0%		0%	7.00E+02	100%
	Human toxicity, total	disposable	6.80E-04	92%	2.44E-05	3%	0.00E+00	0%	3.75E-05	5%	-6.69E-06	-1%	7.36E-04	100%
		reusable	3.90E-05	20%	2.29E-07	0%	1.60E-04	80%	3.42E-07	0%		0%	1.99E-04	100%
CED total		disposable	3.62E+05	97%	1.19E+04	3%	0.00E+00	0%	2.21E+03	1%	-2.94E+03	-1%	3.73E+05	100%
		reusable	3.70E+03	7%	1.12E+02	0%	4.87E+04	93%	2.16E+01	0%		0%	5.25E+04	100%

Source: Own calculation

4.2.2.1. Focus on disposable crockery: Contributions from the production stage

As for the contribution analysis of the hospital scenario, an in-depth analysis has also been carried out for the impact indicator results addressing the GWP for the school scenario. The absolute CO_2-eq. emissions from the production stage of the disposable system in the school scenario sums up to 12,930 kg CO_2-eq. (80% of the overall GWP, see Table 4-4) (Figure 4-7).

Figure 4-7: Disposable crockery production for school scenario; contributions to GWP by materials and processes

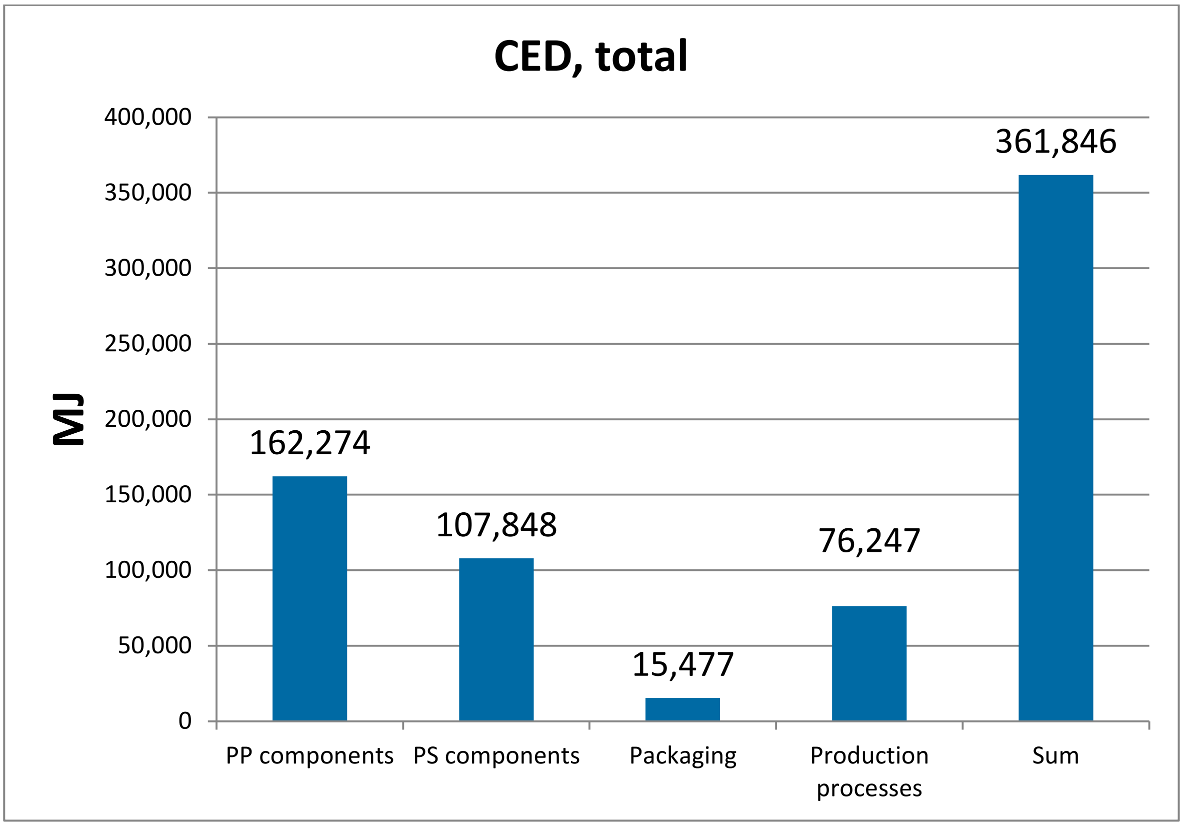


Source: Own calculation

The largest proportion of the overall results comes from the provision of the required polypropylene (34%) and polystyrene (32%), serving as raw materials for the production of the disposable crockery items (compartment tray made of foamed PS and the desert cup, the packaging cup for vegetables and the disposable cutlery items made from solid PP). The contributions are driven both by the material flow and the comparably high specific GWP emissions arising from the extraction of mineral oil and the further processing steps of polymerisation.

The required production processes, summing up the production of the above-mentioned PP and PS components, contribute further 30% to the indicator results. The specific GWP of PP provision (2.05 kg CO_2-eq./kg; 0.5 kg CO_2-eq./2.204 lb) compared to the higher GWP of 3.54 kg CO_2-eq. per kg of PS (3.54 kg CO_2-eq./2.204 lb) largely offsets the higher material demand for PP, resulting in a similar GWP for both PP and PS components. Furthermore, the demand for packaging crockery items for distribution has been taken into account. The production of corrugated board boxes and packaging film for all crockery items, altogether make up 5% of GWP emissions.

Figure 4-8: Disposable crockery production for school scenario; contributions to CED, total by materials and processes



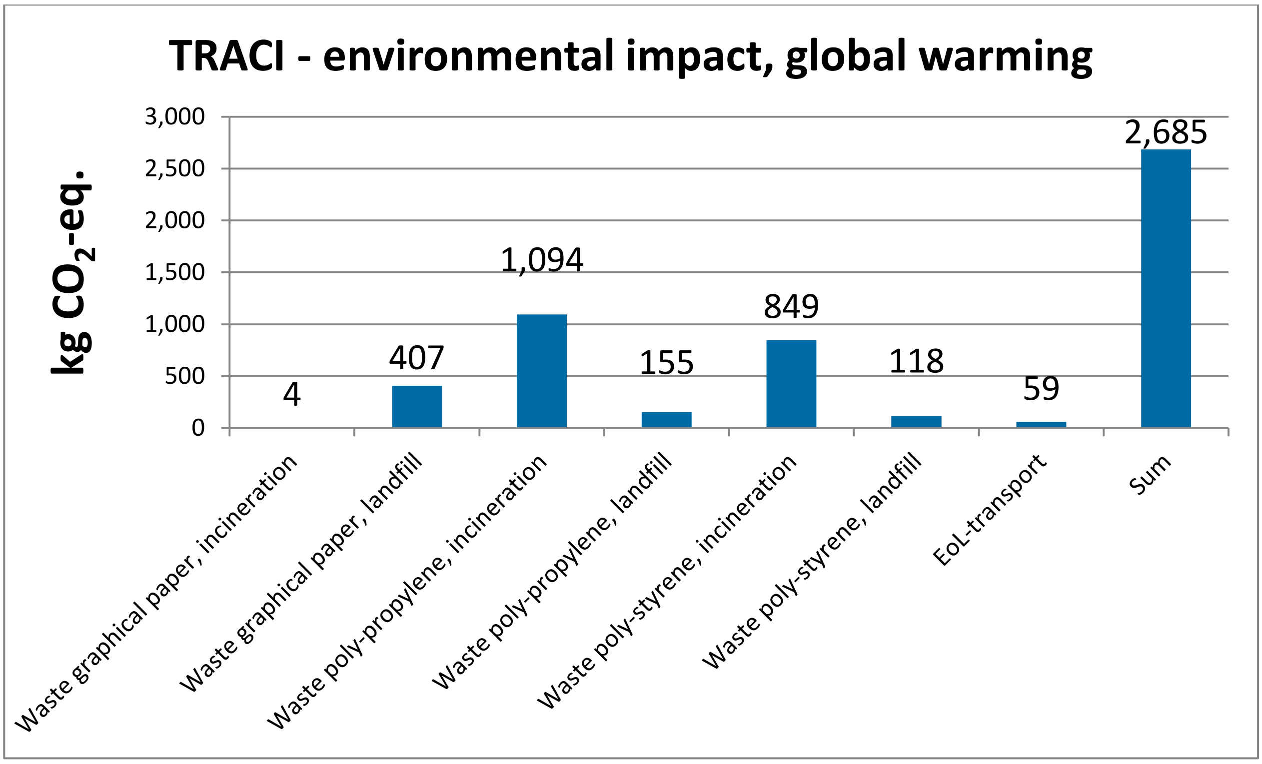
Source: Own calculation

With regard to the Indicator CED, total the situation is similar as to the GWP. However, the contribution arising from the provision of PP components (45%) exceeds the contribution from the PS components (30%) more clearly than for the indicator GWP, with the deciding factor of higher PP material flow compared to the PS material flow, together with only minor differences in the CED, total per kg of both materials. Furthermore, the packaging contributes 4% and the production processes altogether 21%.

Taking into account the results of the contribution analysis, the weight of disposable crockery items is also a significant parameter for the disposable system in the schools scenario. Due to this fact, the parameter of crockery weight has been further assessed within the scope of a sensitivity analysis (section 4.3.1).

4.2.2.2. Focus on disposable crockery: Contributions from the end-of-life treatment of disposable dishes

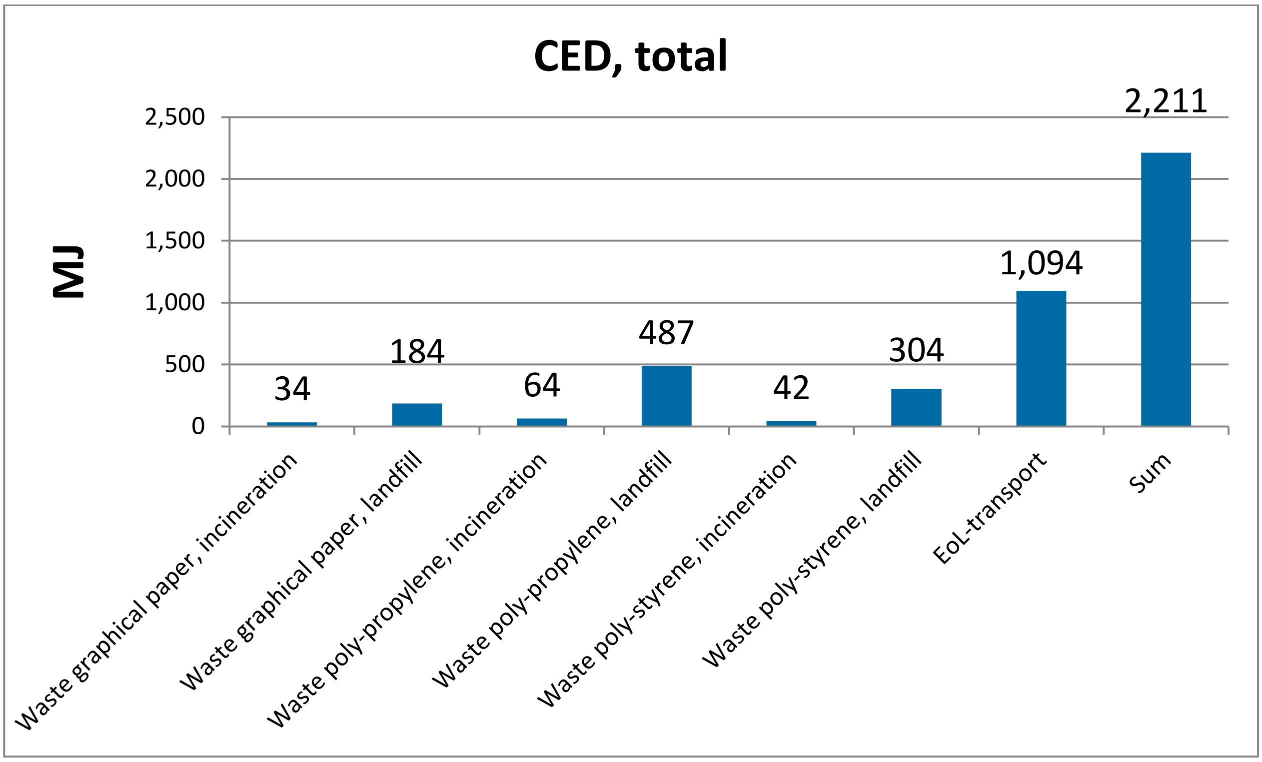
Figure 4-9: Contribution to the GWP of the end-of-life stage in disposable "school" scenario



Source: Own calculation

With regard to the EoL phase, see Figure 4-9, the treatment processes of waste polypropylene and waste polystyrene make up the highest contributions (83% of overall GWP emissions). Especially the treatment of the fossil-based materials in an MSWI, and the respective emissions from the combustion process cause GWP impacts, compared to the minor contribution of the treatment of the same materials in a sanitary landfill. As for all scenarios, the end-of-life transport is of only minor importance, contributing only about 2% to the overall GWP emissions of the EoL treatment.

Figure 4-10: Contribution to the CED, total of the end-of-life stage in disposable "school" scenario



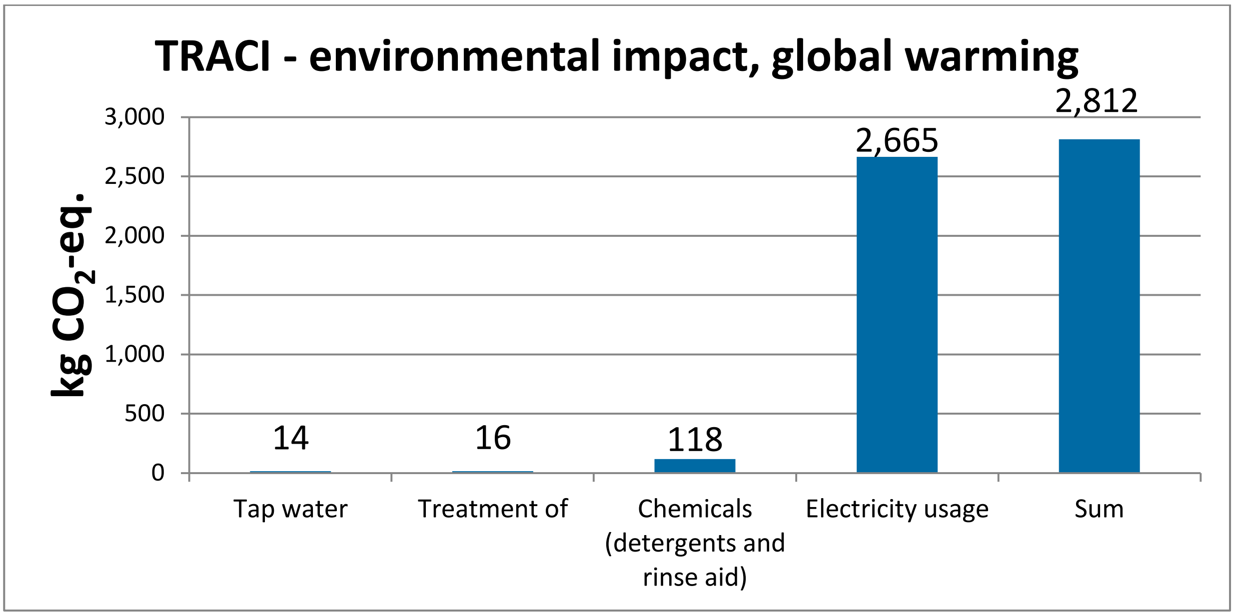
Source: Own calculation

Different from the GWP the CED, total results show higher contributions from the landfilling of the mineral-oil based crockery items (36%) compared to the contributions from the treatment within an MSWI (5%) Figure 4-10. It should also be noted that the contribution from waste graphical paper (incineration and landfill, together 10%) are caused by the EoL treatment of the packaging of the disposable crockery items. Another aspect worth noting is the contribution of nearly 50% from the required EoL transports.

4.2.2.3. Focus on the reusable crockery: Contributions from the dishwashing of reusable dishes

With regard to the impacts from the use phase of reusable dishes in the modelling of the school scenario, only the dishwashing process has been considered. As overall results show, also in this scenario the use phase dominates the overall LCIA results of the reusable system. Figure 4-11 shows the contributions from the dishwashing process.

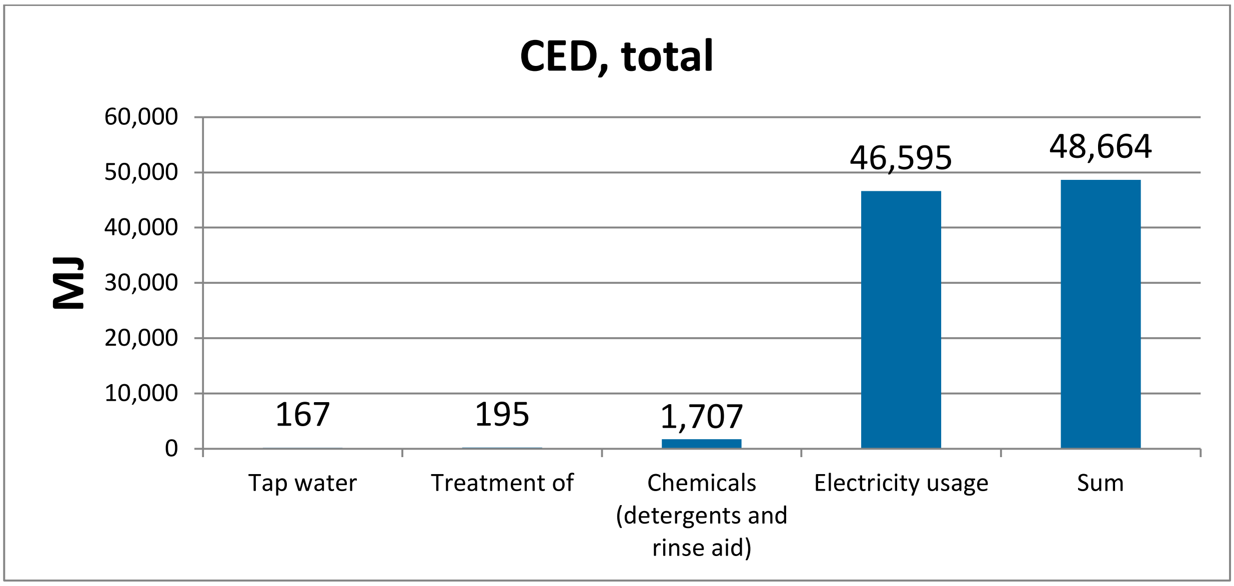
Figure 4-11: Contribution to the GWP of the dishwashing process in reusable "school" scenario



Source: Own calculation

Focusing on the dishwashing process, results show that, also in the school scenario, GWP emissions from the electricity usage for running the dishwasher dominate the outcome. Contributions from the provision of the used electricity amount to 95%. As found for the dishwashing process of the hospital scenario, also in this scenario, the provision of water and the treatment of wastewater are negligible in terms of GWP emissions. With regard to the GWP, the contribution caused by the production of the detergents and rinse aid (4%) can also be considered as being of only minor importance. An overview of the contributions to the dishwashing process for all impact indicators is given in the technical Annex (section 9.2.1) in Table 9-6.

Figure 4-12: Contribution to the CED, total of the dishwashing process in reusable "school" scenario



Source: Own calculation

With regard to the results for the indicator CED, total the results are largely identical to the GWP results. Here also, the electricity usage of the dishwashing machine contributes about 96% of the overall CED, total from the dishwashing process in the school scenario.

Results from the contribution analysis confirm the finding that the choice of a distinct type of dishwashing machine, including machine-specific operation parameters and LCI datasets used for modelling the dishwashing process, are parameters of high significance for the description of the reusable system.

4.2.3. Hotel scenario

Table 4-5 shows the contributions by life cycle stages for both systems in absolute and in system-specific, relative terms. As for the two other scenarios, it is the use phase that dominates the over-all results for the reusable dishes system, while the production and provision of the single-use crockery is the dominant contributor to the results of the disposable dishes system.

Impacts from the use phase of the reusable system contribute by more than 90% to the overall indicator results. Only one impact indicator (TRACI human health carc.) shows a use phase contribution slightly lower than 90% (88%). The EoL treatment, as well as the distribution phase are of only minor importance for the overall results of the reusable system. The contributions from the production of the reusable crockery items contribute by 1-12%.

Regarding the single-use system, the production stage (73%-100%), followed by the EoL treatment (0-23%), contribute considerably to the overall impact indicator results. A remarkable result is the contribution to the impact indicator eutrophication, were the production causes only 39% and the EoL tretament 57% of the overall result (see also Figure 4-15).

The magnitude of the differences between the reusable and single-use systems is less than in the hospital and school scenarios. Still for the majority of impact indicators, the reusable system proved to be superior to the disposable system, the only exception being the two acidification-related indicators (ReCiPe TAP100 and Traci acidification) were results lie more or less within the same range and the water depletion potential, where the water demand for the dishwashing process in the reusable system significantly exceeds the water demand for the production of disposable crockery items. With regard to the acidification potential, the contributions from the electricity usage for running the dishwasher and the contributions from the provision of the single-use crockery items are almost the same.

The context of the GWP results as well as the results for CED, total will be discussed in more detail in the following sections.

Table 4-5: Hotel scenario: absolute and relative contributions by life cycle stages for both systems

	LCIA indicator	System	Production		Distribution		Use phase		EoL treatment		EoL credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
ReCiPe	ALOP	disposable	9.38E+03	100%	4.70E+00	0%	0.00E+00	0%	2.56E+00	0%	-5.18E+00	0%	9.38E+03	100%
		reusable	1.14E+01	4%	9.06E-02	0%	2.52E+02	96%	4.24E-02	0%			2.64E+02	100%
	FDP	disposable	1.94E+03	93%	1.33E+02	6%	0.00E+00	0%	2.49E+01	1%	-2.29E+01	-1%	2.08E+03	100%
		reusable	5.52E+01	5%	2.57E+00	0%	1.10E+03	95%	4.52E-01	0%			1.16E+03	100%
	NLTP	disposable	6.07E-01	88%	1.47E-01	21%	0.00E+00	0%	-5.61E-02	-8%	-5.66E-03	-1%	6.92E-01	100%
		reusable	1.74E-02	5%	2.83E-03	1%	3.42E-01	95%	-1.40E-03	0%			3.61E-01	100%
	TAP100	disposable	2.24E+01	93%	1.66E+00	7%	0.00E+00	0%	5.53E-01	2%	-5.08E-01	-2%	2.42E+01	100%
		reusable	1.50E+00	6%	3.21E-02	0%	2.43E+01	94%	7.25E-03	0%			2.59E+01	100%
	WDP	disposable	2.24E+01	98%	2.85E-01	1%	0.00E+00	0%	4.29E-01	2%	-2.46E-01	-1%	2.28E+01	100%
		reusable	6.49E-01	1%	5.50E-03	0%	6.57E+01	99%	1.64E-03	0%			6.64E+01	100%
TRACI	Acidification	disposable	1.30E+03	92%	1.08E+02	8%	0.00E+00	0%	3.67E+01	3%	-2.84E+01	-2%	1.41E+03	100%
		reusable	8.24E+01	6%	2.09E+00	0%	1.36E+03	94%	4.78E-01	0%			1.45E+03	100%
	Ecotoxicity	disposable	8.62E+03	100%	3.36E+01	0%	0.00E+00	0%	3.97E+01	0%	-6.47E+01	-1%	8.63E+03	100%
		reusable	1.40E+02	4%	6.49E-01	0%	3.50E+03	96%	1.45E-01	0%			3.64E+03	100%
	Eutrophic-cation	disposable	1.85E+00	39%	1.95E-01	4%	0.00E+00	0%	2.68E+00	57%	-9.13E-03	0%	4.72E+00	100%
		reusable	2.50E-02	1%	3.76E-03	0%	1.83E+00	98%	7.58E-04	0%			1.86E+00	100%
	Global warming	disposable	4.86E+03	73%	3.48E+02	5%	0.00E+00	0%	1.54E+03	23%	-8.53E+01	-1%	6.67E+03	100%
		reusable	2.00E+02	5%	6.71E+00	0%	4.08E+03	95%	9.50E-01	0%			4.29E+03	100%
	Ozone depletion	disposable	2.29E-04	75%	6.82E-05	22%	0.00E+00	0%	1.19E-05	4%	-2.76E-06	-1%	3.06E-04	100%
		reusable	7.97E-06	5%	1.32E-06	1%	1.38E-04	94%	2.19E-07	0%			1.47E-04	100%
	Photochem. oxidation	disposable	1.29E+01	83%	2.05E+00	13%	0.00E+00	0%	8.01E-01	5%	-1.62E-01	-1%	1.56E+01	100%
		reusable	3.81E-01	5%	3.96E-02	0%	7.89E+00	95%	9.49E-03	0%			8.32E+00	100%
	Human health, carc.	disposable	8.27E+00	93%	1.88E-01	2%	0.00E+00	0%	5.85E-01	7%	-1.79E-01	-2%	8.87E+00	100%
		reusable	8.56E-01	12%	3.63E-03	0%	6.15E+00	88%	7.80E-04	0%			7.01E+00	100%
	Human health, non-carc.	disposable	4.66E+04	97%	8.69E+02	2%	0.00E+00	0%	1.07E+03	2%	-4.03E+02	-1%	4.82E+04	100%
		reusable	1.52E+03	7%	1.68E+01	0%	2.11E+04	93%	5.00E+00	0%			2.26E+04	100%
	Human health, resp. eff.	disposable	8.77E+00	97%	3.01E-01	3%	0.00E+00	0%	1.19E-01	1%	-1.12E-01	-1%	9.07E+00	100%
		reusable	4.19E-01	7%	5.81E-03	0%	5.46E+00	93%	1.58E-03	0%			5.89E+00	100%

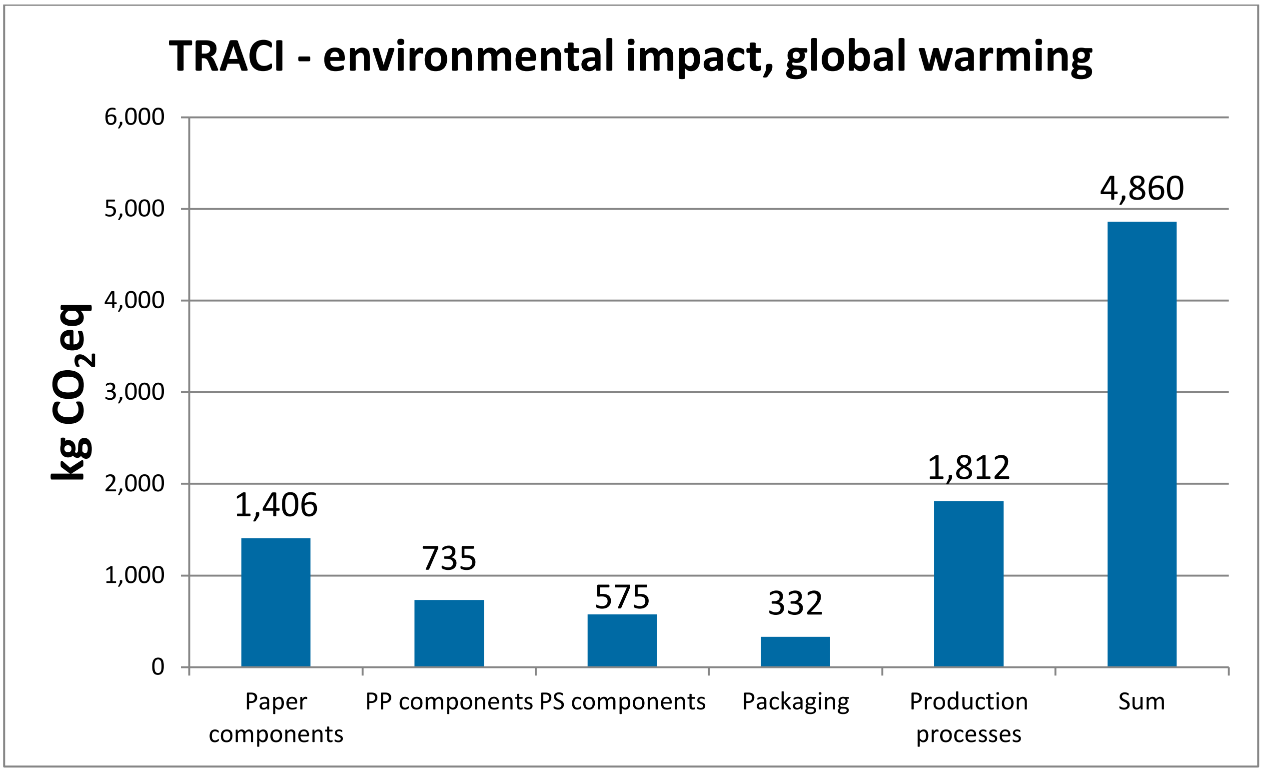
LCIA indicator		System	Production		Distribution		Use phase		EoL treatment		EoL credits		Totals	
			abs.	rel.	abs.	rel.	abs.	rel.	abs.	rel.			abs.	rel.
USEtox	Ecotoxicity, total	disposable	2.67E+03	94%	5.94E+01	2%	0.00E+00	0%	1.36E+02	5%	-1.65E+01	-1%	2.85E+03	100%
		reusable	7.90E+01	8%	1.15E+00	0%	8.86E+02	92%	2.40E-01	0%			9.66E+02	100%
	Human toxicity, total	disposable	1.65E-03	98%	1.24E-05	1%	0.00E+00	0%	2.78E-05	2%	-3.38E-06	0%	1.69E-03	100%
		reusable	2.35E-05	9%	2.38E-07	0%	2.44E-04	91%	5.13E-08	0%			2.68E-04	100%
CED total		disposable	1.60E+05	96%	6.03E+03	4%	0.00E+00	0%	1.32E+03	1%	-1.48E+03	-1%	1.66E+05	100%
		reusable	3.35E+03	5%	1.16E+02	0%	7.06E+04	95%	2.08E+01	0%			7.40E+04	100%

Source: Own calculation

4.2.3.1. Focus on disposable crockery: Contributions from the production stage

The absolute CO_2-eq. emissions from the production stage of the disposable system in the hotel scenario sum up to 4.860 kg CO_2-eq., thus accounting for 73% of the overall GWP in this scenario. With regard to the disposable crockery, the main contributions arise from the production process of the several crockery items, summing up to 37% of the overall GWP emissions from the production phase Figure 4-13.

Figure 4-13: Disposable crockery production for hotel scenario; contributions to the GWP by materials and processes

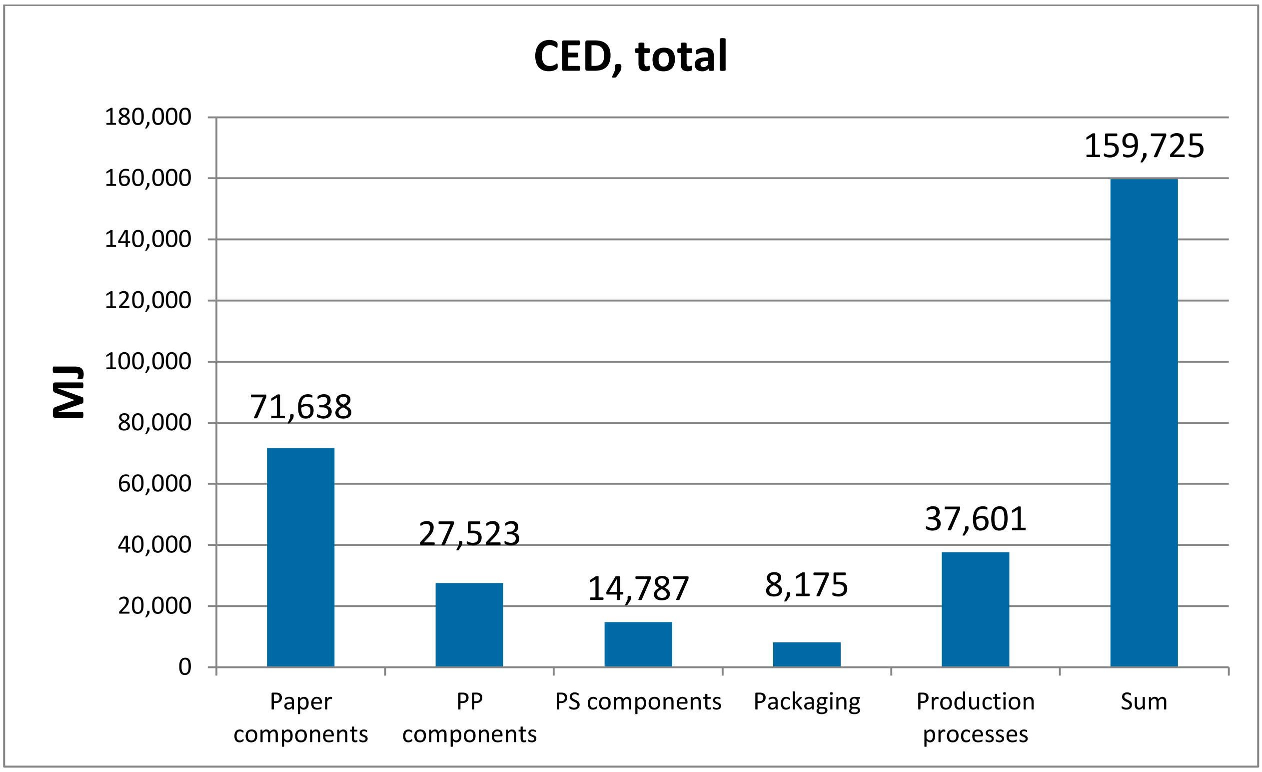


Source: Own calculation

The largest proportion arises from the provision of the required paper (29%), used as raw material for the production of plates and cereal bowl cup. In this context, too, it must be borne in mind that the material flow of the paper-based crockery items, sums up to 1,230 kg (2711 lb) of paper and represents 70% of the overall material flow (1752 kg; 3861.4 lb). Taking together the provision of the crockery items made of polypropylene and polystyrene (cutlery, drink and coffee cup), the provision of raw materials for the production of crockery items sums up to kg 1310 kg CO_2-eq. The remaining 7% arise from the provision of packaging materials required for the distribution of the crockery items.

The results for the indicator CED, total (Figure 4-14) show the highest contributions from the production of paper-based crockery items (45%). While the contributions from the PP- and PS- based components contribute 17% and respectively 9% the relative contributions from the required production processes (24%) are lower than for the GWP, where production processes summed up to 37%.

Figure 4-14: Disposable crockery production for hotel scenario; contributions to the CED, total by materials and processes



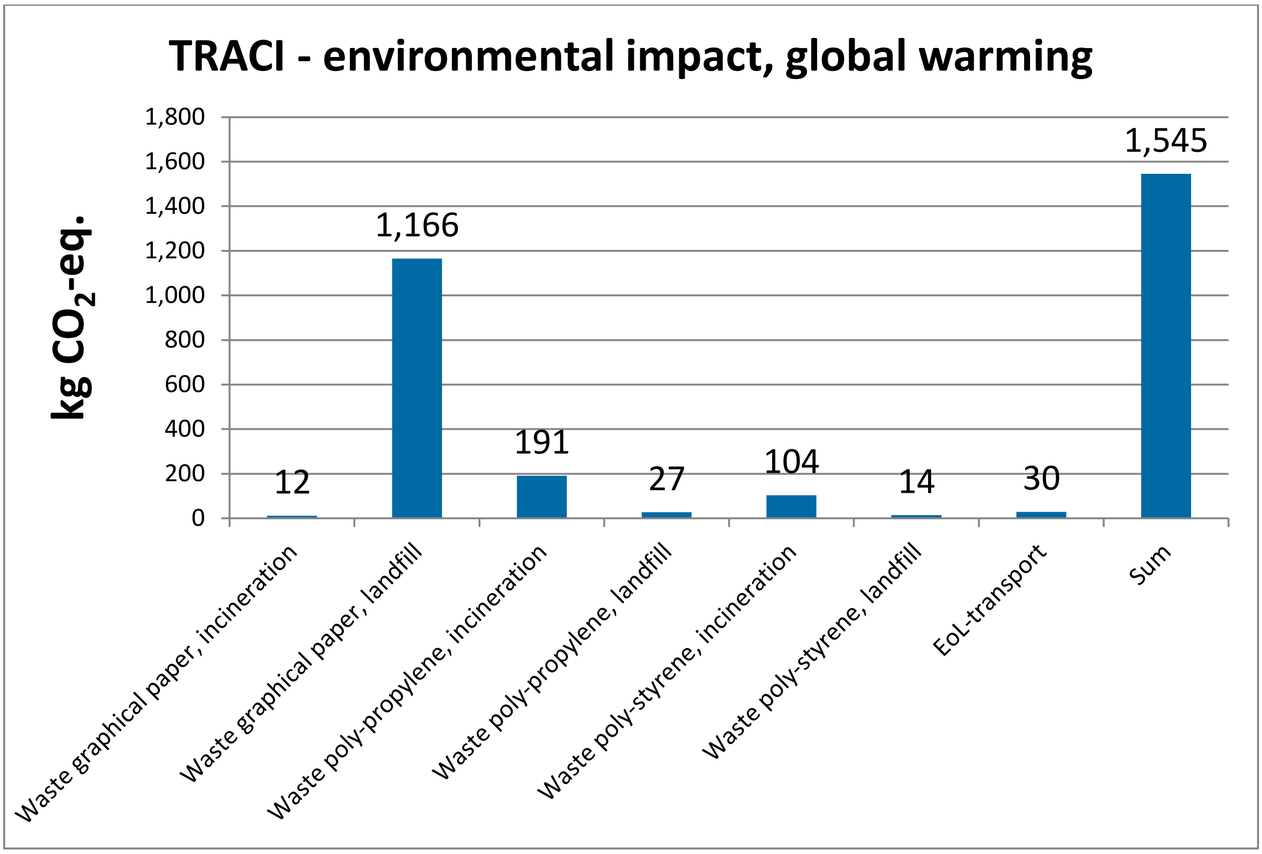
Source: Own calculation

In this case, too, it has been confirmed that the weight of the disposable crockery is a key driving and highly significant parameter for the disposable system.

4.2.3.2. Focus on disposable crockery: Contributions from the end-of-life treatment of disposable dishes

The absolute CO_2-eq. emissions from the EoL treatment stage of the disposable system in the hotel scenario sums up to 1545 kg CO_2-eq., accounting for 23% of the overall GWP (Figure 4-15).

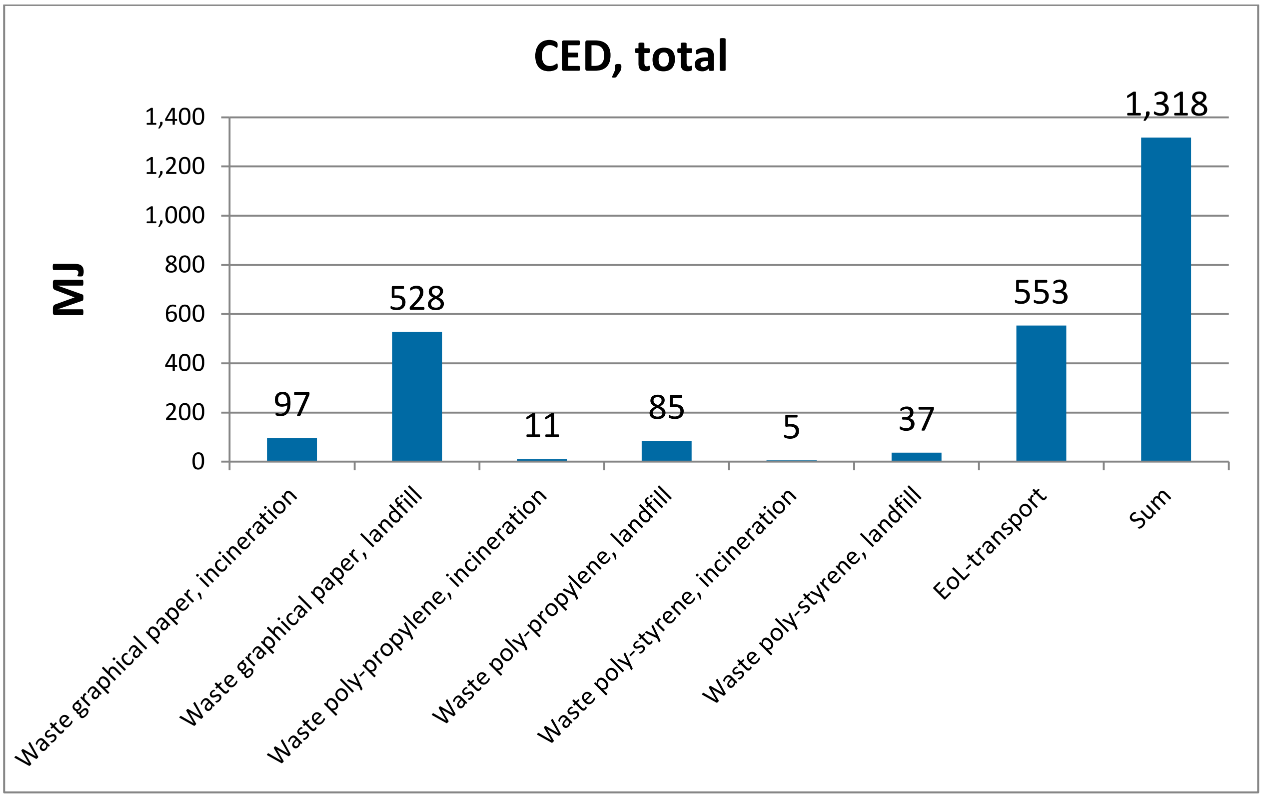
Figure 4-15: Contribution to the GWP from the end of life stage in disposable “hotel” scenario



Source: Own calculation

With regard to the emissions arising from the EoL treatment processes given in Figure 4-15, the treatment of waste paper, modelled as treatment of waste graphical paper shows the highest contributions 76% (75% alone coming from landfill), followed by the treatment of polypropylene, accounting for 14% (12% alone coming from incineration) and the treatment of polystyrene (8%, 7% alone coming from incineration). Results for the hotel scenario are therefore comparable to the ones of the hospital scenario, were the paper-based products also contributed most to the overall result. The fact that paper-based product-specific contributions mainly arise through the treatment in a sanitary landfill, while the treatment of mineral oil-based products in a MSWI shows specifically higher impacts, is also in line with the arithmetic of the hospital scenario. The EoL transport by refuse truck contributes only 2% to the GWP emissions of the EoL treatment stage in the hotel scenario.

Figure 4-16: Contribution to the CED, total from the end of life stage in disposable "hotel" scenario



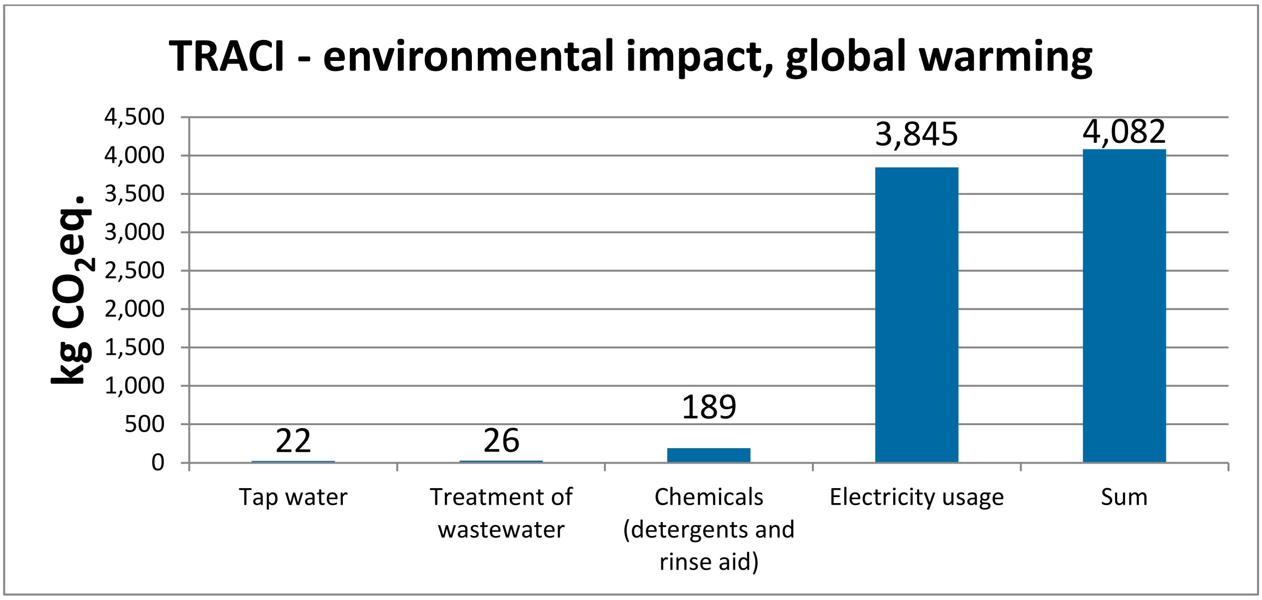
Source: Own calculation

As already found for the other two scenarios (see Figure 4-4 and Figure 4-10), the high contributions from the required EoL transports summing up to 42% of the overall EoL CED, total results, should also be noted for the hotel scenario.

4.2.3.3. Focus on the reusable crockery: Contributions from the dishwashing of reusable dishes

With regard to the impacts from the use phase in the hotel scenario, as for the school scenario, there are only impacts from the dishwashing process that have to be considered. As applying for all three reusable scenarios, the production, the distribution and the EoL treatment are of only secondary importance. Figure 4-17 shows the contributions from the dishwashing process in the hotel scenario with reusable dishes. The GWP emissions arising from the dishwashing process sum up to 4,082 kg CO_2-eq. (95% of the overall GWP) in the hotel scenario.

Figure 4-17: Contribution to the GWP from the dishwashing process in reusable "hotel" scenario

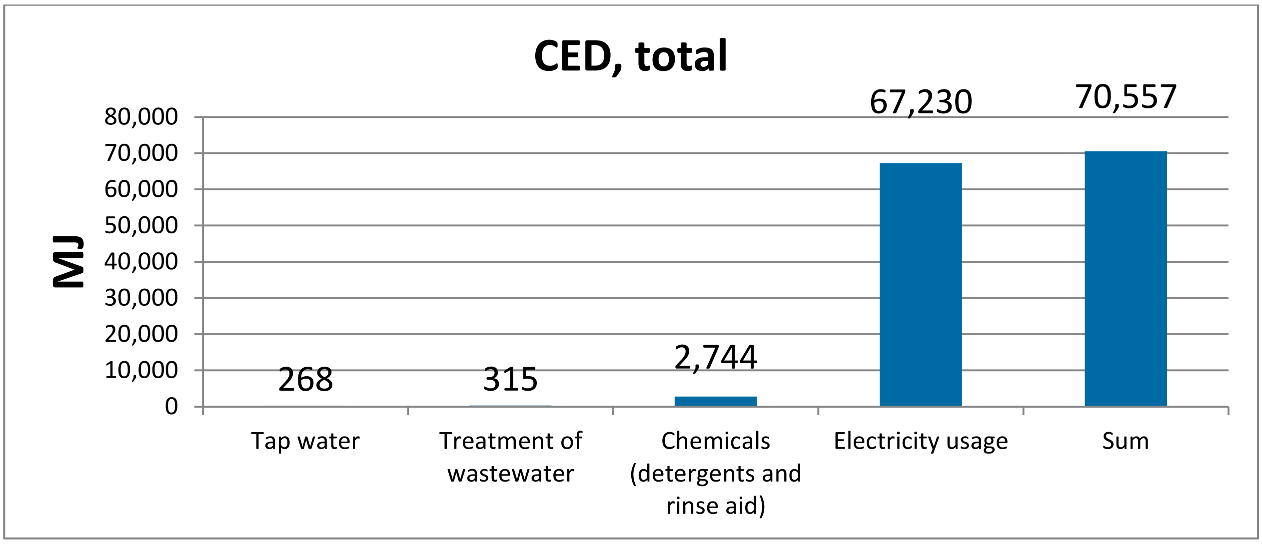


Source: Own calculation

Regarding the GWP, the relative contribution to the overall result of the dishwashing process are more or less the same as for the other two scenarios. As it had been proved for those scenarios, the contributions from the demanded electricity dominate the results, accounting for 94%. Chemicals contribute further 5%, while the demand for water and the treatment of wastewater are of only minor importance (1%).

A situation quite similar shows Figure 4-18 with regard to the respective results for the indicator CED, total. Once more the electricity consumption of the dishwashing machine dominates the contributions by 95%, while chemicals contribute only 4%.

Figure 4-18: Contribution to the CED, total from the dishwashing process in reusable "hotel" scenario



Source: Own calculation

Once more, the parameters found as highly significant for describing the reusable system concern the choice of dishwashing machine, operation parameters and LCI datasets used for modelling the dishwashing process.

4.3. Sensitivity analysis

In the framework of contribution analyses, key driving factors for both systems have been identified and selected fur further evaluation within the scope of sensitivity analyses. With respect to parameters which significantly influence the results of the analyzed systems, the sensitivity analyses described in the following have been carried out:

Table 4-6: Overview on performed sensitivity analyses

System	Variation in relation to base case	Section
Disposable system	Higher weight of crockery	4.3.1
Disposable system	Shorter and longer transport distances	4.3.2
Disposable system	Cooling of the waste disposable crockery	4.3.3
Reusable system	Higher energy demand representing dishwashing machines in stock instead of BAT machines for the dishwashing process	4.3.4
Reusable system	Electricity datasets with alternative geographical coverage (and subsequently different emission profiles)	4.3.5
Reusable system	Higher and lower life time of reusable crockery	4.3.6
Disposable system	Variants in the disposable place setting of the hotel scenario	4.3.7
Disposable system	Variant (use of a reusable tray instead of a disposable cardboard tray) in the disposable crockery hospital scenario	4.3.8
Disposable system	100:0 Allocation rule for end-of-life credits from thermal recycling of disposable crockery	4.3.9

Source: own compilation

4.3.1. Higher weight of disposable crockery

The weight of disposable crockery has been retrieved from original items that have been picked up at the respective hospitals. Even on the assumption that these are typical products available on the US market, it is certainly possible that there may be other products with a higher weight. The examined single-use crockery items appeared to be largely optimized in terms of a reduced material demand. The respective items are already of very low weight, so a further mass reduction does not seem feasible and a further reduction of weight would seriously affect the functional properties. As the overall results of the disposable crockery system are strongly influenced by this parameter, a sensitivity analysis has been calculated:

- Sensitivity 1_hospital: 125% of disposable crockery weight in hospital scenario
- Sensitivity 1_school: 125% of disposable crockery weight in school scenario
- Sensitivity 1_hotel: 125% of disposable crockery weight in hotel scenario

The results of the calculation are shown in Table 4-7 - Table 4-9. As all processes in all life cycle stages of the disposable system have been modelled in relation to mass as for the required disposable crockery, the results for all sensitivities are in line with the arithmetic of the base case.

Table 4-7: Sensitivity 1: Higher weight of disposable crockery in the hospital scenario

LCIA indicator		Unit	S1_hospital / Base case[36]_ diposable	BC_disposable / BC_dis-posable	BC_reusable / BC_disposable
ReCiPe	ALOP	m²a	125%	100%	1%
	FDP	kg Oil-eq.	125%	100%	31%
	NLTP	m^2	125%	100%	25%
	TAP100	kg SO_2-eq.	125%	100%	54%
	WDP	m³	125%	100%	29%
TRACI	Acidification	moles-H^+-eq.	126%	100%	52%
	Ecotoxicity	kg 2,4-D-eq.	125%	100%	21%
	Eutrophication	kg N	125%	100%	13%
	Global warming	kg CO_2-eq.	125%	100%	33%
	Ozone depletion	kg CFC-11-eq.	125%	100%	24%
	Photochemical oxidation	kg NOx-eq.	125%	100%	26%
	Human health, carc.	kg benzene-eq.	124%	100%	40%
	Human health, non-carc.	kg toluene-eq.	125%	100%	22%
	Human health, resp. eff.	kg PM2.5-eq.	125%	100%	34%
USEtox	Ecotoxicity, total	CTU	125%	100%	12%
	Human toxicity, total	CTU	127%	100%	7%
CED total		MJ	125%	100%	25%

Source: Own calculation

In the base case hospital, the LCIA results for all impact indicators (compare the last two columns of the above Table 4-7) present a clear benefit for the reusable system. If as in the S1_hospital case (Table 4-7) a higher weight of disposable crockery items is assumed, the base case results will be confirmed and there will be even greater benefits attributable to the reusable system.

[36] The term "Base case" in Table 4-5 and the following tables stands for the standard scenario assessed within this study. The base case scenarios must be distinguished from the scenarios assessed within the respective sensitivity analysis. So the sensitivity analysis, in this case S1_hospital (regarding a variation of disposable crockery weight) are to be seen as variation of parameters of the respective base case scenarios. With regard to the percentages given in the tables that show results of the sensitivity analyses, the respective base case is set to 100%. Deviations relative from 100% in the sensitivity columns are due to the varied parameters. In order to also allow for a cross-system comparison, also the base case of the other system (e.g. in Table 4-5, this means that also the base case reusable impact indicator results are given relative to the base case disposable) is presented.

Table 4-8: Sensitivity 1: Higher weight of disposable crockery in the school scenario

LCIA indicator		Unit	S1_school / BC_disposable	BC_disposable / BC_dis-posable	BC_reusable/ BC_disposable
ReCiPe	ALOP	m²a	125%	100%	12%
	FDP	kg Oil-eq.	125%	100%	11%
	NLTP	m^2	126%	100%	30%
	TAP100	kg SO_2-eq.	125%	100%	35%
	WDP	m³	125%	100%	122%
TRACI	Acidification	moles-H^+-eq.	125%	100%	34%
	Ecotoxicity	kg 2,4-D-eq.	125%	100%	77%
	Eutrophication	kg N	125%	100%	26%
	Global warming	kg CO_2-eq.	125%	100%	19%
	Ozone depletion	kg CFC-11-eq.	125%	100%	23%
	Photochemical oxidation	kg NOx-eq.	125%	100%	17%
	Human health, carc.	kg benzene-eq.	125%	100%	52%
	Human health, non-carc.	kg toluene-eq.	125%	100%	38%
	Human health, resp. eff.	kg PM2.5-eq.	125%	100%	26%
USEtox	Ecotoxicity, total	CTU	125%	100%	24%
	Human toxicity, total	CTU	125%	100%	27%
CED total		MJ	125%	100%	14%

Source: Own calculation

In the base case school, the LCIA results for all impact indicators, with the only exemption being the WDP, show a clear advantage for the reusable system. If as here in Table 4-8 a higher weight of disposable crockery items is assumed (designated the “S1_school” case), the advantage for the reusable system shown in the base case results will be confirmed and magnified. Regarding the WDP, there is now even a slight disadvantage of the disposable system regarding the WDP, but the differences between S1_school and base case reusable can be regarded as lying within calculation inaccuracy.

Table 4-9: Sensitivity 1: Higher weight of disposable crockery in hotel scenario

LCIA indicator		Unit	S1_hotel/ BC_disposable	BC_dis-posable/ BC_disposable	BC_reusable/ BC_disposable
ReCiPe	ALOP	m²a	125%	100%	3%
	FDP	kg Oil-eq.	125%	100%	56%
	NLTP	m^2	125%	100%	52%
	TAP100	kg SO_2-eq.	125%	100%	107%
	WDP	m³	125%	100%	291%

LCIA indicator		Unit	S1_hotel/ BC_disposable	BC_dis-posable/ BC_disposable	BC_reusable/ BC_disposable
TRACI	Acidification	moles-H^+-eq.	126%	100%	103%
	Ecotoxicity	kg 2,4-D-eq.	125%	100%	42%
	Eutrophication	kg N	125%	100%	39%
	Global warming	kg CO_2-eq.	125%	100%	64%
	Ozone depletion	kg CFC-11-eq.	125%	100%	48%
	Photochemical oxidation	kg NOx-eq.	124%	100%	53%
	Human health, carc.	kg benzene-eq.	125%	100%	79%
	Human health, non-carc.	kg toluene-eq.	125%	100%	47%
	Human health, resp. Eff.	kg PM2.5-eq.	125%	100%	65%
USEtox	Ecotoxicity, total	CTU	125%	100%	34%
	Human toxicity, total	CTU	125%	100%	16%
CED total		MJ	125%	100%	45%

Source: Own calculation

Regarding S1_hotel, for the majority of the impact indicators, the reusable system shows an advantage as compared to the disposable system. Only the indicator WDP still possesses an advantage as regards the disposable system, if a higher weight of disposable crockery is assumed. With regard to acidification, both impact indicators (ReCiPe TAP, and TRACI, acidification) show higher results for S1_hotel compared to base case results of the reusable system. While differences for the results in ReCiPe TAP cannot be seen as significant (difference only 18% and therefore below the 20% criterion as defined in section 4.1), results for the indicator TRACI, acidification show significant advantages for the reusable system (difference 23%).

Regarding the WDP, where the water demand for the dishwashing process in the reusable system significantly exceeds the water demand for the production of disposable crockery items, the advantage of the disposable system is slightly lower, but still significant. With regard to acidification, the earlier advantage of the disposable systems has become an advantage for the reusable system for both of the two acidification indicators.

4.3.2. Shorter and longer transport distances for distribution of disposable crockery

Transport distances have been assumed to be typical distances for the US market. To determine the importance of this parameter as well as the effects of its variance, two scenarios with varying transport distances have been calculated. As this parameter affects, more or less exclusively the disposable system, we present results only for a variance in the disposable system transport distances.

- Sensitivity 2_A1: 1,000 km (621 miles; resp. 66.7% of base case) transport distance in hospital scenario
- Sensitivity 2_A2: 2,000 km (1242 miles; resp. 133.3% of base case) transport distance in hospital scenario
- Sensitivity 2_B1: 1,000 km (621 miles; resp. 66.7% of base case) transport distance in school scenario

- Sensitivity 2_B2: 2,000 km (1242 miles; resp. 133.3% of base case) transport distance in school scenario
- Sensitivity 2_C1: 1,000 km (621 miles; resp. 66.7% of base case) transport distance in hotel scenario
- Sensitivity 2_C2: 2,000 km (1242 miles; resp. 133.3% of base case) transport distance in hotel scenario

The results of the calculation are shown in Table 4-10. While the remaining impact indicator results only showed minor changes, the result for the indicator NLTP are 7% lower, $TRACI_{ozone\ depletion}$ respectively 5% lower, in comparison to the result for the base case when assuming a transport distance of only 1000km (621 miles). On the other hand, the indicator results slightly increase when a prolonged transport distance of 2,000 km (1242 miles) is assumed for the distribution of the disposable crockery items. Regarding the indicator $TRACI_{ozone\ depletion}$, the reason for this result is the bromotrifluoromethane emission occurring as process-specific emission from the processing of petroleum out of crude oil. The transport-related impact indicator result for NLTP arises from two forest transformation processes (transformation, from forest, intensive [natural resource/land] and transformation, from forest, unspecified [natural resource/land]).

Table 4-10: Sensitivity 2: Shorter and longer transport distances for distribution of disposable crockery in hospital scenario

	LCIA indicator	Unit	S2_A1 / BC_disposable	S2_A2 / BC_disposable	BC_disposable/ BC_disposable	BC_reusable/ BC_disposable
ReCiPe	ALOP	m²a	100%	100%	100%	1%
ReCiPe	FDP	kg Oil-eq.	97%	102%	100%	31%
ReCiPe	NLTP	m^2	93%	108%	100%	25%
ReCiPe	TAP100	kg SO_2-eq.	98%	103%	100%	54%
ReCiPe	WDP	m³	100%	100%	100%	29%
TRACI	Acidification	moles-H+-eq.	98%	103%	100%	52%
TRACI	Ecotoxicity	kg 2,4-D-eq.	100%	100%	100%	21%
TRACI	Eutrophication	kg N	99%	101%	100%	13%
TRACI	Global warming	kg CO_2-eq.	98%	102%	100%	33%
TRACI	Ozone depletion	kg CFC-11-eq.	93%	107%	100%	24%
TRACI	Photochemical oxidation	kg NOx-eq.	95%	105%	100%	26%
TRACI	Human health, carc.	kg benzene-eq.	99%	101%	100%	40%
TRACI	Human health, non-carc.	kg toluene-eq.	100%	101%	100%	22%
TRACI	Human health, resp. eff.	kg PM2.5-eq.	99%	101%	100%	34%
USEtox	Ecotoxicity, total	CTU	99%	101%	100%	12%
USEtox	Human toxicity, total	CTU	100%	100%	100%	7%
CED total		MJ	99%	101%	100%	25%

Source: Own calculation

In general, it can be found that variances in the transport distances for distribution of disposable crockery are of only secondary relevance to the result of the system comparison. For the sake of completeness and transparency, the results of the respective sensitivity analyses carried out for the scenarios school and hotel are given in the data annex Table 9-10 and Table 9-11.

4.3.3. Regarding a cooling demand for waste disposable dishes

As the investigation could not clarify with certainty that there is the need for cooling waste disposal dishes in order to avoid odor nuisance and microbial growth, and due to the fact that possible relevance could not have been ruled out from the outset, it has been decided to assess the efforts related to the energy demand for cooling the waste disposal dishes within the framework of a sensitivity analyses in order to get a feel for the relevance of the question whether cooling is required or not. The sensitivity analysis takes only into account the energy usage of a garbage cooler while the materials needed to construct the cooler (e.g. a refrigerant like R-134a) have not been taken into account.

As a basis for the estimated preliminary figure, a garbage cooler for two standard garbage cans, each with a volume of 240 liters (63.36 gallons), has been chosen[37].

For the rough calculation, an electricity demand of 10% of the connected value over time and 365 operating days per year have been assumed. As around 50 kg (110 lb) of waste is generated in the hospital cafeteria every day, and assuming a waste density of 35 kg/m³, this corresponds to a waste volume of about 1.43 m³. Therefore it can be stated that a garbage cooler volume of 1,440 l is sufficient to take up the daily amount of waste disposable crockery. This corresponds to an overall energy demand of 946 kWh per year for the garbage coolers.

The following sensitivity analysis has been carried out:

- Sensitivity 3_hospital: disposable base case in the hospital scenario plus cooling demand

Table 4-11: Sensitivity 3: Regarding a cooling demand for waste disposable dishes in the hospital scenario

LCIA indicator		Unit	S3_hospital/ BC_disposable	BC_disposable/ BC_disposable	BC_reusable/ BC_disposable
ReCiPe	ALOP	m²a	100%	100%	1%
	FDP	kg Oil-eq.	101%	100%	31%
	NLTP	m^2	101%	100%	25%
	TAP100	kg SO_2-eq.	102%	100%	54%
	WDP	m³	100%	100%	29%
TRACI	Acidification	moles-H+-eq.	102%	100%	52%
	Ecotoxicity	kg 2,4-D-eq.	101%	100%	21%
	Eutrophication	kg N	100%	100%	13%
	Global warming	kg CO_2-eq.	101%	100%	33%
	Ozone depletion	kg CFC-11-eq.	101%	100%	24%

[37] Model Nordcap Garbage Cooler KK 480; connected value 360 watts: (http://www.gastromegastore.de/nordcap-kuehlmoebel/abfallkuehler/

	LCIA indicator	Unit	S3_hospital/ BC_disposable	BC_disposable/ BC_disposable	BC_reusable/ BC_disposable
	Photochemical oxidation	kg NOx-eq.	101%	100%	26%
	Human health, carc.	kg benzene-eq.	102%	100%	40%
	Human health, non-carc.	kg toluene-eq.	101%	100%	22%
	Human health, resp. eff.	kg PM2.5-eq.	101%	100%	34%
USEtox	Ecotoxicity, total	CTU	101%	100%	12%
USEtox	Human toxicity, total	CTU	100%	100%	7%
CED total		MJ	101%	100%	25%

Source: Own calculation

As it is shown in Table 4-11, the assumption of an additional cooling demand for the waste disposable crockery does not lead to distinct changes in the overall indicator results. In view of the fact that the cooling demand for the waste is of only minor importance, also the assumptions underlying the calculation of the energy demand for the garbage cooler can be seen as not affecting the comparison of the systems significantly. Even an energy demand of more than 10% of the connected value over time, for example, will also not lead to remarkable changes in results.

4.3.4. Dishwashing machines in stock instead of BAT machines for the dishwashing process

As discussed in section 4.3, the energy demand in the use phase of the reusable crockery (dishwashing) significantly affects the overall results of the reusable crockery system. For the base case scenario, this parameter has been reported by MEIKO by calculating the energy demand per place setting by using a porcelain equivalent (e.g. for the drinking glass) and, according to the goal of the study, by using a dishwashing machine representing best available technology (BAT).

In order to also account for dishwashing machines that can be seen as representative machines for typical stock in the US, a washing cycle with a higher energy demand has been calculated. As it has to be assumed that machines in stock show a wide variety and since no specific data on the energy consumption of a machine representing typical stock in the US has been available during the implementation period of this study an increased energy demand of 110% of the base case energy demand has been assumed for the dishwashing process (Table 4-12).

- Sensitivity 4_hospital: 110% of base case energy demand for the hospital scenario
- Sensitivity 4_school: 110% of base case energy demand for the school scenario
- Sensitivity 4_hotel: 110% of base case energy demand for the hotel scenario

Table 4-12: Sensitivity 4: Regarding a higher energy demand for washing of reusable dishes in the hospital scenario

	LCIA indicator	Unit	S4_hospital / BC_reusable	BC_reusable / BC_reusable	BC_disposable/ BC_reusable
ReCiPe	ALOP	m²a	109%	100%	6712%
ReCiPe	FDP	kg Oil-eq.	109%	100%	318%
ReCiPe	NLTP	m^2	107%	100%	398%

	LCIA indicator	Unit	S4_hospital / BC_reusable	BC_reusable / BC_reusable	BC_disposable/ BC_reusable
	TAP100	kg SO_2-eq.	109%	100%	186%
	WDP	m³	102%	100%	343%
TRACI	Acidification	moles-H+-eq.	109%	100%	193%
	Ecotoxicity	kg 2,4-D-eq.	108%	100%	470%
	Eutrophication	kg N	103%	100%	792%
	Global warming	kg CO_2-eq.	109%	100%	300%
	Ozone depletion	kg CFC-11-eq.	108%	100%	423%
	Photochemical oxidation	kg NOx-eq.	109%	100%	381%
	Human health, carc.	kg benzene-eq.	107%	100%	251%
	Human health, non-carc.	kg toluene-eq.	107%	100%	458%
	Human health, resp. eff.	kg PM2.5-eq.	108%	100%	294%
USEtox	Ecotoxicity, total	CTU	106%	100%	829%
	Human toxicity, total	CTU	105%	100%	1436%
CED total		MJ	109%	100%	407%

Source: Own calculation

As the investigation of the Sensitivity 4_school shows the same trends as given above for the hospital scenario, it has been decided not to display another table with school results. The fundamental statements of the discussion of the base case results (4.2.2) do not change when assuming a scenario with only a 10% higher energy demand, representing dishwashing machines in stock instead of BAT machines, for the dishwashing process.

The base case comparison of the systems only showed minor differences for the hotel. Accordingly, the results for the Sensitivity 4_hotel have to be discussed in more detail Table 4-13.

Table 4-13: Sensitivity 4: Regarding a higher energy demand for washing of reusable dishes in the hotel scenario

	LCIA indicator	Unit	S4_hotel / BC_reusable	BC_reusable / BC_reusable	BC_disposable / BC_reusable
ReCiPe	ALOP	m²a	109%	100%	3557%
	FDP	kg Oil-eq.	109%	100%	180%
	NLTP	m^2	108%	100%	192%
	TAP100	kg SO_2-eq.	108%	100%	93%
	WDP	m³	102%	100%	34%
TRACI	Acidification	moles-H+-eq.	108%	100%	98%
	Ecotoxicity	kg 2,4-D-eq.	108%	100%	237%
	Eutrophication	kg N	102%	100%	253%
	Global warming	kg CO_2-eq.	109%	100%	155%
	Ozone depletion	kg CFC-11-eq.	108%	100%	208%
	Photochemical oxidation	kg NOx-eq.	109%	100%	187%

	LCIA indicator	Unit	S4_hotel / BC_reusable	BC_reusable / BC_reusable	BC_disposable / BC_reusable
	Human health, carc.	kg benzene-eq.	107%	100%	127%
	Human health, non-carc.	kg toluene-eq.	107%	100%	213%
	Human health, resp. eff.	kg PM2.5-eq.	108%	100%	154%
USEtox	Ecotoxicity, total	CTU	106%	100%	295%
USEtox	Human toxicity, total	CTU	104%	100%	630%
CED total		MJ	109%	100%	224%

Source: Own calculation

If stock machines instead of machines representing best available technology slightly are assumed, the reusable system will be less advantageous, as shown in the base case for the majority of impact indicators. In general, the reusable system, even when assuming a 10% higher electricity demand for running the dishwasher, for the majority of the impact indicators presents lower values than the disposable system. The only exception is the WDP (higher impacts of the reusable system) and the two acidification-related impact indicators (ReCiPe TAP and TRACI acidification), where, as in the base case comparison, indicator results show more or less the same impacts for the disposable and the reusable system.

All in all, it can therefore be stated that, assuming a stock machine with higher energy demand, the outcome will not be affected significantly in any of the assessed indicators. With even a 10% increase in electricity demand, the reusable system is seen to remain the clear winner over the single-use system. Further it can be seen that for just a 10% increase in energy consumption alone, the average of all indicators increases by 7.29% for the Hospital and 7.12% for the Hotel cases respectively.

During finalization of the final report of this study, the consumer advocacy group Fisher-Nickel, located in San Francisco, USA has published measurements analyzing the energy and water usage between machines using BAT and standard technology (Delagah 2015). As the results are important for this study, an excerpt out of the recently published data has been added (Table 4-14).

Table 4-14: Measured water and energy use per hour of rinse operation for flight-conveyor dishwashers

	Measured Water Use Per Hour of Rinse Operation (g/h)	Measured Energy Use Per Hour of Rinse Operation (Btu/h)
highest usage	1,770	2,748,224
lowest usage	232	595,852
range	663%	361%

Source: adapted from Fischer-Nickel (2016); (Table ES-2)

Here it can be seen that energy usage ranges by an astounding 361% and water usage by a phenomenal 663%. This highlights the importance of choosing the best available technology when ordering dishwashing machines.

4.3.5. Change in the emission profile of the used electricity within the use phase of reusable crockery

The goal of this scenario analysis was to find out whether it is of relevance for the overall results, and the comparison of reusable crockery to disposables on system level, which regional grid of the US is assumed to provide the electricity for the energy of the dishwashers. Besides the SERC Reliability Corporation dataset that has been applied for calculation of the base case, results of the reusable system have been compared to alternative US-specific datasets available in the ecoinvent LCA database.

Table 4-15: Sensitivity analyses on the emission profile of the used electricity within the use phase of reusable crockery

Sensitivity	
Sensitivity 5_A	Midwest Reliability Organization (MRO, US only)
Sensitivity 5_B	Florida Reliability Coordinating Council (FRCC)
Sensitivity 5_C	Hawaiian Islands Coordinating Council (HICC)
Sensitivity 5_D	Southwest Power Pool (SPP)
Sensitivity 5_E	Alaska Systems Coordinating Council (ASCC)
Sensitivity 5_F	Texas Regional Entity (TRE)
Base case_reusable	SERC Reliability Corporation (SERC)
Sensitivity 5_H	ReliabilityFirst Corporation (RFC)
Sensitivity 5_I	Western Electricity Coordinating Council, US part only (WECC, US only)
Sensitivity 5_J	Northeast Power Coordinating Council (NPCC), US ONLY

Source: Own compilation

Table 4-16: Sensitivity 5: Change in the emission profile of the used electricity within the use phase of reusable crockery in hospital scenario

LCIA indicator		Unit	S5_A	S5_B	S5_C	S5_D	S5_E	S5_F	BC_reus	S5_H	S5_I	S5_J	BC_disp
ReCiPe	ALOP	m²a	94%	94%	134%	59%	15%	21%	100%	58%	78%	167%	6712%
	FDP	kg Oil-eq.	154%	144%	149%	142%	142%	129%	100%	91%	103%	72%	318%
	NLTP	m^2	125%	200%	481%	134%	252%	147%	100%	85%	117%	155%	398%
	TAP100	kg SO_2-eq.	110%	100%	151%	107%	104%	74%	100%	127%	58%	56%	186%
	WDP	m³	106%	87%	89%	99%	80%	90%	100%	103%	88%	96%	343%
TRACI	Acidification	moles-H+-eq.	117%	100%	152%	111%	105%	74%	100%	126%	60%	55%	193%
	Ecotoxicity	kg 2,4-D-eq.	179%	51%	46%	132%	38%	83%	100%	102%	76%	40%	470%
	Eutrophication	kg N	127%	111%	235%	117%	139%	94%	100%	103%	97%	86%	792%
	Global warming	kg CO_2-eq.	146%	116%	129%	145%	107%	106%	100%	105%	87%	59%	300%
	Ozone depletion	kg CFC-11-eq.	56%	360%	528%	135%	404%	222%	100%	65%	162%	171%	423%
	Photochemical oxidation	kg NOx-eq.	187%	115%	213%	155%	155%	72%	100%	114%	89%	50%	381%
	Human health, carc.	kg benzene-eq.	114%	107%	96%	109%	90%	96%	100%	103%	83%	87%	251%
	Human health, non-carc.	kg toluene-eq.	103%	109%	121%	93%	94%	96%	100%	98%	82%	96%	458%
	Human health, resp. eff.	kg PM2.5-eq.	101%	99%	150%	101%	100%	76%	100%	127%	56%	59%	294%
USEtox	Ecotoxicity, total	CTU	77%	265%	394%	124%	294%	176%	100%	77%	139%	146%	829%
	Human toxicity, total	CTU	123%	104%	114%	113%	100%	105%	100%	113%	90%	85%	1436%
CED total		MJ	125%	120%	113%	108%	108%	106%	100%	93%	98%	92%	410%

Source: Own calculation

Table 4-16 shows that the provision of electricity is the dominant and most significant parameter for the overall result in the reusable system. As the provision of electricity, or respectively the mix of energy carriers for the provision of electricity varies throughout the USA, it is not a surprise that the overall result of the reusable system – that is mainly driven by the electricity demand – shows comparably high variations for the different impact indicators. However, it can be seen that in the vast majority of impact indicators, the advantageousness of the reusable systems persists, irrespective of which electricity provision dataset is chosen as modelling basis. Regarding the 170 indicator scores showing the overall results of the reusable system given in Table 4-16, only two impact indicators show higher scores than the disposable base case scenario. Both of these indicator results refer to the HICC dataset, representing energy provision on the Hawaiian Islands. Furthermore, in only one additional case (concerning the ODP in dataset S5_E) do indicator results lie in the same range. With regard to the other 167 impact indicator results, the reusable system in the hospital scenario shows clear benefits.

Table 4-17: Sensitivity 5: Change in the emission profile of the used electricity within the use phase of reusable crockery in school scenario

LCIA indicator		Unit	S5_A	S5_B	S5_C	S5_D	S5_E	S5_F	BC_reus	S5_H	S5_I	S5_J	BC_disp
ReCiPe	ALOP	m²a	95%	95%	133%	61%	19%	24%	100%	60%	79%	165%	850%
	FDP	kg Oil-eq.	152%	143%	147%	141%	141%	128%	100%	91%	103%	73%	876%
	NLTP	m^2	123%	193%	454%	132%	242%	144%	100%	86%	116%	151%	338%
	TAP100	kg SO_2-eq.	111%	100%	151%	107%	104%	74%	100%	127%	58%	56%	285%
	WDP	m³	104%	91%	92%	99%	85%	93%	100%	102%	91%	97%	82%
TRACI	Acidification	moles-H+-eq.	117%	100%	152%	111%	105%	74%	100%	126%	60%	55%	296%
	Ecotoxicity	kg 2,4-D-eq.	174%	54%	50%	130%	42%	84%	100%	102%	78%	44%	130%
	Eutrophication	kg N	120%	108%	201%	113%	129%	96%	100%	102%	98%	90%	381%
	Global warming	kg CO_2-eq.	145%	116%	128%	144%	107%	105%	100%	105%	87%	60%	540%
	Ozone depletion	kg CFC-11-eq.	55%	364%	533%	135%	407%	223%	100%	65%	162%	172%	439%
	Photochemical oxidation	kg NOx-eq.	184%	114%	209%	154%	153%	73%	100%	113%	89%	51%	599%
	Human health, carc.	kg benzene-eq.	113%	106%	96%	108%	91%	96%	100%	102%	85%	88%	194%
	Human health, non-carc.	kg toluene-eq.	103%	108%	119%	94%	95%	97%	100%	98%	84%	97%	264%
	Human health, resp. eff.	kg PM2.5-eq.	101%	99%	148%	101%	100%	76%	100%	126%	58%	61%	379%
USEtox	Ecotoxicity, total	CTU	81%	236%	342%	120%	260%	163%	100%	81%	132%	138%	424%
	Human toxicity, total	CTU	116%	103%	110%	110%	100%	103%	100%	109%	93%	89%	369%
CED total		MJ	124%	120%	113%	108%	108%	106%	100%	93%	98%	92%	711%

Source: Own calculation

Results for the school scenario are largely identical with the results for the hospital scenario. Besides the WDP and the two impact indicators already mentioned (NLTP and ODP in S5c HICC), additionally the indicator TRACI ecotoxicity in dataset S5A shows an higher impact score compared to the base case scenario of the disposable dishes. Nonetheless, also when considering the school scenario, the reusable system shows a clear advantage over the disposable system in the vast majority of impact indicator scores regardless of energy mix.

Table 4-18: Sensitivity 5: Change in the emission profile of the used electricity within the use phase of reusable crockery in hotel scenario

	LCIA indicator	Unit	S5_A	S5_B	S5_C	S5_D	S5_E	S5_F	BC_reus	S5_H	S5_I	S5_J	BC_disp
ReCiPe	ALOP	m²a	94%	94%	133%	60%	17%	22%	100%	59%	78%	166%	3557%
	FDP	kg Oil-eq.	154%	144%	149%	142%	142%	129%	100%	91%	103%	72%	180%
	NLTP	m^2	122%	191%	445%	131%	238%	143%	100%	87%	116%	149%	192%
	TAP100	kg SO_2-eq.	110%	100%	150%	107%	104%	75%	100%	126%	59%	57%	93%
	WDP	m³	104%	91%	92%	99%	87%	94%	100%	102%	92%	98%	34%
TRACI	Acidification	moles-H+-eq.	117%	100%	151%	111%	105%	74%	100%	125%	61%	56%	98%
	Ecotoxicity	kg 2,4-D-eq.	172%	55%	51%	129%	43%	85%	100%	102%	78%	45%	237%
	Eutrophication	kg N	119%	108%	195%	112%	127%	96%	100%	102%	98%	90%	253%
	Global warming	kg CO_2-eq.	145%	116%	128%	144%	107%	105%	100%	105%	87%	60%	155%
	Ozone depletion	kg CFC-11-eq.	56%	358%	525%	134%	401%	221%	100%	66%	161%	170%	208%
	Photochemical oxidation	kg NOx-eq.	185%	115%	210%	154%	154%	73%	100%	113%	89%	51%	187%
	Human health, carc.	kg benzene-eq.	115%	107%	96%	109%	90%	96%	100%	103%	83%	87%	127%
	Human health, non-carc.	kg toluene-eq.	103%	108%	119%	93%	95%	96%	100%	98%	84%	96%	213%
	Human health, resp. eff.	kg PM2.5-eq.	101%	99%	148%	101%	100%	77%	100%	126%	58%	61%	154%
USEtox	Ecotoxicity, total	CTU	80%	243%	354%	121%	267%	166%	100%	81%	133%	139%	295%
	Human toxicity, total	CTU	118%	103%	111%	110%	100%	104%	100%	110%	93%	88%	630%
CED total		MJ	124%	120%	113%	108%	108%	106%	100%	93%	98%	92%	224%

Source: Own calculation

With regard to the hotel scenario the result pattern is more diverse. A comparison of the results shows that for some of the assessed electricity datasets, there are impact indicator results showing higher overall impacts for the reusable system than for the disposable system. However, this only applies for a small minority of the assessed impact indicators. Specifically; for six indicators at least one dataset shows higher results for the reusable system.

4.3.6. Higher and lower average service life of reusable crockery

Also regarding the assumption on the typical service life of reusable crockery (1,000 reuse cycles in the base case scenario), lower (750) and upper (1,700) estimates have been assessed:

- Sensitivity 6_A: 750 instead of 1,000 reuse cycles
- Sensitivity 6_B: 1,700 instead of 1,000 reuse cycles.

As results in Table 4-19 show, taking into account a higher and lower average service life of reusable crockery does not affect the overall results in any remarkable way. The maximum deviations from the base case differ between -9% and +7%. Therefore, it can be stated that the average lifetime of the reusable dishes is not a significant parameter for this study. The same applies for the two other scenarios, which therefore are not shown in separate tables.

Table 4-19: Sensitivity 6: Higher and lower average service life of reusable crockery in hospital scenario

LCIA indicator		Unit	S6_A1/ BC_reusable	S6_A2/ BC_reusable	BC_reusable/ BC_reusable	BC_disposable/ BC_reusable
ReCiPe	ALOP	m²a	102%	97%	100%	6712%
	FDP	kg Oil-eq.	103%	97%	100%	318%
	NLTP	m^2	104%	95%	100%	398%
	TAP100	kg SO_2-eq.	102%	97%	100%	186%
	WDP	m³	101%	99%	100%	343%
TRACI	Acidification	moles-H+-eq.	102%	97%	100%	193%
	Ecotoxicity	kg 2,4-D-eq.	101%	98%	100%	470%
	Eutrophication	kg N	102%	98%	100%	792%
	Global warming	kg CO_2-eq.	102%	97%	100%	300%
	Ozone depletion	kg CFC-11-eq.	104%	95%	100%	423%
	Photochemical oxidation	kg NOx-eq.	102%	97%	100%	381%
	Human health, carc.	kg benzene-eq.	107%	91%	100%	251%
	Human health, non-carc.	kg toluene-eq.	104%	96%	100%	458%
	Human health, resp. eff.	kg PM2.5-eq.	103%	96%	100%	294%
USEtox	Ecotoxicity, total	CTU	105%	94%	100%	829%
	Human toxicity, total	CTU	105%	94%	100%	1436%
CED total		MJ	102%	97%	100%	407%

Source: Own calculation

4.3.7. Variants in the disposable crockery hotel scenario

It should be noted that, strictly speaking the original intention of comparing pure disposable to pure reusable crockery systems is here abandoned. On the other hand it is justified to assume that in practice there exist facilities with systems combining disposable and reusable crockery items. For example, in most fast food restaurants this is the case. This sensitivity has mainly been carried out due to the very low weight of disposable paper-based plates in the hotel scenario, resulting in a low level of stability of the plates.

Therefore, it may well be that, in order to cope with the flimsy plates, multi-use trays are made available to guests. On the other hand, another realistic scenario is the one that, if no trays are available, at least some of the hotel's guests may decide to double up their plate, in order to get a higher level of stability. Also some guests inadvertently double-up, not realizing that two items have stuck together. For these two variants of the hotel scenario, referred to as representing plausible alternatives, a sensitivity analysis has been carried out.

- Sensitivity 7_A: Use of a reusable tray also due to flimsy plates
- Sensitivity 7_B: 50% of catering participants doubling up due to flimsy plates

Table 4-20: Sensitivity 7: Variants in the disposable crockery hotel scenario

	LCIA indicator	Unit	S7_A / BC_dispos	S7_B / BC_dispos	BC_dispos / BC_dispos	BC_reus / BC_dispos
ReCiPe	ALOP	m^2a	101%	137%	100%	3%
ReCiPe	FDP	kg Oil-eq.	125%	119%	100%	56%
ReCiPe	NLTP	m^2	123%	132%	100%	52%
ReCiPe	TAP100	kg SO_2-eq.	147%	129%	100%	107%
ReCiPe	WDP	m^3	230%	130%	100%	291%
TRACI	Acidification	moles-H+-eq.	145%	129%	100%	102%
TRACI	Ecotoxicity	kg 2,4-D-eq.	119%	137%	100%	42%
TRACI	Eutrophication	kg N	118%	133%	100%	39%
TRACI	Global warming	kg CO_2-eq.	129%	125%	100%	64%
TRACI	Ozone depletion	kg CFC-11-eq.	121%	131%	100%	48%
TRACI	Photochem. oxidation	kg NOx-eq.	124%	127%	100%	54%
TRACI	Human health, carc.	kg benzene-eq.	132%	134%	100%	79%
TRACI	Human health, non-carc.	kg toluene-eq.	120%	134%	100%	47%
TRACI	Human health, resp. eff.	kg PM2.5-eq.	128%	130%	100%	65%
USEtox	Ecotoxicity, total	CTU	114%	132%	100%	34%
USEtox	Human toxicity, total	CTU	107%	136%	100%	16%
CED total		MJ	120%	126%	100%	45%

Source: Own calculation

Results of the sensitivity analysis show higher impact indicator scores for both variants of the disposable system. Only the WDP remains lower for the disposable than for the reusable system. All other indicators, for both variants of the disposable place setting in the hotel scenario show clear advantages for the reusable system. With regard to Sensitivity S 7_A it should be noted, that the environmental burdens are higher than for the disposable base case scenario. This is due to the fact that in the base case of the disposable hotel scenario no tray has been taken into account. The multi-use tray, therefore, does not replace a disposable tray, but is rather an additional multi-use crockery item. The reprocessing (dishwashing of the additional tray) therefore causes higher environmental burdens.

4.3.8. Regarding a variant (use of a reusable tray instead of a disposable cardboard tray) in the disposable crockery hospital scenario

The main reason for carrying out this sensitivity analysis is the high contribution of the cardboard tray in the base case results of the disposable system of the hospital scenario, and the fact that, in practice, facilities with systems combining disposable and reusable crockery items can be found. Once more, it should be noted here that, with this sensitivity, the original intention of a comparison at system level, focusing pure disposable to pure reusable crockery systems is here abandoned. Another aspect to be mentioned with regard to Sensitivity S8_hospital is the fact that it is not an analogous sensitivity for hospital to Sensitivity S7_A, because S8_hospital considers an alternative use of a multi-use tray instead of a single-use tray.

- Sensitivity 8_hospital: Using a multi-use tray instead of a cardboard tray

Table 4-21: Sensitivity 8: Variant in the disposable crockery hospital scenario

LCIA indicator		Unit	S8_hospital / BC_disposable	BC_disposable / BC_dispos	BC_reusable / BC_dispos
ReCiPe	ALOP	m²a	31%	100%	1%
	FDP	kg Oil-eq.	105%	100%	31%
	NLTP	m^2	91%	100%	25%
	TAP100	kg SO_2-eq.	112%	100%	54%
	WDP	m³	128%	100%	29%
TRACI	Acidification	moles-H+-eq.	109%	100%	52%
	Ecotoxicity	kg 2,4-D-eq.	50%	100%	21%
	Eutrophication	kg N	62%	100%	13%
	Global warming	kg CO_2-eq.	93%	100%	33%
	Ozone depletion	kg CFC-11-eq.	76%	100%	24%
	Photochemical oxidation	kg NOx-eq.	82%	100%	26%
	Human health, carc.	kg benzene-eq.	95%	100%	40%
	Human health, non-carc.	kg toluene-eq.	69%	100%	22%
	Human health, resp. eff.	kg PM2.5-eq.	95%	100%	34%
USEtox	Ecotoxicity, total	CTU	69%	100%	12%
	Human toxicity, total	CTU	41%	100%	7%
CED total		MJ	84%	100%	25%

Source: Own calculation

The employment of a multi-use tray in the disposable hospital scenario leads to less impacts in most impact indicators. Exceptions are the two acidification-related indicators and FDP, which show a slight increase while WDP shows a significant increase in impact indicator scores. The increase of acidification-related indicators is due to the use of chemicals (detergents and rinse aid) in the dishwashing process. However, on no occasion does improvement reach so far that the advantageousness of the complete reusable systems would be placed at risk.

4.3.9. Regarding a 100:0 allocation rule for credits from thermal recycling of disposable crockery in all three scenarios

According to requirements of the ISO 14040 series, an additional sensitivity has been carried out regarding the allocation on system level for the EoL treatment processes of the disposable crockery. Supplementary to the 50:50 base case allocation rule (see section 2.7), the results for the disposable systems have also been calculated, for the case that the complete benefit from combustion to energy recovery is allocated to the disposable system.

- Sensitivity 9_A: 100:0 Allocation rule for credits from thermal recycling of disposable crockery in hospital scenario
- Sensitivity 9_B: 100:0 Allocation rule for credits from thermal recycling of disposable crockery in school scenario
- Sensitivity 9_C: 100:0 Allocation rule for credits from thermal recycling of disposable crockery in hotel scenario

Table 4-22: Sensitivity 9: 100:0 allocation instead of 50:50 in base case for credits from thermal recycling of disposable crockery in all three scenarios

LCIA indicator		Unit	Hospital scenario			School scenario			Hotel scenario		
			S9_A/ BC_dispos	BC_dispos / BC_dispos	BC_reus/ BC_dispos	S9_B/ BC_dispos	BC_dispos / BC_dispos	BC_reus/ BC_dispos	S9_C/ BC_dispos	BC_dispos / BC_dispos	BC_reus/ BC_dispos
ReCiPe	ALOP	m²a	100%	100%	1%	99%	100%	12%	100%	100%	3%
	FDP	kg Oil-eq.	99%	100%	31%	99%	100%	11%	99%	100%	56%
	NLTP	m^2	99%	100%	25%	99%	100%	30%	99%	100%	52%
	TAP100	kg SO_2-eq.	98%	100%	54%	98%	100%	35%	98%	100%	107%
	WDP	m³	100%	100%	29%	99%	100%	122%	99%	100%	291%
TRACI	Acidification	moles-H+-eq.	98%	100%	52%	98%	100%	34%	98%	100%	102%
	Ecotoxicity	kg 2,4-D-eq.	99%	100%	21%	96%	100%	77%	99%	100%	42%
	Eutrophication	kg N	100%	100%	13%	100%	100%	26%	100%	100%	39%
	Global warming	kg CO_2-eq.	99%	100%	33%	99%	100%	19%	99%	100%	64%
	Ozone depletion	kg CFC-11-eq.	99%	100%	24%	99%	100%	23%	99%	100%	48%
	Photochemical oxidation	kg NOx-eq.	99%	100%	26%	99%	100%	17%	99%	100%	54%
	Human health, carc.	kg benzene-eq.	98%	100%	40%	97%	100%	52%	98%	100%	79%
	Human health, non-carc.	kg toluene-eq.	99%	100%	22%	98%	100%	38%	99%	100%	47%
	Human health, resp. eff.	kg PM2.5-eq.	99%	100%	34%	99%	100%	26%	99%	100%	65%
USEtox	Ecotoxicity, total	CTU	100%	100%	12%	99%	100%	24%	99%	100%	34%
	Human toxicity, total	CTU	100%	100%	7%	99%	100%	27%	100%	100%	16%
CED total		MJ	99%	100%	25%	99%	100%	14%	99%	100%	45%

Source: Own calculation

As results in Table 4-22 show, the change to a 100:0 allocation rule in favor of the disposable system has no effect on the results of the comparison of the two systems. On no account does swapping to a 100:0 allocation rule instead of a 50:50 allocation rule change results in a significant manner. This applies to all impact indicators in all scenarios.

4.4. Normalization

According to ISO 14044, normalization is an optional element which can be used depending on the goal and scope of the LCA. Generally spoken, in the framework of the normalization, the magnitude of category indicator results relating to reference information is calculated. For this study, the respective reference information is the updated US normalization factors for TRACI 2.1 (released in 2012) as reported in Ryberg et al (2013). Therein included are the impact categories and units given in the first two columns of Table 4-23.

Table 4-23: Updated US normalization factors for TRACI 2.1

Normalization (Ryberg et al. 2013)		Equivalent in this study	
Impact category	Unit	Impact category equivalent	Unit
Ecotoxicity-non-metals	CTUe	USEtox$_{ecotox_total}$	CTU
Ecotox-metals	CTUe		
Carcinog.-non-metals	CTUcanc.	USEtox$_{humantox_total}$	CTU
Carcinog.-metals	CTUcanc.		
non-carc-non-metal	CTUnon-canc.		
non-carc-metal	CTUcanc.		
Global Warming	kg CO_2-eq.	Global Warming	kg CO_2-eq.
Ozone Depletion	kg CFC-11-eq.	Ozone Depletion	kg CFC-11-eq.
Acidification	kg SO_2-eq.	ReCiPe Terrestrial acidification (TAP)	kg SO_2-eq.
Eutrophication	kg N-eq.	Eutrophication	kg N-eq.
Photochemical Ozone Formation	kg O_3-eq.	Photochemical Oxidation	kg NO_x-eq.
Respiratory effects	kg PM2.5-eq.	Respiratory effects	kg PM2.5-eq.
Fossil fuel depletion	MJ surplus	Cumulative Energy Demand	MJ

Source: Own compilation

The original Version of TRACI was released in August 2002 (Bare et al 2003) followed by a release of TRACI 2.0 in 2011. Due to the fact that the latest version of TRACI has not been implemented in the ecoinvent LCIA database yet, this version has been unavailable for the LCIA in this study. Given the further fact that, in the course of the release of TRACI 2.1, some of the TRACI impact indicators have been updated with latest scientific consensus models, some substantial changes have to be noted. First of all, this applies for the implementation of the USEtox consensus model, instead of the former toxicity-related impact categories and indicators (Bare 2012). Not least because of that, it has been decided to evaluate the USEtox$_{ecotox,\ total}$ and the USEtox$_{humantox,\ total}$ indicators accompanying the former TRACI indicators related to toxicity aspects within this study.

As, within the course of the TRACI update, also reference indicators underlying impact assessment models and/or equivalent units have changed, a reassignment of equivalent of impact categories had to be established as starting point for the normalization. The reassigned impact categories are given in the two columns on the left hand side of Table 4-23. Out of the set of impact indicators for which information on normalization factors is available in Ryberg et al. (2013), only for the photo-chemical ozone formation, given in kg O_3-eq., was no suitable reassignment possible and the photochemical oxidation has therefore been excluded from the scope of normalization. The same applies to the land use-related impact categories ALOP and NLTP and the WDP, as they are not implemented in the latest version of TRACI.

With respect to the WDP, and against the background of several US regions facing severe water scarcity, the WDP has been grouped qualitatively to the Impact Indicators of high concern for the discussion of the results in this study.

Based on the calculated person equivalents (see Annex section 9.2.3) for each scenario, the impact indicators have been grouped into five categories, as shown in Table 4-24. It should be noted that conclusions and recommendations derived from grouping are based on value choices. ISO 14044 does not specify any specific methodology, or support the underlying value choices used to group the impact categories.

Table 4-24: Grouping of Impact indicators based on normalization results

Groups	Hospital scenario		School scenario		Hotel scenario	
	disposable	reusable	disposable	reusable	disposable	reusable
10-100 person equivalents	CED, USEtox humantox	CED	CED	/	/	/
1-10 person equivalents	USEtox ecotox TAP, respire-tory effects, global warming, eutrophication,	USEtox humantox	/	CED	CED, USEtox humantox	CED
0.1-1 person equivalents	/	Global warming, eutrophication, USEtox ecotox	USEtox humantox, global warming, TAP, eutrophication, resp. Effects, USEtox ecotox	USEtox humantox, global warming, TAP	Global warming, TAP, eutrophication, resp. Effects, USEtox ecotox	USEtox humantox global warming, TAP, resp. effects,
0.01-0.1 person equivalents	Ozone depletion	/	/	USEtox ecotox, eutrophication, resp. effects	/	USEtox ecotox, eutrophication,
0.001-0.01 person equivalents	/	Ozone depletion	Ozone depletion	Ozone depletion	Ozone depletion	Ozone depletion

Source: Own compilation

Based on the results for the grouping of LCIA impact categories, conclusions may be drawn on which impact categories are of special interest for the comparative assertion of systems to serve meals on disposable and reusable crockery in stationary out-of-home facilities. As results show, there is in no case a wider deviation between disposable and reusable system for the grouping results higher than one person equivalent group. It is therefore considered justified to take the impact indicators CED, $USEtox_{humantox}$ as to be particularly relevant for the comparative assertion. As mentioned above, the WDP is also considered to be particularly relevant, at least for the sake of US regions facing water scarcity.

Furthermore, also the impact indicators TAP, Global warming, eutrophication $USEtox_{ecotox}$ and the respiratory effects category can be seen as relevant. Ozone depletion results in any case show the lowest person equivalent results.

5. Life Cycle Interpretation

According to the requirements set out in the ISO 14040 series of standards, this chapter shall frame the study by interpreting the results of the LCI and LCIA phases according to the goal and scope of the study. Goal and scope are defined in section 2. Primary objective of this chapter is to provide a readily understandable, complete and consistent presentation of the results, taking into account limitations of the results, especially given the uncertainty as well as the sensitivity of the results.

5.1. Appropriateness of the definitions of system functions, functional unit and system boundary

The intended application of this study is an evaluation and comparison of potential environmental impacts of two types of crockery systems, namely reusable and disposable ones, which are commonly used in stationary catering facilities in the US (see section 2.1). Therefore, non-stationary or only temporarily installed catering facilities (e.g. music festivals, temporary sport events) have been excluded from the scope of this study.

The reason for carrying out this study is to communicate the environmental performance in distinct catering facilities. Out of the US catering market, three submarkets (hospital cafeteria, school cafeteria, hotel serving breakfast) were selected with a view to their respective relevance in the US catering market as well as their relevance for MEIKO as a manufacturer of professional dishwashing machines. From each of the three submarkets, a typical and, as far as possible, representative scenario was constructed. It should be noted that this study does not attempt to compare catering facilities existing in real life, but to compare realistic and representative system alternatives. Therefore, for the base case scenarios, it has been decided not to mix systems (e.g. multi-use crockery items in the disposable crockery system, and vice versa), even if, in practice, this might occur to some extent.

According to the ISO 14040 series of standards, the equivalence of the systems compared shall be evaluated before interpreting the results, taking into account the evaluation of the appropriateness of the definitions of system functions, functional unit and system boundaries. With regard to the systems functions, both reusable and disposable systems have been evaluated to be functionally equivalent with regard to the functional unit, defined as “Provision of dishes for the hygienic delivery of X portions of food a day within a year in a stationary out-of-home cafeteria in the USA” (see section 2.3).

The system boundary as defined in section 2.4 includes the entire life cycle (“cradle to grave”) of both, reusable and disposable crockery items. With regard to the multi-use system it should be noted that the production or manufacturing of the dishwashing machines has not been taken into account in this study. Within the scope of the European eco-design directive, Lot 24, the entire life cycle of professional dishwashing machines (inter alia hood-type machines and conveyor-type machines) has been assessed, showing that the contribution of the production as well as of end-of-life of dishwashing machines is almost negligible compared to the use phase (e.g. less than 1% to the overall GWP) (Rüdenauer et al. 2011). Therefore, the omission of the production phase of the dishwashing machines does not impair a well-balanced comparison of the two system alternatives.

For the purpose of data quality assessment, a prerequisite relating to the time-related coverage of the data used for modelling the two systems has been established, i.e. not to use data older than 10 years (or respectively older than 5 years for processes which contribute significantly to the overall results). For those cases where this requirement could not be met (namely: detergent ingredient composition and the production of porcelain) it could be demonstrated by the LCIA that these parameters only have a minor impact on the overall results (see section 4.2.1-4.2.3).

With respect to the technological coverage it should be noted that this study aims at showing the transition of the U.S. market from the commonly used disposable systems towards an increased use of reusable solutions. Therefore, the base case scenarios in the multi-use systems take into account dishwashing with BAT machines, because this should be the case if a facility comes to the decision to switch to a reusable system. As shown in a sensitivity analysis (4.3.4), the consideration of BAT machines compared to machines representing the technological standard for stock machines leads to lower environmental impacts across the board. While an increase in energy usage of only 10% does not have a relevant impact on the overall results, a usage span of nearly 400%, as reported by the Fischer-Nickel consumer advocacy group, highlights the importance of choosing a BAT machine. For an elaborate discussion of relevant data quality requirements applied in this study we refer to section 2.5.

5.2. Identification of the significant issues based on the results of the LCI and LCIA phases of the LCA

According to the requirements set out in the ISO 14040 series of standards, the interpretation shall include a statement on whether the LCI data can be seen as satisfactory and appropriate to meet the study's goal and scope. With regard to both systems that have been compared in this study, the underlying LCI data applied for the main contributing processes in both systems under consideration is deemed to be sufficient to meet the study's goal and scope: The selection of LCI data has been made in a way that allows for an appropriate comparison of both systems. For instances where the specification of LCI data is relevant, further sensitivity analyses were carried out in order to ensure that the specification does not negatively affect the meaningfulness of the study's fundamental findings. The results of the sensitivity analysis are interpreted in section 5.3.

With regard to the production phase, the input raw materials for both, single-use and multi-use crockery items (PP; PS, PLA, paper for single use; porcelain glass, PP) are traded on the world market. Respectively, the provisions of these materials, as well as the required manufacturing processes have been modelled by using generic market datasets from the ecoinvent database (V.3.1). The applied datasets therefore represent a suitable representation of and the best information available on the typical material provision. The modelling assumption of taking into account generic market datasets is therefore in line with this study's goal and scope. On the other hand, this also implies that different manufacturers or maybe different production processes or techniques used by these manufacturers have not been compared and assessed. The results are therefore not intended to be used as a benchmark between different producers or producer groups of single-use items. Conversely, the same applies to the assessment of different producers or producer groups of multi-use crockery items.

Considering the end-of-life phase and, within its scope, the different possible disposal routes (recycling, incineration and sanitary landfill) of single-use crockery, the underlying assumptions on relative mass flows have been discussed with the Review Panel, in particular with the North American branch and LCA experts in the panel, in order to ensure that we deal with realistic and up-to-date information. Based on recommendations by the Review Panel it has been assumed that, for the single-use system, 20% of the used crockery items are handed over to and treated in a municipal incineration facility with energy recovery (waste to energy), taking into account a credit for the electric energy derived from the incineration process. To quantify these credits, actual US-specific data on the typical WTE parameters have been applied and allocated to the respective product system (section 3.1.4, for allocation procedures see also section 2.7). The remaining 80% of the used single-use crockery items are assumed to be transported and treated in a sanitary landfill. It should be noted here that this is based on the assumption (also discussed with and agreed upon by the Review Panel) that mixed waste from stationary out-of-home catering facilities at present is not being materially recycled. Nonetheless, a further or fully developed recycling system could lead to lower environmental burdens arising from the EoL treatment of the single-use crockery systems, although, in this case, the additional effort for cleaning up the material must be taken into account. Regarding the EoL contributions in the single-use scenarios, a fully developed material recycling system would result in a reduction of the single-use system's negative environmental effects as compared to the multi-use system's effects. At the same time, it should be noted that, even if a fully developed material recycling system has to be taken into account, the overall result, or, in other words, the advantageousness of the multi-use system in all impact indicators regarded in the study at hand will not change significantly. Nevertheless, with respect to hygiene requirements, it should be assumed that disposable crockery items will not be materially recycled. Furthermore, we assume that the implementation of a material recycling system would initially focus on waste fractions of which material recycling is technically and economically far easier and cheaper.

With regard to the multi-use systems, in all three scenarios, the use phase and, more specifically, the dishwashing process, contributes the most to the overall results whereas the other life cycle stages are only of secondary importance. This also applies in particular to the provision of porcelain, where process-specific information older than 10 years had to be used for the modelling of the crockery production. Although this data-set exceeds the originally defined time-related coverage of LCI-data, it becomes apparent that the impact on the results is of minor importance.

With regard to the dishwashing parameters (water consumption, energy demand, detergent and rinse aid consumption), the modelling could be based on specific data directly retrieved from experimental testing conducted by MEIKO. Data on process parameters for the dishwashing process in all three multi-use scenarios are valid for the best dishwashing technology currently available (BAT). As mentioned above, it was considered appropriate to take into account BAT machines as this study's ultimate purpose has been to explore the environmental effects of the transition from single-use to multi-use ware in the US out-of-home catering market, thus being in line with the goal and scope definition. Nonetheless, the usage of machines representing typical technology standards for machines in stock has also been assessed in the framework of a sensitivity analysis (see section 4.3.4). As results from the sensitivity analysis show, taking into account dishwashing machines with an increased energy usage of 10% would not lead to different results. With regard to the recently published report of the consumer advocacy group Fisher-Nickel, showing a usage span of nearly 400% for dishwashing machines in stock, highlights the importance of choosing a BAT machine.

While the production and EoL stages in the single-use system and the dishwashing process in the multi-use system contribute most significantly to the overall results, the transport distances turned out to be of only secondary importance (see section 4.3.2).

With regard to the selection of environmental impact indicators used for this study, increasing attention has been paid on selecting a set of impact indicators that allow for adequate consideration of relevant environmental aspects. In concrete terms, this means that, beside the standard impact indicators that are typically addressed within LCA studies, further impact indicators (e.g. WDP, ALOP and NLTP) specifically designed for environmental impacts related to the systems under consideration, and being discussed in the geographical context of this study, have been selected for the impact assessment.

Based on the results of the impact assessment (section 4) and with regard to the three single-use scenarios, the production of the required crockery items and their end-of-life treatment (disposal processes) contribute most to the overall environmental impacts along the product life cycle.

5.3. Evaluation considering completeness, sensitivity and consistency checks

With regard to completeness and consistency, every effort has been made to ensure that, in both systems, none of the processes contributing significantly to the results of the single-impact category results have been disregarded or excluded from the scope of the investigation along the entire life cycle. Furthermore, the results from the base case scenarios have been substantiated by a set of nine sensitivity analyses. The results of these sensitivity analyses have been included as part of the impact assessment results in section 4.3 of this study report.

Based on the findings of the contribution analyses, key driving factors for both systems have been identified and selected for further evaluation within the scope of the sensitivity analyses that have been conducted. With respect to parameters significantly influencing the results of the analyzed systems, the results from the most important sensitivity analyses shall be interpreted in the following:

- Weight and material composition of disposable crockery items are the key driving factors in the single-use system. The weight of disposable crockery, taken into account in the base case scenarios, has been retrieved from original items that have been picked up at US catering facilities. The examined items appeared to be optimized as far as possible in terms of a reduced material demand. Against this background, a further reduction of weight would seriously affect the functional properties. On the other hand, items of higher weight could provide better functional characteristics (e.g. improved stability). In the event that crockery items of higher weight are used in US catering facilities or will be used in the course of future developments, this would cause higher overall environmental burdens and lead to an even more marked trend regarding the environmental advantageousness of the multi-use system. Sensitivity analyses reveal that assuming a disposable crockery weight of 125% (as compared to 100% in the base case), only the WDP shows a higher environmental burden from the multi-use system, and this only applies to the hotel scenario.
- As contribution analyses show, the electricity demand for running the dishwashing machines is the key driving factor for the three multi-use scenarios. Due to the high relevance of the electric energy demand for the dishwashing process, the selection of the electricity dataset considerably affects the overall results. In the US, there are ten regional electricity grids, each based on its own electricity generation system and having a specific mix of energy carriers. According to the US-wide geographical scope of this study, an analysis was carried out on how the overall environmental impacts would change depending on the selected electricity dataset. As derived from the respective sensitivity analysis (see section 4.3.5), the overall impact indicator results revealed comparably high variations with factors up to 5 in either direction in the case of individual impact indicators, , this applying in particular to the land use-related indicators ALOP and NLTP. This is mainly due to the generation systems (coal, oil, nuclear, renewables, etc.) in the respective electricity mix. Furthermore, it should be noted that the generation mix will change depending on the further development of renewable energies. We currently assume that the share of renewable energies will increase in the nearby future; while there will be a simultaneous decline in the share of fossil-based energies. This will lead, for example, to a lower GWP per kWh of electric energy consumed. At the same time, it cannot be ruled out that the increased share of renewable energies in the electricity production will cause an increase, for example, with regard to agricultural land occupation through the cultivation of energy plants or crops. This

trend, however, mainly depends on the energy system transition pathways which will differ considerably between the US states. Details on this issue could not be elaborated within the scope of this study. Finally, it should be noted that the selection of the electricity dataset may lead to substantial disparities in terms of absolute results of the multi-use scenarios, while having only a minor or no effect on the conclusions regarding the comparison of the single- and multi-use system.

- With regard to the low weight of single-use crockery items in the base case hotel scenario, the effects of using an additional multi-use tray has also been assessed within the scope of a sensitivity analysis (see section 4.3.7). Adding a multi-use tray, due to the additional dishwashing process, results in an increasing demand for water, and leads to a higher WDP of the single-use system. In this case, the multi-use system shows overall even lower levels of impacts with respect to all assessed impact indicators except WDP. Canteens guests may choose to use a double plate in order to carry their meals safely to the dining corner or, without meaning to, use two items that are stuck together. In order to cover this behavior, it was assumed that 50% of the catering participants use a double plate. Compared to the base case, the sensitivity analysis on this alternative reveals significant advantages of the multi-use system for all assessed impact indicators, with the only exception being the water depletion potential. Regarding the WDP, the single-use system has lower overall impacts, even if 50% of the catering participants use two plates, i.e. one above the other, as a reaction to cope with the flimsy plates.
- As mentioned in section 5.1, it has been decided for the base-case scenarios not to mix systems (e.g. multi-use crockery items in the disposable crockery system, and vice versa). Nonetheless, in the course of conducting the sensitivity analyses, also variants of the base case have been assessed. In one particular case, the usage of a multi-use tray as part of the single-use hospital and hotel system was evaluated. Results of the sensitivity analysis on the hospital scenario (see section 4.3.8) show, that the usage of a multi-use tray, in comparison to the usage of a single-use cardboard tray, in all assessed impact indicators except for FDP, WDP and acidification potential, leads to lower overall environmental impacts of the single-use system in absolute terms (assessed by TRACI, acidification and ReCiPe, Terrestrial Acidification Potential). At the same time, it has to be stated that the goal and scope of the present study is the comparison of uniform single-use and multi-use systems. Even though, there are systems mixing single-use and multi-use items in practice, the inclusion of mixed systems would not contribute to a better understanding of the systems under consideration in this study.

Within the scope of the life cycle interpretation, a cross-scenario comparison has been carried out, while also providing a plausibility check. Due to the existence of scenario-specific functional units and respectively different reference flows for each scenario, it has been decided not to include the cross-scenario comparison in the main section of this study. The cross-scenario comparison has been included in the annex as section 9.3.

5.4. Statement on limitations, conclusions and recommendations

The main goal and intended application of this study is an evaluation and comparison of the potential ecological impacts of two types of crockery systems, namely reusable and disposable ones, which are used in stationary US catering facilities, throughout the whole life cycle of the crockery items. The focus of this study is therefore an equitable comparison of two system alternatives, noting, however, that the investigation does not aim at comparing different cafeterias or crockery items from different manufacturers within the two systems. In concrete terms, it is not the purpose of this study to conduct a benchmark comparison between cafeterias or crockery producers, as the underlying data basis and especially the modelling approach of this study are suitable for the comparison of single-use and multi-use systems, while, however, they are not suitable for benchmarking within one of the systems.

With regard to the toxicity-related impact indicators, it must be noted that a comparison should be undertaken only with due caution. Besides the ongoing scientific discussion on the best way to handle complexity and uncertainty in building toxicity equivalents, the toxicity-related input parameters in currently available LCI databases raised concerns whether a data consistency beyond the datasets contained in these databases can be ensured. Due to the modelling approach chosen in this study (e.g. taking into account aggregated market datasets for the provision of raw materials) it has not been possible to exhaustively trace back every toxicity-related input parameter. Likewise, in these circumstances, it cannot be established with sufficient certainty that the toxicity-related impact indicator results are based on adequate data symmetry for all datasets that have been applied. As a result, it can be concluded that it was not possible to define a clear criterion on the significance of the toxicity-related indicator results. Ultimately, this leads to the limitation that the results for toxicity-related impact indicators must be considered as not meeting the data quality requirements set out for this study. Accordingly, it was decided not to draw definite conclusions on the comparison of single-use and multi-use crockery systems with respect to the toxicity-related environmental impacts.

Based on the findings of the life cycle interpretation, in the following chapter full conclusions will be drawn and detailed.

6. Conclusions

According to ISO 14044, the objective of this part of the life cycle interpretation is to draw conclusions, to identify limitations and make recommendations for the intended audience of the LCA.

With respect to the definition of the study's goal and scope, to data collection, the modelling and calculation of scenario-specific systems as well as the reporting of the LCA at hand, the methodological requirements provided by ISO 14044 were considered for the assessment. This includes the accompanying third party critical review (critical review report can be found in the Annex, i.e. section 9.1). In order to ensure a consistently high documentation quality of both the methodological approach as well as the calculation results, the data basis was reviewed in terms of completeness (see section 2.5).

The Life Cycle Impact Assessment (LCIA) has been carried out for 17 impact indicators out of four different impact assessment methods. As the geographical scope of this study is the US, the TRACI-Model, as implemented in the ecoinvent database, forms the basis for the LCIA. In order to provide an adequate basis for the comparison of single-use and multi-use systems, also impact indicators from other LCIA-Models, namely ReCiPe, CED and USEtox, (e.g. fossil and water depletion potential, agricultural land occupation and natural land transformation) have been selected for evaluation, as they are not covered by the TRACI-Model. Even though, they are essential for the description of all relevant environmental impacts, thus enabling a meaningful comparison. Regarding acidification, it has been decided to evaluate both the TRACI acidification indicator and the terrestrial acidification potential (TAP100a) as implemented in ReCiPe, showing qualitatively same result with only slight differences between the two indicators lying within calculation inaccuracy. Accordingly, the environmental issue of acidification is presented through two impact indicators, without implying that acidification should be given more weight.

As turned out in the course of the Life Cycle Interpretation phase, it was not possible to define a decisive criterion on the significance of the toxicity-related indicator results, and the respective indicator results have therefore been excluded from the drawing of full conclusions. Apart from this limitation, the authors of the study consider that, with regard to the relevant data and assumptions, the applied data is correct and appropriate and fulfills data quality requirements as set up in section 2.5. The authors therefore assume that the results can be considered to be meaningful with regard to the defined goals of the study. In effect, this means that the conclusions drawn in the sections below are based on eleven impact indicator results and impact indicators addressing ten environmental issues (acidification addressed by two indicators, as mentioned above).

6.1. Conclusions from the sensitivity analyses

Additionally, a set of nine sensitivity analyses (section 4.3) has been carried out in order to test the base case results and underlying assumptions for sensitivity and consistency according to those parameters that were found to be of great relevance during the contribution analyses. The respective parameters were assessed in order to ascertain their effects on the overall results. The results of the sensitivity analyses show that

- the material weight of disposable crockery items is a significant parameter for the description of the disposable system, and taking into account a higher material weight confirms the results of the standard scenarios, according to which the reusable system shows significant advantages in the hospital and school scenarios (in the latter case with the only exemption of the WDP). The same applies with regard to the scenario hotel, with the only difference being that for the impact acidification-related indicators ReCiPe TAP and TRACI, acidification. Even though the acidification results show a slight advantageousness of the reusable systems, the difference has to be seen as not significant, according to the criteria as set out in section 4.1. For the impact indicator WDP in the hotel scenario, showing an advantage for the disposable system, the advantageousness of the disposable system decreases but remains significant;

- taking into account shorter and longer distribution distances in the disposable system is of only minor importance, or in other terms, has no effect on the overall results;
- taking into account a cooling of waste disposable crockery is also of minor importance;
- taking into account dishwashing machines with an increase in energy usage of 10% for machines in stock would not lead, overall, to different results. At the same time, the recently published report of the consumer advocacy group Fisher-Nickel (showing a usage span of nearly 400%), highlights the importance of choosing a BAT machine;
- a change in the emissions profile of the electricity dataset, as applied for the energy demand of the dishwashing process, leads to significant variations of the reusable system's impact indicator results. While this does not affect the general conclusions for the hospital and school scenarios, it turned out that the results from the comparison of systems in the hotel scenario, depending on the applied electricity dataset, in few cases leads to an impact indicator result that differs from the base case scenario insofar that results of both systems lie within the same range, or are even higher for the multi-use system. In concrete terms, this implies that the implementation of a multi-use system, generally speaking a desirable practice, in exceptional cases and in relation to individual impact indicators, can lead to comparable or even lower burdens for the single-use system;
- taking into account either a higher or lower average service life of reusable crockery has no effects on the overall results;
- taking into account possible and realistic variants (e.g. using of a reusable tray, accounting for catering participants doubling up plates) of the disposable system in the hotel scenario may change the comparison results significantly in favor of the reusable system, leading for example to the result that, for the acidification-related impact indicators, both systems can be considered to lie more or less within the same range;
- taking into account a 100:0 instead of a 50:50 allocation rule has no effect on the overall results.

6.2. Conclusions on the hospital scenario

In general, for the hospital base case scenario, a hospital cafeteria serving meals to non-patients has been assessed. The non-patient meals served in the hospital's cafeterias are assumed to be currently served with single-use crockery. By taking into account a hypothetical multi-use place setting in the hospital's cafeterias, the potential environmental impacts of a transition to a multi-use crockery system have been assessed. Overall, in the hospital scenario, there is the highest number of catering participants per functional unit (146,000), which is why in the multi-use scenario a medium size conveyor belt transport dishwashing machine has been considered.

Under these conditions and under the general conditions of the comparison of single-use and multi-use systems in this study, the results can be summarized as follows: the reusable system – as compared to the respective disposable system – proved to be particularly advantageous for all of the assessed impact indicators. Unlike in the other scenarios, in the hospital scenario this also applies to the water depletion potential (WDP), which is mainly due to the high water demand for the provision of PLA-based crockery items. In summary, the overall results can be explained by the fact that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase (dishwashing process) of the reusable system.

With regard to the general decision-making situation in this scenario, it can be established that a transition from single-use to multi-use crockery systems in hospitals cafeterias will lead to lower environmental burdens.

6.3. Conclusions on the school scenario

Regarding the school cafeteria scenario, both single-use and multi-use systems appear to be common in US facilities. In this study, it has been assumed that meals in school cafeterias are served on compartment trays together with a set of cutlery. With regard to the single-use system, it has been assumed that some meal components (e.g. dessert) are additionally pre-packed when served to students. Overall, in the school scenario, a number of 90,000 catering participants per functional unit has been considered, which is why a hood-type dishwashing machine has been assumed in the multi-use scenario.

Taking into account these conditions and also the general conditions of the comparison of single-use and multi-use systems, it turns out that the reusable systems again shows significant benefits for all assessed impact indicators, with the only exception of the impact indicator WDP. With regard to the WDP, it has to be noted that the water demand of the reusable system (dishwashing) in the standard scenario significantly exceeds the water demand of the disposable system. For the other impact indicators, the overall results can also be explained by the already mentioned fact that the absolute contributions from the production phase of the disposable system exceed the absolute contributions from the use phase (dishwashing process) of the reusable system.

Also here with regard to the general decision-making situation in the school scenario, it can be established that the use of multi-use crockery systems leads to lower environmental burdens, with the exception of the WDP.

6.4. Conclusions on the hotel scenario

Within the hotel scenario, the serving of breakfast to hotel guests has been taken into consideration. In this scenario, the self-serving of breakfast from a buffet on single-use and multi-use crockery items and the related environmental burdens have been compared. The place setting has been defined in such a way as to reflect the specific situation of a self-serving buffet. In general it should be noted that in practice, the variation of the place setting per catering participant is comparably high, as the catering participants choose from a selection of crockery items which items to use for their breakfast. However, in order to enable a fair comparison, every effort has been made to allow for an adequate comparison. An overall number of about 40,000 catering participants has been assumed for the hotel scenario. To meet the requirements in terms of the dishwashing capacity needed, based on both the scenario-specific place setting and the number of hotel guests, a hood type dishwashing machine has also been selected for the multi-use system. The hood-type machine selected from MEIKO's product portfolio is the same as for the school scenario.

Regarding the hotel scenario, the comparison of the disposable and the reusable systems yields results broadly similar to those obtained in the other two scenarios. However, it should be noted that the differences between the two systems in the hotel scenario are less pronounced than in the other two scenarios. As in the school scenario, the multi-use system proved to be advantageous in environmental terms, with the exemption of the WDP. In this scenario again, the water demand for the dishwashing process in the reusable system exceeds the water demand caused by the production processes of the disposable crockery items. With regard to the acidification, related impact indicators (TRACI acidification and ReCiPe TAP) they lie more or less within the same range.

Nonetheless, and with the exemption of WDP and acidification, the multi-use systems have shown lower overall environmental impacts. With regard to the general decision-making situation, it can therefore be concluded that, from an environmental perspective, the use of multi-use crockery systems is advantageous for the hotel scenario as well.

7. Recommendations

The recommendations are based solely on the evaluation of environmental aspects. As some aspects (e.g. economic aspects) are out of the scope of this study, the recommendations are not based on any other than environmental considerations.

Commonly there is no scientific-based system commonly acknowledged which provides the weighing and aggregating of the different impact indicators to one single environmental indicator. Against this background recommendations necessarily have a subjective character. But at the same time, from the perspective of the Oeko-Institut, it is justified to claim that the higher water demand in the reusable systems is less relevant in comparison with the advantages of the reusable system in the other impact indicators. Under this condition, and based on conclusions on findings in the study at hand, and with regard to the intended audience, it may be recommended for environmental reasons:

- to implement reusable crockery systems instead of disposable crockery systems;
- to examine whether the implementation of a reusable crockery system is possible where a disposable system is currently implemented and where space requirements and building services (e.g. electrical connections) for dishwashing machines are well suited.
- to examine whether the implementation of a reusable crockery system is possible, if there is a need to decide which system should be implemented (e.g. in the course of renovation or in new facilities);
- not to change from reusable crockery systems to disposable crockery systems if a reusable system is already implemented.

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9. Annex

9.1. Critical Review Report

Critical Review Statement according to ISO 14040 and 14044

of the study

Life cycle comparison of reusable and non-reusable crockery for mass catering in the USA

Conducted by Öko-Institut e.V., Freiburg, Germany

(the "Practitioner")

Performed for

MEIKO Maschinenbau GmbH & Co. KG, Offenburg, Germany

(the "Commissioner")

by

Birgit Grahl (chair)

Terrie Boguski

Ed Morano

10th March 2017

Content

1. Procedural Aspects of the Critical Review

The Critical Review was commissioned by MEIKO Maschinenbau GmbH & Co. KG, Offenburg, Germany MEIKO) 19th January 2015 as a three-stage process. The LCA study was conducted by Öko-Institut e.V. Freiburg, Gemany (Öko-Institut). The reviewers received the First Draft Report of the study 5th September 2015 and the Final Draft Report 13th May 2016.

In both steps of the review process the reviewers sent a list of detailed comments by 21st September 2015 and 30th May 2016 to the practitioner in order to prepare for the respective telephone conferences on 2nd October 2015 and 22nd June 2016. During the conference calls the comments were elaborated by the panel members and discussed with the practitioner in detail. The commissioner was involved in this process. An online model and data check was performed by Terrie Boguski on the 24th May 2016.

The review panel received the Final Report 23rd December 2016 and sent some comments concerning some issues with further need for clarification 6th February 2017 to the practitioner. The review panel received the updated Final Report 4th March 2017. The statements and comments below are based on this final version.

Formally this critical review is a review by “interested parties” (panel method) according to ISO 14040 section 7.3.3 [1] and ISO 14044 section 4.2.3.7 and 6.3 [2] because the study includes comparative assertions of reusable and disposable crockery and is intended to be disclosed to the public.

Despite this title, however, the inclusion of further representatives of "interested parties" is optional and was not explicitly intended in this study. The review panel is neutral with regard to and independent from particular commercial interests. The panel had to be aware of issues relevant to other interested parties, as it was outside the scope of the present project to invite governmental or non-governmental organizations or other interested parties, e.g. competitors or consumers.

The reviewers emphasise the open and constructive atmosphere of the project. All necessary data were presented to the reviewers and all issues were discussed openly. All comments of the panel have been treated by the practitioner with sufficient detail in the final report. The resulting critical review (CR) statement represents the consensus between the reviewers.

Note: The present CR statement is delivered to MEIKO Maschinenbau GmbH & Co. KG (MEIKO). The CR panel cannot be held responsible of the use of its work by any third party. The conclusions of the CR panel cover the full report from the study for MEIKO ” Life cycle comparison of reusable and non-reusable crockery for mass catering in the USA – 4th March 2017" and no other report, extract or publication which may eventually be undertaken. The CR panel conclusions are given with regard to the current state of the art and the information which has been received. The conclusions expressed by the CR panel are specific to the context and content of the present study only and shall not be generalised any further.

2. General Comments

The study investigates the environmental performance of reusable and non-reusable crockery for mass catering in the USA. In the case of reusable crockery, a cleaning process is involved and cleaning in a dishwashing machine is an essential process in the use phase of the product system.

Three different scenarios (hospital cafeteria, school cafeteria, hotel serving breakfast) were investigated. Key criteria for the selection were the market relevance for the US out-of-home food market, as well as the relevance to MEIKO as a manufacturer of professional dishwashing machines. The choice of scenarios is comprehensible and transparently described.

In the goal definition, the intended application and the not intended application are clearly described and thus provide a clear reference framework for the interpretation:

- "The main goal and intended application of the project is an evaluation and comparison of the potential ecological impacts of two types of crockery systems, namely reusable and disposable ones, which are used in stationary catering facilities, throughout the whole life cycle of the crockery items. Against the background described in the introduction of this study, the focus is on the U.S. market. "
- Explicitly it is stated in the study that "the study results refer solely to the analyzed and defined systems and therefore the results are not intended for application in relation to other than the US market (e.g. Europe, Asia) nor in relation to non-stationary or temporarily installed catering facilities."

In order to avoid misinterpretation the panel emphasizes particularly that the results of the study refer exclusively to the investigated scenarios.

Each scenario is defined by specified place settings. Specifications of the disposable and reusable system refer to number of pieces, weight and material. The reference flow is based on these specifications. The substantiations of choices in the study is meaningful, key variables are investigated in sensitivity analyses. Also, the technical specifications of dishwashing machines are clearly defined for the reusable scenarios.

The results of the study are intended to be communicated to planning experts in the field of commercial kitchens, responsible persons or decision-makers in US commercial kitchens and if relevant, competent authorities. Thus, the study contains comparative assertions intended for external communication.

3. Statements by the reviewers as required by ISO 14044

According to ISO 14044 section 6.1
"The critical review process shall ensure that:

- *the methods used to carry out the LCA are consistent with this International Standard,*
- *the methods used to carry out the LCA are scientifically and technically valid,*
- *the data used are appropriate and reasonable in relation to the goal of the study,*
- *the interpretations reflect the limitations identified and the goal of the study and*
- *the study report is transparent and consistent."*

In the following sections 3.1 to 3.5, these items are discussed according to our best judgement and considering the ISO standards 14040 and 14044.

3.1 Consistency of the methods with ISO 14040 and 14044

The study has been performed according to the general structure of LCA required in ISO 14040 and also to the requirements stated in ISO 14044. The structure of the report reflects the general structure of LCA (Goal & Scope definition – Life cycle inventory analysis (LCI) – Life cycle impact assessment (LCIA) and Interpretation). Conclusions and recommendations are clearly presented.

The functional unit and the system boundary are meaningfully defined and discussed thoroughly according to the goal of the study, and the reference flows are transparently deduced from the functional unit. The use of the Umberto NXT Universal software facilitates an appropriate modelling of the systems investigated.

The inventory analysis methods applied are consistent with the ISO standards 14040 and 14044. The choice of impact categories and characterization models is justified and meaningful.

Nine sensitivity analyses addressing system allocation, weight of disposable crockery, transport distances, cooling demand of waste disposable dishes, technical standard of dishwashing machines, electricity mix for dishwashing machines, service life of reusable crockery and variants mixing reusable and disposable crockery were performed to check the robustness of the results. The choice of the considered sensitivity analyses is comprehensible and meaningful within the context of the study. The findings are differentiated, discussed and show the robustness of the results.

The CR panel concludes that the methods used are consistent with the international standards.

3.2 Scientific and technical validity of the methods used

The methods used represent the scientific and technical state-of-the-art for such analyses. Some specific aspects performed in the study are highlighted below:

Within the critical review, an online database and model check was conducted. Terrie Boguski was shown the system models by Öko-Institut to check that the raw materials, product manufacture, transport and end-of-life steps were logically connected and the system models represented the systems described in the report. Material quantities were spot checked. No deficiencies were identified.

The model, software and the organization of the product systems for the LCA were of a high standard and meet the requirements of ISO 14040 and ISO 14044. The session was conducted with full openness and transparency and the practitioner addressed all questions and challenges with competence and completeness.

In ISO 14040/1044 no obligation is included to consider mandatory impact categories but the choice must be substantiated and meaningful and support the goal and scope of the study. The impact categories considered in the study and the characterization models chosen are state of the art. The results are clearly presented in tables and meaningfully discussed. Explicitly, the study justifies that an evaluation of toxicity indicators results is not appropriate because of data asymmetries in the background data sets. Normalized data enable the estimation of relevance of burdens per impact category.

In case of reusable systems, the technical equipment used in the cleaning process is most important concerning energy and water use. The study includes a transparent presentation of technical data of dishwashing machines considered in the study. The data were provided by MEIKO. A critical discussion based on published data concerning substantial differences in energy and water use of dishwashing machines according to their technical standard points out the strong necessity to consider detailed information concerning the technical equipment.

The dependency of environmental burdens due to the considered electricity mix in the use phase of reusable systems is evaluated in the study very carefully in a sensitivity analysis. The results are deeply analyzed and meaningfully interpreted.

All results are discussed considering data and model limitations, completeness and consistency. The conclusions take these limitations into account.

The results of all sensitivity analyses are carefully analyzed, and the reasons and relevance of results are evaluated comprehensively in a critical discussion.

The CR panel concludes that the methods used are scientifically and technically valid.

3.3 Appropriateness of data in relation to the goal of the study

As usually practice for Critical Reviews, the correctness of all items of primary and other data could not be checked but the data used in the study were reviewed for appropriateness and plausibility.

The foreground data used are documented and plausible. The place settings for the three scenarios, which are needed to calculate the reference flow, were deduced based on field studies in the United States in order to generate the data for reusable and disposable crockery as realistically as possible.

The consumption data of the washing machines are based on measurements and calculations performed by MEIKO. The choice of dishwashing machine for each of the three scenarios is reasonable and the measured data provided by MEIKO are plausible.

The background data used are based predominantly on the database of Ecoinvent v3.1 supplemented by meaningful selected and quoted literature. Limitations of the data are adequately discussed. The documentation of the considered data sets increases transparency.

A complete review of every item of data and every calculation in the study is not included in the critical review process. This is not possible because of the amount of data to be considered. Therefore, it was important to examine the data horizontally (general plausibility, plausibility of the relevance of certain impacts to the results) as well as vertically (detailed checks of parts of the calculation model – see chapter 3.2 (data and model check)). The handling of data and sensitivity analyses demonstrate a sufficient robustness of the calculated data. The data and calculation methods were judged to be appropriate for the goal of the study. All data were available for the review panel by request.

Furthermore, it can be stated that no over-interpretation of the data has been detected.

The CR panel concludes that the data used are appropriate and reasonable in relation to the goal of the study.

3.4 Assessment of interpretation referring to limitations and goal of the study

The interpretation is based on a detailed data analysis, is transparently deduced from the results and is meaningfully performed with due regard to the limitations and the goal of the study. Limitations are thoroughly described, and it is particularly emphasised that the results cannot be transferred to other systems than those defined and analyzed the in this study.

Clearly arranged tables and charts including numerical results and contribution analyses are presented so that the interpretation of data is comprehensible. A highly informative annex provides information regarding data (contributional analyses, additional sensitivity analyses and normalization calculation) and cross-comparison of the three assessed scenarios.

The derivation of the conclusions and recommendations is comprehensible from the interpretation undertaken.

The CR panel concludes that the interpretations reflect the limitations identified and the goal of the study.

3.5 Transparency and consistency of study report

The report is clearly presented and follows the specification in ISO 14040 and 14044. The systems analyzed together with the sensitivity analyses are rather complex. Nonetheless the study is transparently structured. The data documentation in respective tables and figures supplement the text and allow a deep understanding of the results. Inconsistencies in the report could not be identified. The line of argument is transparent and comprehensible.

The CP panel concludes that the report is transparent and consistent.

4 Conclusion

The CR panel considers that the study has been conducted according to and in compliance with the ISO standards 14040 and 14044.

References:

[1] DIN EN ISO 14040:2006: Environmental management - Life cycle assessment - Principles and framework

[2] DIN EN ISO 14044:2006: Environmental management - Life cycle assessment - Requirements and guidelines

Heidekamp, 10th March 2017

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9.2. Data Annex

9.2.1. Contributional analyses

9.2.1.1. Hospital scenario

Table 9-1: Contributions per process from the production process of disposable crockery in the hospital scenario

LCIA indicator		Unit	Paper components	Cardboard tray	PP components	PS components	PLA components	Packaging	Production processes	Sum
ReCiPe	ALOP	m^2a	2.0E+04	5.9E+04	7.7E-01	9.0E+00	1.7E+03	2.9E+03	2.9E+03	8.7E+04
	FDP	kg Oil-eq.	1.2E+03	3.0E+03	6.3E+02	6.7E+03	1.3E+03	1.2E+03	3.1E+03	1.7E+04
	NLTP	m^2	1.0E+00	2.0E+00	1.2E-02	1.0E-01	6.2E-01	6.4E-01	1.2E+00	5.6E+00
	TAP100	kg SO_2-eq.	2.4E+01	6.3E+01	2.4E+00	3.7E+01	2.8E+01	1.4E+01	5.0E+01	2.2E+02
	WDP	m^3	2.1E+01	4.0E+01	4.2E-01	1.3E+01	5.7E+02	5.5E+01	5.1E+01	7.5E+02
TRACI	Acidification	moles-H^+-eq.	1.4E+03	3.7E+03	1.4E+02	2.1E+03	1.5E+03	8.3E+02	2.8E+03	1.2E+04
	Ecotoxicity	kg 2,4-D-eq.	1.5E+04	5.0E+04	1.6E+01	3.5E+02	1.7E+03	8.2E+03	3.9E+03	7.8E+04
	Eutrophication	kg N	3.6E+00	7.2E+00	2.2E-01	2.1E+00	6.6E+00	2.0E+00	1.9E+00	2.4E+01
	Global warming	kg CO_2-eq.	4.0E+03	1.0E+04	8.0E+02	1.2E+04	4.8E+03	3.4E+03	1.1E+04	4.6E+04
	Ozone depletion	kg CFC-11-eq.	3.6E-04	9.4E-04	5.6E-06	1.5E-04	2.6E-04	2.2E-04	3.9E-04	2.3E-03
	Photochemical oxidation	kg NOx-eq.	1.5E+01	4.0E+01	1.5E+00	2.1E+01	1.0E+01	8.0E+00	3.3E+01	1.3E+02
	Human health, carc.	kg benzene-eq.	1.3E+01	3.2E+01	6.9E-02	1.8E+00	1.3E+01	7.4E+00	1.7E+01	8.4E+01
	Human health, non-carc.	kg toluene-eq.	8.0E+04	2.4E+05	1.8E+03	2.0E+04	3.2E+04	3.7E+04	4.2E+04	4.5E+05
	Human health, resp. eff.	kg PM2.5-eq.	9.8E+00	2.5E+01	5.3E-01	8.1E+00	9.7E+00	4.7E+00	2.3E+01	8.1E+01
USEtox	Ecotoxicity, total	CTU	4.8E+03	1.3E+04	8.5E+01	1.5E+03	7.6E+03	3.2E+03	2.6E+03	3.3E+04
	Human toxicity, total	CTU	2.9E-03	9.7E-03	1.4E-05	1.9E-04	1.2E-05	7.2E-04	1.1E-03	1.5E-02
CED total		MJ	1.9E+05	5.1E+05	3.0E+04	3.2E+05	1.1E+05	8.4E+04	2.1E+05	1.4E+06

Source: Own calculation

Table 9-2: Contributions per process from the EoL treatment of disposable crockery in the hospital scenario

	LCIA indicator	Unit	Waste graphical paper, incineration	Waste graphical paper, landfill	Waste poly-propylene, incineration	Waste poly-propylene, landfill	Waste poly-styrene, incineration	Waste poly-styrene, landfill	EoL transport	Sum
ReCiPe	ALOP	m^2a	1.3E+00	1.6E+01	3.6E-02	4.3E-01	2.4E-01	2.7E+00	1.3E+00	2.2E+01
	FDP	kg Oil-eq.	2.0E+01	7.6E+01	3.4E-01	2.7E+00	2.2E+00	1.7E+01	1.0E+02	2.2E+02
	NLTP	m^2	-5.7E-03	-5.0E-01	8.4E-05	-2.0E-02	4.3E-04	-1.2E-01	1.2E-01	-5.3E-01
	TAP100	kg SO_2-eq.	7.5E-01	1.7E+00	3.0E-02	3.3E-02	2.0E-01	2.0E-01	2.2E+00	5.2E+00
	WDP	m^3	1.8E+00	8.9E-01	1.2E-01	1.6E-02	7.4E-01	9.8E-02	1.4E-01	3.8E+00
TRACI	Acidification	moles-H^+-eq.	5.0E+01	1.1E+02	2.0E+00	2.1E+00	1.3E+01	1.3E+01	1.5E+02	3.4E+02
	Ecotoxicity	kg 2,4-D-eq.	3.2E+01	3.1E+02	7.8E-01	1.2E+00	6.1E+00	7.8E+00	1.7E+01	3.8E+02
	Eutrophication	kg N	2.2E-01	2.6E+01	2.9E-03	1.7E-02	2.2E-02	1.6E-01	2.3E-01	2.6E+01
	Global warming	kg CO_2-eq.	1.2E+02	1.1E+04	2.9E+02	4.1E+01	2.2E+03	3.1E+02	2.6E+02	1.5E+04
	Ozone depletion	kg CFC-11-eq.	7.3E-06	3.5E-05	2.1E-07	1.2E-06	1.3E-06	7.5E-06	5.5E-05	1.1E-04
	Photochemical oxidation	kg NOx-eq.	1.0E+00	2.7E+00	4.3E-02	3.9E-02	2.9E-01	2.5E-01	3.3E+00	7.6E+00
	Human health, carc.	kg benzene-eq.	1.8E+00	9.6E-01	2.9E-01	6.9E-03	1.8E+00	4.4E-02	7.6E-02	5.0E+00
	Human health, non-carc.	kg toluene-eq.	1.4E+03	4.5E+03	3.2E+02	6.5E+01	2.0E+03	3.7E+02	6.2E+02	9.3E+03
	Human health, resp. eff.	kg PM2.5-eq.	1.3E-01	4.8E-01	4.3E-03	9.7E-03	2.8E-02	6.0E-02	3.6E-01	1.1E+00
USEtox	Ecotoxicity, total	CTU	2.6E+02	4.1E+02	2.5E+01	5.4E+01	1.5E+02	7.4E+01	3.8E+01	1.0E+03
	Human toxicity, total	CTU	1.5E-04	6.8E-05	3.1E-06	5.6E-07	3.2E-05	3.9E-06	5.8E-06	2.7E-04
CED total		MJ	9.6E+02	5.2E+03	1.7E+01	1.3E+02	1.1E+02	8.0E+02	4.7E+03	1.2E+04

Source: Own calculation

Table 9-3: Contributions per process to the dishwashing process of reusable crockery in the hospital scenario

	LCIA indicator	Unit	Tap water	Treatment of wastewater	Chemicals (detergents and rinse aid)	Electricity usage	Sum
ReCiPe	ALOP	m²a	3.1E+00	2.5E+00	3.6E+01	1.1E+03	1.2E+03
	FDP	kg Oil-eq.	1.5E+01	1.7E+01	1.0E+02	5.1E+03	5.2E+03
	NLTP	m^2	1.7E-02	6.6E-03	1.6E-01	1.2E+00	1.4E+00
	TAP100	kg SO_2-eq.	3.9E-01	5.9E-01	2.4E+00	1.1E+02	1.2E+02
	WDP	m³	1.6E+02	8.9E-01	3.9E+00	5.4E+01	2.2E+02
TRACI	Acidification	moles-H^+-eq.	2.2E+01	3.2E+01	1.3E+02	6.3E+03	6.4E+03
	Ecotoxicity	kg 2,4-D-eq.	3.5E+02	1.4E+03	2.0E+02	1.4E+04	1.6E+04
	Eutrophication	kg N	9.1E-03	4.0E+00	1.4E-01	2.0E+00	6.2E+00
	Global warming	kg CO_2-eq.	6.5E+01	7.8E+01	3.7E+02	1.9E+04	1.9E+04
	Ozone depletion	kg CFC-11-eq.	1.2E-06	4.2E-06	2.8E-05	6.0E-04	6.3E-04
	Photochemical oxidation	kg NOx-eq.	1.7E-01	2.8E-01	9.0E-01	3.6E+01	3.7E+01
	Human health, carc.	kg benzene-eq.	1.5E-01	5.1E-01	1.8E+00	2.5E+01	2.7E+01
	Human health, non-carc.	kg toluene-eq.	2.7E+02	5.5E+03	7.5E+03	7.6E+04	8.9E+04
	Human health, resp. eff.	kg PM2.5-eq.	1.2E-01	1.7E-01	7.7E-01	2.4E+01	2.5E+01
USEtox	Ecotoxicity, total	CTU	2.2E+01	5.3E+02	3.5E+02	2.6E+03	3.5E+03
	Human toxicity, total	CTU	7.4E-06	2.4E-04	1.0E-04	5.4E-04	8.9E-04
CED total		MJ	8.0E+02	9.4E+02	5.4E+03	3.3E+05	3.4E+05

Source: Own calculation

9.2.1.2. School scenario

Table 9-4: Contributions per process from the production process of disposable crockery in the school scenario

	LCIA indicator	Unit	PP components	PS components	Packaging	Production processes	Sum
ReCiPe	ALOP	m²a	4.2E+00	3.2E+00	5.6E+02	1.0E+03	1.6E+03
ReCiPe	FDP	kg Oil-eq.	3.4E+03	2.3E+03	2.2E+02	1.1E+03	7.0E+03
ReCiPe	NLTP	m^2	6.2E-02	3.5E-02	1.2E-01	4.4E-01	6.5E-01
ReCiPe	TAP100	kg SO_2-eq.	1.3E+01	1.2E+01	2.7E+00	1.8E+01	4.6E+01
ReCiPe	WDP	m^3	2.3E+00	2.4E+00	1.0E+01	1.8E+01	3.3E+01
TRACI	Acidification	moles-H^+-eq.	7.6E+02	7.1E+02	1.5E+02	1.0E+03	2.7E+03
TRACI	Ecotoxicity	kg 2,4-D-eq.	8.5E+01	1.2E+02	1.6E+03	1.5E+03	3.2E+03
TRACI	Eutrophication	kg N	1.2E+00	9.2E-01	3.7E-01	6.8E-01	3.1E+00
TRACI	Global warming	kg CO_2-eq.	4.3E+03	4.1E+03	6.3E+02	3.9E+03	1.3E+04
TRACI	Ozone depletion	kg CFC-11-eq.	3.0E-05	7.1E-05	4.2E-05	1.4E-04	2.9E-04
TRACI	Photochemical oxidation	kg NOx-eq.	8.3E+00	6.8E+00	1.5E+00	1.3E+01	3.0E+01
TRACI	Human health, carc.	kg benzene-eq.	3.7E-01	6.8E-01	1.4E+00	6.2E+00	8.7E+00
TRACI	Human health, non-carc.	kg toluene-eq.	9.9E+03	7.0E+03	7.0E+03	1.5E+04	3.9E+04
TRACI	Human health, resp. eff.	kg PM2.5-eq.	2.8E+00	2.7E+00	8.8E-01	8.4E+00	1.5E+01
USEtox	Ecotoxicity, total	CTU	4.6E+02	4.9E+02	6.0E+02	9.3E+02	2.5E+03
USEtox	Human toxicity, total	CTU	7.4E-05	6.7E-05	1.4E-04	4.0E-04	6.8E-04
CED total		MJ	1.6E+05	1.1E+05	1.5E+04	7.6E+04	3.6E+05

Source: Own calculation

Table 9-5: Contributions per process from the EoL treatment of disposable crockery in the school scenario

	LCIA indicator	Unit	Waste graphical paper, incineration	Waste graphical paper, landfill	Waste poly-propylene, incineration	Waste poly-propylene, landfill	Waste poly-styrene, incineration	Waste poly-styrene, landfill	EoL transport	Sum
ReCiPe	ALOP	m^2a	4.5E-02	5.6E-01	1.4E-01	1.6E+00	9.1E-02	1.0E+00	7.5E-01	4.3E+00
	FDP	kg Oil-eq.	7.1E-01	2.7E+00	1.3E+00	1.0E+01	8.5E-01	6.4E+00	2.4E+01	4.6E+01
	NLTP	m^2	-2.0E-04	-1.8E-02	3.2E-04	-7.5E-02	1.7E-04	-4.6E-02	2.8E-02	-1.1E-01
	TAP100	kg SO_2-eq.	2.7E-02	6.1E-02	1.1E-01	1.2E-01	7.5E-02	7.8E-02	4.8E-01	9.6E-01
	WDP	m^3	6.4E-02	3.2E-02	4.6E-01	6.0E-02	2.8E-01	3.7E-02	5.0E-02	9.8E-01
TRACI	Acidification	moles-H^+-eq.	1.8E+00	4.0E+00	7.5E+00	7.9E+00	5.0E+00	5.0E+00	3.2E+01	6.3E+01
	Ecotoxicity	kg 2,4-D-eq.	1.1E+00	1.1E+01	2.9E+00	4.4E+00	2.3E+00	3.0E+00	6.0E+00	3.1E+01
	Eutrophication	kg N	7.9E-03	9.1E-01	1.1E-02	6.6E-02	8.3E-03	6.2E-02	4.9E-02	1.1E+00
	Global warming	kg CO_2-eq.	4.3E+00	4.1E+02	1.1E+03	1.6E+02	8.5E+02	1.2E+02	5.9E+01	2.7E+03
	Ozone depletion	kg CFC-11-eq.	2.6E-07	1.2E-06	7.8E-07	4.6E-06	5.1E-07	2.9E-06	1.2E-05	2.3E-05
	Photochemical oxidation	kg NOx-eq.	3.5E-02	9.5E-02	1.6E-01	1.5E-01	1.1E-01	9.5E-02	6.8E-01	1.3E+00
	Human health, carc.	kg benzene-eq.	6.4E-02	3.4E-02	1.1E+00	2.6E-02	7.1E-01	1.7E-02	3.2E-02	2.0E+00
	Human health, non-carc.	kg toluene-eq.	5.0E+01	1.6E+02	1.2E+03	2.5E+02	7.7E+02	1.4E+02	1.9E+02	2.8E+03
	Human health, resp. eff.	kg PM2.5-eq.	4.6E-03	1.7E-02	1.6E-02	3.7E-02	1.1E-02	2.3E-02	8.6E-02	1.9E-01
USEtox	Ecotoxicity, total	CTU	9.3E+00	1.5E+01	9.3E+01	2.0E+02	5.6E+01	2.8E+01	1.1E+01	4.2E+02
	Human toxicity, total	CTU	5.5E-06	2.4E-06	1.2E-05	2.1E-06	1.2E-05	1.5E-06	2.2E-06	3.8E-05
CED total		MJ	3.4E+01	1.8E+02	6.4E+01	4.9E+02	4.2E+01	3.0E+02	1.1E+03	2.2E+03

Source: Own calculation

Table 9-6: Contributions per process to the dishwashing process of reusable crockery in the school scenario

	LCIA indicator	Unit	Tap water	Treatment of wastewater	Chemicals (detergents and rinse aid)	Electricity usage	Sum
ReCiPe	ALOP	m²a	6.4E-01	5.1E-01	1.1E+01	1.6E+02	1.7E+02
	FDP	kg Oil-eq.	3.2E+00	3.6E+00	3.2E+01	7.2E+02	7.6E+02
	NLTP	m^2	3.5E-03	1.4E-03	5.0E-02	1.8E-01	2.3E-01
	TAP100	kg SO_2-eq.	8.1E-02	1.2E-01	7.6E-01	1.6E+01	1.7E+01
	WDP	m³	3.3E+01	1.9E-01	1.2E+00	7.7E+00	4.2E+01
TRACI	Acidification	moles-H^+-eq.	4.6E+00	6.7E+00	4.2E+01	8.8E+02	9.4E+02
	Ecotoxicity	kg 2,4-D-eq.	7.4E+01	3.0E+02	6.2E+01	1.9E+03	2.4E+03
	Eutrophication	kg N	1.9E-03	8.4E-01	4.4E-02	2.8E-01	1.2E+00
	Global warming	kg CO_2-eq.	1.4E+01	1.6E+01	1.2E+02	2.7E+03	2.8E+03
	Ozone depletion	kg CFC-11-eq.	2.4E-07	8.8E-07	8.8E-06	8.4E-05	9.4E-05
	Photochemical oxidation	kg NOx-eq.	3.6E-02	5.8E-02	2.8E-01	5.1E+00	5.4E+00
	Human health, carc.	kg benzene-eq.	3.0E-02	1.1E-01	5.6E-01	3.5E+00	4.2E+00
	Human health, non-carc.	kg toluene-eq.	5.6E+01	1.1E+03	2.4E+03	1.1E+04	1.4E+04
	Human health, resp. eff.	kg PM2.5-eq.	2.6E-02	3.5E-02	2.4E-01	3.4E+00	3.8E+00
USEtox	Ecotoxicity, total	CTU	4.6E+00	1.1E+02	1.1E+02	3.6E+02	5.9E+02
	Human toxicity, total	CTU	1.5E-06	4.9E-05	3.3E-05	7.6E-05	1.6E-04
CED total		MJ	1.7E+02	2.0E+02	1.7E+03	4.7E+04	4.9E+04

Source: Own calculation

9.2.1.3. Hotel scenario

Table 9-7: Contributions per process from the production process of disposable crockery in the hotel scenario

	LCIA indicator	Unit	Paper components	PP components	PS components	Packaging	Production processes	Sum
ReCiPe	ALOP	m^2a	8.5E+03	7.1E-01	4.1E-01	2.9E+02	5.3E+02	9.4E+03
	FDP	kg Oil-eq.	4.0E+02	5.8E+02	3.1E+02	1.2E+02	5.4E+02	1.9E+03
	NLTP	m^2	3.2E-01	1.1E-02	4.7E-03	6.3E-02	2.1E-01	6.1E-01
	TAP100	kg SO_2-eq.	8.7E+00	2.2E+00	1.8E+00	1.4E+00	8.3E+00	2.2E+01
	WDP	m^3	6.7E+00	3.9E-01	7.1E-01	5.5E+00	9.1E+00	2.2E+01
TRACI	Acidification	moles-H^+-eq.	5.1E+02	1.3E+02	1.0E+02	8.1E+01	4.8E+02	1.3E+03
	Ecotoxicity	kg 2,4-D-eq.	7.1E+03	1.4E+01	1.6E+01	8.2E+02	6.5E+02	8.6E+03
	Eutrophication	kg N	1.0E+00	2.0E-01	8.9E-02	2.0E-01	3.4E-01	1.8E+00
	Global warming	kg CO_2-eq.	1.4E+03	7.3E+02	5.7E+02	3.3E+02	1.8E+03	4.9E+03
	Ozone depletion	kg CFC-11-eq.	1.3E-04	5.1E-06	5.8E-06	2.2E-05	6.8E-05	2.3E-04
	Photochemical oxidation	kg NOx-eq.	5.6E+00	1.4E+00	9.8E-01	7.9E-01	4.1E+00	1.3E+01
	Human health, carc.	kg benzene-eq.	4.5E+00	6.3E-02	8.4E-02	7.4E-01	2.9E+00	8.3E+00
	Human health, non-carc.	kg toluene-eq.	3.3E+04	1.7E+03	9.5E+02	3.7E+03	7.3E+03	4.7E+04
	Human health, resp. eff.	kg PM2.5-eq.	3.5E+00	4.8E-01	3.9E-01	4.7E-01	4.0E+00	8.8E+00
USEtox	Ecotoxicity, total	CTU	1.8E+03	7.8E+01	7.0E+01	3.2E+02	4.5E+02	2.7E+03
	Human toxicity, total	CTU	1.4E-03	1.3E-05	8.7E-06	7.2E-05	2.0E-04	1.7E-03
CED total		MJ	7.2E+04	2.8E+04	1.5E+04	8.2E+03	3.8E+04	1.6E+05

Source: Own calculation

Table 9-8: Contributions per process from the EoL treatment of disposable crockery in the hotel scenario

	LCIA indicator	Unit	Waste graphical paper, incineration	Waste graphical paper, landfill	Waste poly-propylene, incineration	Waste poly-propylene, landfill	Waste poly-styrene, incineration	Waste poly-styrene, landfill	EoL transport	Sum
ReCiPe	ALOP	m²a	1.3E-01	1.6E+00	2.4E-02	2.9E-01	1.1E-02	1.3E-01	3.8E-01	2.6E+00
	FDP	kg Oil-eq.	2.0E+00	7.7E+00	2.3E-01	1.8E+00	1.0E-01	7.9E-01	1.2E+01	2.5E+01
	NLTP	m^2	-5.7E-04	-5.1E-02	5.6E-05	-1.3E-02	2.0E-05	-5.7E-03	1.4E-02	-5.6E-02
	TAP100	kg SO_2-eq.	7.6E-02	1.7E-01	2.0E-02	2.2E-02	9.2E-03	9.6E-03	2.4E-01	5.5E-01
	WDP	m³	1.8E-01	9.1E-02	8.0E-02	1.0E-02	3.5E-02	4.6E-03	2.5E-02	4.3E-01
TRACI	Acidification	moles-H^+-eq.	5.1E+00	1.1E+01	1.3E+00	1.4E+00	6.2E-01	6.1E-01	1.6E+01	3.7E+01
	Ecotoxicity	kg 2,4-D-eq.	3.2E+00	3.1E+01	5.1E-01	7.8E-01	2.9E-01	3.7E-01	3.0E+00	4.0E+01
	Eutrophication	kg N	2.3E-02	2.6E+00	2.0E-03	1.2E-02	1.0E-03	7.6E-03	2.5E-02	2.7E+00
	Global warming	kg CO_2-eq.	1.2E+01	1.2E+03	1.9E+02	2.7E+01	1.0E+02	1.4E+01	3.0E+01	1.5E+03
	Ozone depletion	kg CFC-11-eq.	7.4E-07	3.6E-06	1.4E-07	8.1E-07	6.3E-08	3.5E-07	6.3E-06	1.2E-05
	Photochemical oxidation	kg NOx-eq.	1.0E-01	2.7E-01	2.9E-02	2.6E-02	1.3E-02	1.2E-02	3.5E-01	8.0E-01
	Human health, carc.	kg benzene-eq.	1.8E-01	9.8E-02	2.0E-01	4.6E-03	8.7E-02	2.1E-03	1.6E-02	5.9E-01
	Human health, non-carc.	kg toluene-eq.	1.4E+02	4.6E+02	2.1E+02	4.3E+01	9.5E+01	1.7E+01	9.7E+01	1.1E+03
	Human health, resp. eff.	kg PM2.5-eq.	1.3E-02	4.9E-02	2.8E-03	6.4E-03	1.3E-03	2.8E-03	4.3E-02	1.2E-01
USEtox	Ecotoxicity, total	CTU	2.7E+01	4.2E+01	1.6E+01	3.6E+01	6.9E+00	3.5E+00	5.6E+00	1.4E+02
	Human toxicity, total	CTU	1.6E-05	6.9E-06	2.0E-06	3.7E-07	1.5E-06	1.8E-07	1.1E-06	2.8E-05
CED total		MJ	9.7E+01	5.3E+02	1.1E+01	8.5E+01	5.2E+00	3.7E+01	5.5E+02	1.3E+03

Source: Own calculation

Table 9-9: Contributions per process to the dishwashing process of reusable crockery in the hotel scenario

	LCIA indicator	Unit	Tap water	Treatment of wastewater	Chemicals (detergents and rinse aid)	Electricity usage	Sum
ReCiPe	ALOP	m²a	1.0E+00	8.3E-01	1.8E+01	2.3E+02	2.5E+02
	FDP	kg Oil-eq.	5.1E+00	5.8E+00	5.1E+01	1.0E+03	1.1E+03
	NLTP	m^2	5.6E-03	2.2E-03	8.0E-02	2.5E-01	3.4E-01
	TAP100	kg SO_2-eq.	1.3E-01	2.0E-01	1.2E+00	2.3E+01	2.4E+01
	WDP	m³	5.2E+01	3.0E-01	2.0E+00	1.1E+01	6.6E+01
TRACI	Acidification	moles-H^+-eq.	7.4E+00	1.1E+01	6.8E+01	1.3E+03	1.4E+03
	Ecotoxicity	kg 2,4-D-eq.	1.2E+02	4.8E+02	9.9E+01	2.8E+03	3.5E+03
	Eutrophication	kg N	3.1E-03	1.4E+00	7.1E-02	4.1E-01	1.8E+00
	Global warming	kg CO_2-eq.	2.2E+01	2.6E+01	1.9E+02	3.8E+03	4.1E+03
	Ozone depletion	kg CFC-11-eq.	3.9E-07	1.4E-06	1.4E-05	1.2E-04	1.4E-04
	Photochemical oxidation	kg NOx-eq.	5.8E-02	9.3E-02	4.5E-01	7.3E+00	7.9E+00
	Human health, carc.	kg benzene-eq.	4.9E-02	1.7E-01	9.0E-01	5.0E+00	6.1E+00
	Human health, non-carc.	kg toluene-eq.	9.0E+01	1.8E+03	3.8E+03	1.5E+04	2.1E+04
	Human health, resp. eff.	kg PM2.5-eq.	4.1E-02	5.7E-02	3.9E-01	5.0E+00	5.5E+00
USEtox	Ecotoxicity, total	CTU	7.4E+00	1.8E+02	1.8E+02	5.2E+02	8.9E+02
	Human toxicity, total	CTU	2.5E-06	7.9E-05	5.3E-05	1.1E-04	2.4E-04
CED total		MJ	2.7E+02	3.1E+02	2.7E+03	6.7E+04	7.1E+04

Source: Own calculation

9.2.2. Additional sensitivity analyses

9.2.2.1. Sensitivity Analysis 2

Table 9-10: Sensitivity 2: Shorter and longer transport distances for distribution of disposable crockery in school scenario

LCIA indicator		Unit	S2_B1	S2_B2	BC_disposable	BC_reusable
ReCiPe	ALOP	m²a	100%	100%	100%	12%
	FDP	kg Oil-eq.	99%	101%	100%	11%
	NLTP	m^2	89%	112%	100%	30%
	TAP100	kg SO_2-eq.	98%	102%	100%	35%
	WDP	m³	99%	101%	100%	122%
TRACI	Acidification	moles-H+-eq.	98%	102%	100%	34%
	Ecotoxicity	kg 2,4-D-eq.	99%	101%	100%	77%
	Eutrophication	kg N	97%	103%	100%	26%
	Global warming	kg CO_2-eq.	99%	102%	100%	19%
	Ozone depletion	kg CFC-11-eq.	90%	110%	100%	23%
	Photochemical oxidation	kg NOx-eq.	96%	104%	100%	17%
	Human health, carc.	kg benzene-eq.	99%	101%	100%	52%
	Human health, non-carc.	kg toluene-eq.	99%	101%	100%	38%
	Human health, resp. Eff.	kg PM2.5-eq.	99%	101%	100%	26%
USEtox	Ecotoxicity, total	CTU	99%	101%	100%	24%
	Human toxicity, total	CTU	99%	101%	100%	27%
CED total		MJ	99%	101%	100%	14%

Source: Own calculation

Table 9-11: Sensitivity 2: Shorter and longer transport distances for distribution of disposable crockery in hotel scenario

LCIA indicator		Unit	S2_C1	S2_C2	BC_disposable	BC_reusable
ReCiPe	ALOP	m²a	100%	100%	100%	3%
	FDP	kg Oil-eq.	98%	102%	100%	56%
	NLTP	m^2	93%	107%	100%	52%
	TAP100	kg SO_2-eq.	98%	102%	100%	107%
	WDP	m³	100%	100%	100%	291%
TRACI	Acidification	moles-H+-eq.	98%	103%	100%	102%
	Ecotoxicity	kg 2,4-D-eq.	100%	100%	100%	42%
	Eutrophication	kg N	99%	101%	100%	39%
	Global warming	kg CO_2-eq.	98%	102%	100%	64%

	LCIA indicator	Unit	S2_C1	S2_C2	BC_disposable	BC_reusable
	Ozone depletion	kg CFC-11-eq.	93%	108%	100%	48%
	Photochemical oxidation	kg NOx-eq.	96%	104%	100%	54%
	Human health, carc.	kg benzene-eq.	99%	101%	100%	79%
	Human health, non-carc.	kg toluene-eq.	100%	100%	100%	47%
	Human health, resp. Eff.	kg PM2.5-eq.	99%	101%	100%	65%
USEtox	Ecotoxicity, total	CTU	99%	101%	100%	34%
USEtox	Human toxicity, total	CTU	100%	100%	100%	16%
CED total		MJ	99%	101%	100%	45%

Source: Own calculation

9.2.2.2. Sensitivity Analysis 4

Table 9-12: Sensitivity 4: Regarding a higher energy demand for washing of reusable dishes in the school scenario

	LCIA indicator	Unit	S4_school	BC_reusable	BC_disposable
ReCiPe	ALOP	m²a	109%	100%	850%
ReCiPe	FDP	kg Oil-eq.	109%	100%	876%
ReCiPe	NLTP	m^2	108%	100%	338%
ReCiPe	TAP100	kg SO_2-eq.	109%	100%	285%
ReCiPe	WDP	m³	102%	100%	82%
TRACI	Acidification	moles-H+-eq.	109%	100%	296%
TRACI	Ecotoxicity	kg 2,4-D-eq.	108%	100%	130%
TRACI	Eutrophication	kg N	102%	100%	381%
TRACI	Global warming	kg CO_2-eq.	109%	100%	540%
TRACI	Ozone depletion	kg CFC-11-eq.	109%	100%	439%
TRACI	Photochemical oxidation	kg NOx-eq.	109%	100%	599%
TRACI	Human health, carc.	kg benzene-eq.	106%	100%	194%
TRACI	Human health, non-carc.	kg toluene-eq.	107%	100%	264%
TRACI	Human health, resp. eff.	kg PM2.5-eq.	109%	100%	379%
USEtox	Ecotoxicity, total	CTU	105%	100%	424%
USEtox	Human toxicity, total	CTU	104%	100%	369%
CED total		MJ	109%	100%	711%

Source: Own calculation

9.2.2.3. Sensitivity Analysis 6

Table 9-13: Sensitivity 6: Higher and lower average service life of reusable crockery in school scenario

LCIA indicator		Unit	S6_B1	S6_B2	BC_reus	BC_disp
ReCiPe	ALOP	m²a	102%	97%	100%	850%
	FDP	kg Oil-eq.	103%	96%	100%	876%
	NLTP	m^2	102%	98%	100%	338%
	TAP100	kg SO_2-eq.	101%	98%	100%	285%
	WDP	m³	100%	99%	100%	82%
TRACI	Acidification	moles-H+-eq.	101%	98%	100%	296%
	Ecotoxicity	kg 2,4-D-eq.	101%	99%	100%	130%
	Eutrophication	kg N	101%	99%	100%	381%
	Global warming	kg CO_2-eq.	102%	98%	100%	540%
	Ozone depletion	kg CFC-11-eq.	102%	98%	100%	439%
	Photochemical oxidation	kg NOx-eq.	102%	97%	100%	599%
	Human health, carc.	kg benzene-eq.	108%	90%	100%	194%
	Human health, non-carc.	kg toluene-eq.	104%	95%	100%	264%
	Human health, resp. eff.	kg PM2.5-eq.	103%	97%	100%	379%
USEtox	Ecotoxicity, total	CTU	105%	93%	100%	424%
	Human toxicity, total	CTU	107%	92%	100%	369%
CED total		MJ	102%	97%	100%	711%

Source: Own calculation

Table 9-14: Sensitivity 6: Higher and lower average service life of reusable crockery in hotel scenario

LCIA indicator		Unit	S6_C1	S6_C2	BC_reus	BC_disp
ReCiPe	ALOP	m²a	101%	98%	100%	3557%
	FDP	kg Oil-eq.	102%	98%	100%	180%
	NLTP	m^2	102%	98%	100%	192%
	TAP100	kg SO_2-eq.	102%	98%	100%	93%
	WDP	m³	100%	100%	100%	34%
TRACI	Acidification	moles-H+-eq.	102%	98%	100%	98%
	Ecotoxicity	kg 2,4-D-eq.	101%	98%	100%	237%
	Eutrophication	kg N	101%	99%	100%	253%
	Global warming	kg CO_2-eq.	102%	98%	100%	155%
	Ozone depletion	kg CFC-11-eq.	102%	97%	100%	208%

LCIA indicator		Unit	S6_C1	S6_C2	BC_reus	BC_disp
	Photochemical oxidation	kg NOx-eq.	102%	98%	100%	187%
	Human health, carc.	kg benzene-eq.	104%	95%	100%	127%
	Human health, non-carc.	kg toluene-eq.	102%	97%	100%	213%
	Human health, resp. eff.	kg PM2.5-eq.	102%	97%	100%	154%
USEtox	Ecotoxicity, total	CTU	103%	97%	100%	295%
USEtox	Human toxicity, total	CTU	103%	96%	100%	630%
CED total		MJ	102%	98%	100%	224%

Source: Own calculation

9.2.3. Normalization Calculation

The results of the normalization for the hospital scenario are given in Table 9-15.

Table 9-15: Normalization for the LCIA results of the hospital scenario

Impact category	Unit	Impact per year	Impact per person	Base case hospital [abs.]		Hospital share per year [share BC of total/y]		Hospital person equiv. [share BC of person/y]	
				single-use	multi-use	single-use	multi-use	single -use	multi -use
Ecotoxicity-non-metals	CTU-eq.	2.30E+10	7.60E+01						
Ecotox-metals	CTU-eq.	3.30E+12	1.10E+04						
Sum Ecotox_total	CTU	3.32E+12	1.11E+04	3.52E+04	4.19E+03	1.06E-08	1.26E-09	3.2	0.4
Carcinog.-non-metals	CTUcanc.	1.70E+03	5.50E-06						
Carcinog.-metals	CTUcanc.	1.40E+04	4.50E-05						
non-carc-non-metal	CTUnon-canc.	1.10E+04	3.70E-05						
non-carc-metal	CTUcanc.	3.10E+05	1.00E-03						
Sum Human-tox_total	CTU	3.37E+05	1.09E-03	1.57E-02	1.06E-03	4.65E-08	3.14E-09	14.4	1.0
Global Warming	kg CO_2eq	7.40E+12	2.40E+04	5.24E+04	2.13E+04	7.08E-09	2.88E-09	2.2	0.9
Ozone Depletion	kg CFC-11-eq.	4.90E+07	1.60E-01	2.91E-03	7.26E-04	5.94E-11	1.48E-11	0.018	0.005
Acidification	kg SO_2-eq.	2.80E+10	9.10E+01	2.13E+02	1.27E+02	7.59E-09	4.54E-09	2.3	1.4
Eutrophica-tion	kg N-eq.	6.60E+09	2.20E+01	3.50E+01	6.58E+00	5.30E-09	9.96E-10	1.6	0.3
Photochem. Ozone Formation	kg O_3-eq.	4.20E+11	1.40E+03	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Respiratory effects	kg PM2.5-eq.	7.40E+09	2.40E+01	7.67E+01	2.87E+01	1.04E-08	3.88E-09	3.2	1.2
Fossil fuel depletion	MJ surplus	5.30E+12	1.70E+04	1.48E+06	3.77E+05	2.80E-07	7.12E-08	87.3	22.2

Source: Own calculation based on Ryberg et al. (2013)

The results of the normalization for the school scenario are given in Table 9-16.

Table 9-16: Normalization for the LCIA results of the school scenario

Impact category	Unit	Impact per year	Impact per person	Base case school [abs.]		School share per year [share BC of total/y]		School person equiv. [share BC of person/y]	
				single-use	multi-use	single-use	multi-use	single-use	multi-use
Ecotoxicity-non-metals	CTUe	2.30E+10	7.60E+01						
Ecotox-metals	CTUe	3.30E+12	1.10E+04						
Sum Eco-tox_total	CTU	3.32E+12	1.11E+04	2.99E+03	7.99E+02	9.01E-10	2.40E-10	0.3	0.07
Carcinog.-non-metals	CTUcanc.	1.70E+03	5.50E-06						
Carcinog.-metals	CTUcanc.	1.40E+04	4.50E-05						
non-carc-non-metal	CTUnon-canc.	1.10E+04	3.70E-05						
non-carc-metal	CTUcanc.	3.10E+05	1.00E-03						
Sum Human-tox_total	CTU	3.37E+05	1.09E-03	7.14E-04	2.24E-04	2.12E-09	6.65E-10	0.7	0.2
Global Warming	kg CO_2-eq.	7.40E+12	2.40E+04	1.66E+04	3.19E+03	2.25E-09	4.31E-10	0.7	0.13
Ozone Depletion	kg CFC-11-eq.	4.90E+07	1.60E-01	4.37E-04	1.11E-04	8.91E-12	2.27E-12	0.003	0.001
Acidification	kg SO_2-eq.	2.80E+10	9.10E+01	4.93E+01	1.87E+01	1.76E-09	6.68E-10	0.5	0.2
Eutrophi-cation	kg N-eq.	6.60E+09	2.20E+01	3.89E+00	1.29E+00	5.90E-10	1.96E-10	0.2	0.06
Photochem. Ozone Formation	kg O_3-eq.	4.20E+11	1.40E+03	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Respiratory effects	kg PM2.5-eq.	7.40E+09	2.40E+01	1.49E+01	1.29E+00	2.02E-09	1.75E-10	0.6	0.05
Fossil fuel depletion	MJ surplus	5.30E+12	1.70E+04	3.80E+05	5.57E+04	7.18E-08	1.05E-08	22.4	3.3

Source: own calculation

The results of the normalization for the hotel scenario are given in Table 9-17.

Table 9-17: Normalization for the LCIA results of the hotel scenario

Impact category	Unit	Impact per year	Impact per person	Base case hotel [abs.]		Hotel share per year [share BC of total/y]		Hotel person equiv. [share BC of person/y]	
				single use	multi-use	single-use	multi-use	single-use	multi-use
Ecotoxicity-non-metals	CTUe	2.30E+10	7.60E+01						
Ecotox-metals	CTUe	3.30E+12	1.10E+04						
Sum Eco-tox_total	CTU	3.32E+12	1.11E+04	2.20E+03	9.71E+02	6.62E-10	2.92E-10	0.2	0.09
Carcinog.-non-metals	CTUcanc.	1.70E+03	5.50E-06						
Carcinog.-metals	CTUcanc.	1.40E+04	4.50E-05						
non-carc-non-metal	CTUnon-canc.	1.10E+04	3.70E-05						
non-carc-metal	CTUcanc.	3.10E+05	1.00E-03						
Sum Human-tox_total	CTU	3.37E+05	1.09E-03	1.33E-03	2.71E-04	3.96E-09	8.05E-10	1.2	0.2
Global Warming	kg CO_2eq	7.40E+12	2.40E+04	4.40E+03	4.26E+03	5.95E-10	5.75E-10	0.2	0.2
Ozone Depletion	kg CFC-11eq	4.90E+07	1.60E-01	2.25E-04	1.46E-04	4.59E-12	2.99E-12	0.001	0.001
Acidification	kg SO_2-eq.	2.80E+10	9.10E+01	1.68E+01	2.56E+01	6.02E-10	9.14E-10	0.2	0.3
Eutrophi-cation	kg N-eq.	6.60E+09	2.20E+01	2.46E+00	1.86E+00	3.72E-10	2.82E-10	0.11	0.08
Photochem. Ozone Formation	kg O_3-eq.	4.20E+11	1.40E+03	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Respiratory effects	kg PM2.5-eq.	7.40E+09	2.40E+01	6.39E+00	5.84E+00	8.63E-10	7.90E-10	0.3	0.2
Fossil fuel depletion	MJ surplus	5.30E+12	1.70E+04	1.22E+05	7.35E+04	2.29E-08	1.39E-08	7.1	4.3

Source: Own calculation based on Ryberg et al. (2013)

9.3. Cross-comparison of the three assessed scenarios

Even though a direct or cross-comparison of the three assesses scenarios is of little significance, because of the different functional units or respectively different reference flows, the tabular summary was relevant for the review process. For reasons of checking plausibility, a cross-scenario comparison shows that even though the overall material flow is lowest for the school scenario as compared to the hotel scenario, some of the absolute impact indicator results, at least regarding the disposable system, show higher values than for the hotel scenario. More details on contributions a plausibility check are therefore discussed in the following sections.

The assessed scenarios differ as well as with regard to the meals served per year as well as with regard to the material composition of crockery items. In order to be able to compare the LCIA results of all three scenarios, Table 9-18 gives an overview of the assessed mass flows in the compared scenarios, serving as a starting point for cross-scenario analyses below.

Table 9-18: Overview comparison regarding mass flows in compared scenarios

		Scenario 1: hospital	Scenario 2: school	Scenario 3: breakfast hotel	Hospital/ school	School/ hotel
	Meals per year	146,000	90,000	38,325	162%	235%
Disposable	Mass per FU (kg)	17,375	3,465	1,752	501%	198%
Reusable		252	38	39	669%	96%

Source: Own calculation

With regard to the comparison of data in Table 9-18, and as mentioned above, it has to be kept in mind that a scenario-specific place setting has been defined for each scenario, and that also the number of meals served per year varies depending on the scenario. The fundamental assumption, according to which a larger material flow per functional unit is reflected in higher overall impact indicator results, therefore has not materialized in all three scenarios of the disposable system. This is due to the fact that the materials of which the place setting components are made of, as well as material-related environmental burdens, differ between the school and the hotel scenarios.

Table 9-19 gives an overview comparison of the LCIA results in the compared scenarios, supplemented by the presentation of cross-scenario ratios in the last two columns of the table.

Table 9-19: Overview comparison regarding LCIA results in compared scenarios

	LCIA indicator	Unit	System	Hospital	School	Hotel	Hospital/ school	School/ hotel
ReCiPe	ALOP	m^2a	disposable	90,700	1,520	7,330	5959%	21%
			reusable	1,310	198	263	659%	75%
	FDP	kg Oil-eq.	disposable	17,700	7,470	1,490	238%	500%
			reusable	5,940	881	1,150	674%	77%
	NLTP	m^2	disposable	6.39	0.78	0.51	820%	151%
			reusable	1.63	0.27	0.36	606%	75%
	TAP	kg SO_2-eq.	disposable	213	48	17	442%	285%
			reusable	127	19	26	679%	73%
	WDP	m^3	disposable	739	32	16	2313%	197%
			reusable	221	45	66	495%	67%
TRACI	Acidification	moles-H+-eq.	disposable	12,300	2,800	990	441%	283%
			reusable	7,100	1,050	1,430	679%	73%
	Ecotoxicity	kg 2,4-D-eq.	disposable	79,800	3,020	6,600	2640%	46%
			reusable	16,800	2,630	3,630	637%	73%

LCIA indicator		Unit	System	Hospital	School	Hotel	Hospital/ school	School/ hotel
	Eutrophication	kg N	disposable	35	4	2	904%	158%
			reusable	6.58	1.29	1.86	509%	70%
	Global warming	kg CO_2-eq.	disposable	52,400	16,400	4,400	319%	373%
			reusable	21,300	3,190	4,260	669%	75%
	Ozone depletion	kg CFC-11-eq.	disposable	2.9E-03	4.3E-04	2.3E-04	677%	191%
			reusable	7.3E-04	1.1E-04	1.5E-04	653%	76%
	Photochemical oxidation	kg NOx-eq.	disposable	139	32	11	435%	284%
			reusable	41	6	8	661%	75%
	Human health, carc.	kg benzene-eq.	disposable	89	11	7	840%	156%
			reusable	33	6	7	522%	89%
	Human health, non-carc.	kg toluene-eq.	disposable	471,000	42,700	36,500	1103%	117%
			reusable	101,000	17,800	22,800	565%	78%
	Human health, resp. Eff.	kg PM2.5-eq.	disposable	77	15	6	523%	230%
			reusable	29	4	6	651%	75%
USEtox	Ecotoxicity, total	CTU	disposable	35,200	2,950	2,200	1192%	134%
			reusable	4,190	799	971	524%	82%
	Human toxicity, total	CTU	disposable	1.6E-02	7.1E-04	1.3E-03	2219%	53%
			reusable	1.1E-03	2.2E-04	2.7E-04	472%	83%
CED total		MJ	disposable	1,484,000	380,000	122,000	390%	313%
			reusable	377,000	55,700	73,500	677%	76%

Source: Own calculation

Generally spoken, the above-mentioned influence of diverging results, deviating from the assumption that higher overall material flows also reflect in higher LCIA results, is especially of interest when comparing the results of the disposable system scenarios.

Results for the three reusable scenarios do not differ from the above-mentioned general assumption to such a large extent, as the LCIA results of all reusable systems is dominantly driven by the contributions from the use phase and due to the fact that the environmental burdens from the dishwashing process do not differ as much as the variations in numbers of meals served per year and variations in the composition of the assessed place setting in the disposable scenarios.

Overall, the LCIA results for the two hospital scenarios (both disposable and reusable) show the highest potential environmental impacts, compared to the two other scenarios. It should be noted that the comparison of the reusable scenarios hospital and school, shows by factor 5-7 higher impacts for the hospital scenario, reflecting fairly well the differences in the overall mass flows per functional unit (6.4 times higher for hospital scenario than for school scenario) in the respective scenarios. Results show a quite uniform image over all assessed impact indicators. A significant divergence is only given for the WDP. This is mainly due to the different type of dishwashing machines (resp. the diverging water demand) of the machines applied in the respective scenarios. The water demand for the Hob-machine in scenarios school and hotel is slightly higher than for the band machine applied in the hospital scenario.

Another impact indicator showing broader deviations from the overall arithmetic of results is the indicator USEtox humantox. Here it is not directly obvious which LCI flows cause to the deviation. In-depth analysis of contributions to impact indicator results shows, that the specific contribution of the chemicals (detergents and rinse aid) in the hospital scenario contributes 10% to the USEtox humantox result of the dishwashing results, while the chemicals in the school scenario contribute by 20% to the indicator results of the dishwashing process.

Comparing the disposable scenarios hospital and school, results for LCIA overall impact indicators are less conclusive (at least in terms of differences between the compared systems).

Strong upward discrepancies in the ratio disposable hospital versus disposable school arise for the impact indicators ALOP, NLTP; WDP, ecotoxicity, Usetox ecotox, eutrophication, human health carcinogenics and human health non-carcinogenics. As regards the land use indicators and the WDP, this is due to the fact that in the hospital scenario a higher relative share of bio-based raw materials are used for the production of crockery items. Regarding the toxicity-related indicators, detailed analyses showed that the strong upward discrepancies are also caused mainly by the impacts from paper-based crockery items, and particularly by the cardboard tray.

Strong downward discrepancies in the ratio disposable hospital versus disposable school arise for the impact indicators FDP, GWP, CED. Here, the comparably high share of mineral oil based products, both in material provision and even more in the course of the end of life treatment contributes to the indicator results in the school scenario, yielding in a decreased ratio comparing disposable hospital and school.

Comparing the reusable scenarios school and hotel, in any case the hotel scenario shows higher impact indicator results. This can be explained by the comparable reduced place setting (only compartment tray and cutlery) in schools, versus several crockery items in the hotel scenario (e.g. two plates, coffee cup and drink cup, cutlery).

This also applies regarding the FDP for the comparison of the disposable scenarios for school and hotel. As it has been mentioned above the FDP is mainly driven by the mineral oil based products, while the paper-based crockery items in the hotel scenario show a less specific FDP. Regarding the indicators NLTP, TAP, acidification and respiratory effects, result arithmetic is similar, but not as clear as for the FDP. It should be noted that for some of the assessed impact indictors, results for the hotel scenario are even higher than for the school scenario. So for example the hotel results for the disposable system for ALOP, ecotoxicity and USETox humantox are 2-5 times higher, than for the disposable system in the school scenario. As the contributional analyses showed, this is once more, due to the specific differences between the mainly paper product-based hotel place setting compared to the mainly mineral oil product-based place setting in the disposable school scenario.