Applying streamlined LCA to assess the environmental impact of the hotel branch

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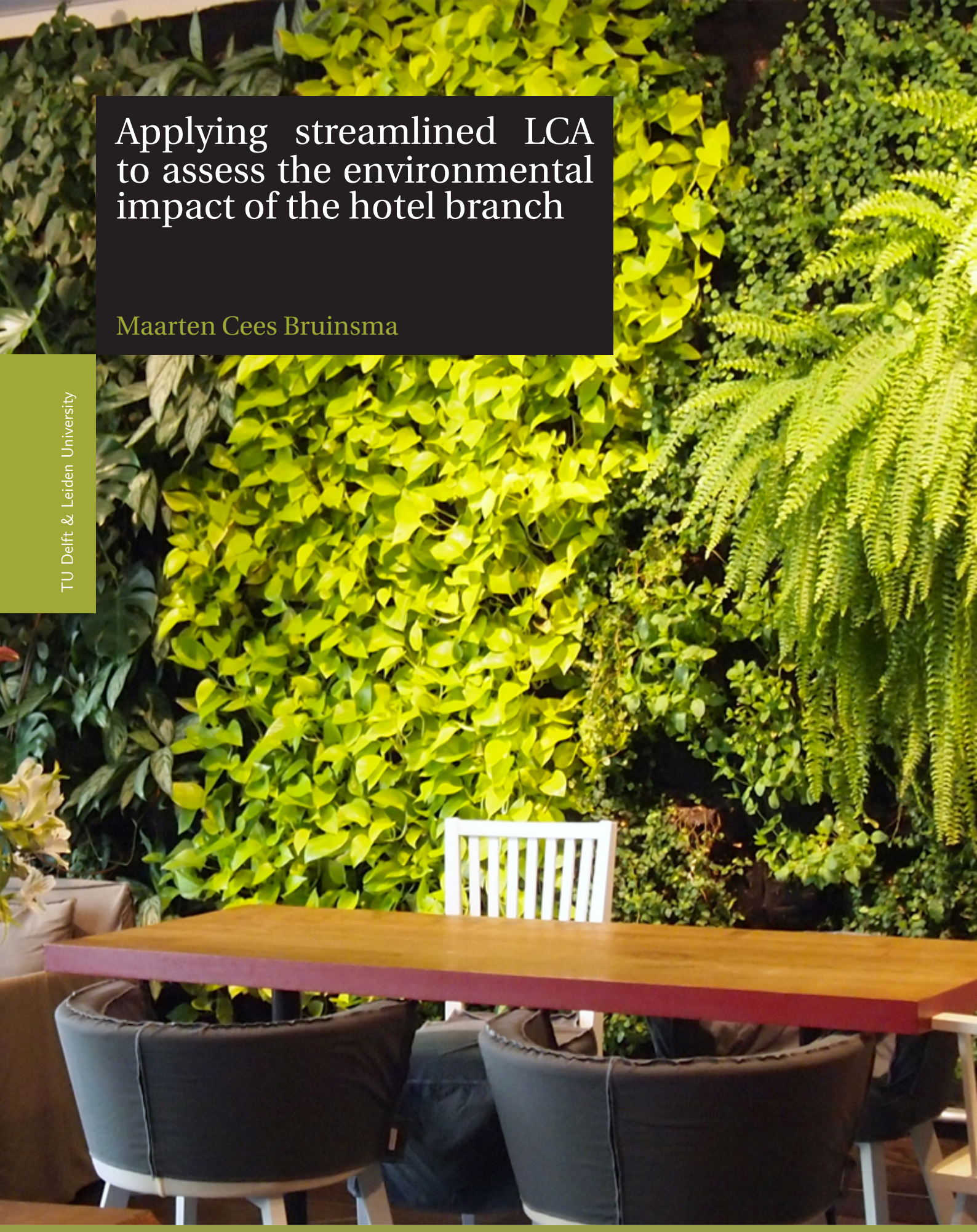

MSc Study Programme Industrial Ecology

CONSCIOUS HOTELS

TU Delft Delft University of Technology

Universiteit Leiden

Applying streamlined LCA to assess the environmental impact of the hotel branch

MASTER THESIS

by

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Cover photo: Conscious Vondelpark Hotel lobby
Retrieved from: `http://www.degroenemeisjes.nl/wp-content/uploads/P5044563.jpg` *Conscious*

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ABSTRACT

The tertiary sector of the economy is generally not perceived to be associated with high environmental impacts. Providing services does not appear to result in direct emissions, but in fact the environmental impact of most services is much higher than seems at first glance. Contrary to other economic sectors, such as the secondary (manufacturing) sector, most emissions of these complex services do not occur during their operation, but are predominantly associated with their supply chain. The environmental impact is therefore hidden from plain view, making them less tangible.

Most modern developed countries have service-based economies, where the tertiary sector makes up two thirds or more of the economy. As such, due to its sheer size alone the environmental impact of this sector is high. These impacts are already considered to some extent, but efforts to uncover or reduce them are often limited to the operation of services and the consumption of utilities such as electricity, and usually consider little other impact categories besides climate change. A large share of the environmental impacts are therefore not taken into account, and the potential to further reduce the impact of the tertiary sector therefore appears to be high.

In order to improve the environmental impact of the tertiary sector a holistic approach has to be adopted, as insight must be gained into the supply chain of services, in other words their life-cycle, rather than just their operation. By uncovering the impact of life-cycle processes beyond the operation of services, the origins of the environmental impact of services can be uncovered. As such, efforts to reduce these impacts can be aimed at those processes which offer the most opportunity, increasing the effectiveness of efforts and additionally preventing problem shifting between processes.

During this thesis an attempt has been made to uncover the environmental impact of complex services within the tertiary sector by using Life Cycle Assessment (LCA). LCA offers the opportunity to investigate the environmental impact of both the operation and life-cycle processes of systems, and measures their impact on several impact categories. As such it provides the holistic insight necessary to uncover the environmental impact of services in the hotel branch, which little other methods or techniques can offer.
The thesis has been focused on the hotel branch, as not all services could be investigated at once. This choice has been made since hotels are present in high numbers throughout the world, make high use of many products, utilities and activities, and often possess extensive documentation and knowledge with regards to their operation. As such hotels are seen as a suitable representation of services within the tertiary sector. The Conscious Vondelpark hotel will serve as a case-study, as this hotel is already intrinsically interested in reducing their environmental impact, making an exploratory study of this hotel possible. As such, during this thesis the way in which LCA can be applied to contribute to a better understanding of the holistic environmental impacts of the hotel branch has been investigated, in order to discover how hotels and possibly other services within the tertiary sector could make use of LCA in the future.

LCA has originally been developed to investigate individual products rather than complex services, however, and its application therefore had to be adapted. This has been done by streamlining the LCA application, in order to allow a myriad of product, utilities and activities to be incorporated within one LCA study within a limited time-frame of approximately three to four months. Due to this streamlining, it has become possible to use LCA in order to investigate complex services such as hotels.

STREAMLINING EFFORTS

The streamlining efforts have predominantly been focused on the goal and scope and life cycle inventory (LCI) phases, in order to increase the speed with which a high amount of products, utilities and activities could be incorporated. These efforts have predominantly been focused on reducing the required detail of the life cycle stages and input data.
During the goal and scope, the choice has been made to set-up an attributional LCA focused on uncovering hotspots. As such results of the LCA had to be accurate enough to represent the specific hotel service under

study, and had to provide detailed insight into the different origins of the impacts within its system. The results were not meant to provide an exact measurement of the environmental impact of the hotel, however, opening up the opportunity for further streamlining during the LCI phase. The LCA has additionally been focused on the hotel service itself, while the hotel building has not been considered. A large selection of products, utilities and activities related to this hotel services have been included, based on high mass/energy, high quantity and high importance for the hotel's functionality. As such, products, utilities and activities which were assumed to be associated with a low impact, were present in low quantities or were not deemed important for the hotel's functionality were disregarded. The use by guests has been set as the dominant life-cycle stage, and all products, utilities and activities have been combined in simple services within the complex hotel service, in order to make them tangible for use by guests. Additionally, even though all life-cycle stages have been taken into account, the use of surrogate data has been allowed and processes not directly related to the dominant life-cycle stage have been treated as background processes, with the exception of processes which directly facilitate the dominant life-cycle. These background processes were taken from the Ecoinvent 2.2 database.
In order to investigate the influence of past or possible future adaptations to the hotel impact, detailed studies have been incorporated in the attributional LCA as well. As such scenarios could be developed to compare the current hotel situation with the hotel situation containing adaptations to the system. Additionally, to illustrate how the potential of possible changes in the system could be quickly assessed, less detailed scenarios have been included as well, which could be used to determine if more detailed studies were desirable.

During the LCI phase only the use of products and services by guests, and on the processes directly facilitating this use have been treated as foreground processes. An additional distinction has been made between primary foreground processes and secondary foreground processes. Primary foreground processes encompassed the use of products and services by guests, while secondary foreground processes encompassed those processes who directly facilitate this use. For products this secondary foreground process was their production process. For services this was the use of products, utilities and activities by the service and service employees. The distinction between them was predominantly associated with the detail and sources of data that are used. Primary foreground processes have almost entirely been based on primary data, secondary foreground processes of services on primary data with calculated estimations, and secondary foreground processes of products on a combination of primary and specific surrogate data. Most surrogate data for secondary foreground processes has been based on the Ecoinvent 2.2 database, but other sources have also been used. Detailed studies for scenarios have been based on more primary data, while less detailed scenarios were associated with the same level of detail as the remaining foreground processes.

The LCIA phase the CML-IA midpoint method 'CML-2001' has been used, in combination with the baseline impact categories of land use, eutrophication, acidification, photochemical oxidation, terrestrial ecotoxicity, freshwater aquatic ecotoxicity, stratospheric ozone depletion and human toxicity. the CMLCA software tool was used as well, and as the midpoint method and impact categories had already been integrated into this software, further classification was not required.

The interpretation phase has been limited to a consistency and completeness check, as well as a contribution and sensitivity analysis. This contribution analysis has been predominantly focused on the overall impact of the services per impact category, after which high-impact processes were investigated in more detail. The impact of the different utilities, activities and combined products at the hotel has been investigated as well, while the origin of these impacts has been focused on high contributing processes within the life-cycle.
The sensitivity analysis has been focused on investigating the influence of the streamlining choices of the LCI phase in particular, and also contained some literature research to compare the results of individual products with the results of similar products in part studies. It only considered a selection of products, utilities and activities, however, based on sensitivities they might be associated with. From the findings of this selection more general observations could then be made with regards to the uncertainty of the study.

CONCLUSION & RECOMMENDATIONS

The streamlining efforts appears to have made it possible to include a myriad of products, utilities and activities in one LCA, which is required if LCA is to be used to contribute to a better understanding of the holistic environmental impacts of the hotel branch. The results of the LCA appeared to represent the hotel, and could provide comprehensive insight into its impact within three to four months, depending on the availability

of data. The cooperation of the hotel and its suppliers and partners in particular has been of importance, however, and the LCA could not have been performed without intrinsic interest of the hotel to lower its environmental impact.
Some inaccuracy was present in the results, but they could still provide comprehensive insight into the environmental impact of a hotel, as contributions of services as well as products, utilities and activities could be constructed, and the origin of their impact could be investigated. By including detailed studies it was also possible to investigate the influence of different scenarios on the hotel, which could provide valuable information to hotels.

Improvement and further development of the LCA application is also possible, however. The use of LCA could additionally become even more valuable if hotels could execute comparisons themselves, which could potentially be facilitated by an easy-to-use tool. The LCA application could further potentially be used for complex services in the tertiary sector, especially those which also facilitate the use of products and services by a form of inhabitants.

RESULTS FOR THE CONSCIOUS VONDELPARK HOTEL

For the Conscious Vondelpark hotel it has been investigated what the approximate environmental impacts are related to residing in this hotel during one day and night for one average guests, and where these impacts derive from. The consumption of utilities by the different (pseudo-)services has been based on yearly, monthly and hourly measurements at Conscious in combination with generic hotel consumption data, and the use of products and activities has been based on accounts from hotel employees. Some products with possible high impacts had to be omitted due to a lack of data, however, which were the bedframes, closets and showerheads.

Two detailed studies have been included to create scenarios for the hotel, which are related to the electricity and laundry service of the hotel. Both have been chosen in advance based on their assumed importance. The first detailed study has been used to investigate the influence of using electricity from PV to supply 10% of the yearly electricity demand at Conscious on the environmental impact of the hotel, while the remaining 90% would still be supplied by wind. The second detailed study has been used to investigate the influence of the efforts of the Van der Kleij laundry facility to lower its environmental impact. Additionally, one quick scenario is added to assess the possible influence the addition of insulation to the boiler system could have on the environmental impact of the hotel.

The rooms at the hotel in particular appeared to be associated with a high contribution to the hotel's impact to most impact categories, while the F&B service seemed to be responsible for a high impact to the impact categories of land use, eutrophication and acidification. It furthermore looked like the impact of the hotel was predominantly associated with the use of gas and food & beverages, although there were significant differences between the impact categories. The products appeared to be responsible for a small contribution to all impact categories, which could mainly be attributed to the Auping mattress, LED TVs and plastic tables in the rooms for most impact categories. The origin of the impacts differed between the products, utilities and activities, but was mostly associated with the production of materials, especially metals, and use of energy. The use of PV-panels to supply 10% of the yearly electricity demand appeared to slightly increase the hotel impact to most impact categories, and the use of an alternative laundry service was associated to an even higher increase of the hotel's impact on all impact categories. The increases were slight for both scenarios, however.

Even though the impact of the hotel increased slightly, it is still recommended to install PV-panels to supply 10% of the yearly electricity demand of the hotel, as this would increase the amount of renewable electricity in the Netherlands. In case of the Van der Kleij company it is recommended they use a renewable source of electricity to lower their impacts even further. The use of insulation, finally, is also recommended. The impact of the hotel could potentially decrease further if less energy is lost in rooms, when less animal products are used within the F&B service, when the lifetimes of products would increase, when less employee commute by cars and when more waste is recycled.

PREFACE

The idea of applying LCA to investigate the impact of hotels goes all the way back to 2014, when I started studying Industrial Ecology. I had just finished my Bachelor's degree in Architecture and was enthusiastic that I had finally started with my new Master. In the first semester alone I had the impression that I had gained enough knowledge to apply for an internship besides my study, which I wanted to combine with my interest in the built environment. When I pitched this idea to my girlfriend, she introduced me to a hotel branch in Amsterdam called Conscious Hotels, which were actively involved in reducing their environmental impact and were considering to open a new hotel. Even though I did not join the hotel at that time, the thought of this sustainable chain of hotels remained with me until I entered a course in advanced LCA as part of my Master program. It was at this time that I realised that LCA might be used to uncover the environmental impact of the Conscious hotel as well, an idea that has been received with great enthusiasm by Marco Lemmers, one of the owners of the hotel chain. Half a year and a few meetings later, I started with the thesis you now have before you.

I would first like to thoroughly thank Conscious hotels for supporting my research, and showing such great enthusiasm for LCA and sustainability. I would like to thank Marco Lemmers in particular, as he has been the one who has made this thesis possible, and has allowed me to gain comprehensive insight into his hotel. I would also like to wholeheartedly thank Kristine Kotsbakk of Conscious, as she has actively helped me to uncover all data I needed to carry out the LCI, and was always quick to reply my many requests, and I would like to thank Xavier Kropman, Jan Sistermans and all other employees who have provided me with information and data.

I would also like to thank all suppliers and partners of Conscious who have provided me with data for their products. In particular Jaap Hobbel and the people at the Van der Kleij company who have provided me with a plethora of information and welcomed me into their facility, for which I am very grateful.

I am also very grateful for the support of my girlfriend, Nadine Vermeer, who has stood by me throughout the project, especially when times were tough. Thank you Nadine, your feedback, support and positive mentality has helped me finish what I've started.

I would furthermore like to thank my parents for their support, and for always being there to provide feedback on my work. I would like to thank JC Sioux as well for the much needed distractions and company they have provided. Especially Job, Serge, Thijs and Jasper, who were always willing to hear me out, provide feedback, and often joined me in the library for coffee and small talk, and Justus, who has provided me with the basic set-up for my LaTeX file. My gratitude also goes out to Ivan aan den Toorn, who has provided me with feedback and valuable advice with which I could finish my thesis.

Finally, I would like to thank my supervisors, dr. ir. Jeroen Guinée and dr. ir. Gijsbert Korevaar. I have gained an incredible amount of new information during this project, much of which has been provided by your guidance. Thank you for supporting my research, and for guiding me through this thesis.

Maarten Cees Bruinsma
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Contents

GLOSSARY

This glossary provides definitions of the key terms and abbreviations used in this thesis. All definitions are based on the Handbook on Life Cycle Assessment by Guinée et al. (2002a), except for terms marked with an asterisk (*), which are specifically defined for this particular study.

activity *
Any activity within a service, process or location, ranging from manufacturing a product to ventilating rooms

allocation
multifunctionality and allocation

alternative
one of a set of product systems studied in a particular LCA, e.g. for comparison (note: some LCA steps are carried out for all alternatives together (e.g. selection of impact categories), while others are repeated for each alternative (e.g. characterisation)

avoided burden approach *
Closed loop recycling

background system/process
a system or process for which secondary data, viz. databases, public references, estimated data based on input-output analysis, are used in an LCA

boundary *
system boundary

category indicator
a quantifiable representation of an impact category, e.g. infrared radiative forcing for climate change

category indicator result
indicator result

characterisation
a step of Impact assessment, in which the environmental interventions assigned qualitatively to a particular impact category (in classification) are quantified in terms of a common unit for that category, allowing aggregation into a single score: the indicator result; these scores together constitute the environmental profile

characterisation factor
a factor derived from a characterisation model for expressing a particular environmental intervention in terms of the common unit of the category indicator, e.g. (photochemical ozone creation potential of methanol)

characterisation method
a method for quantifying the impact of environmental interventions with respect to a particular impact category; it comprises a category indicator, a characterisation model and characterisation factors derived from the model

characterisation model
a mathematical model of the impact of environmental interventions with respect to a particular category indicator

characterisation result
environmental profile

classification
a step of Impact assessment, in which environmental interventions are assigned to predefined impact categories on a purely qualitative basis

closed loop recycling
recycling of material within one and the same product system

completeness check
a step of the Interpretation phase to verify whether the information yielded by the preceding phases is adequate for drawing conclusions in accordance with the Goal and scope definition

complex service *
a service containing a myriad of products, utilities and activities, which are all associated with their own life-cycles. One example of a complex service is a hotel

consistency check
a step of the Interpretation phase to verify whether assumptions, methods and data have been applied consistently throughout the study and in accordance with the Goal and scope definition

contribution analysis
a step of the Interpretation phase to assess the contributions of individual life cycle stages, (groups of) processes, environmental interventions and indicator results to the overall LCA result (e.g. as a percentage)

data quality
a data characteristic relevant for the capacity of the data to satisfy stated requirements

descriptive LCA
a type of LCA focusing on the contribution of a particular way of fulfilling a certain function to the entire spectrum of environmental problems as they currently exist or are being created

detailed LCA
LCA complying with the ISO 1404X standards and representative of studies typically requiring between 20 and 200 person-days of work

economic flow
a flow of goods, materials, services, energy or waste from one unit process to another; with either a positive (e.g. steel, transportation) or zero/negative (e.g. waste) economic value

economic process
unit process

elementary flow
matter or energy entering or leaving the product system under study that has been extracted from the environment without previous human transformation (e.g. timber, water, iron ore, coal) or is emitted or discarded into the environment without subsequent human transformation (e.g. or noise emissions, wastes discarded in nature) see also: environmental intervention

emission
a chemical or physical discharge (of a substance, heat, noise, etc.) into the environment, considered as an environmental intervention

environmental effect
environmental impact

environmental impact
a consequence of an environmental intervention in the environment system

environmental intervention
a human intervention in the environment, either physical, chemical or biological; in particular resource extraction, emissions (incl. noise and heat) and land use; the term is thus broader than ('elementary flow')

environmental process
a physical, chemical or biological process in the environment system that is identified as part of the causal chain linking a particular environmental intervention to a particular impact, e.g. pollution leaching or bioaccumulation; for a given impact category, the environmental processes together form the environmental mechanism

environmental profile
the overall result of the characterisation step: a table showing the indicator results for all the predefined impact categories, supplemented by any other relevant information

extraction
withdrawal of a biotic or abiotic resource from the environment in a unit process, considered as an environmental intervention

foreground system/process
a system or process for which primary, site-specific data are used in an LCA, for whatever reason

full LCA *
Detailed LCA

function
a service provided by a product system or unit process

functional flow
any of the flows of a unit process that constitute its goal, viz. the product outflows of a production process and the waste inflows of a waste treatment process

functional unit
the quantified function provided by the product system(s) under study, for use as a reference basis in an LCA, e.g. 1000 hours of light (adapted from ISO)

goal and scope definition
the first phase of an LCA, establishing the aim of the intended study, the functional unit, the reference flow, the product system(s) under study and the breadth and depth of the study in relation to this aim

hotspot *
high impact within a system, associated with a process. This process could possibly be adapted to reduce this impact

impact category
a class representing environmental issues of concern to which environmental interventions are assigned, e.g. climate change, loss of biodiversity

indicator result
the numerical result of the characterisation step for a particular impact category, e.g. 12 kg CO2-equivalent for climate change

input/inflow
a product (goods, materials, energy and services), waste for treatment or environmental intervention (including resource extraction, land use, etc.) modelled as 'entering' a unit process (adapted from ISO)

interpretation
the fourth phase of an LCA, in which the results of the Inventory analysis and/or Impact assessment are interpreted in the light of the Goal and scope definition (e.g. by means of contribution, perturbation and uncertainty analysis, comparison with other studies) in order to draw up conclusions and recommendations

intervention
a human intervention in the environment, either physical, chemical or biological; in particular resource extraction, emissions (incl. noise and heat) and land use; the term is thus broader than ('elementary flow')

inventory analysis
the second phase of an LCA, in which the relevant inputs and outputs of the product system(s) under study throughout the life cycle are, as far as possible, compiled and quantified

inventory table
the result of the Inventory analysis phase: a table showing all the environmental interventions associated with a product system, supplemented by any other relevant information (adapted from ISO)

land transformation
the change in the quality of a given plot of land due to a particular mode of human use, measured in terms of changes in biodiversity and life support functions

LCA process
the integral series of exchanges among the individuals and organisations participating in an LCA project, from project initiation and guidance through to interpretation and discussion of the results

LCA project
a project that seeks to obtain particular results by means of an LCA study and LCA process; besides commissioning parties and practitioners, it may also involve other organizations and individuals, in the capacity of data supplier, peer reviewer or interest group, for example

LCA study
an environmental study in which LCA methodology is employed, performed by practitioners who may or may not be affiliated to the party or parties commissioning the study

life-cycle
the consecutive, interlinked stages of a product system, from raw materials acquisition or natural resource extraction through to final waste disposal

life cycle assessment (LCA)
compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle; the term may refer to either a procedural method or a specific study

life cycle impact assessment (LCIA)
the third phase of an LCA, concerned with understanding and evaluating the magnitude and significance of the potential environmental impacts of the product system(s) under study

life cycle inventory analysis (LCI)
inventory analysis

midpoint approach
problem-oriented approach

multifunctional process
a unit process yielding more than one functional flow, e.g. co-production, combined waste processing, recycling

multifunctionality and allocation
a step of the Inventory analysis in which the inventory model is refined and the input and output flows of multifunctional processes are partitioned to the functional flows of those processes

natural resource
a biotic or abiotic resource that can be extracted from the environment in a unit process

normalisation
a step of Impact assessment in which the indicator results are expressed relative to welldefined reference information, e.g. relative to the indicator results for global interventions in 1995

output/outflow
an economic flow (e.g. energy, waste for treatment) or environmental intervention (e.g. pollutant or noise emission) modeled as 'leaving' a unit process (adapted from ISO)

phase *
there are four phases in an LCA: the goal and scope definition, the life cycle inventory analysis (LCI), the life cycle impact assessment (LCIA) and the interpretation

primary foreground process *
product/service directly used by hotel guests (e.g. use of front-office service, use of mattress, etc.)

problem shifting *
the transfer of a problem to another party, area or environmental impact. This means the decrease of an impact can be associated with the increase of an impact elsewhere

process
unit process

process tree
a graphic representation of the interlinked unit processes comprising the product system

product *
object. Used by user, service, or process

(product) system
a set of unit processes interlinked by material, energy, product, waste or service flows and performing one or more defined functions

pseudo-service *
location with objects which are directly used by user (i.e. public spaces, rooms). These pseudo-services do not deliver services themselves, but provide guests with a myriad of products they directly use, such as beds and tables. Also makes use of hotel utilities, for example for lighting or heat

primary data *
data which has been collected at the source, either by documentation, measurements or interviews

secondary foreground process *
product/service directly facilitating primary foreground process (e.g. use of paper in front-office, production of mattress, etc.)

sensitivity and uncertainty analysis
a step of the Interpretation phase to assess the robustness of the overall LCA results with respect to variations and uncertainties in the methods and data used

service *
function provided to a user by other party (i.e. front-office service, back-office service, food & beverages (F&B) service, housekeeping service, laundry service). Also makes use of hotel utilities, for example for lighting or heat

simple service *
sub-service within a complex service, such as the front-office service in a hotel

simplified LCA
a simplified variety of detailed LCA conducted according to guidelines not in full compliance with the ISO 1404X standards and representative of studies typically requiring from 1 to 20 person-days of work

stakeholder
an individual group or organisation concerned about or affected by the environmental performance of a product system or the outcome of an LCA. Note: the LCA commissioner is also a stakeholder

step
a discrete element of any of the four phases of an LCA; some steps (e.g. data format, calculation method) are areas of concern rather than actions

streamlining *
adapting the phases of the LCA technique by simplifying or removing steps in order to increase the speed with which an LCA can be conducted

surrogate data *
data which has not been collected at the source, but from databases, literature of other sources. Specific surrogate data matches the processes under investigation, seemingly similar surrogate data is a rough approximation of the processes under investigation

system boundary
the interface between a product system and the environment system or other product systems

third party *
a party other than the commissioner

transparency
open, comprehensive and understandable presentation of information

unit process
the smallest portion of a product system for which data are collected in an LCA

use process *
a unit process in which the final product, resource or activity is consumed or used

utility *
electricity, gas and/or water

1

INTRODUCTION

Modern Western economies are predominantly based on the tertiary sector, which encompasses activities such as transport, retailing, entertainment and tourism. The impact of this sector on the environment is considerable due to its sheer size alone, but to this day this impact has not yet received much scrutiny globally. It is therefore important to find ways to include the environmental impacts of the supply chain as well. During this thesis the potential of Life Cycle Assessment (LCA) to accomplish this is investigated.

One of the many branches within the tertiary sector is the hotel industry, which is associated with a considerable impact on the environment. Hotels are notoriously inefficient in terms of utility use and use of products, and are additionally rapidly growing in numbers. Especially in cities like Amsterdam tourism has been on the rise for years, and with it a high number of new hotels has come into existence. Combined with the fact that data and information in hotels are often extensively documented and available from centralised sources, such as owners and maintenance personnel, this makes hotels a suitable case-study to investigate how the holistic environmental impact of the tertiary sector can be better understood.

Measuring the environmental impact of the hotel branch already takes place, but is often only focused on the consumption of resources and/or the building which houses the hotel, rather than on the hotel service itself. A myriad of products, resources and activities are involved in providing a hotel service, however, who's impact can only be investigated when a holistic approach is adopted. Life Cycle Assessment can provide such a holistic approach, as it entails the investigation of not just the use stage, but all life-cycle stages related to a function. This technique has been designed to investigate and compare single products, however, not to uncover the environmental impact of an entire hotel. As such, adaptations to the method or its application are required to be able to use it for the purpose of this study.
In this report the application of LCA is streamlined in order to enable the assessment of a myriad of products and services within one study. This will predominantly be done by streamlining the way in which data is gathered and processed, but also by streamlining the goal and scope definition, and interpretation of results. This could thereby provide a whole new use of LCA for the tertiary sector, which would open up possibilities of targeted recommendations on a case-to-case basis for any service, including hotels. In order to explore the practicality and value of the proposed LCA application, it will be implemented on the case-study of the Conscious Vondelpark Hotel in Amsterdam. This thesis will therefore not only investigate the opportunities of LCA for the tertiary sector, but will also provide insight for the Conscious Vondelpark hotel into its environmental impact.

First the problem definition and research aim and question will be presented in chapter 2. In chapter 3 an extensive literature research will be performed into LCA and LCA streamlining, after which the application of streamlining in this study will be presented. In chapter 4-10 the LCA will be applied to the case-study of the Conscious Vondelpark hotel. Chapter 4 entails the goal and scope definition phase, chapter 5 and 6 the LCI phase, chapter 7 the LCIA phase, and chapter 8-10 the interpretation phase. In chapter 11 the effects of the streamlining efforts on the LCA results, and the results of the Conscious Vondelpark will be discussed, in chapter 12 the conclusion of the LCA application is given, and in chapter 13 the conclusion for the case-study is given. In chapter 14 the recommendations for both the LCA application and case-study will be presented.

2

PROBLEM DEFINITION

The tertiary sector is generally perceived as an environmentally friendly one. The operation of most activities within this sector of the economy are assumed to be associated with relatively minor resource and energy use, when compared to other sectors such as the manufacturing industry. When a holistic approach is adopted, however, it is clear that the environmental impact of this sector is far greater than is currently assumed, as it largely indirectly derives from activities in the supply chains of services (Alcántara & Padilla, 2009; Djellal & Gallouj, 2015; Gaidajis & Angelakoglou, 2011). It is therefore important to find approaches which can include the environmental impacts of the supply chain as well. One such approach is investigated during this thesis, and is focused on Life Cycle Assessment (LCA).

All modern developed countries are predominantly associated with service-based economies (Djellal & Gallouj, 2015; Junnila, 2006). In the Netherlands, for example, the tertiary sector accounted for almost 75% of the gross domestic product in 2014 (CIA, 2015), while the average for all developed countries is estimated at around two-thirds (Djellal & Gallouj, 2015; Junnila, 2006). This sheer size alone results in a high contribution to environmental impacts from this sector. In fact, recent studies have shown that countries with a predominantly service-based economy are the most polluting of all (Djellal & Gallouj, 2015). The impact of this sector has historically not received much attention, though, from neither corporate nor political directions (Alcántara & Padilla, 2009; Djellal & Gallouj, 2015; Foster, Sampson, & Dunn, 2000; Graedel, 1998; Junnila, 2006; Rosenblum, Horvath, & Hendrickson, 2000). Even in the European Directive 2002/358/EC, under which the Kyoto Protocol was approved, it is barely mentioned (Alcántara & Padilla, 2009).

This perceived low impact and consequential negligence of the tertiary sector can be attributed to the fact that most impacts in this sector do not occur during the operational activities. Instead, they primarily derive from activities that are indirectly linked to the services provided. Among these are all products, resources and energy necessary for the service to perform its function, but also activities related to human interaction and ICT (Djellal & Gallouj, 2015; Junnila, 2006; Rosenblum et al., 2000; Zhang, Joglekar, & Verma, 2010). This is problematic, as service activities are generally seen as intangible. Their main purpose is related to a function rather than a product and they are therefore perceived as not being directly related to materials or manufacturing. This has resulted in a great underestimation of the environmental impact of the tertiary sector (Chiarini, 2014; Djellal & Gallouj, 2015). As recent research has shown, the sector is actually responsible for a notable and constantly growing environmental impact in society (Alcántara & Padilla, 2009; Djellal & Gallouj, 2015; Junnila, 2006).

The underestimation of the service industry is becoming increasingly relevant, since sound environmental management is becoming a major part of the socio-economic as well as the political agenda (Curkovic & Sroufe, 2011; Djellal & Gallouj, 2015; Jones, Hillier, & Comfort, 2014). The financial benefits due to reductions in resource and energy costs are also being recognised (Djellal & Gallouj, 2015; Houdre, 2008; Jones et al., 2014). Although initially mainly focused on the manufacturing industry, current efforts are slowly moving towards other sections as well, including the tertiary sector. These efforts are still limited, however, and often only focused on popular impact categories such as climat change (Djellal & Gallouj, 2015; Foster et al., 2000; Graedel, 1998).

Within the tertiary sector, tourism in particular is responsible for a considerable impact on the environment (Djellal & Gallouj, 2015). Especially hotels are associated with high and inefficient use of products and utilities (Bohdanowicz, 2006). Additionally, hotels are rapidly growing in numbers (Jones et al., 2014), and as such the potential to reduce environmental impacts in the hotel branch is considerable. In line with the entire tertiary sector, however, this potential is not only present in the operation of hotels, but also in their supply chain (Houdre, 2008). As hotels often document their consumption and activities in detail, they provide a suitable case-study to investigate how the holistic environmental impact of the tertiary sector can be better understood. The hotel branch will therefore be at the focus of this research.

Active involvement towards reduced environmental impact appears to be already present in the tourism sector, which is partly caused by high customer interaction. This trend is also visible in hotels, who are increasingly making their operations run more sustainable (Bohdanowicz, 2006; Houdre, 2008; Jones et al., 2014; Zhang et al., 2010). It is unfortunately also apparent that many companies, and especially hotels, are still only considering their impacts to seek competitive advantage or to comply with regulations. Life cycle impacts beyond the operation are often still not taken into account. (Bohdanowicz, 2006; Chiarini, 2014; Curkovic & Sroufe, 2011; Djellal & Gallouj, 2015; Houdre, 2008; Jones et al., 2014; Zhang et al., 2010).

Hotels that are intrinsically motivated to reduce their environmental impact beyond the regulatory requirements also exist, of course. For these hotels a high amount of certifications is already present, although a global standard does not exist yet (Bohdanowicz, 2006; Houdre, 2008; Zhang et al., 2010). Green Key, Greenglobe and Travelife are examples of global certifications specifically for the tourism industry. Another example is the EU ecolabel, which is involved with a wider arrange of non-food products and services, but also has specific standards for hotels (Duurzame hotels, 2015). Finally there are more general sustainability assessment certifications for the buildings which house hotels. Of these building-specific certification systems the European BREEAM and North American LEED are the most widely used (Duurzame hotels, 2015; Icibaci & Haas, 2012).

The ISO 14001 standards are often at the base of the environmental regulations and certifications (ISO, 2015). Not all companies and researchers are convinced that these standards are an effective strategy to improve the environmental performance of a supply chain, however, as they do not actively encourage companies to be responsible. Part of the problem here lies in the fact that ISO-based certifications generally do not consider the specific properties, strategies or life cycles of different hotels. Rather, they are often focused on a generic selection, based on pre-defined checklists (Chiarini, 2014; Curkovic & Sroufe, 2011).

In order to allow for a more specific and comprehensive assessment of the environmental impact of services within the tertiary sector and hotel branch, Life Cycle Assessment (LCA) can be used. LCA offers a holistic approach, as it considers the life-cycle processes beyond the operational stage in detail. This is necessary if hotels and other services want to effectively reduce their environmental impact (Bohdanowicz, 2006; Jones et al., 2014). LCA could be more effective than certification, as LCA results are specifically focused on the product or service at hand and produce measurable and comprehensive results (Chiarini, 2014; Graedel, 1998). This way hotels that are intrinsically motivated can gain potentially insight into their own environmental performance and that of their suppliers (Chiarini, 2014). Such insight can be used to direct investments to be used as effectively as possible, prevent problem shifting, and compare the influence of different alternatives to products, utilities or services in the hotel.

Even though LCA can present a tremendous potential to support environmental and cost considerations (Foster et al., 2000; Rosenblum et al., 2000), it has been under-represented in the tertiary sector and hotel branch so far. This is partly caused by the aforementioned underestimation of the impacts and lack of motivation among companies, but is also related to the operation principle of LCA, which is based on finished products (Djellal & Gallouj, 2015; Graedel, 1998; Junnila, 2006). Rather than finished products, however, the tertiary sector delivers services, which are still generally considered to be intangible. As such, many LCA studies focused on the tertiary sector and hotel branch only concentrate on the buildings and their energy consumption, without including the supply chain (Junnila, 2006). Within this thesis it is hypothesised that LCA can be used to assess the impact of the entire supply chain of services within the tertiary sector such as hotels as well, when the application of LCA is streamlined.

2.1. RESEARCH AIM & QUESTION

This research aims to investigate how the application of LCA can be streamlined to uncover the life-cycle environmental impact of services within the tertiary sector, and focuses on the hotel branch. Of course sustainability in hotels goes beyond the supply chain alone and also includes social elements, guest and employee awareness, and financial aspects. A focus on the supply chain has been adopted during this research, however, as it represents a significant but currently under-represented potential which could be utilised using existing methods such as LCA.

By streamlining the application of LCA within the existing LCA framework (figure 2.1), it could become possible to perform relatively quick assessments of complex services such as hotels, which are associated with large amounts of products, utilities and activities. This can be done by streamlining the way in which the goal and scope is defined, data is collected and processed, and analyses are performed. By leaving out or simplifying certain steps time can be saved, while the implementation of strict and general assumptions within the LCA will assure a myriad of different processes can be included while consistency between them is maintained. This could thereby provide a new use of LCA for the tertiary sector.
Using LCA to assess the environmental impact of services would additionally make targeted recommendations on a case-to-case basis possible for hotels and any other service. This could provide valuable environmental insight for the owners of such services, and can prevent problem-shifting of impacts within services. This research could therefore also represent a first step towards a comprehensive and easy-to-use LCA tool specifically designed for hotels or other services, which could guide decisions with regards to products, activities and utilities used. The actual development of such a tool falls out of the scope of this specific research, however, but could present a follow-up project.

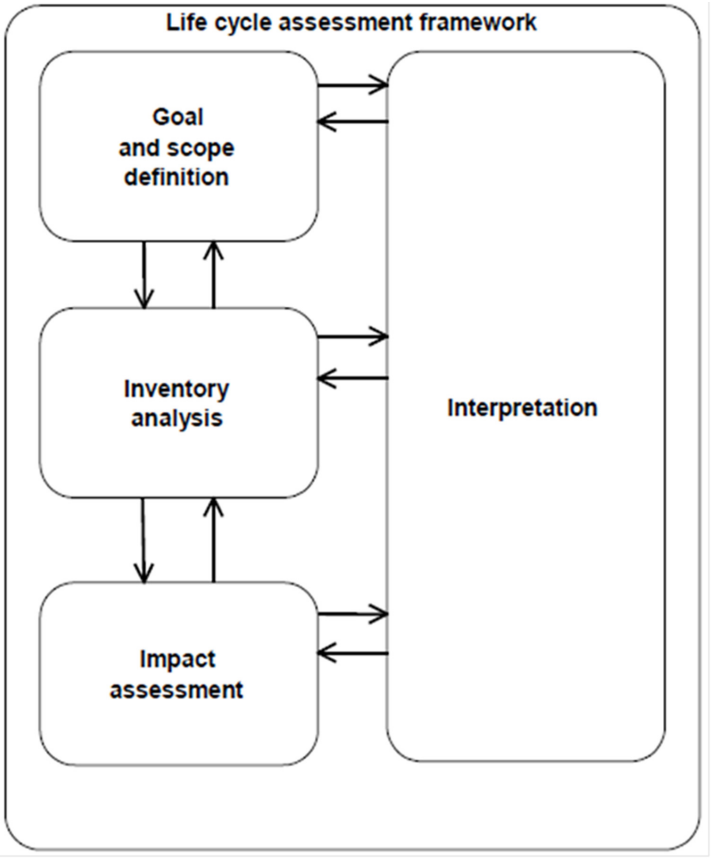

Figure 2.1: LCA framework (ISO 14040:1997(E) via (Guinée et al., 2002b))

The main research question of the thesis can be formulated as:

> *"How can Life Cycle Assessment be adapted and applied to contribute to a better understanding of the holistic environmental impacts of hotels, as an example of complex services within the tertiary sector?"*

This research question will be answered by investigating the application of LCA, during which concrete measures to adapt this application will be developed. This new LCA application which will consequently be implemented on a case-study hotel. As such it can be divided into four sub-questions, all with several aspects:

"What adjustments can be made to the application of LCA to quickly measure the approximate life cycle impacts of a complex hotel service, uncover where this impact derives from, and investigate the influence of changes in the system?"

- *Streamlining the LCA application to investigate the environmental impacts of a complex hotel service and accurately uncover their origin within the hotel in a limited time frame*
- *Accurately comparing the life cycle impact of currently applied products/services within the hotel system, with hypothetical or past alternatives*
- *Accurately comparing the life cycle impact of currently applied products/services within the hotel system, with proposed future alternatives*
- *Quickly assessing the potential of proposed future alternatives for currently applied products/services within the hotel system, without the need for highly detailed data*

"How can the proposed LCA application be implemented on a case-study hotel?"

- *Requirements for the hotel's attitude towards sustainability and its relationship with partners and suppliers*
- *Requirements for data availability*
- *Strategies to gather data and mitigate data-gaps*

"What are the effects of streamlining the application of LCA on the results?"

- *Speed of the study*
- *Validity and sensitivity of the results overall*

"How could the proposed LCA application be used by the hotel branch and other complex services within the tertiary sector in the future?"

- *Opportunities of results to improve the overall sustainability of hotels*
- *Generalisability of the proposed application to the hotel branch and tertiary sector*

The case-study will be represented by Conscious Hotels in Amsterdam, which will be introduced in the next section. In order to carry out this case-study investigation, the first sub-question will be translated into specific LCA-goals as well. As such, this case-study will not only facilitate in answering the second research question, but will also lead to concrete LCA results which can be used by Conscious.

2.2. CONSCIOUS HOTELS

The case-study under investigation during this project is the Conscious hotel chain in Amsterdam. Conscious is an eco design hotel, which seeks to bring sustainability to its guests in an attractive shell. This is done by choosing products and services which are environmentally friendly, by inspiring their guests to think about their own environmental impact, and by involving environmentally motivated staff. The hotel also holds up close relations with their suppliers and partners.

The chain describes itself as being eco-friendly, but not eco-fundamentalist. Instead of forcing sustainability onto their guests, they try to get them interested by raising their awareness. This is done by subtle and playful messages throughout the hotel, but also by showcasing attractive 'green' options such as green walls, tables made from recycled coffee cups and organic food. Besides these showcasing products, Conscious is also actively involved in reducing their environmental impact behind the scenes. Every decision is not only assessed in terms of economics, but also by its potential environmental and even social impact.

The choice for this chain is made due to the intrinsic motivation already present among the owners and staff. The owners see sustainable business as the core concept behind the chain, rather than just a means to increase their revenue. Of course they do promote their environmental awareness as a selling point, but they are also constantly engaged in actually improving their business in terms of environmental and social sustainability. This means there is a high willingness to cooperate with further research present at Conscious.

At present the main focus of Conscious lies at their operation, as is the status-quo for the tertiary sector. They are not limited to their operation alone, however, and also focus on using environmentally certified products and services. Products certified by Cradle 2 Cradle, FCS/PEFC or Fairtrade and services which use less energy and environmentally friendlier resource are not uncommon in their hotels. The life-cycle of their supply chain is therefore already being considered, but is still predominantly limited to descriptions from manufacturers and universal certifications. A more detailed investigation into the life-cycle behind their operation could provide Conscious with more comprehensive insight into their environmental impact, which could guide their decisions in the future.

Conscious is especially interested in the impact of different sections within the hotel, in order to investigate if the right choices were made and to identify hotspots for improvement. This interest goes beyond energy consumption and CO_2 emissions, and is also focused at other utility use as well as other detrimental impacts to the environment. Additionally, Conscious strives to make well thought-through decisions for their future hotels, and are therefore looking for ways to compare options.

Conscious is therefore interested in investigating their supply chain in more detail. This means both the hotel owners and the researcher are interested in how the life-cycle impacts behind the hotel's operation can be better understood, and how the hotel branch can be supported in making environmentally sound decisions.

2.3. SUMMARY PROBLEM DEFINITION & RESEARCH AIM

In summary, even though the tertiary sector is generally perceived as an environmentally friendly one, it is associated with a high impact on the environment due to the impact of its supply chain. In particular the hotel branch is responsible for a considerable impact on the environment. As the use of products, utilities and activities within this branch is usually documented quite well and centralised, it is relatively accessible for research and can thereby serve a suitable case-study to investigate how the environmental impact of the tertiary sector can be uncovered.
To uncover this environmental impact Life Cycle Assessment can be used, which offers a holistic approach to investigate the environmental impact of the entire life-cycle of products and services. LCA is principally designed for product systems, however, and needs to be adapted in order to be applied to complex services such as hotels.
The aim of this research is therefore to investigate how the application of LCA can be streamlined in order to uncover the life-cycle environmental impact of the complex services within the tertiary sector. The hotel branch will serve as a case-study, in particular the Conscious Vondelpark hotel in Amsterdam. As such this research will not only illustrate how LCA can be used within the tertiary sector, but will also provide insight for Conscious into its holistic environmental impact.

3

LCA FRAMEWORK & STREAMLINING

In order to use LCA to assess the holistic environmental impact of services within the tertiary sector such as hotels, its framework and application must first be investigated. In this chapter the LCA framework is described in detail, after which the possibilities to streamline LCA are reviewed. Streamlining could enable broader uses for LCA, including the comprehensive assessment of a hotel.
The current application of LCA in the tertiary sector is also reviewed, after which conclusions with regards the possibilities of streamlining will be made. At the end of this chapter the application of LCA for this particular study will be developed.

3.1. LCA FRAMEWORK

An increased societal awareness of the effects of human activities on the global climate has led to an increase in efforts to understand and avoid the causes behind these effects. Life Cycle Assessment (LCA) is one of the quantitative techniques developed for this purpose within the field of Industrial Ecology (ISO, 2006). According to Guinée et al. (2002b, p. 407) "the purpose of LCA is to compile and evaluate the environmental consequences of different options for fulfilling a certain function".

More broadly speaking LCA is designed to investigate the potential environmental burden of products, services and processes (hereafter called 'products' in this section) which fulfil a certain function. The assessment is based on a system's perspective. As such it looks beyond the use stage of the product, and also considers the environmental burden of all other related stages within the life cycle. Resource extraction, material processing, product production, use and waste processing are all part of this life cycle (Guinée et al., 2002c; ISO, 2006).

During an LCA all inputs and outputs related to the product system are compiled and consequently evaluated. This product system can be described as a collection of small processes with one or more defined functions, which are connected by flows of intermediate products (ISO, 2006). An LCA is principally based on these smaller processes, also known as unit processes, as these are the portions of the product system for which specific data is collected. All these processes are associated with consumption and emissions. As such, by viewing the whole system rather than just the use stage, the potential environmental burden of the product system can be uncovered and 'problem shifting' from one area to another can be exposed and avoided (Guinée et al., 2002c; ISO, 2006).

The results of an LCA can be used in decision-making by industry, government and non-governmental organisations. Decisions on investments, policy issues as well as strategy determination and marketing can all be guided with LCA results and recommendations (Guinée et al., 2002a; ISO, 2006). In this sense LCA can be viewed as an organisational process which can be carried out in a number of ways (Guinée et al., 2002a). Social or economic aspects are often not addressed by LCA, although the process could be combined with other methodologies to include these aspects (ISO, 2006).

Two main types of LCA exist, namely attributional and consequential. With attributional LCAs the environ-

mental burden of an existing system which fulfils a specific function can be assessed. With consequential LCAs the environmental burden between alternative ways to fulfil a function can be compared (Guinée et al., 2002b).

3.1.1. LCA PROJECT PHASES

LCA is an iterative process which consist of four phases (figure 3.1), namely 'goal and scope definition', 'inventory analysis', 'impact assessment' and finally the 'interpretation' of results (Guinée et al., 2002b; ISO, 2006). As this process is iterative, changes throughout the phases often occur during the project, and even the goal and scope can be slightly altered during a project based on new findings (Guinée et al., 2002b).

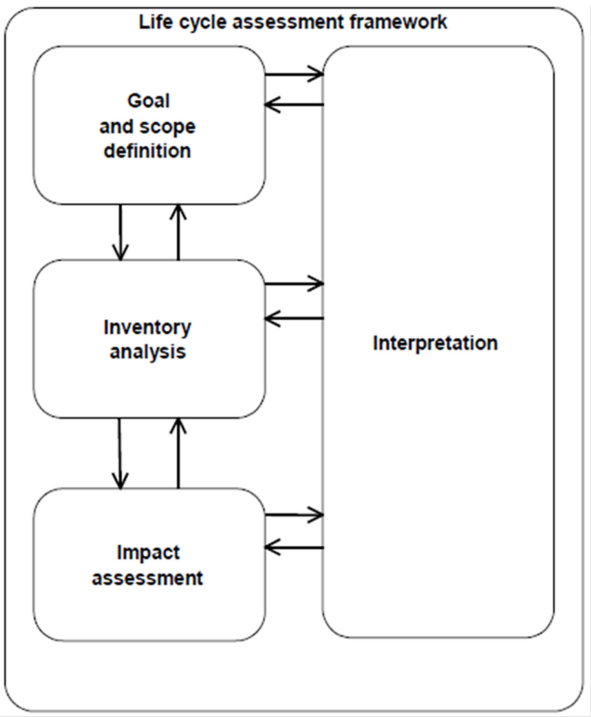

Figure 3.1: LCA framework (ISO 14040:1997(E) via (Guinée et al., 2002b))

3.1.2. GOAL AND SCOPE DEFINITION

During the goal and scope phase the direction of the project is chosen. The intended audience and commissioner, the boundaries of the project, the type of information necessary, the decision-making process, the extent of accuracy required, how the results should be interpreted and reported, and of course the goal of the project are all decided upon during this phase. It is important that these matters are all consistent with the intended application of the study and that they are accurately and unambiguously described (Guinée et al., 2002b; ISO, 2006). The goal definition could additionally be focused on the underlying reason of the research, rather than on the project aim alone (Guinée et al., 2002b).

The influence of limitations such as data uncertainties and time constraints must also be considered when defining the scope, as these could potentially lead to revisions later on in the project (Guinée et al., 2002b; ISO, 2006). Guinée et al. (2002b) also recommend to establish in advance what differences in results are significant for determining whether an option is more environmentally sound than its alternative.

An important aspect of the scope definition is the determination of a transparent and comprehensive 'Functional Unit'. This unit forms the basis of the LCA and represents the reference to which all unit processes in the product flows are scaled. The importance of this unit is emphasised by Guinée et al. (2002b, p. 407), as they state that "the pivot of the analysis is the function, not the material product it is colloquially associated with". This is reflected in the fact that the functional unit is used for all different product flows under investigation.

This is done by translating the functional unit into a measure of output of one of the processes in a product flow, known as a reference flow. This reference flow also enables the comparison of different product systems under investigation. (Guinée et al., 2002b; ISO, 2006) The result of the goal and scope definition phase is a ground plan for the whole study, on which all other phases are based (Guinée et al., 2002b).

3.1.3. INVENTORY ANALYSIS

In the second phase of the LCA the process systems necessary to meet the goal of the study are constructed, which is called the life cycle inventory analysis (LCI) phase (Guinée et al., 2002a). During this phase all relevant unit processes related to the product system are identified within the defined system boundaries. Additionally the economy-environmental system boundaries are established, which describes the distinction between the product system and its environment.
Consequently the input and output data associated with these processes are gathered. These input and output data can be divided into economic and environmental flows. Here economic flows represent products and services (including waste), and environmental flows represent in- and outflows that cross the boundary between the economy and environment. They are mainly associated with energy and physical (utility) inputs, (co-)products and waste, releases to air water and soil, but also with other environmental aspects (Guinée et al., 2002b; ISO, 2006).

A simplified representation of the LCI procedures is given in figure 3.2.

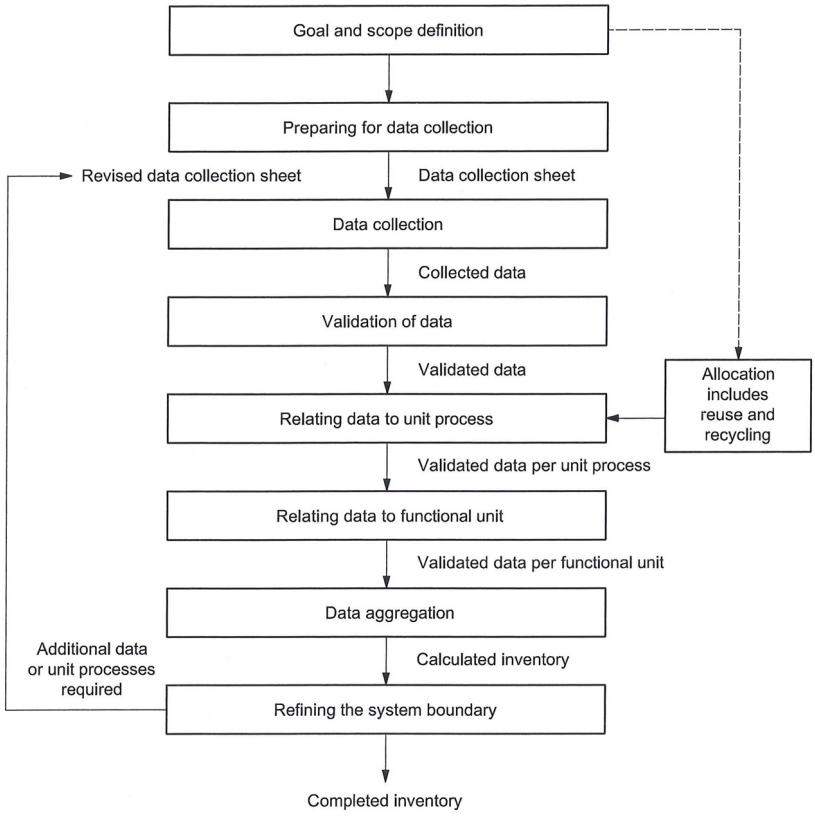

Figure 3.2: Simplified LCI procedures (ISO, 2006)

The LCI phase prepares an inventory by first qualitatively determining the relevant processes of the product systems, and then gathering quantitatively data for those processes. As can be seen in figure 3.2 calculation procedures such as allocations and cut-offs, relating data to the reference flow, and the translation of emissions to comparable units are also part of this phase. Especially the choice of allocations and cut-offs, caused by multifunctional processes or limited system boundaries respectively, can have a high influence on the results (Guinée et al., 2002b).

During the LCI a flow diagram of the product system is also constructed for all relevant products, which visualises the main identified processes and flows and their interrelationships within the system boundaries. This is a highly iterative process which initially provides a practical aid for data collection, and eventually becomes a coherent overview of the product system. The use stage of the product system is often taken as the process from which the reference flow derives. Many unit processes are linked to this reference process, which in turn are linked to other unit processes through (mostly economic) in- and outflow exchanges. As such the product system is not solely associated with the most visible unit processes alone, but with a complex network of different unit processes, both upstream and downstream (before and after the reference process, respectively) (Guinée et al., 2002b).

When considering the product system a general distinction can be made between 'foreground' and 'background' processes. Guinée et al. (2002b) define foreground processes as "those processes for which primary, site-specific data are used in an LCA (for whatever reason)" and background processes as "those processes for which surrogate data from databases, public references or estimated data based on IOA models are used". An LCA becomes more detailed when more foreground processes are included, as these offer the most relevant data.

Data can be gathered by measuring or calculating, and it can be estimated through literature research or process modelling. Validation and detailed documentation of each unit process is necessary, as data is often associated with uncertainties and could be collected from multiple sources (Guinée et al., 2002b; ISO, 2006). This data must also be converted into units which coincide with the reference flow. This entails the volume produced by all unit processes must be exactly the amount which is required to produce the amount of products of the reference flow. For this a calculation method must be used, for which Guinée et al. (2002b) recommend a matrix inversion. This calculation method is incorporated in most LCA software (Guinée et al., 2002b).

The quality of data, both in terms of reliability and validity, is paramount for achieving qualitative results. Both the collection and evaluation of data is therefore important, as is the relevance of the collected data. The age, collection method, accuracy and source of the data are also of importance when evaluating the data quality (Guinée et al., 2002b).

The main result in the LCI phase is an inventory table. In this table all inputs and outputs are quantified relative to the functional unit. Part of this inventory table are the LCI results, which are the emissions of all processes per functional unit (ISO, 2006). Partly due to the amount of processes and data which need to be identified, collected and validated, this phase is often the most time consuming (Guinée et al., 2002b).

3.1.4. IMPACT ASSESSMENT

The third phase of the LCA is the life cycle impact assessment (LCIA) phase, during which the environmental significance of the product system's LCI results are assessed (Guinée et al., 2002b; ISO, 2006). This is done by translating the LCI results into understandable impacts. These impacts can be given for a range of different categories, such as 'climate change' or 'acidification', which are known as impact categories. The relevant impact categories for the study have to be identified before translation can take place. Then the LCI results can be assigned to their respective impact categories, which is known as the classification step. Emissions related to climate change such as CO_2 and CH4, for example, can be assigned to the impact category 'climate change' (Guinée et al., 2002a).

After all LCI results have been classified, the actual translation of those results into understandable impacts can take place. This is done in the characterisation step. Here all LCI results are converted into common units, which are consequently aggregated to showcase their effect (Guinée et al., 2002b; ISO, 2006).

The LCI results are initially converted into a common unit according to a category indicator, which differs per impact category. For climate change, for example, all emissions can be expressed in terms of infrared radiative forcing (W/m2). Using this common indicator, all emissions can consequently be aggregated into a category indicator result, which showcases what effect the emissions have within their given impact category. This is done by using a categorisation factor. A well-known example of such a factor for climate change is the CO_2-equivalent, where the global warming potential of all related LCI emissions are aggregated into the

equivalent global warming potential of CO_2. This final aggregation is known as the category indicator result. (ISO, 2006)

The category indicator results, or modelling results (Guinée et al., 2002a), can optionally also be subjected to a normalisation step. This step can shed light on the effect of the modelled results in relation to a geographic or temporal reference context. This way the relative magnitude of the results can be better understood. Normalisation is also useful to check for inconsistencies (Guinée et al., 2002b).

The (normalised) results can further be grouped if relevant to the study. With grouping selections of impact categories are aggregated into sets though sorting or ranking. With sorting grouping takes place on a nominal basis, which relates to characteristics such as spatial scales, amount of resources or amount of emissions. With ranking grouping takes place on an ordinal basis, which results in a hierarchic structuring based on value-choices (Guinée et al., 2002b; ISO, 2006). Grouping could potentially help in facilitating communication to outsiders, as it is able to present results in a more meaningful, relatable way for an audience not familiar with LCA. It could even provide a simplified way to evaluate the environmental impacts of alternatives, as opposed to a detailed LCA (Sun, Rydh, & Kaebernick, 2003).

A final optional step is weighting, where the normalised results are assigned weighting factors representing their relative importance. This is done according to value choices. Weighting can either convert the results according to the weighting factors, or aggregated according to their impact categories (Guinée et al., 2002b; ISO, 2006). This means prior normalisation is necessary to ensure all units used are equal (Guinée et al., 2002b). Weighting allows for a comparison of environmental impacts between different products, as it gives one comprehensible LCA score per category. This also facilitates communication to outsiders, as a single score is more graspable than several. (Bengtsson & Steen, 2000) As such weighting expresses the significance, rather than the magnitude, of the study results in relation to the goal (Finnveden et al., 2009). Due to the high level of subjectivity associated with weighting, it is usually not advisable to use (Guinée et al., 2002b).

The main result of the LCIA phase is an LCIA profile of the product system, which is formed by combining all impact category results (Guinée et al., 2002b; ISO, 2006). Optionally a normalised environmental profile, grouping results or weighting profile could be added (Guinée et al., 2002b).

3.1.5. INTERPRETATION

The life cycle interpretation phase is the final phase of the LCA, during which the results of the LCI and LCIA are interpreted, qualified and evaluated. This will lead to conclusions, recommendations and possibly to further research. The evaluation of consistency, completeness and robustness of the results make up an important part of this phase. If any of these evaluations uncover problems, the LCI or LCIA phases could be revisited. Alternatively the goal and scope definition can be adjusted according to the findings (Guinée et al., 2002a; ISO, 2006).

According to Guinée et al. (2002a), the first step during the interpretation phase should be the consistency check. Here the assumptions, models, methods and data are checked for their consistency with the goal and scope of the study (Guinée et al., 2002b; ISO, 2006). As the consistency of the model influences the significance of all other interpretation steps, this step is most relevant in the beginning of the interpretation phase (Guinée et al., 2002b).

When the consistency is assured, a completeness check must be performed. During this step the availability of all relevant data for the interpretation phase is determined. Assumptions, model choices and data are also checked for errors (Guinée et al., 2002b; ISO, 2006). During this step experts can also be involved to check the methodology, data and parameters (Guinée et al., 2002b).

When the consistency and completeness are confirmed a contribution analysis can be carried out. This analysis gives insight into the overall contribution of the processes, impacts or specific environmental flows relative to the overall environmental score (Guinée et al., 2002b).

A perturbation analysis can also be carried out during the interpretation phase. During this step deliberate changes are made to the model to see how these influence the results. It can be performed for the inventory

table, indicator results, normalised indicator results and weighting results. Not only environmental, but also economic flows are taken into account during this analysis, meaning it can help in improving the model on multiple levels (Guinée et al., 2002b).

An important step is the sensitivity and uncertainty analysis. This analysis allows LCA to be used for decision making, as it delivers information about the robustness of the results. During this step the influence of variations in model choices, process data and other variations are assessed by deliberately changing these variations (Guinée et al., 2002b). This way the reliability of the final results can be evaluated and possibly improved (ISO, 2006).

Using the results from all phases conclusions can be drawn for the intended audience as part of the last step of the interpretation phase. Additionally limitations can be pointed out and recommendations can be made (Guinée et al., 2002b; ISO, 2006).

3.2. STREAMLINING LCA

Conducting a full LCA is comprehensive and complex, and hence requires a considerable time and resource investment. Data availability in particular forms a hurdle when conducting an LCA (Curran & Young, 1996; Guinée et al., 2002b; Hunt, Boguski, Weitz, & Sharma, 1998; Todd et al., 1999). To be able to carry out a multitude of LCAs in less time and with potentially limited data, as is the case with hotels, streamlining of the application of LCA is necessary.

With streamlining, the application of LCA is adapted by reducing its complexity by leaving out or simplifying certain steps. Areas and processes which do not have a significant effect on the results in particular can be omitted or simplified, speeding up the process without significantly harming the results. This way LCA could be used in more applications and for an increased number of products, services and processes (EeB Guide, 2012a; Guinée et al., 2002b; Hur, Lee, Ryu, & Kwon, 2005; Todd et al., 1999). Also, due to the limited time investment, results from a streamlined LCA can have more immediate relevance (Todd et al., 1999), which could support a wider range of decisions and regulations (Curran & Young, 1996). Generally speaking streamlined LCAs are applied to either guide decision making for upstream processes, find hotspots within life cycles, or investigate if a full LCA is necessary. As such streamlining is recommended when LCA is used to explore options, to investigate innovation on a company or sector-wide level, or to plan strategies. When comparing alternatives a higher level of detail is recommended (Curran & Young, 1996; Graedel & Saxton, 2002; Guinée et al., 2002b; Hochschorner & Finnveden, 2003; Todd et al., 1999).

Due to the complexity of LCAs and the need for artificial boundaries, all LCAs can be perceived as having been streamlined to some extent. Depending on the intended application of the study, this can be carried out in a myriad of ways, although there is no standard working procedure. This also implies there is no one-size-fits-all for streamlining. In principle, however, streamlining can be considered to consist of three steps (Christiansen et al., 1997; Todd et al., 1999):

- Screening
- Simplifying
- Assessing reliability

During screening the use of the results are considered to determine how detailed the study likely needs to be, and which steps and data could potentially be omitted from the LCA. When this has been determined to the extent this is possible, steps within the LCA are omitted or simplified, and the LCA is carried out. The exact effect of the streamlining efforts is often not exactly known from the outset, however, due to which the reliability of the results is often assessed afterwards. (Christiansen et al., 1997; Todd et al., 1999).
A general representation of the extremes between a full and streamlined LCA is given in table 3.1. Even though highly streamlined LCAs as presented in this table cannot be considered to be an LCA anymore, the table does give insight in how far streamlining can go. In those extreme cases, methods such as environmental assessment, environmental audit or ecoprofiling are better denominations.

The simplest form of an LCA is known as a 'screening LCA', which could be considered to be streamlined to the farthest extent while still being an LCA. This type of LCA does consider all life-cycle stages, but exclusively makes use of surrogate data from literature and databases and omits data when none is available. The effect of this data is not explicitly investigated to save time. This type of LCA is primarily used to uncover hotspots or to see if further study is useful (EeB Guide, 2012a; Todd et al., 1999).

Table 3.1: Difference highly streamlined & full LCA (Todd et al., 1999)

Study feature	**Highly streamlined**	**Full LCA**
Life-cycle stages	Only one stage	All stages
Breadth of impacts	Single impact	All impacts
Data	Qualitative	Quantitative
Data detail	Generic	Specific
Data quality	Estimated	Measured
Transparency	Final results	Full study
Temporal specific	No specificity	Some specificity
Spatial specific	No specificity	Some specificity
Scale	Local	Global
Data aggregation	Only aggregated data used	No aggregated data used

Streamlining can occur at the life-cycle stages, the inventory categories and even at the assessment level (Curran & Young, 1996; Hochschorner & Finnveden, 2003; Todd et al., 1999). This is also illustrated in figure 3.3. Before any decisions on these components can be made, though, the goal and scope of the study must be (re)defined to facilitate streamlining (Curran & Young, 1996; Todd et al., 1999).

When working with a streamlined LCA it is of importance that the information provided maintains its meaningfulness, can provide confidence in results and is in line with the requirements of the study. Here lies the main challenge of streamlining, as the simplification or alteration of LCAs is inherently associated with a loss of information and an increase of uncertainty, which decreases the representativeness of the results (Curran & Young, 1996; Graedel & Saxton, 2002; Guinée et al., 2002b; Hunt et al., 1998; Padey, Girard, Boulch, & Blanc, 2013; Todd et al., 1999). For all processes with substituted data, accuracy is therefore of high importance. This also illustrates a streamlined LCA is not necessarily easier, but mainly quicker (Guinée et al., 2002b).

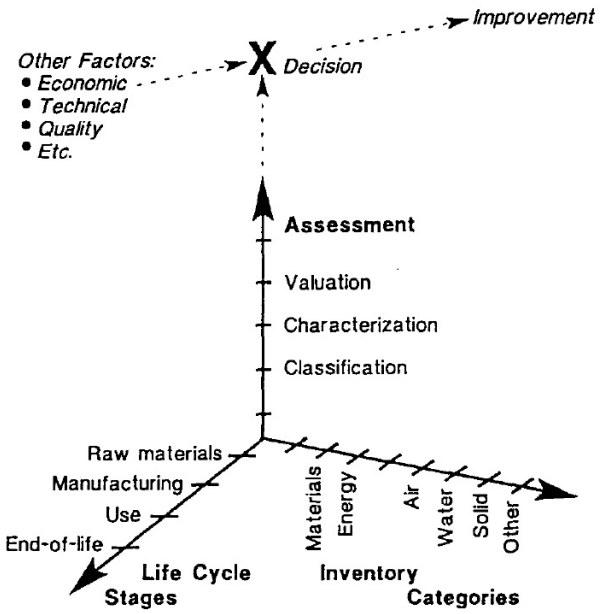

Figure 3.3: Components of streamlining LCA (Curran & Young, 1996)

To determine what the opportunity for streamlining is for a specific study, Todd et al. (1999) and Christiansen et al. (1997) developed a set of considerations in their final report from the SETAC Workgroup which is presented in table 3.2. The findings and procedures of this study could be considered as one of the fundamental bases for LCA streamlining, and have been used by a high amount of studies to this day.

Table 3.2: General considerations for streamlining opportunities (Todd et al., 1999)

Considerations	**High opportunity**	**Low opportunity**
Use of results	Identifying hotspots/screening	Marketing, policy, labelling
Dominant life-cycle stages	Dominant stage present	No dominant stage
Study audience	Internal	External
Threshold for uncertainty	High	Low
Recycling	Recycled & Re-used materials	Virgin materials
Product definition	Generic product	Specific product
Life cycle stage knowledge	High knowledge	Low knowledge

According to Todd et al. (1999), there are two main types of streamlining:

- Using existing LCA frameworks
- Alternative streamlining based on life-cycle concepts

When using existing LCA frameworks, the application itself and/or the life cycle processes can be streamlined. The streamlining of the application mainly focuses on the goal and scope definition and LCI phases. When using alternative streamlining based on life-cycle concepts, the use of automated tools or matrices are common in generating input for data and processes used in LCA studies (Hochschorner & Finnveden, 2003; Todd et al., 1999).
In the next sections the specific simplification procedures are explained per LCA phase, after which alternative streamlining methods are described.

3.2.1. GOAL & SCOPE DEFINITION

The goal and scope determine how an LCA can be streamlined, as all decisions must be in line with the boundaries set in this phase. Simplification within this phase can therefore support further decisions in later phases. Three elements are of importance to streamlining the goal and scope (Guinée et al., 2002b; Hur et al., 2005; Todd et al., 1999):

- Identifying the application for the results
- Determining what information is required
- Defining the goal and setting the boundaries for the study

This step should be well thought-through for every LCA, before any research is conducted. Geographical, temporal and technological aspects especially could help in acquiring a more streamlined LCA. Finally, in the case of comparative LCAs, concentrating on the differences between product alternatives can also be a form of streamlining (Guinée et al., 2002b; Todd et al., 1999).

Temporal and geographic limitations, available time for the study and especially data constraints in terms of availability and confidentiality should be taken into account. These will guide decisions in either what to omit, or what to include during the study (Guinée et al., 2002b; Todd et al., 1999). Involvement of the commissioner is vital during this phase, as the decisions will determine what kind of outcomes the study will yield (Guinée et al., 2002a, 2002b).

3.2.2. INVENTORY ANALYSIS

The most extensive streamlining can occur at the LCI phase. Here, the inventory can be streamlined by cutting-off (excluding) or simplifying some parts of the product system, or by substituting certain foreground processes with background processes. Both economic and environmental data can also be substituted, estimated or excluded to further simplify the assessment. The choice to simplify the processes or data used can be made to save time during data collection, but is also often made due to the lack of readily available information (Curran & Young, 1996; Guinée et al., 2002b; Hunt et al., 1998; Hur et al., 2005; Ryu, Kim, Kwon, & Hur, 2003; Todd et al., 1999). Mass, energy and environmental relevance can all serve as criteria in deciding where to simplify the inventory (EeB Guide, 2012a; Guinée et al., 2002b).

Before substituting, simplifying or excluding any processes it is important that the whole life cycle is taken into consideration, as well as economic and environmental flows. Immediately removing information can seriously affects the results, as important aspects could be overlooked. (Curran & Young, 1996; Guinée et al., 2002b; Hunt et al., 1998; Todd et al., 1999). The eventual omission of life cycle modules is possible, but must be justified with scientific proof of their insignificance (EeB Guide, 2012a; Hur et al., 2005; Todd et al., 1999).

Data simplification can be performed for all processes, but can also be applied to a selection of life cycle stages alone, while individual processes are examined in more detail (EeB Guide, 2012a). Often a focus on primary material in- and outputs is present, while emissions are more easily derived from surrogate data sources. When only surrogate data is used, a study can be considered a screening LCA. Three different types of data can be used to substitute primary data (Curran & Young, 1996; Hunt et al., 1998; Hur et al., 2005; Ryu et al., 2003; Todd et al., 1999):

- Data from databases, either embedded in a tool or separate
- Surrogate data from literature
- Averages or estimations

Capital goods in particular could potentially be omitted depending on the use and lifetime of the goods, without significantly affecting the results. For certain products, however, the effect of capital goods might be larger than others, such as non-fossil electricity, transport services and waste management services (Frischknecht et al., 2007; Guinée et al., 2002b).

Alternatively for data collection the LCI phase could be combined with an additional method of data collection in a hybrid model. In such a model multiple techniques are used complementary to each other by sharing data flows. This way sector-based data can be used for generic products and services, while process-specific data is used for the remaining processes (Junnila, 2006; Suh et al., 2004; Udo de Haes, Heijungs, Suh, & Huppes, 2004). The most well-known application of a hybrid model is the combination of an LCA with Input-Output Analysis (IOA) data, mainly in the form of an Economic Input-Output LCA (EIO-LCA). Especially with lacking data, to prevent cut-offs, or for background processes this type of data can be useful (Treloar, Love, Faniran, & Iyer-Raniga, 2000; Udo de Haes et al., 2004).

As stated before, any form of simplifying processes and data generally results in less representative results with higher uncertainty. Decisions must therefore be made on a case-to-case basis. Additionally, when a study goes beyond screening, a comparison with other streamlined LCA's or a full LCA is advisable to determine what the effects of simplifications are (Hur et al., 2005; Ryu et al., 2003). When data is already available a sensitivity analysis can help to determine which flows and processes are of less relevance, but this is often not possible when dealing with data constraints. Any differences in data and processes should be made explicit (Guinée et al., 2002b; Todd et al., 1999).

Of high importance during any streamlining activities is consistency and uniform alignment with the goal and scope. Especially when performing a comparative study, consistency between the different products in terms of parameters, assumptions and data used has to be ensured. When considering substitution, it is advisable to use data corresponding with the technology and geography of the subject under investigation (EeB Guide, 2012a; Guinée et al., 2002a).
From 1996 until 1999 extensive research by the SETAC Workgroup has been conducted into different approaches to streamline the LCI phase. Curran and Young (1996) initially developed seven approaches, which were further developed by Hunt et al. (1998) and Todd et al. (1999) into 10 extensive approaches:

- Removing all or some upstream components
- Removing downstream components (use stage also removed)
- Removing up- and downstream components (only primary manufacture)
- Using specific environmental impacts
- Using specific entries to represent LCI (focus on LCI data comparable to full LCI)
- Using "showstoppers" or "knockout criteria"
- Using qualitative or less accurate data (highly generic data)
- Using surrogate process data (surrogate data)
- Limiting raw materials (exclude raw materials that represent less than 10% of mass)

Removing up- or downstream components proved to skew the results, due to the elimination by potentially important life-cycle stages, especially the use stage. The use of specific environmental impacts or entries

to represent LCI also generally resulted in significant differences in results, as not all relevant aspects were taken under consideration. As such, these approaches were not generally considered to be LCAs anymore, but rather environmental or process assessments (Hunt et al., 1998; Todd et al., 1999).

The use of "showstoppers" or "knockout criteria" entailed a focus on an arbitrary choice of the relative importance of processes and impacts. Even though this approach was considered an LCA, significant prior research into the relevance of the showstoppers selected would be required to prevent biased and unrepresentative results (Hunt et al., 1998; Todd et al., 1999). The use of qualitative data was also bound to arbitrariness due to the need for scoring criteria (Hunt et al., 1998; Todd et al., 1999).

The most promising streamlining approach proved to be the use of surrogate data for processes. Surrogate data was found to be able to replace primary data without a significant effect on the outcomes. This way the practitioner could use the best data available, without exclusively having to use primary data. Cutting-off raw materials that represent less than 10% of the total mass was also associated with a minimal effect on the outcomes. Exact differences between products and processes cannot be predicted, however, and should therefore be approached with caution (Hunt et al., 1998; Todd et al., 1999).

Ryu et al. (2003) and Hur et al. (2005) took a different approach, and investigated the data requirements for seven different life cycle stage levels which can be found in virtually any product's life-cycle:

1. Pre-manufacturing: resource acquisition and materials production
2. Pre-manufacturing: sub-components manufacturing
3. Pre-manufacturing: components manufacturing
4. Manufacturing
5. Distribution and use
6. End-of-life: components recycling
7. End-of-life: materials disposal

Between these seven stages data was either gathered from the field, substituted by databases or omitted. This way eleven alternative combinations could be compared to a reference LCA, which was represented by the least streamlined LCA which applied all available primary data.

The use and manufacturing stages especially were found to be of particular importance to the accuracy of the results, which therefore required the use of primary data. The resource acquisition and materials production, components manufacturing, and material disposal stages were all associated with only minor differences in results when data was acquired via databases, while the sub-components manufacturing could be excluded altogether without significantly altering the results. Only the effect of data in the recycling stage was unknown, as the case-study used was focused on electrical equipment in South Korea, where recycling was practically non-existent (Hur et al., 2005). The other findings should therefore also not be considered hard facts for all products, processes and services, although they do give insight into the importance of different life-cycle stages.

3.2.3. IMPACT ASSESSMENT

During the LCIA phase the use of baseline characterisation methods such as CML-2001 or eco-indicator-99 can be used to save time, which is often done with detailed LCAs as well. Using these methods ensures results are comprehensive and comparable to other studies (Guinée et al., 2002a; Ryu et al., 2003). Normalisation of results can be included, which must be based on well-defined geographical-temporal reference systems. The use of existing reference systems can further save time. Weighting and grouping is not recommended, as both are based on value choices (Guinée et al., 2002a).

Alternatively, the SETAC work group mentioned impact categories could be selected before data is collected, classification can be done within a pre-determined matrix and characterisation can take place with scoring criteria (Curran & Young, 1996; Todd et al., 1999). These methods are further explained in the 'alternative streamlining' section.

3.2.4. INTERPRETATION

During the interpretation, not much streamlining can occur. A consistency check, completeness check, contribution analysis and sensitivity analysis are required (Guinée et al., 2002a). The sensitivity and uncertainty analyses can be confined to a limited checklist, though. This checklist should then include product system specifications, allocation rules, the characterisation method and potential weighting. During the contribution analysis processes and flows which are assumed to be of key importance could be central (Guinée et al., 2002b).

A sensitivity analysis which investigates how much the different processes contribute to the total in particular is recommended, as this procedure can determine where more accurate data is required (Hunt et al., 1998; Todd et al., 1999). Additionally, a comparison with other streamlined or a full LCAs is advisable to determine what the effects of simplification are (Guinée et al., 2002b; Hur et al., 2005).

3.2.5. ALTERNATIVE STREAMLINING

Besides streamlining within existing LCA frameworks, there are also efforts to create alternative streamlining methodologies based on life-cycle concepts. These methodologies aim to conduct an LCA through different qualitative means, often by using scoring criteria, matrices or automated algorithms.

MATRIX LCAS

Two examples of qualitative matrix-level LCAs are the Environmentally Responsible Product Assessment matrix (ERPA) and Materials, Energy, Chemicals and Others matrix (MECO). These are based on matrices containing a predefined set of life-cycle stages and environmental impact scores. In both matrices the premanufacture (materials), product manufacture, transport, product use and disposal stages are considered to be the most important life-cycles. MECO does go further in detail with regards to the life-cycle stages, though (Graedel & Saxton, 2002; Hochschorner & Finnveden, 2003; Todd et al., 1999). The environmental impacts of both materials and energy are also present in both matrices. Additionally ERPA considers solid residues, liquid residues and gaseous residues, where MECO considers chemicals and 'others'. To be able to assess and compare the impacts of the product systems, aggregating and weighting the results is a necessary step for these matrix methods (Hochschorner & Finnveden, 2003).

The main problem with matrices lies in the arbitrary choice of scoring criteria, aggregating and weighting, which is highly dependent on the interpretation of the researcher. The use of qualitative data can provide insight into potential hotspots, but is generally not recommended to use (Guinée et al., 2002b; Hochschorner & Finnveden, 2003; Hunt et al., 1998; Todd et al., 1999). For this research, matrices will not be used.

AUTOMATED LCAS

In order to assess large amounts of products and processes within one company in little time automated algorithms are currently under development. These make use of default and uniform data from databases, in combination with estimated standard deviations, automated estimations of emission factors, and Functional Units based on single stockable units sold. The databases used are often linked to the company under investigation, based on firm's enterprise resource planning systems. They are designed to produce results which are in line with certification frameworks. As such they also strive for a unification of streamlined LCAs, both in terms of application and results. Due to the large scale of these assessments, most still focus entirely on GHG emissions (Meinrenken, Garvan, & Lackner, 2013; Meinrenken, Kaufman, Ramesh, & Lackner, 2012; Padey et al., 2013).

With automated LCAs, all data is structured in a uniform way. Often bills of materials and country averages are used as input data from databases, while the use of products and materials is based on sector-specific literature research. This way all data can be easily aggregated. Capital goods are not taken into account. Emission factors are additionally automatically assigned to the materials under investigation, based on generic data. This way data can be quickly filtered and cleaned and used to represent the specific products under investigation (Meinrenken et al., 2013; Meinrenken, Sauerhaft, Garvan, & Lackner, 2014).

In order to further streamline the LCA and allow for easy aggregation of results, Key Performance Indicators (KPIs) can be used. These are firm-wide annual figures across the life cycle at any level (Meinrenken et al., 2013, 2014). They represent performance measurements which account for the chemical and physical

characteristics of life cycle stages, and focus solely on the most critical operational activities, now and/or in the future. The specific operational activities are selected through an assessment of the core operation and state of the business. Life cycle stages are selected in advance through literature research and rating, based on either results or performance indicators (Parmenter, 2015; Singhal et al., 2004). This way less information is required to make decisions, as the LCI phase is essentially replaced by predefined KPIs using data from databases (Singhal et al., 2004). By using KPIs, automated LCAs could also include more impact categories besides those related to GHG emissions, based on the selected life-cycle stages (Meinrenken et al., 2014).

As automated LCAs are often company-based, they rely heavily on supplier cooperation to acquire data (Meinrenken et al., 2014; Singhal et al., 2004). They also require the development of dedicated software to run the algorithms. As such a significant amount of time and expertise is required before quick results can be generated. For this research, automated LCAs will therefore not be used.

3.3. LCA WITHIN THE TERTIARY SECTOR

As previously stated in the problem definition, LCA is not yet well represented in the tertiary sector of the economy. Some examples focused on the operational tasks do exist, although a general methodological consensus appears to be lacking. Seven studies which focus on the environmental impact of the tertiary sector have been found and reviewed, namely those of Alcántara and Padilla (2009), Gaidajis and Angelakoglou (2011), Graedel (1998), Junnila (2006), Kofoworola and Gheewala (2009), Lehmann and Hietanen (2009), and Rosenblum et al. (2000).

3.3.1. GOAL & SCOPE DEFINITION

In general it appeared most studies focused on the analysis of a selection of products and activities necessary to perform a given service. These were often based on user-experience or pre-defined assumptions of relevance. In 1998, for example, Graedel proposed a life-cycle scope for services consisting of five foreground processes, namely 'site and service development' (facility), 'service provisioning' (all necessary products/services and people), 'performing the service' (direct consumption & use), 'facility operations' (indirect consumption & use + transportation) and 'site and service closure' (disposal).

Studies which applied a form of EIO-LCA (Junnila, 2006; Kofoworola & Gheewala, 2009; Rosenblum et al., 2000) or IOA (Alcántara & Padilla, 2009) usually only identified a selection of relevant processes associated to the service, thereby disregarding other elements of the life cycle. Gaidajis and Angelakoglou (2011), who conducted a screening LCA on the use of a university office, additionally identified specific life-several cycle stages related to the service, comparable to the subdivision proposed by Graedel. As in any full LCA these life cycle stages ranged from material acquisition and production to equipment use and disposal. The building which housed the office was not taken into account, as Gaidajis and Angelakoglou (2011) focused on the impact of the provided service alone. Low mass consumables were also disregarded, due to a lack of readily available data. The study was therefore associated with high uncertainty, but did give useful insight into the environmental impact of the office.

Lehmann and Hietanen (2009), who focused exclusively on comparing the execution of a service by different work-profiles, took a different approach. They identified 13 variables ranging from technology use to transportation. These variables were consequently linked to products and materials, which correlated with specific emissions. The variables were based on this particular study alone, however, and are therefore not necessarily applicable to other studies.

3.3.2. INVENTORY ANALYSIS

All considered studies were predominantly focused on exploring the potential environmental impacts and/or identifying hotspots of service systems. The IOA-based studies of Rosenblum et al. (2000) and Alcántara and Padilla (2009), as well as the work-profiles comparison study by Lehmann and Hietanen (2009) and screening LCA by Gaidajis and Angelakoglou (2011) predominantly used data from databases. The IOA-based studies of Kofoworola and Gheewala (2009) and Junnila (2006) additional used primary data for foreground processes. Consumption behaviour was predominantly based on estimations and literature research in all studies. The proposal by Graedel (1998) was based on a subjective qualitative assessment, and hence did not require any data.

3.3.3. IMPACT ASSESSMENT & INTERPRETATION

The LCA studies used baseline characterisation methods to calculate the environmental impact of the LCI results. The IOA-based studies used sector-specific indices (industry coefficients of consumption and emission) to calculate the aggregated environmental impact of processes. (Alcántara & Padilla, 2009; Gaidajis & Angelakoglou, 2011; Junnila, 2006; Kofoworola & Gheewala, 2009; Lehmann & Hietanen, 2009; Rosenblum et al., 2000). The proposal by Graedel (1998) made use of a selection of five environmental concerns, which were used in a matrix to qualitatively assess the impact of the five foreground processes.

3.4. CONCLUSION LITERATURE RESEARCH

The LCA framework is principally made up of four phases, namely the goal and scope definition, inventory analysis, impact assessment and interpretation. All these phases can be streamlined to some extent, but most streamlining efforts can be carried out during the inventory analysis. Streamlining the way in which LCA is applied can allow LCAs to be conducted in less time and with less data, without significantly harming the results. Streamlining could also enable the use of LCA for a larger number of products simultaneously. It can therefore be a useful alternative to a full LCA, which is more complex and thereby requires the investment of more time and resources.

Streamlining usually takes place by adapting the way in which an LCA is performed, and most efforts are focused on the goal and scope definition and LCI phases. By carrying out streamlining on a case-to-case basis the results can retain their meaningfulness and representativeness. Streamlining based on life-cycle concepts is also possible, but usually relies on automated tools or matrices.

The definition of the goal and scope determine the direction and opportunities for streamlining. The application of the results, information requirements and boundaries should all be in line with a streamlined LCA. This could reduce efforts in later phases.

During the LCI phase the most extensive streamlining can occur. Life-cycle processes as well as data used can be simplified, substituted or even cut-off. The criteria for such simplifications can be based on mass, energy and even environmental relevance. It is of importance, however, that the whole life cycle is considered before any streamlining occurs.
The use of surrogate data is common, especially for emissions. This data can derive from either databases or literature, although the estimation of processes or data is also possible. Alternatively, the use of Input-Output data can be combined with an LCA to simplify the formulation of generic products and services. The use of data from literature and databases was shown to be associated with relatively minor effects on the final results by the SETAC workgroup. The use and manufacturing stages are likely more susceptible to errors, however, and therefore require additional primary data. Any streamlining efforts within the LCI phase are associated with an increased uncertainty in results, however. Justification of streamlining efforts is therefore important, and must be documented in detail. Uniformity and consistency is also of high importance, especially when comparing products. Streamlining does not give the same results as detailed LCAs, but can be useful when the effects of streamlining are considered.

Streamlining can also occur in the LCIA phase, although to a lesser extent. The use of baseline characterisation methods is common, even for full LCAs, and saves a considerable amount of time. The use of these methods also ensures results between different studies are more similar. Alternatively, impact categories can be selected in advance.

During the interpretation phase, streamlining efforts are limited to restricting the analyses to the completeness, consistency, contribution and sensitivity analyses alone, and using check-lists for contribution and sensitivity analyses. Due to the increased uncertainty associated with streamlining, however, additional comparison with other similar LCA studies is recommended to uncover the effects of the streamlining efforts.

Within the tertiary sector LCA is not yet well represented, but some examples do exist. They often focus on a selection of products to represent a service, although the use of IO-databases within a EIO-LCA is also common. Studies focused solely on LCA are rare, although one study exists which investigates the impact of the use of a university office with a screening LCA. The results of this study are thereby associated with high

uncertainty. Data in nearly all studies derives primarily from literature and databases, and the impact of pure LCA studies is assessed with the use of baseline characterisation methods.

3.5. APPLICATION OF STREAMLINING IN THIS STUDY

In order to perform an attributional LCA on a complex service containing a myriad of products, utilities and activities within a limited time frame, while minimising the loss of data accuracy, the application of LCA will be streamlined. This will apply mainly to the detail of life cycle stages, the data requirements, and the data analyses. Most streamlining will occur during the goal and scope definition and the life cycle inventory phase.

When applying the streamlining considerations by Todd et al. (1999) to this project, the opportunity for streamlining appears to be relatively high (table 3.3).
The use of the results is mainly aimed at identifying and exploring hotspots, and creating an indicative environmental profile of a complex hotel service. As such the results are not meant to provide exact measurements of the impact of the complex service, but must be accurate enough to represent this specific service and provide detailed insight into the different origins of the impacts within the service.
The use of the products and services in the hotel by hotel guests is the dominant life-cycle stage, which will be explained in more detail in the goal and scope chapter. The study audience is Conscious Hotels themselves, and possibly its selection of partners. The threshold for uncertainty is medial, as the study will be mainly focused on developing a first insight into environmental impacts with an attributional LCA. Some detailed studies within the LCA will also occur, which require more detailed data associated with less uncertainty.

Table 3.3: Opportunity for streamlining

Considerations	**High opportunity**	**Low opportunity**	**Opportunity for this study**
Use of results	Identifying hotspots/screening	Marketing, policy, labelling	Identifying hotspots/screening
Dominant life-cycle stages	Dominant stage present	No dominant stage	Dominant life-cycle stages
Study audience	Internal	External	Internal
Threshold for uncertainty	High	Low	Medium
Recycling	Recycled & Re-used materials	Virgin materials	Mostly virgin materials
Product definition	Generic product	Specific product	Generic and specific products
Life cycle stage knowledge	High knowledge	Low knowledge	Medium knowledge

The potential for recycling differs per product, but is high for some products such as the Interface carpet tiles and Auping matresses. The consumption and generic material make-up of these and other products is largely known, and supplemented with data from literature and databases. Knowledge of the life-cycle stages is also relatively high, as many producers are transparent about their production processes. The exact material make-up and process consumption is not known for all products, however.

The general streamlining efforts per LCA phase are explained in the next sections. Most streamlining will occur during the goal and scope definition and the life cycle inventory phase, and will be focused on increasing the speed of the LCA study and reducing the data requirements, while still maintaining representative results.

3.5.1. GOAL AND SCOPE DEFINITION

The LCA will be an attributional one, which will be focused on investigating the causes of the environmental impact of a hotel as a case-study for complex services within the tertiary sector. This will be done by investigating the approximate overall environmental impact of the hotel, exploring where impacts derive from, and uncovering hotspots for future change. The attributional LCA additionally contains scenarios to investigate the influence past and future changes to the system. This LCA is thereby mainly an exploratory study into the

impacts of the hotel, which can give insight into where further study is useful, and where improvements in the hotel can be made.

The use of products utilities and activities by guests will be set as the dominant life-cycle stage. Products can usually be directly used by guests, but utilities and especially activities are often less tangible for guest use. In order to instantly link all to the dominant life-cycle stage of use by guests, all products, utilities and activities will therefore be combined in simple services in the hotel. A distinction will be made between 'services' and 'pseudo-services' as well. Services are directly used by guests, such as the front-office, and contain products, utilities and activities which are used by the service and hotel employees. Pseudo-services contain the products which are directly used by guests, such as rooms, and do not deliver a service as such. They are associated with a location which makes use of the hotel's utilities, however, for example for lighting or heat.
To enable the investigation of the hotel service, the focus of the LCA will be put on this complex services rather than on the building which houses the service. Hotel services are often specific concepts which can be applied in several buildings, especially when hotels are chains, and as such the impact of buildings is not necessarily associated with the impact of the service. Additionally, the consumption of utilities and other factors which directly affect the service can still be taken into account, even when the building itself is not. As such, by not including the building, the service can still be investigated in a comprehensive manner, while the amount of processes to include is reduced.
Additionally, a large selection of products, utilities and activities used by the hotel will be included, but not all. This selection will be based on high-mass/energy and high quantity, under the assumption that high-mass/energy and especially high quantity elements in the hotel will likely be associated with higher impact. The perceived importance of products, utilities and activities for the hotel's functionality will also be considered during this selection, as it is assumed important processes should be included regardless of their possible impact. An example of an important process could be a bed, as guests have to sleep. For all processes, all life-cycle stages will be taken into account. This way the myriad of products, utilities and activities can be quickly included, and analyses can be focused on their combined impact in the services. For all other processes surrogate data can be used from the Ecoinvent 2.2 database, and to a lesser extent from specific literature, estimations and assumptions to fill in data-gaps. As such the LCA study will be faster, but still comprehensive.

In order to showcase how hotspots can be explored, the influence of a small selection of services will be investigated in more detail within the attributional LCA. This will be done by comparing them to alternative products or services by using scenarios for the hotel, the results of which can act as a guidance for the choice of current and future products by Conscious. These detailed would ideally be focused on those products and services which are shown to have a high influence. Unfortunately this is not yet possible due to time constraints. They will therefore be chosen beforehand, to investigate how such detailed studies can be included. Additionally, to illustrate how the potential of possible changes in the system could be quickly assessed, less detailed scenarios can also be included. Such less detailed scenarios can provide insight in the potential influence of hotspots, in order to determine if detailed studies are desirable.

3.5.2. INVENTORY ANALYSIS

During the LCI phase foreground processes for the attributional LCA will be limited to the direct use of products and services by hotel guests, and those processes which directly facilitate this use. The remaining processes, such as material acquisition and waste disposal, will be treated as background processes. Among the foreground processes a distinction is also made between primary and secondary foreground processes.
The use of products and services by guests will be treated as primary foreground processes, which be entirely based on primary data from the hotel, its suppliers and measurements. The use-facilitating processes will be treated as secondary foreground processes, which will be based on primary data in combination with specific surrogate data. For products the secondary foreground processes encompass their production processes, while the secondary foreground processes of services encompass the use of products, utilities and activities of the service and its employees. As products in pseudo-services are directly used by guests, only the use of utilities and activities are regarded as secondary foreground processes for these.
To ensure a lot of different secondary foreground processes can be included in a fairly consistent manner, a strict hierarchy will be adhered with regards to the data sources which can be used. This is necessary, as the availability of primary data differs between products and services.
All secondary foreground processes will initially be based on primary data. As data can be difficult to ac-

quire for products, however, their production processes can be based partly based on specific surrogate data from the Ecoinvent 2.2 database. If the processes in this database are insufficient as well, data from scientific literature can be used. In case data-gaps are still present at this point, data from data from non-scientific literature can be used. At least the basic material composition, production location and weight must derive from primary data, however, otherwise the product is deemed too unreliable and must be disregarded from the investigation. Capital goods in particular are estimated, and often omitted altogether to prevent unnecessary estimations.
The secondary foreground processes of services, however, should not directly make use of surrogate data. These processes are highly specific for the hotel, and as such no surrogate processes exist which can accurately represent them. They can be based on a combination of known primary data and specific literature to calculate their use for the hotel, however, although data-gaps should generally be avoided.
Both primary and secondary will also have to make use of some assumptions to allow data to fit the background processes. Additionally, to further ensure all products and services in the hotel are consistent with each other despite the difference in data origin and detail, a set of general assumptions will be adopted which cover all products and services. When it is not clear if a process should be treated as a primary or secondary foreground process, it will always be treated as a primary foreground process to prevent the loss of data.

The remaining underlying processes, such as material acquisition and waste disposal, are treated as background processes. These almost entirely derive from the Ecoinvent database, as they can likely make use of less detailed data without significantly affecting the results. All foreground processes are associated with background processes, and as such the length of the supply chain of all services and products is roughly the same.

For the products and services of the detailed studies within the attributional LCA, more primary data will be used for the secondary foreground processes. Additionally, highly specific background processes will also make use primary and specific surrogate data, in order to ensure the processes and materials used in the detailed studies closely relate reality. In the case of the less detailed study, no difference will be present when compared to the other products and services in the hotel.
The detailed studies and less detailed study will be selected in advance and narrowed down along the way. The initial selection will be based on assumptions of their contribution to the hotel's environmental impact and on preferences of the hotel, and the final selection will be based on the availability of data for the different options.

3.5.3. IMPACT ASSESSMENT & INTERPRETATION

The impact assessment will be carried out by using existing baseline characterisation methods, as is generally the case with both streamlined and full LCAs. This ensures the impacts of product's and service's alternatives will be more easily comparable. For potential normalisation existing reference systems can also be used, such as the world in 2000.

During the interpretation phase the streamlining choices will be assessed. The consistency and completeness will be checked, and contribution and sensitivity analyses will be carried out. Comparing the results of individual products with existing literature will be incorporated within the sensitivity analyses.
The contribution analysis will be streamlined as well to cope with the vast amount of products, services, activities and processes. Instead of looking at all individual processes in detail, the contribution analysis will initially focus on the contribution of services, and on those products, utilities and activities which are associated to high contributions to the services and hotel. The origin of the impact of products, utilities and activities will be investigated as well, which will be predominantly focused on high contributing elementary flows, while low individual elementary flows will largely be disregarded. If it is clear individual elementary flows can easily be combined, however, as if often the case for energy-related elementary flows, this will be done as well, thereby taking into account the processes these elementary flows are related to. This way comprehensive insight can be gained with regards to the main contributing products and background processes, while not all processes have to be investigated in high detail.
The sensitivity analysis will focus on investigating the influence of streamlining choices, in particular those of the LCI phase, and will also examine the possible influence of the findings from the completeness and consistency checks.

3.5.4. SUMMARY

During this study an attributional LCA will be carried out which is focused on uncovering hotspots of complex services within the tertiary sector. A hotel will be used as a case-study for such complex services. To enable the use of LCA for the tertiary sector, its application has to be streamlined in order to increase the speed of the study, while retaining results which represent the specific hotel service under study, and provide detailed insight into the different origins of the impacts within its system. This will allow a myriad of products, utilities and activities to be investigated simultaneously within a limited time frame of roughly three to four months. The opportunity of streamlining is deemed to be relatively high for this study, and streamlining efforts will mainly be focused on the detail of life cycle stages, the data requirements, and the data analyses. Most streamlining will occur during the goal and scope definition and the life cycle inventory phase, and will be focused on increasing the speed of the LCA study.

Throughout the goal and scope definition the focus will be put on the hotel service itself, while the building which houses the hotel is not considered. Additionally a large selection of products, utilities and activities used by the hotel will be included, the selection of which will be based on products, utilities and activities associated with high mass/energy, of high quantity, or deemed to be of high importance for the hotel's functioning. The utilities and activities will be combined in simple services within the hotel as well, such as the front-office service. The use of these services and the products by guests will serve as the dominant life-cycle stage, and all life-cycle processes will be taken into account. Specific surrogate data from the Ecoinvent 2.2 database, and to a lesser extent from scientific literature, the US LCI database and non-scientific literature will also be used to fill in data-gaps. Moreover, to investigate hotspots with scenarios, detailed studies will be included, while additional simple scenarios can be added to illustrate how the potential of uncovered hotspots can be quickly assessed. As such the LCA study will be faster, but still comprehensive.

The LCI phase will concentrate on the use of products and services by guests, and on the processes directly facilitating this use. These will therefore be treated as foreground processes, while the remaining life-cycle processes will be treated as background processes. The use-facilitating processes will additionally make use of specific surrogate data from various sources. To ensure all products and services are still consistent with each other, and to ensure all necessary primary data is collected, a strict hierarchy will be adhered with regards to the use of surrogate data. General assumptions will also be adopted for all products and services to further improve the consistency between them. This way a high amount of different processes can be included in a fairly consistent manner.
A distinction is made between primary foreground processes, which encompass the use by guests, and secondary foreground processes, which encompass the use-facilitating processes. This distinction is predominantly associated with the detail and sources of data that are used. Primary foreground processes are almost entirely based on primary data from the hotel, its suppliers, and measurements, and only to a very slight extent make use of assumptions to have data fit the background processes from Ecoinvent. Secondary foreground processes, on the other hand, make use of primary data in combination with specific surrogate data to fill in data-gaps. For secondary foreground processes of products, specific surrogate data from the Ecoinvent 2.2 database, and to a lesser extent from the US LCI database and literature can be used. For secondary foreground processes of services surrogate data can only be used to base calculated estimations on specifically for the service at hand. The use of this surrogate data is necessary, as the availability of primary data differs between products and services. Both will also have to make use of some assumptions in order to fit the background data.
When it is not clear if a process should be treated as a primary or secondary foreground process, it will always be treated as a primary foreground process to prevent the loss of data.

The remaining processes, such as material acquisition and waste disposal, will be treated as background processes which will almost entirely derive from the Ecoinvent database. As all foreground processes are associated with these background processes, the length of their supply chain is the same.
The detailed studies within the attributional LCA will be based on more extensive primary data, while their specific background processes will also make use of primary and specific surrogate data. The less detailed study does not differ from the remaining products and services in terms of data. The less detailed study and options for the detailed studies will be chosen in advance based on their assumed importance. The final detailed studies will be chosen based on data availability of the different options.

During the LCIA phase the CML-IA midpoint method 'CML-2001' will be used, in combination with the baseline impact categories. As this midpoint method and these impact categories are already integrated into the CMLCA software this prevents the need for classification, saving considerably in time. The use of methods like CML-2001 is relatively common practice, however, as even full LCAs often make use of them as well.

The interpretation phase will be limited to a consistency and completeness check, as well as contribution and sensitivity analyses. The contribution analysis will focus on the overall impact of the services per impact category, after which high-impact processes can be investigated in more detail. The impact of the combined products, utilities and activities at the hotel will also be investigated, while the origin of these impacts will be focused on high contributing processes within the life-cycle.
The sensitivity analysis will focus on investigating the influence of the streamlining choices of the LCI phase in particular, and will also contain some literature research to compare results. It will be focused of a selection of products, utilities and activities, based on which general observations will be made with regards to the sensitivity of the study.

When considering the differences between highly streamlined and full LCAs as defined by Todd et al. (1999), the LCA application of this study appears to be in between a highly streamlined and full LCA in most aspects (table 3.4). All life-cycle stages are considered but most are background processes, nine baseline impact categories are taken into account, specific data is used for some processes but most are based on generic data, data is measured in some cases but often based on generic data, assumptions and estimations, there is some temporal and spatial specificity for foreground processes, the study is focused on the Netherlands, and some aggregated LCI data is used (but no data from LCA results). Only the use of quantitative data and the transparency of the whole study are fully in line with a full LCA.

Table 3.4: Detail of this LCA application in comparison to highly streamlined & full LCA

Study feature	**Highly streamlined**	**Full LCA**	**This study**
Life-cycle stages	Only one stage	All stages	All stages, but focus on use and use-facilitating
Breadth of impacts	Single impact	All impacts	9 baseline impact categories
Data	Qualitative	Quantitative	Quantitative
Data detail	Generic	Specific	Specific only for use and use-facilitating, generic for rest
Data quality	Estimated	Measured	Measured, but accompanied with generic data, assumptions and estimations
Transparency	Final results	Full study	Full study
Temporal specific	No specificity	Some specificity	Some specificity for use and use-facilitation stages
Spatial specific	No specificity	Some specificity	Some specificy for use and use-facilitation stages
Scale	Local	Global	Local, but based on Ecoinvent database
Data aggregation	Only aggregated data used	No aggregated data used	Some aggregated LCI data used

Compared to a screening LCA as described by Todd et al. (1999), this LCA application appears to be more detailed. Like a screening LCA, this study is focused on uncovering hotspots, considers all life-cycle stages, omits data when none is available, and makes extensive use of specific surrogate data from databases and literature. Contrary to a screening LCA, however, some primary data is used for foreground processes, and the effect of the use of data is investigated to some extent. The largest difference between this LCA and other types

of LCAs, however, is that this LCA application can be used to investigate the environmental impact of a whole hotel system. Like hotels, many other services within the tertiary sector include a myriad of products, utilities and activities, and as such this LCA applications could even offer a way to investigate the environmental impact of the tertiary sector with LCA as well.

4

GOAL & SCOPE CASE-STUDY

In this chapter the goal and scope of the LCA study will be introduced. Also, the audience, use of results and accuracy will be discussed, and the scope will be described.
The goal and scope definition are streamlined in order to allow the myriad of products and services present in the hotel to be included within one study, in a limited amount of time of approximately three to four months. The goal is based on the execution of a function, which will be described in detail after the goal and scope are clarified. Based on this function the selection of products and services will also be illustrated.

4.1. GOAL

The LCA study is an attributional study which also contains some specific detailed studies. Principally a streamlined attributional LCA will be conducted, during which the influence of a small selection of products and simple services within the hotel will be further investigated through comparative scenarios within this attributional LCA. This way an indicative environmental profile of the hotel can be constructed, hotspots within its system can be identified and explored, and the potential benefit of alternatives to products or services in use by the hotel can be investigated. Any other service within the tertiary sector could be approached in the same manner, but for this study a hotel is chosen as a case-study.
The use of the results is mainly aimed at identifying and exploring hotspots, and creating an indicative environmental profile of a complex service, in this case the Conscious Vondelpark hotel. As such the results are not meant to provide exact measurements of the impact of the complex service, but must be accurate enough to represent this specific service and provide detailed insight into the different origins of the impacts within the service.

The LCA is therefore an exploratory one, which could provide insight into where further study is useful, and where improvements in the hotel can be made. Streamlining efforts are predominantly focused on increasing the speed of the LCA study, in order to allow a myriad of products and services to be included in one study. This will be done by focusing on the hotel service itself without including the building, by only including a specific selection of products, utilities and activities, and by using specific surrogate data from databases and to a lesser extent from literature, as well as estimations and assumptions to fill in data-gaps for all but the dominant life-cycle processes. Additionally, all life-cycle stages will be taken into account, while the use of products, utilities and activities by guests will serve as the dominant life-cycle process. Most products are directly used by guests, while the utilities and activities are mainly associated with use by services in the hotel. As such all utilities and activities, as well as the remaining products, are combined in simple services within the hotel. This way the hotel will contain both services and products which can be directly used by guests, making it possible to quickly link all products, utilities and activities to this dominant life-cycle.

The goals of the LCA study are represented by the aspects of the first and third sub-questions presented in chapter 2. As such, the specific research questions for the hotel LCA study are:

> *"What approximate environmental impacts are related to residing in the Conscious Vondelpark hotel during one day and night for one average guest, and where do these impacts derive from?"*
>
> *"What is the influence of using electricity from roof-based PV-panels to supply 10% of the yearly electricity demand on the environmental impact of the Conscious Vondelpark hotel for one average guest during one day and night, compared to the current use of electricity from wind from Windpark de Hondtocht?"*
>
> *"What is the influence of the laundry service by Van der Kleij in Utrecht on the environmental impact of the Conscious Vondelpark hotel for one average guest during one day and night, compared to a nearly identical hypothetical laundry service in Amsterdam which has not made efforts to lower its environmental impact?"*
>
> *"What is the influence of adding Thermatras insulation to the boilers at the Conscious Vondelpark Hotel to its environmental impact for one average guest during one day and night, compared the current situation without such insulation?"*
>
> *"What are the effects of streamlining the application of LCA on the validity of the results for the Conscious Vondelpark hotel?"*

In order to answer the first research question a streamlined attributional LCA will be conducted which includes a large selection of products and services necessary to perform the hotel's function. Additionally, to answer the second and third research question, the influence of the laundry service and electricity production will be investigated through more detailed studies and comparative scenarios within this attributional LCA. To answer the fourth research question the possible influence of boiler insulation is assessed through a simple study. The selection of these detailed studies is explained in section 4.2.1

The comparisons of the detailed studies and quick hotspot assessment will be executed as scenarios within the entire system of Conscious Hotels as well as separately, between the individual alternatives. This way it can be investigated if changing a service/product is associated with less environmental impact, but also if this change is relevant at all when looking at the total impact of the hotel, or that changes in other areas might be more useful. The detailed studies additionally showcase how the influence of identified hotspots can be further investigated. The assessment of the insulation showcases how the potential influence of uncovered hotspots can be investigated, which could lead to the implementation of more detailed studies such as those of the electricity and laundry.

Besides the overall performance of the hotel, the environmental impact of the individual services will also be investigated. In this way an indication can be given with regards to which areas are associated with which impacts, and where these impacts might originate from. Social or economic aspects will not be taken into account, which is an inherent limitation of LCA.

4.1.1. AUDIENCE, RESULTS & ACCURACY

The LCA is carried out for Conscious Hotels in Amsterdam, the commissioner of the study. As this study is part of a master thesis of Industrial Ecology, an exam committee composed of representatives from Leiden University and the Technical University of Delft is also part of the intended audience. Although the results will mainly be communicated internally, it is possible the hotel decides to communicate the research intentions and/or final results towards the guests of Conscious as a form of promotion. Some of Conscious' partners and suppliers will also have access to (a part of) the results.

As the LCA is the first of its kind for Conscious Hotels, its results will mainly be used to gather insight into the environmental impact of their hotels. As such, an exceptional level of accuracy is not deemed necessary, although the results should give a reasonable indication of the environmental impacts and their origin.

The results of the LCA will act as an indication for Conscious of their environmental impact, and will help to identify hotspots for possible future change. The results of the more detailed studies within the attributional LCA could act as a form of guidance for Conscious in their choice of future products.

Information will mainly derive from information delivered by Conscious and its suppliers, and will be complemented by information from databases (especially Ecoinvent 2.2) and literature.

4.2. SCOPE

The LCA is limited to the case-study of the Conscious Vondelpark Hotel in Amsterdam (the Netherlands), and its suppliers. A Dutch environment in 2015 is therefore assumed for the hotel. The production of products is based on the Dutch environment from 2000-2015, as most products were produced a couple of years ago, except when it is explicitly mentioned products derive from other regions.
The products and services in use by Conscious will be at the basis of the assessment. Unless recycled materials are used, the products and services will be modelled from cradle to gate. Recycled materials are allocated according the avoided burden approach by assigning (part of) the disposed materials after use to the recycling process that feeds into production, thereby closing the loop. For comparisons with hypothetical alternatives, averages from specified literature will be used. For comparisons with potential future products, the product choice by Conscious will be used.

The LCA will be performed with the scientific LCA software tool CMLCA V5.2 developed by Institute of Environmental Sciences at Leiden University. The CML-IA midpoint method 'CML 2001' is additionally adopted.

4.2.1. PROCESS, PRODUCT & SERVICE BOUNDARIES

The selection of products, utilities and services that are taken into account during the LCA is based on those associated with high-mass/energy and high-quantity. As such all utilities and most activities are included, but low-mass products such as pens or low-quantity products such as coffee-makers are disregarded.
The selection is additionally focused on what Conscious has indicated as those which are of high importance for the hotel's functionality. Of high importance for the hotel's functioning are products or activities such as mattresses, toilets and ventilation.
In order to make not only products, but also utilities and activities tangible for use, they are all combined in simple services. The exact way in which this is done can be found in chapter 5.
Further extrapolation of the selection is recommended if this study is continued in the future, in order to create a more comprehensive environmental profile of the hotel. Low-mass/energy and low-quantity products or services are not necessarily associated with a low impact, and could in fact alter the environmental profile. For this study, with a highly limited time-frame of approximately three to four months, the initial selection is still necessary in order to make the study feasible.

The study will be focused on the impact from the service provision of the hotel. As such, the building which houses the hotel and its structural elements will not be taken into account. Also, the use-stage of products and services, will serve as the dominant life-cycle. Environmental interventions will derive from databases and literature, and to some extent from available primary data.
The choice for the more detailed studies would have ideally been based on identified hotspots, but as this requires an extensive time investment the choice had to be made beforehand. This choice was based on assumptions with regards to which services were likely to contribute significantly to the hotel's environmental impact, and on indicated preferences by Conscious. Data availability also played a role, as potentially interesting services or products with limited data are not included.

4.3. FUNCTION OF THE HOTEL & PRODUCT AND SERVICE SELECTION

Within the hotel a plethora of products and simple services facilitate the hotel's function, which is described as "providing comfortable residence and services for hotel guests". The functional unit used for the LCA study is based on this function, and is formulated as: "the residence of one average guest during one day and night in a hotel, based on yearly hotel consumption and use averages". Here the 'residence' of one average guest encompasses sleeping in the hotel for one night, and making use of the services provided, such as the front office and breakfast. The consumption and use of products, utilities and services during this residence is based on the yearly average of the hotel for all guests and rooms.

Several reference flows are constructed to gain insight into the environmental impact of the hotel service.
The main reference flow for the hotel is formulated as: "providing comfortable residence for one average guest during one day and night in the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages", which encompasses all products, services and utilities used. Additional reference flows are present for the individual services, which are formulated as: "providing a service to one average guest during one day and night in the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages". When comparisons are made between alternatives within the hotel's system, the reference flows are formulated as "using alternative A instead of alternative B to provide comfortable residence for average one guest during one day and night in one the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages". The reference flow for comparisons between two single product or service alternatives outside of the hotel's system are formulated as "using alternative A instead of alternative B to provide a service to one average guest during one day and night in one the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages". Alternatives (A and B) are represented by either electricity, laundry or gas insulation alternatives.
Finally, the impact of the total amount of electricity, gas, water consumed, and products and activities present at Conscious on a daily basis will also be investigated. Their reference flow is formulated as "consumption of the amount of a product/utility/activity necessary to provide comfortable residence for one average guest during one day and night in the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages".

4.3.1. FUNCTION OF THE HOTEL

The Conscious Vondelpark hotel contains 81 rooms, which are occupied during ***% of the time (***-*** average). On average *** guests stay in one room, of which only ***% stay for one night. Additionally ***% of the guests stay for two nights, ***% for three nights, ***% for four nights and another ***% for five nights or more.

The function of the hotel, earlier on described as 'providing comfortable residence and services for hotel guests', entails more than simply providing guests with a bed to sleep. According to Conscious, three main themes encompass all activities within its hotel, namely 'operation', 'installations' and 'furniture, fixtures & equipment (FF&E)'. These themes are highly related to each other. The installations are responsible for the hotel's core functioning, while the FF&E make the operation of the hotel possible, which in turn supplies services to the hotel guests.

To put this in broader terms, the hotel is provided with energy and water through installations ('installations'). Its guest-rooms and public areas are fitted with furniture, fixtures and equipment ('FF&E'), which make use of the energy, heat and water. Finally the hotel offers services to hotel guests ('operation') by using the furniture, fixtures, equipment, energy, and water.
A more precise descriptions of the processes within these themes is given below.

OPERATION

Under 'operation' fall all of the services which people directly associate with a hotel, such as checking-in and informing guests, facilitating meals and drinks and cleaning services. The rooms and public spaces also fall under this heading, although these are not services as such, and are therefore referred to as 'pseudo-services'. Not all activities are directly visible to guests, but guests make use of them all.

Of particular importance in the operation are the back and front-offices, where the visible and invisible services and products are managed. In the back-office financial and higher-level management of the hotel takes place. Financial and accounting activities, human resource management, communication with suppliers and partners, website maintenance, promotion, and other related activities take place here. Interaction with guests is usually uncommon.
In the front office guest service activities are present, and hence interaction with guests is common. Welcoming and informing guests, handling reservations, taking messages, renting bikes and solving minor problems within the hotel, and other related activities are all part of front-office activities.
Both the front- and back-office contain furniture and electronic equipment, which consume electricity. They also employ people who need to transfer to and from work every day.

The hotel also offers food and beverages (F&B), which need to be produced, served and disposed of. This is partly carried out by front-office personnel, and partly by dedicated F&B personnel, both of which transfer to and from the hotel. Cutlery, plates and cups are also used, which have to be produced and washed.

Finally the operation includes cleaning services, which involves the cleaning of hallways and other public areas, and of rooms. Employees transfer to and from the hotel, and make use of cleaning products. They also distribute large amount of products for guest use, such as bed linen, towels, and shampoo. Re-usable products such as bed linen and towels must also be washed, which takes place externally by the Van der Kleij laundry company. Housekeeping also takes care of the trash produced by nearly all services, which is then disposed of by Milieuservice Nederland.

FURNITURE, FIXTURES & EQUIPMENT (FF&E)

Furniture, fixtures and equipment includes all products which make up the interior of the hotel. This include products such as beds, seats, tables, lights, carpets, etc. These can be found throughout the hotel in large quantities, and are used by employees and guests. Especially in the public areas (lobby) and rooms they are of importance, as they provide guests with direct comfort. The products are produced, used and disposed of, and are associated with relatively short lifetimes.

INSTALLATIONS

The distribution of electricity, gas and water falls under the installations, which includes the consumption of electricity, gas and water. Nearly all services and products make use of these utilities, which are distributed by air handling units and local energy installations such as PV-panels. These distribution installations are produced, used and eventually disposed of, and are associated with relatively long lifetimes.

4.3.2. PRODUCT & SERVICE SELECTION

The selection of services and products for the attributional LCA is given below. For every product and service selected, the life-cycle processes as well as the potential products used by it are considered in general terms.

OPERATION

The services fall under the operation of the hotel, and consist of the front-office service, back-office service, food & beverages service (F&B) and housekeeping service. Additionally the pseudo-service of public spaces in the hotel which are not bound to one specific service are part of the operation, as are all the rooms in the hotel. Finally the hotel makes use of an external laundry service. This laundry service, which presents itself as being highly sustainable, is considered in high detail, and will be compared with a hypothetical alternative laundry service to investigate its impact.

FF&E

The services at Conscious make use of a high amount of products. The front-office makes use of computers and printers, paper and archive boxes, and provides guests with room cards and rentable bicycles. The back-office also makes use of computers, printers, paper and archive boxes, as well as laptop computers. F&B provides guests with glasses, cups, plates, cutlery, food and beverages, and additionally makes use of pans, while housekeeping makes use of two specific cleaning products.
The remaining public spaces predominantly encompass the lobby area, public toilets and hallways in the hotel. In the lobby wooden seats, big wooden tables, small wooden tables, and plastic tables can be found, while its roof is covered with a sedum structure. The toilet area contains five toilets and five wash basins. The floor in the lobby is fitted with hardwood, while the floors in the toilets and hallways are fitted with ceramics and carpet, respectively. All these spaces also contain lights, both LED and CFL. These LED lights can also be found in the rooms, which additionally contain a wooden seat, a plastic table, bedside tables, a TV, a queensized bed with pillows, blankets, and bedlinen. The bathroom in the room contains several towels, a toilet, a wash basin, a shower basin, body wash, and shampoo. The room is fitted with carpet, while the bathroom contains ceramic tiles.
In the hotel more products are present, such as a green wall, shower-heads and napkins, but these are not taken into account due to their low quantity or mass.

INSTALLATIONS

The electricity, water and gas used in the hotel are distributed by the installations. The production of electricity in particular is considered, as this currently derives from a specific wind park in the Netherlands. This

electricity production will additionally be compared with electricity from PV-panels located at Conscious to investigate if PV-panels are associated with considerable benefits.
Ventilation and cooling are also provided by the installations, namely the air handling units, which is therefore considered separately from the remaining electricity use.

DETAILED STUDIES & SCENARIOS

As mentioned in the sections above two detailed studies will be included as well. The source of electricity at Conscious will be investigated. The hotel currently makes use of 100% electricity from wind, which is guaranteed by their energy supplier Pure Energie through energy contracts (Pure Energie, 2016). The hotel is considering installing PV-panels on their new hotels to cover 10% of the yearly electricity requirements, however. During this study the effect of this potential transition will therefore be explored. Four scenarios will be created with regards to electricity to be compared to the current situation, namely the proposed use of 90% wind and 10% PV, a hypothetical use of 50% wind and 50% PV, a hypothetical use of 100% PV and the exclusive use of electricity from the Dutch grid. To be able to make comparisons possible the assumption is made that electricity from all sources can provide the hotel with the necessary amount of base-load electricity. In reality both wind and solar energy need to be complemented by base-load electricity sources from the Dutch grid, often of fossil origin, to ensure a constant and reliable flow of electricity. This is disregarded in this study, however, as it is assumed that the periods during which additional electricity from the Dutch grid is necessary are compensated for by the periods that wind/PV installations feed their overproduction back to this grid.

Additionally the laundry service by Van der Kleij will be documented in detail, and its effort to be more sustainable will be investigated by comparing it to an identical (hypothetical) alternative laundry services which has not implemented these efforts. This alternative laundry service will be placed right across the hotel in Amsterdam, removing the necessity for transport. This way it can be investigated what the effect of the sustainable efforts is approximately, and if these efforts outweigh the transport to Van der Kleij in Utrecht. Three scenarios will be created to be compared to the current situation, namely the use of the alternative hypothetical laundry service in Amsterdam, the use of the Van der Kleij service with 50% less transport, and the use of the Van der Kleij service which makes use of electricity from wind.

These scenarios will provide additional insight for Conscious, but will also showcase two different ways in which hotspots and possibilities can be explored. The electricity production showcases how future adaptations can be investigated, while the laundry service represents a deeper investigation of the source of environmental impacts. All scenarios are very specific, in the sense that they assume hypothetical situations where only very specific changes and assumptions are present. This approach has been adopted as it shows the differences in their purest form, without the influence of other changes. When hotspots are investigated further in the future, a more realistic approach might be required. This way the comprehensive impact of a change can be investigated, which also takes into account the situational circumstances. For now, however, no specific decisions have been made by Conscious as of yet, and hence the exact circumstances are not known.

To investigate the potential of hotspots, quick analyses with a lower level of detail are also possible. These can consequently lead to more detailed studies. As such a simple scenarios exploring the potential of a reduction in gas consumption will also be created. This scenario represents the installation of insulation for the boilers, potentially reducing the gas consumption. As generic data from the Ecoinvent database is used to a large extent this study cannot be considered a detailed study, but it does showcase the possibility of adding simple comparisons within the attributional LCA as well.

4.4. SUMMARY GOAL & SCOPE CASE-STUDY

An attributional LCA of the Conscious Vondelpark hotel is carried out, as a case-study to investigate how LCA can be used within the tertiary sector. To accomplish this the goal and scope definition and other phases of the LCA have been streamlined in order to enable the quick incorporation of a myriad of products, utilities and activities within one study. For the goal and scope definition, the focus of the LCA is put on the hotel service itself, without including the building that houses the hotel. Additionally, only a selection of products, utilities and activities within the hotel are taken into account, based on high mass/energy, high quantity, and high importance for the hotel's functionality, and their use by hotel guests will serve as the dominant life-

cycle. As the utilities, activities and some products are not directly used by guests, these are combined in simple services within the hotel. This way the hotel will contain both services and products which can be directly used by guests, making it possible to quickly link all products, utilities and activities to this dominant life-cycle. Finally, specific surrogate data from the Ecoinvent 2.2 database and to a lesser extent literature can be used to fill-in data-gaps, and all life-cycle processes will be taken into account. As such the LCA study will be faster, but still comprehensive.

The aim of the case-study LCA is to provide the Conscious Vondelpark hotel with holistic insight into their environmental impact, uncover and explore hotspots in its system, and investigate what the influence of alternatives to products or services within its system are. The LCA is therefore predominantly an exploratory one, which could provide insight into where further study within the hotel's system is useful, and where improvements in the hotel can potentially be made. Two detailed studies are included within the LCA, which illustrate how the influence of alternatives to products or services within the system can be investigated with scenarios. Additionally, one less detailed scenario is also included to illustrate how the potential of uncovered hotspots can be quickly assessed in order to determine if detailed studies are desirable. The two detailed studies focus on the source of electricity and laundry services, respectively, while the less detailed scenario focuses on the gas consumption of the hotel.

The LCA is carried out for Conscious Hotels in Amsterdam, the commissioner of the study, but is also part of a master thesis of Industrial Ecology at the TU Delft and Leiden University. The results will therefore predominantly be for internal use, and should be able to give a reasonable indication of the environmental impacts of the hotel and their origin. For the use of products and services in the hotel a Dutch environment in 2015 is assumed, while the production of most products is based on the Dutch environment from 2000-2015, as most products were produced a couple of years ago. Additionally, all products, utilities and activities are modelled from cradle to gate, except in the case of recycled materials, and the scientific LCA software tool CMLCA V5.2 will be used.

The LCA is based on the function of the hotel, which is described as "providing comfortable residence and services for hotel guests". The functional unit of this LCA is formulated as "the residence of one average guest during one day and night in a hotel, based on yearly hotel consumption and use averages", which is associated with several reference flows. The main reference flow is formulated as "providing comfortable residence for one average guest during one day and night in the Conscious Vondelpark Hotel, based on yearly hotel consumption and use averages", while the other reference flows are present for the individual services, comparisons within the hotel's system, comparisons outside of the hotel's system, and the use of products, utilities and activities within the hotel.

5

INVENTORY ANALYSIS – LCI APPROACH & ASSUMPTIONS

In this chapter the approach used to gather data during the inventory analysis is explained, the life-cycles of the hotel are presented, and the data use and availability is clarified. First the generic life-cycle formats for products and services used by Conscious will be introduced, after which the hotel system as used for the LCA is described. The distinction between foreground and background processes will also be made. The use of primary data, databases, literature and assumptions is additionally discussed, as are the assumptions which facilitate the LCA. Data from databases solely derives from the Ecoinvent 2.2 database, which is used as an inherent part of the CMLCA tool. Data from the US LCI database is also sporadically used to base processes and data on, but its data is adapted to fit the Ecoinvent database.

5.1. CONSCIOUS VONDELPARK HOTEL

A myriad of products, utilities and activities are associated with the Conscious Vondelpark hotel. As such the use of products, electricity, gas and water at the Conscious Vondelpark Hotel, as well as guest and employee behaviour is used to calculate the environmental impact of the complex hotel service. Based on this information the life cycle processes behind products and services which facilitate the hotel's function are constructed.

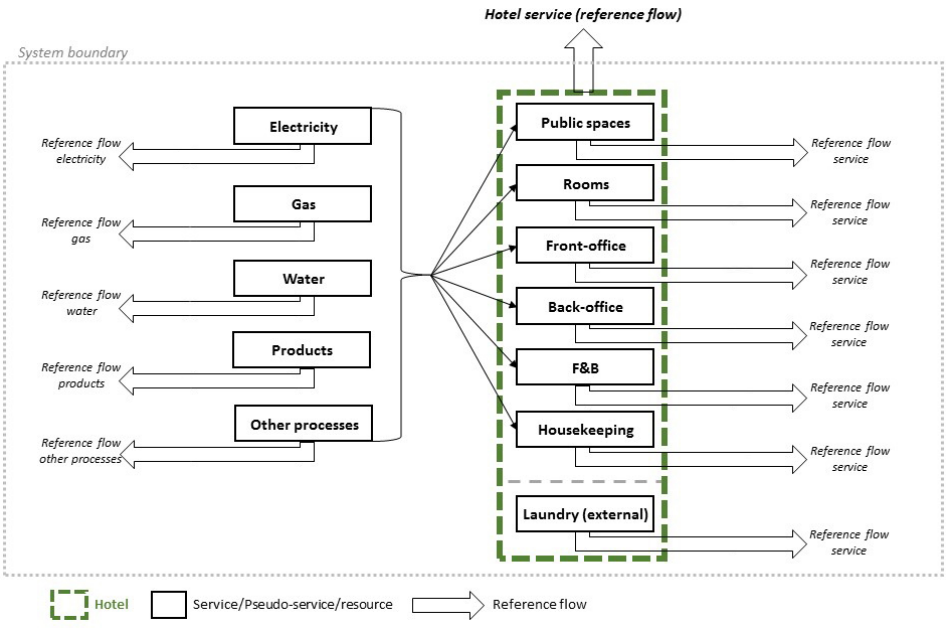

Figure 5.1: Process-tree hotel (simplified)

All products, utilities and activities used in the hotel are linked to their associated services, of which two main ones are identified: services and pseudo-services. As was mentioned in chapter 4, services are provided to guests by employees and encompass the front- and back-office services, F&B service, housekeeping service and laundry service. Pseudo services encompass the public spaces and rooms. These do not deliver a service themselves, but provide guests with many products that they directly use, such as beds and tables. Combined these services and pseudo-services (mainly products) are responsible for the environmental impact of the hotel. This environmental impact is still an approximation, however, as not all products could be included and streamlining of data has taken place.

The process-tree of the hotel and its services can be seen in figure 5.1. In this figure the exact inflows products and utilities for the services are omitted to simplify its appearance, as are the outflows of emissions and waste. As such only the services used are shown, while their underlying processes are not visible. The reference flows as mentioned in chapter 4 can also be seen in this process tree.

All services except for the laundry service make use of electricity, gas and water that is delivered to the hotel. This utility use is divided over the different services, of which more details can be found in subsection 6.2.1. The individual consumption of products within the services are not measured per product, but are combined per service. The external laundry service makes use of utilities on a location outside of the hotel. The underlying life cycle processes of the products and services used by the services in figure 5.1, such as product manufacturing and material acquisition, are nearly always external and therefore also make use of the electricity, gas and water on locations outside of the hotel. Both the internal and external utilities used contribute to the environmental impact of the hotel service.

5.1.1. PRODUCT & SERVICE STREAMLINING

Services and products directly used by guests are at the basis of this LCA, which encompass the products within the pseudo-services and the services introduced in the previous section and represented in figure 5.1. These are therefore investigated in high detail, while their underlying processes are based on less detailed data. Next to the selection of products and services in the goal and scope, this distinction between the application of detailed and less-detailed data for different processes constitutes the main streamlining effort of this LCA.

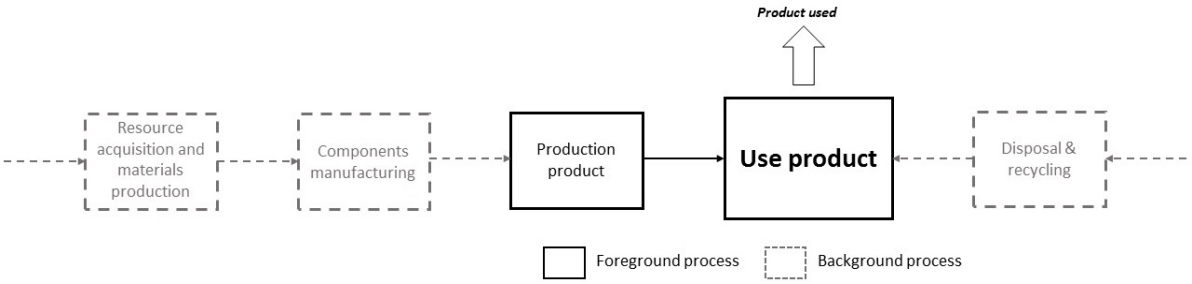

Figure 5.2: Generic product life-cycle process-tree

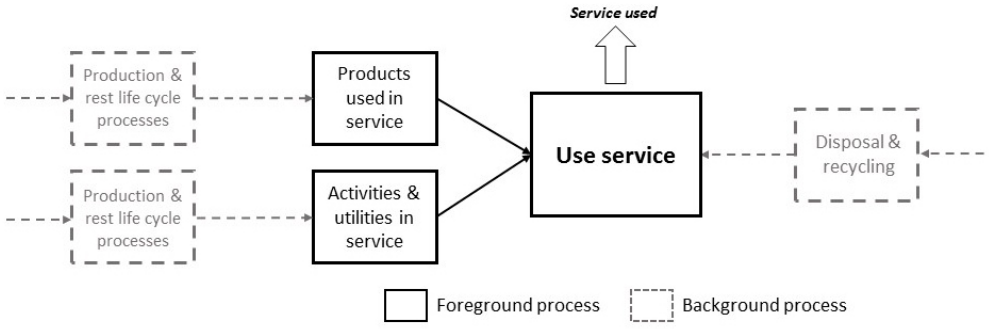

Figure 5.3: Generic service life-cycle process-tree

The structure of the life-cycles of these products and services is based on the findings by Ryu et al. (2003) and Hur et al. (2005), who indicated that for products the use stage, and the stage directly facilitating this use (in their case the manufacturing stage) require the most detailed data to arrive at representative impact results. The remaining underlying processes, such as material acquisition and waste disposal, can likely make use of less detailed data without significantly affecting the results.

The life-cycle of products follow a generic format which highly coincides with the format proposed by Ryu et al. (2003) and Hur et al. (2005), as can be seen in figure 5.2. The generic format for guest services in the hotel can be seen in figure 5.3, and is principally composed of processes directly facilitating the service, and their inputs of products, utilities and activities. All process boxes are associated with the consumption of electricity, gas and/or water, as well as with potential emissions. These are omitted from these figures to simplify their appearance.

The use of the products and services, and the processes directly facilitating these are indicated as 'foreground processes' in these figures, while the remaining processes are indicated as 'background processes'. The difference between these is explained in the next section.

5.2. PROCESS & DATA AVAILABILITY

As stated above products and services used directly by guests are at the foreground of this investigation. This encompasses the use of the products in public spaces and rooms (products in pseudo-services), such as tables, seats and blankets, and the use of all services in the hotel, such as the front-office service and housekeeping service. The use and production of the products used by guests is investigated in detail, and modelled to represent them as correctly as possible. The use of the services by guests is also investigated in detail, as is the use of products, utilities and activities within the services which are vital for their functionality.

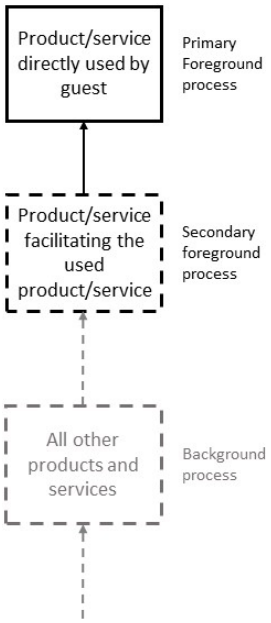

Figure 5.4: Distinction primary foreground, secondary foreground, and background processes

These detailed processes are known as foreground processes, which can be seen in figures 5.2 and 5.3. Such processes are associated with a fairly high level of detail, and are principally based on primary data from the hotel, producers, and on-site measurements. They therefore depict most products and services under investigation relatively accurately, although some specific surrogate data from literature and databases is used to fill-in data-gaps. Especially for process-specific emissions surrogate data is used, as primary data for emissions is often not available due to lack of specific measurements. Transport as well is often estimated, based on the locations of production facilities, retailers and services, while capital goods often have to be based on data from the Ecoinvent database or are omitted due to lack of data.

A further distinction is made between primary and secondary foreground processes, which can be seen in figure 5.4. For products this distinction can be seen in figure 5.5, for services it can be seen in figure 5.6. This subdivision of processes allows the investigation to take place at a quick pace, while preventing the loss of representativeness of the results. As the same availability of data cannot be guaranteed for all products and services, a strict hierarchy with regards to the collection of data has been created for primary foreground, secondary foreground and background processes, which will be described in this section. Additionally, when it is not clear if a process should be treated as a primary or secondary foreground process, it is always treated as a primary foreground process to prevent the loss of data.

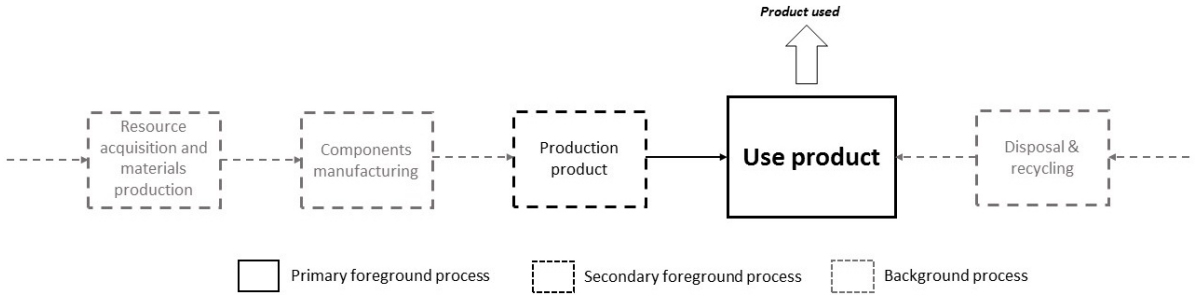

Figure 5.5: Generic product life-cycle process-tree, distinction primary and secondary foreground processes

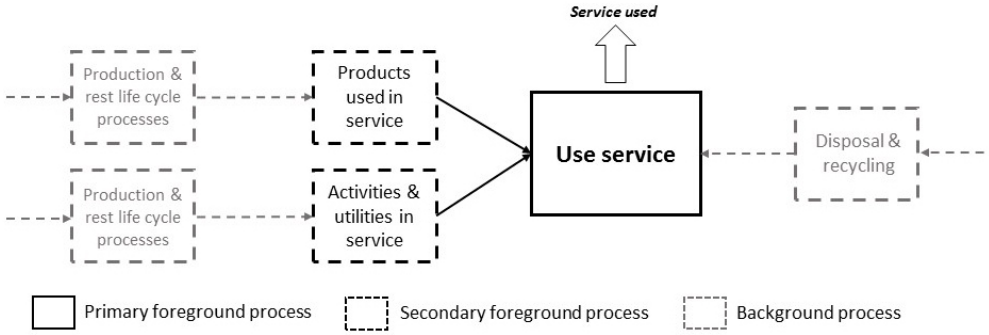

Figure 5.6: Generic service life-cycle process-tree, distinction primary and secondary foreground processes

Primary foreground processes encompass the use of (pseudo-)services in the hotel and use of products of pseudo-services. They are entirely on primary data from the hotel, with some necessary assumptions to match the background processes from the Ecoinvent database. Examples of primary foreground processes are the use of the front-office service mattresses by guests. For services this use includes the amount of employees present, and the functions provided per guest, while the use of the products is predominantly associated with their amount, lifetime and frequency of use. The consumption of electricity, gas and/or water by the products in the hotel, such as electricity use by lights, is allocated to the use of utilities by the (pseudo-)service they are part of.

Secondary foreground processes refer to the processes which facilitate (pseudo-)services and products in pseudo-services. These are not directly used by guests, but vital for the products and services which guests use. They encompass the use of services, activities and products by services and service employees, as well as the production of products present in the pseudo-services of public spaces and rooms which are directly used by guests.
Even though these secondary foreground processes are still principally based on primary data from the hotel and its suppliers, the difference with the primary foreground processes is that secondary foreground processes generally make more use of data from literature and databases. Primary data is still preferred, though. As with primary processes some assumptions are likely necessary to fit the background processes. When primary data is not available for production processes, specific Ecoinvent processes can be used to surrogate production processes or complement product compositions. When data-gaps still exist, specific data from scientific literature, from the US LCI database or non-scientific literature can be used, respectively. At least the basic material composition, production location and weight of products must derive from primary

data, otherwise the product is deemed too unreliable and must be disregarded from the investigation. Capital goods in particular are estimated, and often omitted altogether to prevent unnecessary estimations.
When primary data is not available for services specific surrogate data cannot be used directly, since the use of utilities, activities and products is highly specific for every service. As such no surrogate processes can represent this use correctly. Specific literature can be used in combination with primary data to calculate the their use for the hotel, however, in order to fill-in data-gaps. For secondary foreground processes of services data-gaps should be avoided, however. As products in pseudo-services are directly used by guests, only the use of utilities and activities are regarded as secondary foreground processes for these.
As these secondary foreground processes are still principally based on primary data from the hotel and its suppliers, they cannot be considered background processes. Examples of secondary foreground processes are the frequency of use of computers and printers by front-office employees, and the production of the mattress.

The remaining processes are treated as background processes. This means they are principally based on literature and databases, and are only more specified when primary data becomes available. Examples of background processes are the production of computers for the front-office, and raw material acquisition for the mattress, but also all other underlying processes such as waste disposal and tap water production.

As all foreground processes are eventually linked to background processes from Ecoinvent, the length of the supply-chain of all services and products is roughly the same. This means that all process-trees are eventually linked to raw material acquisition and other basic processes, which ensures no information is left out for any service or product.

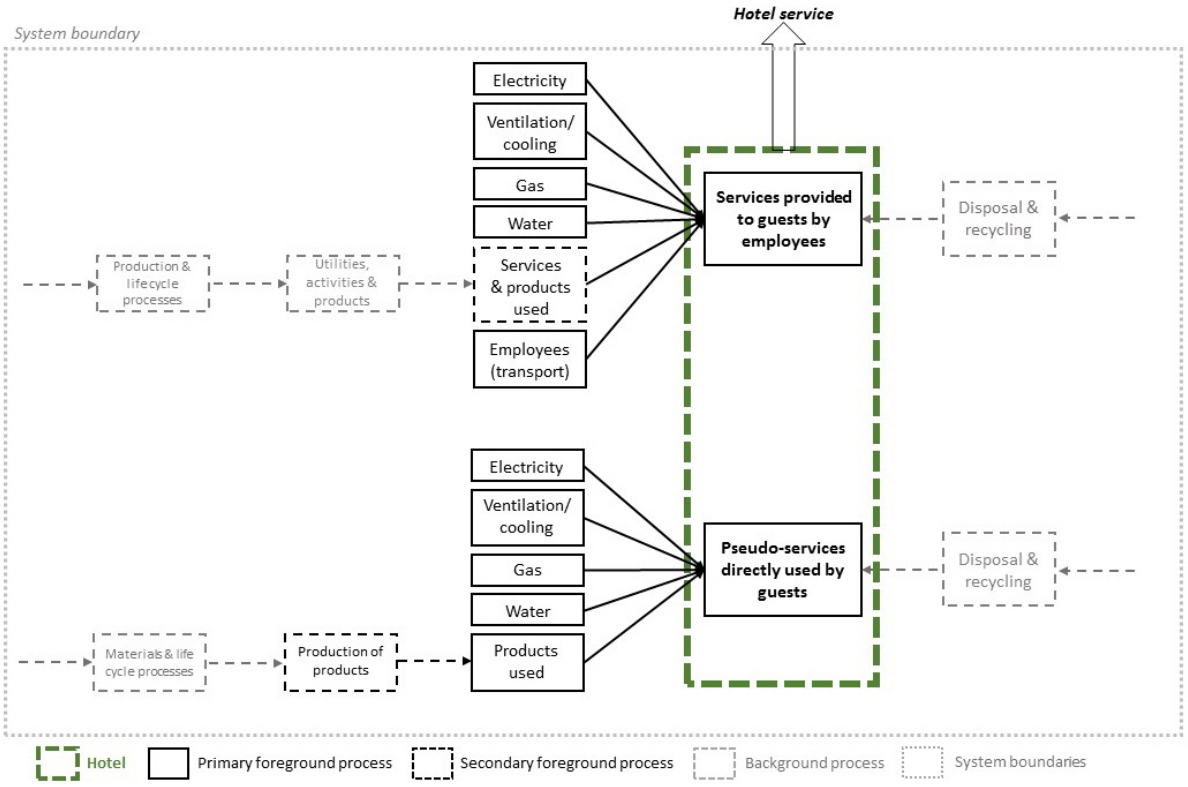

Figure 5.7: Process-tree hotel, detailed pseudo-service and service

The way in which the different processes are incorporated in the simplified process-tree of the hotel (figure 5.1) can be seen in figure 5.7. In this figure one pseudo-service and one service are visualised, which are representative for all (pseudo-)services that make up the complex hotel service. The emissions of the processes are omitted to simplify its appearance, as are the utilities used by the secondary foreground and background processes.

The consumption of utilities during the use stage of products and services are based on average measurements of monthly and hourly consumption at Conscious. Finally, the economy-environmental system boundary as defined by Ecoinvent, which describes the distinction between economic and environmental flows, is assumed for all processes. As many processes are treated as background processes, some economic as well as environmental flows might differ from the actual situation. All choices are uniform, and a list of general assumptions used for the entire LCA is presented below.

5.2.1. GENERAL ASSUMPTIONS

A Dutch environment is assumed for the end-of-life processes. Production and disposal processes are all based on the Dutch environment, unless it is explicitly mentioned they take place elsewhere. Packaging is never taken into account, and capital goods are only taken into account for primary foreground processes, although both packaging and capital goods are not removed from background Ecoinvent processes. Additionally, it is assumed surrogate processes can be scaled linearly to allow them to fit the surrogated process, except when specific scaling instructions are given.

All waste from the hotel is assumed to be managed by Milieuservice Nederland, including the disposal of products. All waste except glass and organic waste is assumed to be transported to Suez Amsterdam, which entails a transport distances of 10 km (appendix B). Transport of auxiliary materials and from the incineration to landfilling sites is already taken into account in Ecoinvent (Doka, 2009). Disposal of most products is assumed to take place according to the Dutch standard, which means most products are incinerated (Rijkswaterstaat, 2015). When the waste disposal of specific materials are not present in Ecoinvent, similar processes are used, and if those cannot be found municipal solid waste is used. Recycling is known to occur for some products, and is performed 'quick-and-dirty'. This means recycling processes are based on generic benchmark processes taken from databases or literature. Allocation of recycling or other beneficial waste-treatment is based on the avoided burden (substitution) approach. This means the environmental benefit of recycled materials or waste-treatment is transposed onto the input of the process, thereby replacing part of the primary material input. The allocation takes place during the sorting process, which is perceived as a multi-functional process which both processes waste and provides base-materials for the production of recycled materials. This allocation is based on mass, and as such all recycled materials that flow into the production process derive from the materials that flow out of the disposal process. The possible loss of material properties is not taken into account, but direct losses during sorting and recycling processes are considered. When not enough material flows out of the process to supply the required input, which could be the case when high amounts of the materials are lost during sorting and recycling, an external source for the recycled material is used as a supplementation. These external recycling processes are identical to the internal recycling processes, but the allocation of the sorting process to waste disposal falls out of the boundaries of the hotel's system, and is therefore not taken into account in the results.
Recycling can be modelled in a more streamlined manner, for example by simply cutting off all recycled content or cutting of the disposal of recycled content. This also leads to a loss of results, however. As the avoided burden approach requires relatively little effort when generic processes are used, the choice is made to include this approach rather than simply cutting off processes. This way the benefit of recycling can be taken into account, while the LCA can still be carried out quickly.
With products that are re-used outside of the boundary the transport to the new location is allocated for 50% to the waste disposal of the product, while the remaining 50% is cut-off, and thereby allocated to the new use outside of the boundary. No disposal is taken into account with these products, as they are given a second life. Sewage is based on Ecoinvent standards.

Transport of all products in use at Conscious is taken into account, as is transport of material constituents to the production process of foreground products. When the exact weight is unknown the transport is based on the weight of the constituents which make up the material or products. For background processes the transport of ingredients is not specified for the specific product, and transport distances present in the Ecoinvent processes us used.
Over long distances or in the case of very large quantities transport is assumed to take place with >28 ton lorries. Direct delivery to Conscious is assumed to take place with 3,5-16 ton lorries. Raw material transport, relatively high quantity transport and the remaining transport is assumed to take place with >16 ton lorries. All finished products are assumed to be directly transported to Conscious. Transport distances are approximated with Google Maps (https://www.google.nl/maps) based on the production locations, while transport

over sea is estimated with Port Distance (https://www.searates.com/reference/portdistance/). Transoceanic transport is assumed to be destined for the Port of Rotterdam, except when products are known to be shipped to Amsterdam. From the Port of Rotterdam products are assumed to be transported to Conscious over a distance of 120 km, while the transport distance from the Port of Amsterdam is assumed to be 15 km. For raw materials of which the origin is unknown, the standard European transport distances as stated by Althaus et al. (2007) are used. These are 300 km for plastics, synthetics, chemicals, and metals, and 200 km for construction materials and plant-based materials.

In some cases exact material or processes properties are not known. As such these must be set at known values, which will be based on a myriad of Google searches of known scientific values. The choice has been made not to mention every single source, but rather give the final assumptions as the basis to work with, since most choices are personal. This way, European oak is assumed to weigh 710 kg/m3, polyurethane sealer 0,06 kg/L, stain/varnish 1,10 kg/L, cleaning solvents/white spirit 0,79 kg/L, lubricating/hydraulic oils: 0,90 kg/L, water 1,00 kg/L 1000 kg/m3, diesel 0,83 kg/L, gasoline 0,75 kg/L, propane 2,01e-3 kg/L, natural gas 6,56e-4 kg/L, and LPG 0,55 kg/L. Similarly, diesel is assumed to burn with 43 MJ/kg, while natural gas is assumed to burn with 38 MJ/m3. All gas for the hotel is burnt with the Ecoinvent process 'natural gas, burned in boiler condensing modulating >100 kW' [P1328/G1241], as the peaks are high. For industrial processes the Ecoinvent process 'natural gas, burned in industrial furnace low-NOx >100kW' [P1330/G628] is used.

The ingredients of soaps and detergents which are not present in Ecoinvent are surrogated by comparable Ecoinvent materials. This is also based on a myriad of Google searches and personal assumptions to find out which Ecoinvent materials are most suitable. Additionally, due to the high complexity of soaps and detergents, all of them are based on the Ecoinvent process of soap, of which only the ingredients are replaced to fit the specific products.

5.2.2. DETAILED STUDIES

Three comparisons will be carried out within the attributional LCA through several scenarios, namely of the electricity production from wind or solar energy, of the laundry service, and of the gas consumption at the hotel. The first two comparisons are based on highly detailed data and processes, and provide insight into influence of potential alternatives or past changes within the system. The third comparison provides insight into the potential influence of installing insulation to reduce the impact of gas, which could be the incentive for more detailed research in the future.

For the highly detailed comparisons it is of high importance the comparable alternatives are of the same quality and detail. The operation of the alternatives, activities within the alternatives and production processes associated to the alternatives are all predominantly based on high-quality data, although the electricity production relies heavily on detailed data from the Ecoinvent database. Since the Ecoinvent data on the production wind mills and PV-panels is extraordinarily specific, it is deemed trustworthy enough for this investigation. Since both electricity alternatives are based on sources specified by Conscious, and filled in with Ecoinvent data, they are comparable. The laundry service is based on highly detailed equipment and consumption data from the Van der Kleij laundry company, largely deriving from measurements. This data is consequently altered based on precise baseline measurements of the specific laundry equipment used to create a hypothetical alternative which does not include any of the efforts towards more sustainability. As such the influence of different alternatives can be investigated within the hotel's system. The boiler insulation is far simpler, but as it is added directly to the existing system rather than via an alternative replacement process it can still be used to gain insight into its potential influence.

5.3. SUMMARY LCI APPROACH

The hotel's system consists of a myriad of products, utilities and activities which are associated with the hotel service. These are present in the different services of the hotel, of which two main types are distinguished: services and pseudo-services. Services provide a service directly to guests, and encompass the front-office, back-office, F&B, housekeeping and laundry services. Pseudo-services are represented by the public spaces and rooms in the hotel, and do not provide a service to guests as such, but do contain a high amount of products which are used by guests.
Every service and pseudo-service is associated with the use of products, utilities and activities, which are

responsible for their environmental impact. Combined these services are in turn responsible for the environmental impact of the whole hotel. This impact not only associated with the use of products, utilities and activities, but also to a large extent with their supply chain.

During the LCI phase the life-cycle processes are streamlined by focusing on the use of products and services by guests, and on the processes directly facilitating this use. Additionally, a distinction is made between primary and secondary foreground processes with regards to the data used. The use of products and services is regarded as a primary foreground process, which almost solely make use of primary data from the hotel, producers and on-site measurements. The use-facilitating processes are regarded as secondary foreground processes, which encompass the production of products directly used by guests and the use of products by service employees. These are principally based on primary data, but also make use of specific surrogate data to fill-in data-gaps. For products this surrogate data can be taken from the Ecoinvent 2.2 database, and to a lesser extent from scientific literature, the US LCI database and non-scientific literature, respectively. For services surrogate data can only be used in combination with primary data to support calculated estimations when data-gaps arise. This way a high number of different secondary foreground processes can be included in a fairly consistent manner, even though the availability of primary data differs between them. When it is not clear if a process should be treated as a primary or secondary foreground process, it is always treated as a primary foreground process to prevent the loss of data.
The remaining processes, such as material acquisition and waste incineration, are treated as background processes and based on processes from the Ecoinvent 2.2 database. All foreground processes are associated with background processes, and as such the length of the supply chain of all services and products is roughly the same. In case of the detailed studies, more primary data is used in both the secondary foreground and background processes.

To ensure all products and services in the hotel are consistent with each other, despite the difference in data origin and detail, a set of general assumptions has been adopted. Among others, these include the assumption that packaging is never considered, that all waste is disposed of by Suez Amsterdam (unless recycled materials), and that transport distances are based on the distance between the production location and Conscious Vondelpark hotel.

6

INVENTORY ANALYSIS - PROCESSES & DATA

In this chapter the implementation of the LCI approach introduced in chapter 5 is described, and the general composition of the inventory data is presented. The difficulty related to differences in data availability, data detail and extensiveness of products and services is introduced first, after which the consequence of these differences for the level of detail of the foreground processes is explained in general terms. The inventory data of the individual services and products is not included in this chapter, but can be found in appendix B. In this appendix the production of renewable electricity and laundry service are discussed first, including their alternatives. After these the pseudo-services of public spaces and rooms are discusses, accompanied by their respective products. Finally the services of the front-office, back-office, F&B, and housekeeping and their products are examined. This appendix additionally contains the datasheets which include all economic and environmental in- and outflows.

The consumption of the utilities of electricity, gas and water in the hotel is described in at the end of this chapter. This consumption is based on measurements at Conscious in combination with general data from experts and specific literature which is used to distribute the consumption among the services present in the hotel. As such this final section is preceded by a brief literature research.

Most of the information in this chapter and appendix B is based on primary data from either Conscious or its suppliers, which can be found in their rough form in appendix A. The translation of this primary data into concrete LCI data is associated with a myriad of calculations and conversions, which can all be found in appendix C. Calculations with regards to the hotel's utilities, floor area and occupancy can be found in appendix D.

6.1. LEVELS OF DETAIL

In order to allow for the data collection during the LCI phase to take place at a fast pace, the processes not directly related to or facilitating the use by hotel guest have been treated as background processes. As explained in the previous chapter the products and services directly used by guests were considered to be foreground processes with a high level of detail, or primary foreground processes, while the processes facilitating this use were considered foreground processes with a lower level of detail, or secondary foreground processes.

Due to the vast amount of products and services, however, it has not been possible to gather highly detailed data for all secondary foreground processes, especially with regards to the production of products used in the pseudo-services. To cope with this, a strict hierarchy has been adhered, as explained in chapter 5. For all primary foreground processes, primary data is supplemented with assumptions to fit the background data. For all secondary foreground processes related to products primary data is preferred, but when this data is not available, Ecoinvent processes can be used as well to surrogate production processes or complement product compositions. When data-gaps still exist, data from scientific literature, the US LCI database, or non-scientific literature can be used, respectively. For secondary foreground processes of services calculated estimations based on specific literature and primary data can be used to fill-in data-gaps.

For primary foreground processes, such as the use of products and services by guests, all data has been based on primary data and measurements from Conscious, primary data from suppliers, and estimations from hotel employees and experts. Their level of detail is therefore all high and similar, and several weeks are required to gather the require data for all primary foreground processes. For secondary foreground processes, such as the production of products and use of products by employees, more variation exists due to the extended hierarchy and increased lack of data. The activities within services have been largely based on accounts from employees, for example with regards to the use of computers or employee commute. The data detail for production processes is less homogeneous, however, as the exact composition and production of some products, such as the Auping mattress, are predominantly based on primary data, while for others, such as Dharmazone shampoo, this is largely based on estimations and specific surrogate data from Ecoinvent and literature. As such four levels of detail can be distinguished within the secondary foreground processes:

1. Highly detailed secondary foreground processes
2. Medially detailed secondary foreground processes
3. Limitedly detailed secondary foreground processes
4. Crudely detailed secondary foreground processes

The first levels are high in detail, but also require relative high time investments to gather data. the last levels are low in detail, but can be constructed in relatively short amounts of time. All are initially based on primary data, which is supplemented with specific surrogate data, estimations and assumptions to varying extents, following the hierarchy described in chapter 5.

6.1.1. HIGHLY DETAILED SECONDARY FOREGROUND PROCESS

The use of all activities and utilities within services are associated with a high level of detail, and there are also some production processes of products in the hotel associated with this level of detail. These activities and production processes are predominantly based on primary data from the hotel and/or suppliers, accompanied by some estimations by employees and experts and possibly calculated estimations. In order to have the data correspond with background processes in Ecoinvent some assumptions are often necessary, but such assumptions are usually backed with literature or data from the hotel. In cases when very specific background processes or materials are not present in the database, an effort is additionally made to approach these by using expert estimations, scientific literature or data from the US LCI database. As such the high level of detail is not only reflected in the secondary foreground processes themselves, but also in the background processes they utilise.

To achieve this high level of detail a relatively high time investment is required to gather data. All involved foreground processes must be investigated in detail, primary data must be measured and/or gathered from suppliers, data-gaps need to be filled with relatively extensive literature research, and assumptions and estimations must be avoided if possible. Achieving this level of detail therefore generally takes a couple of weeks.

Both the services at the hotel and the laundry service contain activities with a high level of detail. Examples of the service activities at the hotel are the use of computers, the use of printers, and the consumption of cleaning products, while examples of the activities at the laundry facility are the washing, drying and folding. Among the production processes at the hotel those of the Auping mattress and Interface carpet tiles are regarded as being highly detailed. The production, installation and distribution network of wind- and PV-based electricity systems is also associated with a high level of detail.
Examples of specifically designed background processes created for highly detailed processes are the recycling of materials for the Auping mattress and Interface carpet tiles, and the production of washing products for the washing process. The vast majority of background processes are unaltered Ecoinvent processes, however, among which are also the production processes of computers, laptops, printers and other products used by the employees that provide services to guests as part of the services.

6.1.2. MEDIALLY DETAILED SECONDARY FOREGROUND PROCESSES

The processes in this category include the production and transport of the utilities of gas and water to the hotel, which are based directly on Ecoinvent processes, and the production of products. The production processes of products are based on existing Ecoinvent processes, which have been adapted to fit the products better. These adaptation are predominantly based on primary data from suppliers, but also partly derive from literature. Assumptions are necessary to make the data from literature coincide with the Ecoinvent processes, while some details might be left out altogether due to a lack of trustworthy data. All background

processes are taken from Ecoinvent, with possible slight alterations based on literature from Ecoinvent itself.

This lower level of detail is associated with a significantly lower time investment, as primary data is used to adapt existing processes rather than develop new ones. This way processes and activities involved only have to be compared to the Ecoinvent processes, and changed whenever they are proven to deviate from the specifications from primary data. Literature research is predominantly focused on specifying the processes rather than filling data-gaps, while assumptions and estimations can be largely based on the existing processes as well. Achieving this level of detail therefore generally takes a couple of days to a week.

Among the production processes at the hotel those of the Mosa floor- and wall-tiles, the LED TV and all lights are regarded as being medially detailed. The investigation of the boiler insulation is also associated with a medial level of detail.

6.1.3. LIMITED DETAILED SECONDARY FOREGROUND PROCESSES

The production of products in this category is largely based on primary data in combination with specific surrogate production processes. The type and amount of materials in the products, their lifetime and their production location is known, but most other production data derives from literature and the Ecoinvent database. These surrogate processes are consequently adapted to fit the specific production processes more precisely. Assumptions are necessary to translate the data from literature to Ecoinvent, and to use Ecoinvent processes to surrogate production processes. The processes are therefore still designed to approach the actual production processes as accurately as possible, but lack some primary data, necessitating the use of data from other sources. Most products in the hotel are of this quality.

The time investment necessary to achieve this level of detail is comparable to the time investment for the medially detailed processes, as it often requires extensive literature research to fill data-gaps, although specific surrogate Ecoinvent processes are used as well. As such achieving this level of detail generally takes a couple of days to a week, and is quicker when Ecoinvent processes can be used directly.

Among the production processes at the hotel those of the wooden furniture, plastic tables, bedside table, wooden floor, sedum roof, Yumeko products, bicycles, towels and bedlinen, room cards, wash basins, shower basins, and toilets are regarded as being associated with a limited level of detail. Of these products, the production processes of the wooden furniture, plastic tables, bedside table, wooden floor, sedum roof and Yumeko products are partly based on literature, while the towels and bedlinen, room cards, wash basins, shower basins and toilets are purely based on a combination of primary data and general Ecoinvent processes to surrogate production. The glasses, ceramic cups and plates, and cutlery present at the F&B service are also associated with this detail level. The production of these products is regarded as a background process for the F&B service, but as they are also directly used by guests, they are modelled at secondary foreground processes.

6.1.4. CRUDELY DETAILED SECONDARY FOREGROUND PROCESSES

The production processes in this category are based on a very limited amount primary data, often restricted to broad product descriptions and estimations from measurements or suppliers, and make extensive use of assumptions and estimations to surrogate both processes and materials. Specific processes in Ecoinvent are often lacking, and specifically for products exact amounts of constituents not known. As such they represent very rough approximations of the secondary foreground processes under investigation.

During the development of these processes, most time is invested in finding specific surrogates in Ecoinvent and attempts to find more detailed data in literature. More detailed data is scarce, however, and as such a large part of the time investment is represented by attempts to find data which does not exist. Developing these processes therefore still generally takes a couple of days to a week. Even though the level of detail could be regarded as being too low for this study, they are still often included to give an indication of what their impact could be, and to investigate their potential importance with regards to the hotel's environmental impact.

Among the production processes at the hotel those of the Dharmazone products are considered to be associated with a very crude level of detail, and the types and production of food and beverages used in the F&B service as well. As with the plates and cutlery, the production of food and beverages is regarded as a

background process for the F&B service, but as they are also directly used by guests, they are modelled at secondary foreground processes. These production processes differ from the products, as they are activities to grow food which are predominantly influenced by the production process itself. The impact of materials for these processes is predominantly influential further down the supply-chain, and hence their contribution to the process' impact is usually slight.

6.2. SERVICES, PRODUCTS AND UTILITIES AT CONSCIOUS

The services and products that are included were introduced in chapter 4, and are based on high mass/energy, high quantity or high importance for the hotel's functioning. Some examples of these services and products were already mentioned in the previous sections, and here all services and products included in this study are presented.
All services in the hotel are taken into account, which are the front-office, back-office, F&B and housekeeping services. The external laundry service at the Van der Kleij company is also included. All services in the hotel contain products, of which more details can be found in appendix B. In total, 58 small LED lights, 55 large LED luminaires and 108 CFL lights are present throughout the hotel, while roughly 220 m^2 of wooden floor, 1.850 m^2 of carpet tiles, 2.000 m^2 of ceramic tiles and 425 m^2 of sedum roof is present throughout the hotel. In the rooms and public spaces, 81 LED TVs, mattresses, bedside tables, plastic room tables and shower basins are present, 86 toilets and shower basins, 23 plastic lobby tables, 4 large wooden tables, 8 small wooden tables, 147 chairs, 324 pillows and 162 blankets are present. Additionally, 8 computers, 2 printers, 9 laptops and 34 bicycles are present in the front- and back-office, which make use of 250 archive boxes, 560 kg paper and 100 room cards per year. In the F&B service approximately 150 porcelain cups, porcelain plates and pieces of cutlery, 500 glasses and bottles and 20 pans are present, alongside a plethora of food and beverages. Finally, 60 litres of Alkastar and 179 litres of Zitrotan are used by the housekeeping service every year. More information regarding the use and lifetime of the products and their distribution among the services can be found in appendix B and C. All services additionally make use of the utilities in the hotel. The distribution of these utilities among the different services is clarified in the next section.

6.2.1. UTILITIES AT CONSCIOUS

At the Conscious Vondelpark hotel the consumption of electricity, gas and water is monitored by a standard meter box and reported on a yearly basis to Green Key for certification. Additionally, monitoring of the hourly consumption of all utilities has been recently implemented by Beyond Energy, and is presented in an online tool by Hello Energy to give the hotel more precise insight of their consumption. The exact consumption per service is not measured, however, and as such this has to be based on a combination of measured data, generic data from experts and literature research. This has been investigated in high detail in appendix B10, of which the main results are summarised in this section. The exact distribution of utilities among the services can be found in this appendix, and an extensive account of all data and calculations can be found in appendix D.

As the documentation of utilities has not been entirely consistent throughout the years, their consumption is based on the best available data. The yearly consumption of electricity at the hotel is based on the hotel average between 2011 and 2015, and is rounded off to 252.000 kWh. The yearly consumption of gas and water is based on the hotel average between 2011 and 2014, and is rounded off to 53.000 m^3 gas and 5.900 m^3 water. Based on data from the meter box in 2013, the consumption of electricity per month appears to be fairly consistent throughout the months, while the consumption of gas shows clear peaks during the colder months due to heating, and water shows peaks in busier months due to its use for showers.
The hourly consumption of utilities has been monitored as well. The average hourly consumption of all utilities has been calculated per hour in order to investigate the trends in consumption behaviour per day. These trends were also calculated per month, in order to ensure the different seasons did not alter the trends. The hourly monitoring has started at different times for electricity, gas and water, but is measured up and until April 2016 for all. After this month consumption data could not be taken into account, as the data was already being processed at that time.
The hourly consumption of electricity was monitored from October 15th 2015 onwards, and shows a clear peak during the morning due to the use of lights by guests waking up. The hourly consumption of gas was monitored from June 18th onwards, and shows a very high peak in the morning due to showers and to a slight extent cooking activities for breakfast, and a smaller peak in the evening for showers. The hourly consump-

tion of water was monitored from September 21st 2015 onwards, and shows a high peak during the morning and lower peak during the evening due to showers as well. The peak for water is more extreme, however, as gas is also largely used for heating.

The exact distribution of the utilities among the services has not been monitored, however, and as such is based on the findings from the hotel consumption, in combination with generic consumption data from Hello Energy (part of Trefoil Energy), accounts from qualified hotel employees and literature. For electricity and gas, Hello Energy was able to supply generic consumption data of hotels from different eras.
For electricity the consumption data of a post-1995 hotel building has been applied, as much of the interior and ICT has recently been updated, for example by using LED lights. As such 10% is assumed to be used for cooling, 10% for ventilation, 50% for lighting, 20% for ICT and 10% for the remaining uses. The consumption of cooling and ventilation is distributed over the rooms and public spaces according to their floor area. The air handling units for the rooms indirectly ventilate the hallways as well, while the air handling units for the public spaces indirectly ventilate the front- and back-office, who's floor areas are therefore also taken into account. The consumption by lights is divided over the different services according to the number of lights they contain, while the consumption by ICT is divided over the front-office, back-office and public areas (lifts, etc.). The remaining 10% is divided over the rooms, public areas, kitchen and housekeeping service.
For gas the consumption data of a hotel building built between 1940-1995 has been applied, as the hotel was built in 1980 and still makes use of the heating installations installed at the time. As such 55% is assumed to be used for heating, while 45% is assumed to be used for tap water. These numbers additionally coincide with the contributions which were specifically calculated for Conscious in appendix D (tab 'Consumption Vondelpark', tile O81). Heating is divided over the rooms and lobby based on their floor area. As with ventilation, these indirectly heat the hallways, and front- and back-office, respectively, who's floor area is therefore also taken into account. Hot tap water is predominantly used for showers in the rooms, to a slight extent for the F&B service, and to a very slight extent to the housekeeping service.
For the water consumption Hello Energy could not provide data, and as such the findings from the hotel consumption are supplemented by literature accounts and estimations by qualified hotel employees. As such water appears to be predominantly used for showers in rooms, and to a lesser extent for tap water and toilets in rooms as well. A slight amount is additionally used in the public toilets, as well as in F&B service for beverages and dishes.

6.3. SUMMARY OF LCI PROCESSES & DATA

The life cycle of the hotel has been streamlined by treating all processes which are not directly related to or facilitating the use by hotel guests as background processes. Additionally, a distinction is made between primary foreground processes, which encompasses the direct use of products and services by guests, and secondary foreground processes, which are those processes that directly facilitate this use. Not all products and services are associated with highly detailed primary data, however.

The data for primary foreground processes derives directly from the hotel, its suppliers or measurements. As such this data is highly detailed and uniform. The available data for secondary foreground processes is not as uniform, however, in particular with regards to the production of products. This is predominantly related with the availability of primary data from suppliers, as well as with the availability of secondary data, which differs between products. As such four levels of detail can be distinguished within the secondary foreground processes, namely highly detailed, medially detailed, limitedly detailed and crudely detailed. The highly detailed secondary foreground processes require the highest time investment, as well as the most primary data. The other detail levels all require considerably less time, but differ in their data requirements. The medially detailed processes are production processes which are based on existing Ecoinvent processes, and have been adapted to fit the products better. These also include the production and transport of utilities. The limitedly detailed processes are production processes for which less primary data is available. There are therefore based on primary data in combination with specific surrogate production processes from literature and the Ecoinvent database, which are adapted to fit the products better. The crudely detailed processes, finally, are production processes for which only the minimal amount of primary data is available, namely the general composition, production location and weight of the product. As such these make extensive use of specific surrogate data from literature and databases, as well as estimations and assumptions, which means they represent very rough approximations of the products under investigations, which can only provide an

indication of what their impact in the hotel could potentially be.

The consumption of electricity, gas and water at the hotel is predominantly based on measurements at Conscious, both on a yearly, monthly and hourly base. The use of these utilities has not been documented with absolute consistency throughout the years, however, and as such some small differences in the temporal scale of data between different utilities exist, although all data derives from 2011 until 2016.
The exact distribution among the different services has not been monitored, and as such has been calculated by combining observations from the measurements at Conscious with generic consumption data from Hello Energy (part of Trefoil Energy), and some specific literature. All inventory data of the individual services and products, as well as an exact account of the utility distribution of the hotel can be found in appendix B.

7

LIFE CYCLE IMPACT ASSESSMENT

During the impact assessment phase the CML-IA midpoint method 'CML 2001' is used, with most of the baseline impact categories as proposed by the SETAC working group. The characterisation factors of this method are already integrated in the CMLCA software, eliminating the need for further classification. Normalisation is also included for a variety of reference situations, such as the World in 2000 and Western Europe in 1995. As such the use of this baseline method allows for a relatively comprehensive impact assessment to be carried out in little time.

More detailed results and the missing characterisation factors can be found in appendix E.

7.1. IMPACT CATEGORIES, CLASSIFICATION AND CHARACTERISATION

Almost all baseline impact categories as proposed by the SETAC working group are used, but in consultation with Jeroen Guinée, and based on the declaration by (Heijungs, de Koning, Lighthart, & Korenromp, 2004), marine aquatic ecotoxicity is not taken into account, however. This choice has been made as the characterisation of this this impact category in particular is associated with high uncertainty for metals, and will likely lead to incorrect conclusions. The impact categories of terrestrial ecotoxicity, freshwater aquatic ecotoxicity and human toxicity have been included, however, although the characterisation of these toxicity-related impact categories is also a current topic of debate (Guinée et al., 2002a). They are less uncertain than marine aquatic ecotoxicity, however. Depletion of abiotic resources is also not taken into account. But land use is, as the hotel makes use of many wood-based products and food, which might be associated with a high influence on the impact on land use. As such the impact on land use, eutrophication, acidification, photochemical oxidation, climate change, terrestrial- and freshwater aquatic ecotoxicity, ozone depletion, and human toxicity is taken into account. The characterisation of each of these nine impact categories is shortly explained below. As stated above the characterisation factors are already integrated in the CMLCA software, eliminating the need for further classification.

7.1.1. LAND USE

The impact on land use represents the (temporary) occupation of land as a resource due to competition, for example by crops taking over forest land or other crops. It affects both natural resources and the man-made environment, and its baseline category indicator is focused on land occupation. No characterisation model is available for land use, and as such the characterisation results are unweighted aggregations accompanied by a dimensionless characterisation factor. The indicator result is expressed in m^2 per year (Guinée et al., 2002a).

7.1.2. EUTROPHICATION

Eutrophication is caused by the release of macronutrients into the environment, in excessive amounts. This may lead to undesirable shifts in species composition, increased biomass production, and polluted drinking water. As such its category indicator is focused nutrient enrichment, or more specifically the deposition of nutrients in biomass. It affects both natural resources and the man-made environment, and can cause depressed oxygen levels in aquatic ecosystems especially, and the main macronutrients are nitrogen and

phosphorus. Its characterisation factor is eutrophication potential (EP) for air, water and soil, which is calculated based a model that identifies the nitrogen and phosphorous equivalents for both terrestrial and aquatic systems, such as the CARMEN model. The indicator result is expressed in KG PO4-equivalent (Guinée et al., 2002a).

7.1.3. ACIDIFICATION

Acidification is caused by pollutants which have an acidifying effect on soil, water, biological organisms, ecosystems and materials. It affects the natural and man-made environment, human health and natural resources, and is predominantly associated with the release of SO2, NOx and NHx. Its category indicator is critical load deposition/acidification, and its characterisation factor is acidification potential (AP), which is calculated by models who describe the way in which acidifying substances are deposited, in this case the RAINS10 model. The indicator result is expressed in kg SO2-equivalent (Guinée et al., 2002a).

7.1.4. PHOTOCHEMICAL OXIDATION

Photochemical oxidation, or photo-oxidant formation, is associated with the formation of reactive chemical compounds from air pollutants due to exposure to sunlight. As such its category indicator is tropospheric ozone formation. It affects the natural and man-made environment, human health, and natural resources, and is also known as summer smog, which differs from winter smog as it mainly involved volatile organic compounds rather than inorganic compounds. Its characterisation factor is photochemical ozone depletion potential (AP), which is calculated by a trajectory model such as UNECE. The indicator result is expressed in kg ethylene-equivalent (Guinée et al., 2002a).

7.1.5. CLIMATE CHANGE

Climate change is caused by changes in the radiative forcing of the atmosphere due to human emissions, mainly resulting in a temperature difference of the earth's surface. Its category indicator is therefore infrared radiative forcing (W/m^2), which affects the natural environment, man-made environment and human health. Its characterisation factor is global warming potential (GWP), which is calculated by models which define the GWP of different greenhouse gasses, in this case the model developed by the IPCC. The indicator result is expressed in kg CO2-equivalent (Guinée et al., 2002a).

7.1.6. TERRESTRIAL ECOTOXICITY

Terrestrial ecotoxicity is related to the release of toxic substances into the environment and their effect on terrestrial ecosystems. The category indicator used is the predicted effect concentration (PEC) and/or the predicted no-effect concentration (PNEC), and as such the impact is only associated with the natural environment and resources. The characterisation factor is terrestrial ecotoxicity potential (TETP), which is calculated by multimedia models describing the effect of toxic substances due to their exposure and fate, in this case the EUSES 2.0 model. The indicator result is expressed in kg 1,4-dichlorobenzene-equivalent (Guinée et al., 2002a).

7.1.7. FRESHWATER AQUATIC ECOTOXICITY

Freshwater aquatic ecotoxicity is related to the release of toxic substances into the environment and their effect on freshwater aquatic ecosystems. As with terrestrial ecotoxicity, the category indicator used is the predicted effect concentration (PEC) and/or the predicted no-effect concentration (PNEC), and as such the impact is only associated with the natural environment and resources. The characterisation factor is freshwater ecotoxicity potential (FETP), which is calculated by multimedia models describing the effect of toxic substances due to their exposure and fate, in this case the EUSES 2.0 model. The indicator result is expressed in kg 1,4-dichlorobenzene-equivalent as well (Guinée et al., 2002a).

7.1.8. STRATOSPHERIC OZONE DEPLETION

The main cause of stratospheric ozone depletion are human emissions which decrease the stratospheric ozone layer thickness, predominantly resulting in an increase of solar UV-B radiation reaching the earth's surface. As such it affects the natural and man-made environment, human health, and natural resources. Its characterisation factor is ozone depletion potential (ODP), which is calculated by models which define this potential for gases, in this case the model developed by the World Meteorological Organisation. The indicator result is expressed in kg CFC–11-equivalent (Guinée et al., 2002a).

7.1.9. HUMAN TOXICITY

Human toxicity is predominantly related to the release of toxic substances into the environment, and their consequent effect on human health. The category indicator is the predicted daily intake (PDI) or acceptable daily intake (ADI), and as such it only affects the man-made environment. The characterisation factor is human toxicity potential (HTP), which is calculated by multimedia models describing the effect of toxic substances due to their exposure and fate, in this case the EUSES 2.0 model. As with the other toxicity indicators, the indicator result is expressed in kg 1,4-dichlorobenzene-equivalent (Guinée et al., 2002a).

7.2. CHARACTERISATION RESULTS

The characterisation results of the hotel and its services are presented in table 7.1 per day for one average guest. These results include all products, services, activities and processes that are involved with the hotel service that have been taken into account in this study. As the hotel is not explicitly compared with another hotel, the weight of the different impact categories is difficult to assess. It is obvious, however, that the rooms are associated with a relatively high contribution to the hotel's impact on almost all impact categories, while the F&B service shows a relatively high impact for land use, eutrophication and acidification. The contribution of the different services will be further investigated in the first section of the interpretation chapter, after which the validity and sensitivity of the results are explored as well.

Table 7.1: Characterisation results of the hotel and its services per day per average guest, per impact category

Impact category	**Conscious Vondelpark Hotel**	**Public spaces**	**Rooms**	**Front-office**	**Back-office**	**F&B**	**House-keeping**	**Laundry**	**Unit**
Land use	2,72	1,09e-1	1,58e-1	1,50e-2	1,09e-2	2,42	2,96e-3	5,92e-3	m2a
Eutrophication	1,44e-2	6,40e-4	3,91e-3	2,39e-4	1,59e-4	8,70e-3	2,14e-4	5,16e-4	kg PO4-Eq
Acidification	2,35e-2	1,09e-3	5,80e-3	4,95e-4	3,16e-4	1,44e-2	3,66e-4	1,10e-3	kg SO2-Eq
Photochemical oxidation	8,88e-4	9,41e-5	4,04e-4	3,23e-5	2,37e-5	2,45e-4	1,41e-5	7,43e-5	kg ethylene-Eq
Climate change (GWP 100a)	6,73	7,61e-1	3,53	1,41e-1	8,31e-2	1,27	6,83e-2	8,68e-1	kg CO2-Eq
Terrestrial ecotoxicity	8,11e-2	2,27e-2	3,88e-2	4,37e-3	4,24e-3	7,22e-3	6,91e-4	3,01e-3	kg 1,4-DCB-Eq
Freshwater aquatic ecotoxicity	3,23	1,58e-1	1,87	1,75e-1	3,83e-2	9,06e-1	1,24e-2	6,50e-2	kg 1,4-DCB-Eq
Stratospheric ozone depletion	6,89e-7	1,03e-7	4,01e-7	1,14e-8	9,77e-9	4,83e-8	1,00e-8	1,06e-7	kg CFC-11-Eq
Human toxicity	3,36	6,04e-1	1,68	2,27e-1	1,24e-1	4,79e-1	3,56e-2	2,04e-1	kg 1,4-DCB-Eq

When comparing the impact of the hotel to the impact of three alternatives, some changes are visible (figure 7.1). When replacing 10% of the yearly average electricity requirements of the hotel with PV, the hotel's impact on most impact categories appears to increase slightly. This is predominantly related to the fact that more materials and more high impact materials are required per kWh output from PV installations, compared to wind turbines. Only for human toxicity and especially terrestrial ecotoxicity a decrease of impact is visible. These decreases can be attributed to the fact that 10% of the yearly average electricity requirements does not have to be distributed to the hotel anymore, which reduces the impact on terrestrial ecotoxicity in particular.

When replacing the laundry service at Van der Kleij with an alternative hypothetical laundry service which has not implemented any efforts to reduce its environmental impact, the impact of the hotel appears to increase in all impact categories. This increase can predominantly be attributed to the increased consumption gas, electricity and washing products, which cannot be outweighed by the omission of transport to and from the hotel.

When adding insulation to the boiler, it appears the hotel's impact on photochemical oxidation, climate change and stratospheric ozone depletion decreases visibly, while a very slight decrease is also present for acidification and human toxicity. This coincides with the reduction of gas consumption in the hotel, which predominantly influences the aforementioned impact categories.
The impact of the hotel on land use and freshwater ecotoxicity shows very little difference for all alternatives, as these impact categories are dominated by the impact of the food and beverages, and of the disposal of waste, respectively.

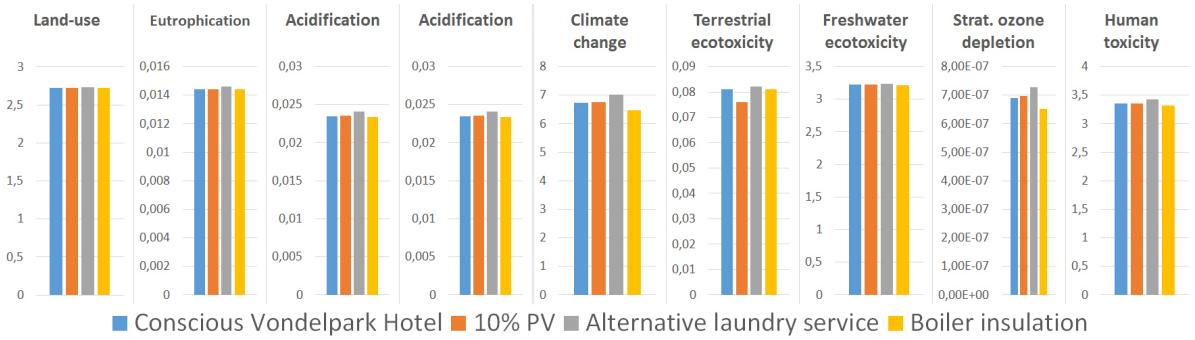

Figure 7.1: Characterisation results of the hotel and its alternative scenarios per day per average guest, per impact category

The toxicity impact categories are generally associated with an impact which is too high, however, as the characterisation of toxicity-related impact categories is still under development (Guinée et al., 2002a) and partly incomplete (Heijungs et al., 2004). Another issue associated with the characterisation results is associated with the data they are based on. Nearly all data in the Ecoinvent 2.2 database refers back to Swiss data, and as such the results are somewhat distorted when background processes from this database are applied to a Dutch environment. This is especially noticeable for terrestrial ecotoxicity, as this impact category is heavily influenced by the use of wooden poles to distribute electricity, as is the status-quo for the distribution network in Switzerland. These poles are coated with a preservative layer which contains chromium. The use of these wooden poles appears to be associated with the leaching of chromium VI and other heavy metals into the soil, resulting in an impact on terrestrial ecotoxicity (Dones et al., 2007). This effect seems to be confirmed by the fact that the impact of chromium VI leaching is considerably less strong for the medium-voltage transmission network, which contains far less wooden poles compared to the distribution network. As the Dutch transmission and distribution network is directly based on Swiss data they are also assumed to contain many of these wooden poles, and these poles combined are responsible for the vast majority of the hotel's impact on terrestrial ecotoxicity. Such poles are actually barely used in the Netherlands, however. In fact, in 2010 only 102 km out of the 195.706 km of the low-voltage distribution network in the Netherlands (0,05%) was located above ground and possibly associated with wooden poles, while the remaining 195.604 km of the network was located underground. Compared to 2009 the above-ground distribution was additionally reduced by 41,40% in 2010, indicating a reduction rather than an increase of the above-ground low-voltage distribution throughout the years (Netbeheer Nederland, 2011). As such the effect of the wooden poles is not applicable at all to the Netherlands, and as a result terrestrial ecotoxicity in particular is associated with an impact that is too high. Such effects caused by the use of Swiss background processes are also present for other impact categories, albeit less conspicuous, and therefore possibly distort their impact results as well.

7.2.1. MISSING CHARACTERISATION FACTORS & PROCESSES

By only including the baseline impact categories from CML2001, except for abiotic resource depletion, not all interventions are associated with characterisation factors. In fact, when considering the classification results, it appears that for 917 interventions no characterisation factors are present (appendix E). Among these interventions are possible important ones such as non-methane volatile organic compounds to air, gold ores in the ground, and lithium in the ground. When including the impact category of abiotic resource depletion, however, only 812 interventions remain with no characterisation factors. Materials especially are taken into account by this impact category, such as gold, lithium and copper ores in the ground. Including more impact categories could therefore possible reduce the interventions which are missing characterisation factors even further, but this would also require a higher time investment which is not in line with the general goal of the LCA application to save time.

Between the primary and secondary foreground processes there appear to be no economic flows which are not followed to the system boundary. The production, use and disposal phase are separated from each other, but these are all combined within the services. Within the background processes, however, the recycling of metals does appear to be cut-off, even though recycling activities fall within the system boundaries. This is due to the allocation that is assumed by Ecoinvent, which places some recycling activities outside of the system boundaries. Besides these recycling processes, however, all product flows appear to follow the system boundary, as all foreground processes and specified background processes are connected to extensive background processes from Ecoinvent.

7.3. SUMMARY OF LCIA

The CML-IA midpoint method 'CML-2001' is used during the impact assessment phase, and the impact categories of land use, eutrophication, acidification, photochemical oxidation, climate change, terrestrial- and freshwater aquatic ecotoxicity, ozone depletion, and human toxicity are taken into account. As this midpoint method and these impact categories are already integrated into the CMLCA software, further classification is not necessary. As such, a considerable amount of time is saved during this phase. The use of methods like CML-2001 is relatively common practice, however, as even full LCAs often make use of them as well.

The characterisation results of the Conscious Vondelpark hotel include all products, services, activities and processes that are involved with the hotel service and have been taken into account in this study. Individually, these results do not provide clear insight in the weight of the hotel's impact, however, as no reference hotel exists, but when the impact of the hotel is compared to the three alternatives, more insight can be gained. The use of PV-panels to replace 10% of the electricity consumption which is now provided by wind, for example, is associated with a slight increase of all impact categories due to the increases use of high impact materials for the PV-installation. A slight decrease is visible for terrestrial ecotoxicity and human toxicity, however, due to the reduces amount of electricity that is distributed to the hotel. The use of the alternative laundry service is associated with an increase of the hotel's impact on all impact categories, which is associated with the increased consumption of gas, electricity and washing products. The boiler insulation, finally, appears to result in a reduction of the hotel's impact on photochemical oxidation, climate change, stratospheric ozone depletion, acidification and human toxicity, which coincides with those impact categories which are mostly influenced by the use of natural gas.

The characterisation of some impact categories is still under development, however, in particular of those which are related to toxicity. The impact on toxicity is therefore generally too high. Furthermore, results are influenced by the use of processes from the Ecoinvent 2.2 database, which is predominantly bases on the Swiss, and to a lesser extent the European environment. As these processes are used in Dutch foreground processes, they distort the results to some extent. This is especially noticeable for terrestrial ecotoxicity, which is predominantly influenced by the use of wooden poles for the distribution of electricity. Even though these wooden poles are the status-quo in Switzerland, they are barely used in the Netherlands. As such, the impact on terrestrial ecotoxicity is likely to be much smaller within the Dutch environment.
The use of baseline impact categories has additionally led to the issue that some interventions are not associated with characterisation factors. By including more impact categories this can be solved to some extent, but would not be in line with the general goal of this thesis to save time by streamlining the application of LCA. There is also a slight discrepancy between the foreground and background processes in terms of recycling allocation. Ecoinvent cuts-off all recycled materials within background processes, while recycling within foreground processes is taken into account with the avoided burden approach. All remaining processes, however, are followed to the system boundary, as all foreground and specified background processes are linked to the Ecoinvent database.

8

INTERPRETATION - CONTRIBUTION ANALYSIS

To investigate where the environmental impact of Conscious derives from an extensive contribution analysis will carried out in this chapter. By performing this analysis the contribution of the services at Conscious can be investigated, while the individual contribution of the products, utilities and activities at Conscious can also be uncovered. The exact origin of the impacts will also be investigated, as the majority of impacts do not occur at the hotel itself, but at different stages in the life-cycles of products, utilities and activities of the hotel. This way a comprehensive overview of the hotel's impact can be constructed, based on which recommendations can be made.

Due to the vast amount of processes that are associated to the life-cycle of the hotel, its products and its services, the contribution analysis is streamlined to some extent as well. Instead of looking at all individual processes in detail, their overall impact on the services will be examined per impact category. Products or activities related to a noticeable impact within a particular impact category will be investigated further to uncover the origin of their impact, which again will be predominantly focused on high contributors, while low individual contributions will largely be disregarded. This way comprehensive insight can be gained with regards to the main contributing products and background processes, while not all processes have to be investigated in high detail. As such the time that is saved during the LCI stage is not entirely lost during the contribution analysis.

First the contribution of the services at Conscious will be discussed, after which the individual contribution of the products, utilities and activities are investigated. After this three different scenarios for the Conscious Vondelpark hotel will be presented, which will go into the source of electricity, laundry service and boilers in use by the hotel.
For all services at Conscious the impact to terrestrial ecotoxicity is largely related to the leaching of chromium VI into soil from wooden poles assumed to be used by distribution network in Ecoinvent (Dones et al., 2007), while the impact of gas to stratospheric ozone depletion is likely caused by the addition of bromine used to increase its density during transport (Acton, 2013).

A highly detailed contribution analysis per impact category can be found in appendix F for both the services and product, utilities and activities. Additionally, an analysis of the main contributing elements per service can be found in appendix G, and calculations in appendix H.

8.1. CONTRIBUTION OF SERVICES AT CONSCIOUS

Within the hotel, the rooms appear to be associated with the highest environmental impact in general terms, while the F&B service has a very high impact on some impact categories as well (figure 8.1). The public spaces seem to be responsible for a much smaller but noticeable part of the overall impact, while the impact of the laundry service at Van der Kleij is similar to that of the public spaces for most impact categories, but lower for some. The impact of the front- and back-offices appear to be associated with relatively low environmental

impacts when compared to the rooms and F&B service, while the housekeeping service is responsible for the smallest impact to nearly all impact categories.

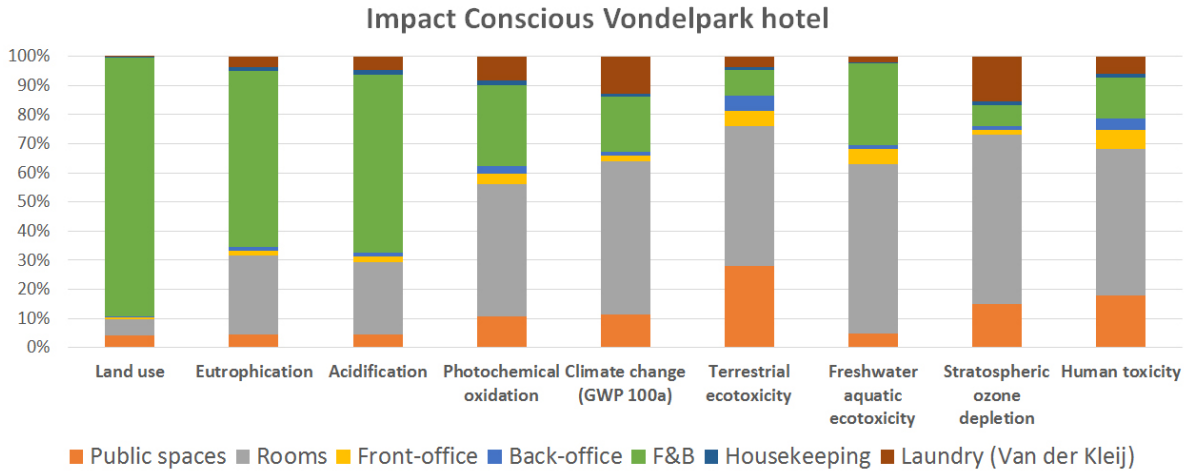

Figure 8.1: Origin environmental impact Conscious Vondelpark hotel, contribution services per impact category

There are significant differences between the nine examined impact categories, however (figure 8.1), and as such the general trend described above should not be interpreted as a rule. This trend can only give an estimated indication to the contribution of the different services to the overall environmental impact of the hotel, under the subjective assumption that all impact categories are equally important. In order to uncover the specific contribution of the services and to investigate the source of their relative impacts, the environmental impact of the hotel must therefore be examined per impact category individually.

First the contribution of the services to different impact categories is discussed, after which the origin of their impact is investigated in more detail, predominantly focused on the impact categories they influence most.

8.1.1. MAIN CONTRIBUTION SERVICES IN THE HOTEL

The rooms appear to be the main contributor for photochemical oxidation, climate change, terrestrial ecotoxicity, freshwater ecotoxicity, stratospheric ozone depletion and human toxicity, while they are the second highest contributor for land use, eutrophication and acidification (figure 8.1). For the impact categories where the rooms are the second highest contributor, the F&B service appears to be the related to the highest contribution, especially with regards to land use, where it represents the vast majority of the impact. The F&B service additionally seems to be the second highest contributor to the impact on photochemical oxidation, climate change and freshwater ecotoxicity, and the third highest contributor to the impact on terrestrial ecotoxicity, stratospheric ozone depletion and human toxicity.

Much smaller contributions are associated with the public spaces, who are the second highest contributor to terrestrial ecotoxicity and human toxicity, and the third highest to land use, eutrophication and photochemical oxidation. The impact of the laundry service is the second highest for stratospheric ozone depletion, and the third highest for climate change, while the contributions of the public spaces and laundry are virtually the same for acidification (third highest), climate change (third highest), and stratospheric ozone depletion (second highest). The front- and back-office are generally related to very small contributions throughout the impact categories, with the front-office generally associated to a higher impact, while the impact of housekeeping is the lowest in every impact category except eutrophication, where the back-office shows the smallest contribution.

The difference between the highest and second-highest, and between the second- and third-highest contributing service is generally quite considerable, however, and involves an impact that is at least double that of the next in line in most cases, albeit not all. The fact that a service is the second- or third-highest contributor therefore does not automatically mean its relative impact is high.

8.1.2. ORIGIN OF IMPACTS

The rooms consume the most gas and water, contain most products, discard most waste, and only consume slightly less electricity than the public spaces. In general the high impact of the rooms seems to predominantly derive from the gas used to heat the rooms and the water they use, and from the products present in the rooms, especially the LED TVs and Auping mattresses and to a lesser extent the Yumeko blankets and plastic tables. The residual waste from the rooms also shows high impacts in some impact categories, especially freshwater aquatic ecotoxicity and human toxicity. Electricity is responsible for a only a small contribution to most impact categories, with the exception of terrestrial ecotoxicity, where it is the highest contributor, and human toxicity, where it shows a significant impact. The impact of water is negligible in all impact categories, while the impact of sewage is only high for eutrophication, and noticeable for terrestrial ecotoxicity.

The lower impact of the public spaces is predominantly associated with their consumption of gas and electricity, which is mainly related to the fact that the public spaces are the highest consumers of electricity. For all impact categories but land use either gas or electricity is the dominant contributor, while the combined products are often the second or third-highest contributors. The impact of the commute of maintenance employees is only noticeable for eutrophication and acidification. This impact is predominantly caused by the use trains, due to their electricity requirements. As with the rooms, the contribution of water production is negligible, while the contribution of sewage is only noticeable for eutrophication, although it is not related to a noticeable contribution to the impact on terrestrial ecotoxicity.

The high impact from the F&B is usually associated with a very different activity, namely the production of food and to a lesser extent of beverages. The impact of food is related to the production of animal products in particular, and to a lesser extent to the production of wheat products and fruit/vegetables. The impact of beverages is almost entirely related to the production of oranges for fresh juice. The disposal of municipal solid waste from the F&B service also shows a relatively high impact for freshwater ecotoxicity and human toxicity, as the F&B service is responsible for the second-highest waste generation, just after the rooms. The front-office, back-office and especially housekeeping services are associated with significantly lower consumption of utilities and contain much less products, according to this study at least. As such they are generally associated with low or very low contributions. The impact of the front-office mainly derives from the products and the commute of employees, the impact of the back-office from the commute of employees and to a lesser extent the products as well, and the impact from housekeeping is almost entirely associated with the commute of employees.

The impact of the laundry service at Van der Kleij, finally, is predominantly related with the ironing of bedlinen and drying of towels due to the use of natural gas and electricity. The impact of the shaking of linen is also an important contributor due to the use of electricity, however, as is the impact of the washing process due to the use of washing agents and chemicals, and electricity. The use of gas mainly contributes to the laundry's impact on acidification, photochemical oxidation, climate change, stratospheric ozone depletion and human toxicity, while the use of electricity mainly influences the impact on land use, eutrophication, terrestrial ecotoxicity and freshwater aquatic ecotoxicity. The impact of the washing agent and chemicals influences all impact categories to some extent, although its influence is highest for land use, acidification, photochemical oxidation, terrestrial ecotoxicity and freshwater ecotoxicity.

8.1.3. SUMMARY CONTRIBUTION OF SERVICES AT CONSCIOUS

It appears that the 81 rooms in the hotel are responsible for the highest contribution to the hotel's impact on most impact categories. This is predominantly related to the high consumption of gas, and to the high presence of products, especially electronic products and mattresses. The rooms are also responsible for most of the trash, and consume almost all water in the hotel.
The F&B service is also responsible for a considerable contribution to the hotel's impact, especially with regards to land use, eutrophication and acidification. This is predominantly related to the production of food, in particular meat and animal products, and to a lesser extent to the production of oranges for orange juice. The impact of the public spaces is considerably smaller than the impact of either the rooms or F&B service depending in the impact category, but is still clearly noticeable. Its impact is predominantly related to the consumption of gas as well as to the consumption of electricity, as most electricity is consumed in the public spaces. For all impact categories, the products within the public spaces are responsible for the third highest contribution to its impact, as far less products are present here than in the rooms.

The impact of the front- and back-offices is considerably lower, due to the fact that they consume considerably less gas and electricity, and contain only a small amount of products. The front-office contains more products than the back-office , however, and as such its impact is predominantly related to these products, and to a slightly lesser extent by the commute of employees. This commute is the main contributor for the back-office, which is related to a much smaller impact from its products. The impact of the housekeeping service is nearly negligible, and almost entirely related to the commute of housekeeping employees.

As the main source of the impact differs substantially between the services and impact categories, the investigation of the services alone cannot provide clear insight into the impact of the products, utilities and activities associated with the hotel. As such the impact of these elements must be reviewed separately from the services as well, which can provide additional insight into the origin of the hotel's environmental impacts. This will be investigated in the next section.

8.2. CONTRIBUTION OF PRODUCTS, UTILITIES & ACTIVITIES AT CONSCIOUS

The relative impact of the products, utilities and activities at the hotel are associated with substantial differences between the impact categories (figure 8.2). Overall the products appear to provide a small but significant contribution to all impact categories, while most of the impact categories are highly influenced by either the food and beverages or the gas consumed in the hotel. It looks like smaller impact are usually related to the laundry, employee commute, waste disposal, electricity, water, and sewage for most impact categories, although there are exceptions between the impact categories.

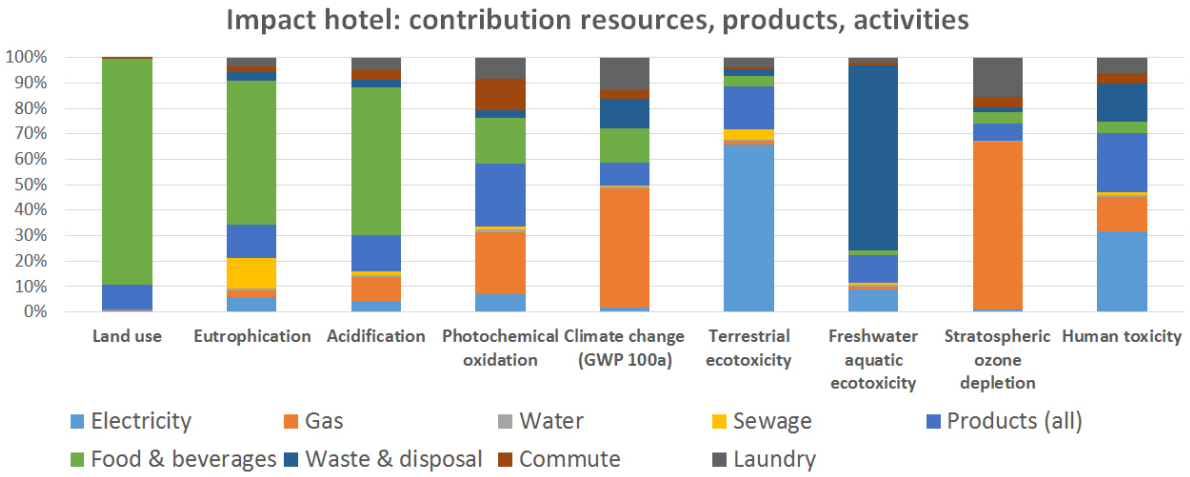

Figure 8.2: Origin environmental impact Conscious Vondelpark, contribution products, utilities and activities per impact category

Even more prominent than for the services, there are significant differences between the nine examined impact categories. As such the trend described above cannot be interpreted as a rule for the products, utilities and activities in the hotel either. In order to uncover their specific contribution and to investigate the source of their relative impacts, the environmental impact of the hotel is examined per impact category individually.

First the contribution of the products, utilities and activities to different impact categories is discussed, after which the origin of their impact is investigated in more detail, which will be predominantly focused on the impact categories they influence most.

8.2.1. MAIN CONTRIBUTING PRODUCTS, UTILITIES & ACTIVITIES IN THE HOTEL

Overall, either the use of gas and consumption of food and beverages are prominent contributors to the hotel's impact on most impact categories. The use of gas at the hotel shows up as the main contributor to the hotel's impact on climate change and stratospheric ozone depletion, is a significant contributor to the impact on photochemical oxidation, and a small contributor to acidification and human toxicity. Food and beverages appear to be the absolute dominant contributors to the hotel's impact on land use, the main contributors to the impact on eutrophication and acidification, and small contributors to photochemical oxidation and climate change.

The products appear to be the only elements which provide a small but significant contribution to all impact categories, especially photochemical oxidation and human toxicity, while the laundry and to a lesser extent commute show slight to small contributions to most impact categories except land use and freshwater aquatic ecotoxicity. The use of electricity at the hotel from wind park De Hondtocht is related to small contributions to most impact categories, but barely contributes to land use, climate change and stratospheric ozone depletion. For human toxicity electricity shows a relatively high impact, however, while it dominates the impact on terrestrial ecotoxicity. The disposal of waste from the hotel is generally associated with only a slight impact, although it does show larger contributions to climate change and human toxicity, and a very high contribution to freshwater aquatic ecotoxicity.
The use of water is a clear low contributor to all impact categories, while the treatment of sewage only shows a considerable contribution to the impact to eutrophication, with a slight contribution to terrestrial ecotoxicity as well.

8.2.2. ORIGIN OF IMPACTS

Within this study, the impact of gas used in the hotel predominantly appears to derive from the combustion of the gas for heat for most impact categories, and to a somewhat lesser extent from the production and transport, depending on the impact category.
The relatively high contribution to climate change and small contribution to human toxicity are caused by the incineration of gas, while the relatively high contribution to stratospheric ozone depletion is due to its transport. Only for acidification and photochemical oxidation the production of gas provides the main impact. Only a very slight contribution from gas derives from the boilers at the hotel and their electricity consumption.

The impact of the different types of food and beverages at the hotel is predominantly related to the production of animal products and to a lesser extent to the production of oranges for fresh juice. The wheat products show smaller contributions, while the fruit/vegetables are associated with a slight impact overall.
Their contribution to the hotel's impact is predominantly related to land use, eutrophication and acidification. This impact on land use, eutrophication and acidification is predominantly associated with the production of ingredients, while the impact on climate change and photochemical oxidation is largely associated with the excretion of methane by animals, and only to a very slight extent by the production of other food and beverages. Climate change and photochemical oxidation are also partly associated with the transport or ingredients, mainly oranges for juice, and with the burning of fossil fuels for energy during production.
The contribution of the food and beverages is related to both the relative impact per kilogram and the consumption rate of different foods and beverages. The high impact of the animal products is primarily related to its high impact per kg, as their consumption rate is not particularly high, while the relatively high impact of oranges and wheat products is mostly related to their high consumption rates.

It looks like the impact of the products to most impact categories is primarily associated with their production and the production of materials. This is largely due to the consumption of electricity and production of metals, and to a lesser extent due to the production of plastic/synthetic materials and cotton. The mattresses and electronic products such as the LED TVs are responsible for the highest impact from the products, although the plastic room tables and Yumeko blankets provide a relatively high impact as well (figure 8.3). The transport of products and their materials also provides a small contribution to the products' impact to most impact categories.

For land use the impact of products is mainly associated with the production of wood and cotton, with smaller contributions from the surrogate feathers for Yumeko products and ingredients for the Dharmazone products. Eutrophication and freshwater ecotoxicity are largely associated with the mining and production of metals, and mining of fossil resources for electricity, with a slight contribution coming from the production of plastics as well. The products' impact on acidification and photochemical oxidation is related to the combustion of fossil fuels for electricity, and to a lesser extent to transport and to the production of metals, cotton and plastics. The combustion of biomass for Interface additionally shows a significant contribution to photochemical oxidation. For climate change the combustion of fossil fuels for electricity and to a lesser extent steel production show the highest contributions, while the impact on stratospheric ozone depletion can be largely attributed to the transport of gas for electricity, and production of crude oil for electricity and

materials such as bitumen and plastics. The products' impact on terrestrial ecotoxicity, finally, is predominantly influenced by the distribution of electricity and production of organic ingredients for the Dharmazone products, while their impact on human toxicity is again related to the production and mining of metals and resources for electricity, as well as the production of electrical components.

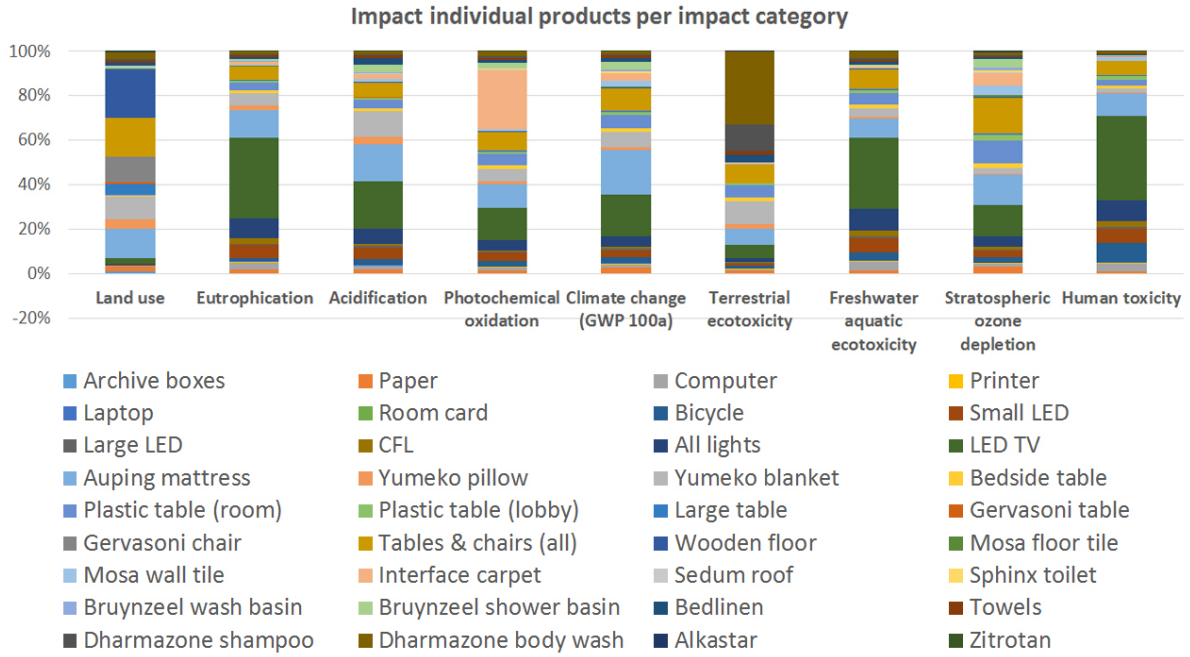

Figure 8.3: Contribution individual products compared to each other, per impact category

Metals are predominantly used in the electrical products, in particular the LED TVs and to a lesser extent the lights and computers as well. The highest impacts are related to copper and gold, with smaller contributions from steel and other metals. Plastics and synthetics can mostly be found in the plastic tables, Interface carpet and Auping mattresses, while cotton is mainly present in the Auping mattresses, Yumeko products and hotel textile. The impact of transport is mostly associated with the electrical products, bicycles and to a lesser extent the furniture and Yumeko products (cotton). Comparable to the food and beverages, the number of individual products also plays an important role, since it is mostly products that are high in numbers and are associated with high energy and/or metal requirements that show the highest contributions. These are the LED TVs and Auping mattresses especially, but the Yumeko blankets, furniture (especially the plastic room tables) and Interface carpet also show relatively high contributions to most impact categories related to their high numbers. The bicycles and shower basins show small impacts to most impact categories, while the paper, computers, Yumeko pillows and Dharmazone products (especially the body wash) are related to slight but noticeable impacts as well.

It looks like the impact of laundry is primarily linked to the use of gas for ironing of linen and drying of towels, and the use of electricity for drying of towels and shaking of linen. The ironing and folding of linen additionally require small amounts of electricity, as does the washing process. Much smaller impacts are attributed to the transport of linen, with slight contributions deriving from the production of washing agents and machines as well.
The slight contribution to the hotel's impact on eutrophication from the laundry service is predominantly caused by the mining of resources for electricity, with smaller contributions from the production of copper for electricity distribution, the burning of natural gas at Van der Kleij, and emissions from the transport of textile. The similar impact to the hotel's impact on acidification and photochemical oxidation is predominantly associated with the burning, production and transport of natural gas, and to a lesser extent to the production of the washing agents and chemicals, and the transport of textile. The somewhat higher contribution to climate change is almost entirely caused by the burning of natural gas, while the comparable contribution to stratospheric ozone depletion is associated with the transport of this gas. Both are additionally influenced by transport. The impact on terrestrial ecotoxicity is mainly associated with the distribution of electricity to the

laundry facility, but is also related to the production of the washing agents and chemicals, while the almost negligible impact on freshwater ecotoxicity is mostly related to the production of metals for the capital goods of gas and electricity. The impact on freshwater ecotoxicity is almost entirely caused by leaching of metals into soil during the mining of resources for electricity production, which is also reflected in the contribution of gas production. The slight contribution to human toxicity, finally, is associated with both the burning and production of gas, and to a lesser extent to the production of copper for electricity distribution and aluminium and steel for the machines, and transport of textile.

The daily commute is highly influenced by the employees, and currently the use of trains and cars show up as the highest contributors for all impact categories. For cars their emission and fuel requirements are the main culprit, while the impact of trains is predominantly influenced by their electricity requirements.
Both cars and trains are also associated with a slight impact from the production of metals, in particular for eutrophication, acidification, photochemical oxidation, climate change, freshwater ecotoxicity and human toxicity. The impact on stratospheric ozone depletion is predominantly associated with the production of crude oil for car fuels, and to a lesser extent to the transport of gas and production of crude oil for electricity used to operate trains. A smaller impact from the commute derives from the busses due to emission and fuel, while slight contributions are delivered by the use of trams due to electricity, and scooters due to emission and fuel. The relative impact per kilometre is highest for cars, however, and the high impact of the trains is predominantly related to the fact that they are used to cover nearly half of the total commute distance every day.

For most impact categories the environmental impact of electricity at the hotel appears to be predominantly related to the mining and production of metals, in particular copper for the distribution network, and to a slighter extent also steel for the windmills and copper and aluminium for the generators. A small portion of the metals is additionally used for the air handling units, although this unit is an approximation, and therefore only gives an indication of the potential impact.
The generation of electricity from fossil fuels used during the production of the windmills also has a slight impact on most impact categories, while the impact on terrestrial ecotoxicity is almost entirely related to the leaking of chromium VI into soil from wooden poles used to distribute the electricity according to Ecoinvent. In the case of eutrophication, acidification, photochemical oxidation and climate change, the production of fibreglass for the blades of the windmills also appears to be responsible for a small contribution.

The environmental impact of waste seems to be predominantly caused by the incineration of municipal solid waste for most impact categories, and to a very slight extent the incineration of paper. The transport of waste also contributes a small impact overall to most categories, while impact on terrestrial ecotoxicity appears to be mainly related with the processing of organic waste. The impact of glass waste seems to be negligible for all impact categories.

The impact from the use of water at the hotel is predominantly caused by the electricity required during its production. Compared to electricity and gas, however, it is associated with little to no contribution to any impact category. The impact of the consequent sewage treatment is predominantly related to the treatment itself, while it is also related to a slight impact from its electricity requirements. The small contribution to the impact on eutrophication is associated with the emission of substances such as ammonium and nitrate to rivers during treatment, while the slight contribution of sewage to the impact on terrestrial ecotoxicity is associated with the disposal of metals to soil due to the treatment of wastewater.

There is not one product, utility or activity that clearly dominated the environmental impact of the hotel in all impact categories. Each of them has a high influence on different impact categories, and the products appear to be the only ones who consistently provide a small contribution all impact categories, albeit varying from slight to small contributions. This impact distribution is partly caused by the choice of electricity, modes of commute and efficiency of utility use, however, and changing certain aspects of the hotel's consumption and employee behaviour could alter the impact. In the next chapter several scenarios are constructed and analysed for certain impact hotspots within the hotel, in order to assess how the influence of the products, utilities and activities can be altered.

8.2.3. SUMMARY CONTRIBUTION OF PRODUCTS, UTILITIES & ACTIVITIES AT CONSCIOUS

Not one single element is responsible for a high impact to all impact categories. Instead, either the use of gas or food and beverages in the hotel appear to be responsible for the highest contribution to most impact categories. It looks like smaller impact are usually related to the laundry, employee commute, waste disposal, electricity, water, and sewage for most impact categories, although there are exceptions between the impact categories.
The contribution of gas appears to be highest to the hotel's impact on photochemical oxidation, climate change and stratospheric ozone depletion, while the impact of food is highest to the hotel's impact on land use, eutrophication and acidification. For terrestrial ecotoxicity, electricity seems to deliver the highest contribution, while the hotel's impact on freshwater ecotoxicity is predominantly associated with the disposal of trash. Human toxicity is mostly influenced by the consumption of electricity and the disposal of trash.
The laundry service and to a slightly lesser extent the employee commute both show slight to small contributions to most impact categories except land use and freshwater aquatic ecotoxicity. The impact of water, finally, appears to be negligible, but the consequent treatment of wastewater shows a small contribution to eutrophication, and a slight contribution to terrestrial ecotoxicity.

The impact of gas is related to its combustion at Conscious, but also to its production and transport. The impact of food is almost entirely related to the production of food and beverages, mainly meat and animal products and to a lesser extent the production of oranges for juice. The impact of electricity consumption during production and the transport of oranges in particular also provides a small contribution.
The production of products and their materials are responsible for most of the impact of the products. This is predominantly related to the electricity consumption and metal production, and to a lesser extent to the production of synthetic materials and cotton. The mattresses and electronic devices such as LED TVs in particular seem to be responsible for the product's impact, although the plastic room tables and Yumeko blankets are also large contributors.
The impact of electricity is generally associated with the production of the wind turbines, in particular with regards to the production of metals and to a lesser extent to the use of electricity. For terrestrial ecotoxicity, however, the impact can almost entirely be attributed to the distribution of the electricity to the hotel. For trash, the incineration of municipal solid waste seems to be responsible for the impact on most impact categories, mainly due to plastics, with smaller contributions from paper incineration and transport as well. For terrestrial ecotoxicity, however, the processing of organic waste is the dominant contributor. The impact of glass disposal appears to be negligible. The slight impact from water, finally, is associated with the energy requirements of its production process, while the impact of sewage treatment is related to the treatment process itself.

8.3. SCENARIOS FOR CONSCIOUS & THEIR CONTRIBUTION

The electricity generation and laundry service for Conscious have been subjected to more detailed studies with the goal of comparing their impact to similar alternatives using scenarios. The possible influence of boiler insulation is additionally assessed through a less detailed study.
First the impact of the two electricity sources are compared to each other, after which several scenarios involving electricity from wind, PV and the Dutch grid are created for the hotel. Then the two laundry services are compared to each other, after which these are also incorporated in several scenarios for the hotel. Finally one scenario will be created for the boiler insulation, to assess its possible influence on the hotel's impact.

8.3.1. ELECTRICITY SCENARIOS

As the hotel is considering installing PV-panels on their new hotels to cover 10% of the yearly electricity requirements, the first scenario is focused on investigating what the effect of using PV-panels would be for the Conscious Vondelpark hotel. The remaining 90% would still derive from wind park De Hondtocht.
The generation of electricity from wind park De Hondtocht and solar panels from Canadian Solar have both been investigated in detail. Their contribution per kilowatthour is investigated first, after which four scenarios are created for the Conscious Vondelpark hotel.

The first scenario is the new envisioned situation by Conscious, where 90% of the yearly average electricity requirements derive from wind and 10% from roof-mounted PV-panels. The third scenario is a hypothetical one, with 50% wind and 50% PV, while the fourth scenario is 100% PV. In all these scenarios the assumption

is made that the source of renewable electricity can in fact provide base load electricity. In reality, however, they would require the support of the Dutch grid which includes base load electricity from fossil sources. In the final scenario the Dutch electricity mix is used, which represents the actual electricity that comes out of the sockets at Conscious, as there is not a direct line between the wind park and hotel.

CONTRIBUTION INDIVIDUAL ELECTRICITY ALTERATIVES

When comparing the production of electricity from wind park de Hondtocht to the production of electricity from roof-mounted PV-panels at Conscious, electricity from wind appears to be related to less environmental impact for most impact categories (figure 8.4). In fact, for acidification, photochemical oxidation, climate change and especially stratospheric depletion the impact of electricity from PV is considerably higher. For eutrophication the differences are relatively marginal and for human toxicity almost similar, with only a slightly higher impact from wind electricity. Only the impact on land-use and especially terrestrial ecotoxicity is noticeably higher for wind. The impact from the PV-installation and windmill themselves can almost entirely be attributed to the production and installation alone. The impact of the electricity from wind is not entirely due to the production of components alone, however, as for five of the impact categories it appears the distribution of electricity is actually associated with a higher impact than the production of the windmill itself. This is most striking with terrestrial ecotoxicity, as this impact category is almost entirely dominated by the distribution of electricity from wind. This has to do with the fact that the distribution and transmission network of Ecoinvent, mainly the low-voltage network, makes use of wooden poles which leach chromium VI into the soil. These wooden poles are also the main contributor to the impact of wind electricity distribution on land use.

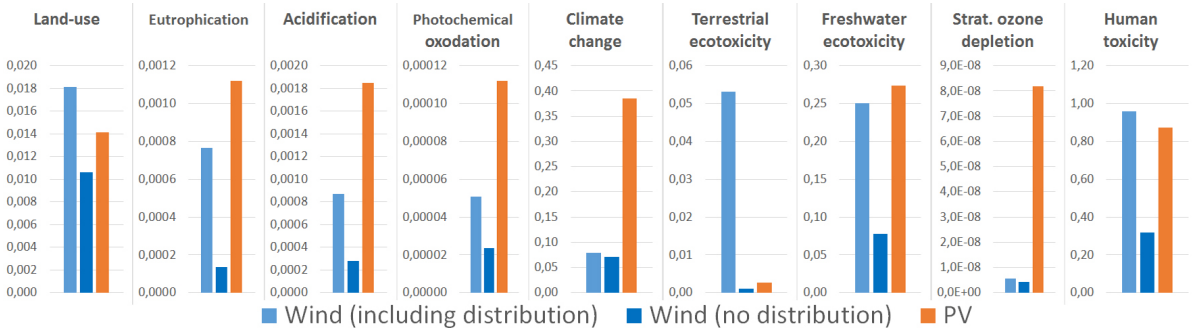

Figure 8.4: Impact electricity from PV and wind per kWh, per impact category

When comparing the impact of the PV-installation and the windmill without distribution, it looks like the PV-installation has a larger impact on all impact categories per kWh produced, ranging from roughly 1,50 times higher for land use to roughly 19,50 times higher for stratospheric ozone depletion. This partly has to do with the fact that the PV-installation is less efficient in producing electricity than the windmill relative to its weight (appendix H1, tab 'contribution processes'). In fact, a rough estimation of their weight indicates the windmill (moving parts and fixed parts combined: 2,73e-3 kg/kWh) produces two and a half times more electricity per kg installation than the PV installation (PV-panels, electric installation, inverter and rooftop construction: 6,92e-3 kg/kWh). The weight alone is not responsible for the sometimes large difference between the two sources, however. This also has to do with the high electricity demands of the PV-panel production compared to the windmills, and with the materials used and the processes involved in manufacturing the installations. The production of silicon in particular is responsible for the high energy demand of the PV-panels, although other materials and the production of the panels and other components themselves also contribute.

The components of the PV installation mainly contain aluminium, silicon and synthetic materials such as plastics, and also contain large amounts of copper and low-alloyed steel. Additionally many different electrical components such as diodes and printed wiring board are present, which contain rare metals such as gold and silver. Some fibreglass reinforced plastic is also present. The components of the windmill installation mainly contain low-alloyed and chromium steel, cast iron and fibreglass, and also contain large amounts of copper, aluminium and synthetic materials such as plastics.

Per kWh produced it looks like the PV-installation contains approximately 30 times more copper, 225 times more aluminium, and 105 times more synthetic materials, based on rough estimations of the composition

of different components (appendix H1, tab 'Check'). It appears to be the increased use of copper in the PV installation in particular that is responsible for its relatively high impact compared to wind. This is due to the strong influence of the production of copper on most of the impact categories, with the exception of climate change and stratospheric ozone depletion. Another material with a high impact that is only used in PV panels, and in large amounts as well, is silicon. The mining, production and processing of this material has a large influence on the impact of land use, climate change, and stratospheric ozone depletion, and also has a relatively large influence on eutrophication and photochemical oxidation. This impact can be attributed to both the material itself and its energy intensity, depending on the impact category. Steel, especially chromium steel, also has a fairly large impact on land use, terrestrial ecotoxicity, freshwater ecotoxicity and human toxicity, but far less than copper. The presence of electrical components which contain rare metals additionally increased the impact of the PV installation, albeit only slightly. Even though the impact of gold is several hundreds of times larger than most materials in most impact categories and the impact of silver is very high as well, they are used in such small quantities their relative impact is minimal.

It therefore appears that the amounts of materials and the materials used in the PV installation result in an impact that is higher than wind in all impact categories. If not for the large amounts of low-alloyed steel present in the tower, and presence of the high impact materials of copper and chromium steel in the moving parts, the difference in impact of the windmills would be even lower. The need for distribution drastically increases the impact of the wind electricity for at least half of the impact categories, however, which is a disadvantage that the PV-panels do not have. The copper requirements in particular are responsible for the high impact of electricity distribution, with the exception of terrestrial ecotoxicity, which is predominantly influenced by the leaching of chromium VI into soil from wooden poles. This impact of copper is most striking for human toxicity as it actually results in a slightly higher impact of the electricity from wind, where the impact of the windmills themselves is significantly lower than that of the PV-panels. Human toxicity is less influenced by the high energy demand and more by the mining and production of metals, resulting in a higher impact for the windmills.

ELECTRICITY AT CONSCIOUS

To investigate the influence of different electricity sources on the environmental impact of the hotel, four scenarios have been created (figure 8.5). In CMLCA this has been done by replacing the electricity input of the process 'Electricity, for Conscious' [P4088].

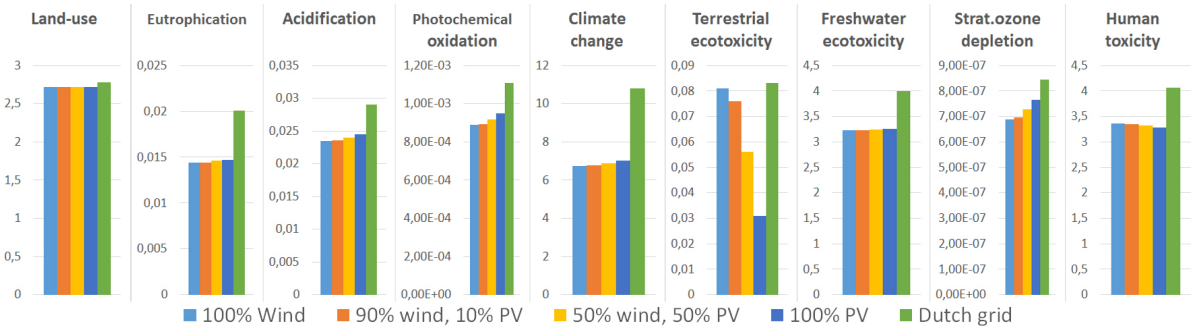

Figure 8.5: Environmental impact Conscious Vondelpark hotel, with different electricity scenarios per 1 day per guest, per impact category

As electricity from PV-panels is related to a higher environmental impact than electricity from wind for most impact categories, increasing the amount of PV-panels instead of wind generators is related to an increase to most impact categories. The use of electricity from wind at Conscious is associated with a relatively low influence on the hotel's impact for most impact categories, however, and as such the differences are marginal for most. Only for terrestrial ecotoxicity a significant decrease is visible with more PV-panels, as the distribution of electricity from the wind park is largely responsible for this impact. For human toxicity, a slight decrease in impact is also visible, largely due to the increase of copper required for distribution.

The contribution of electricity to the hotel's impact on acidification, photochemical oxidation and freshwater ecotoxicity is quite low, but replacing electricity from wind with PV-panels results in noticeable increases on all these impact categories (figure 8.6). This can predominantly be attributed to the increased material and

energy requirements of PV-panels per kilowatt-hour production, largely related to silicon production, and can to a lesser extent be attributed to the increased impact from electrical components and other metals besides copper and as well. The impact on eutrophication is associated with only a very slight increases, as the impact of low-alloyed steel and fibreglass for the windmills has a relatively high impact, reducing the difference due to the increased energy intensity of the PV-panels. For land use no increase is visible, as most of the impact to land use is caused by the food, beverages and products in the hotel, while the lack of increased impact on freshwater ecotoxicity appears to be coincidental. The reduced impact of copper for distribution and steel for the windmills seems to be nearly identical to the increased impact of the energy requirements of the PV-panels predominantly related to the production of silicon. The impact of the PV-panels is, in fact, slightly higher than the impact of the windmills and distribution.

Only when replacing the electricity source with the Dutch mix from Ecoinvent a noticeable increase in all impact categories but terrestrial ecotoxicity is visible. The increased mining and combustion of fossil fuels is responsible for the increase in nearly all impact categories, while the production of crude oil and transport of natural gas is the main contributor to stratospheric ozone depletion, and the distribution of electricity the main contributor to terrestrial ecotoxicity. The slight increase in impact on terrestrial ecotoxicity is therefore predominantly related to the increased losses during transmission, which were assumed to be somewhat lower for electricity from the close-proximity wind-farm.

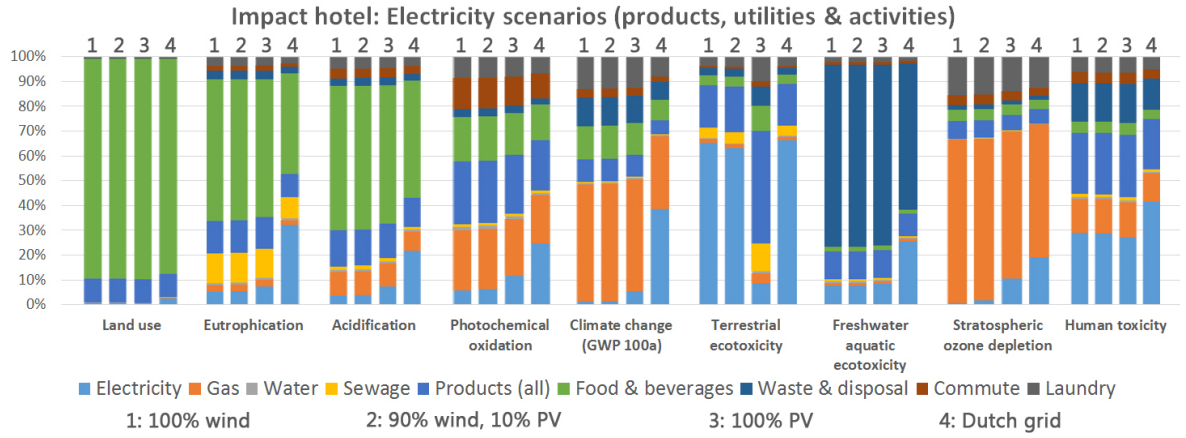

Figure 8.6: Origin environmental impact Conscious Vondelpark hotel, with different electricity sources, per impact category

Changing the source of electricity from wind to PV seems to be related to a small increase in the contribution of electricity for almost all impact categories, with the exception of human toxicity, which shows no noticeable change, and terrestrial ecotoxicity and human toxicity, which show a decreased contribution. For stratospheric ozone depletion the increase of impact is most striking, as the impact from wind electricity is next to nothing, while the impact of PV-panels is noticeable. The differences for the other impact categories are only small, however. Only when replacing electricity from wind with electricity from the Dutch grid it looks like a large increase of its contribution is visible in almost all impact categories, with the exception of land use and terrestrial ecotoxicity where only very slight increases are visible. Especially for eutrophication, acidification, climate change and freshwater ecotoxicity the increase is high, which is largely related to the use of fossil resources to generate electricity. For stratospheric ozone depletion the impact of electricity is predominantly associated with the transport of natural gas, and to a lesser extent with the production of crude oil, both used to generate electricity.

When reviewing the influence of electricity sources to the contribution of services, the changes for all impact categories are very similar (figure 8.7). This is predominantly related to the fact that electricity is used by every service, although the rooms and public spaces do consume the most by far. Their contribution in particular is therefore slightly higher, while the contribution of the other hotel services is lower in comparison. The contribution of laundry is also slightly lower for almost all impact categories, as the overall impact of the hotel has increased. For terrestrial ecotoxicity the reduced distribution requirements mainly influence the impact of the public spaces, as these are more heavily related to the impact of electricity than of gas or products. For eutrophication, acidification and climate change the impact of the rooms and public spaces is

considerably higher when electricity from the Dutch grid is used, which again is largely related to the use of fossil resources to generate electricity. The impact of electricity has less influence on the contribution of the public spaces and especially rooms. This seems to be predominantly related to the relatively high relatively impact of gas and products for these pseudo-services, which increases the relative contribution of electricity consumed by the other services in the hotel. The highest increase can still be attributed to the public spaces, however, as these are most heavily influenced by the electricity consumption of all services.

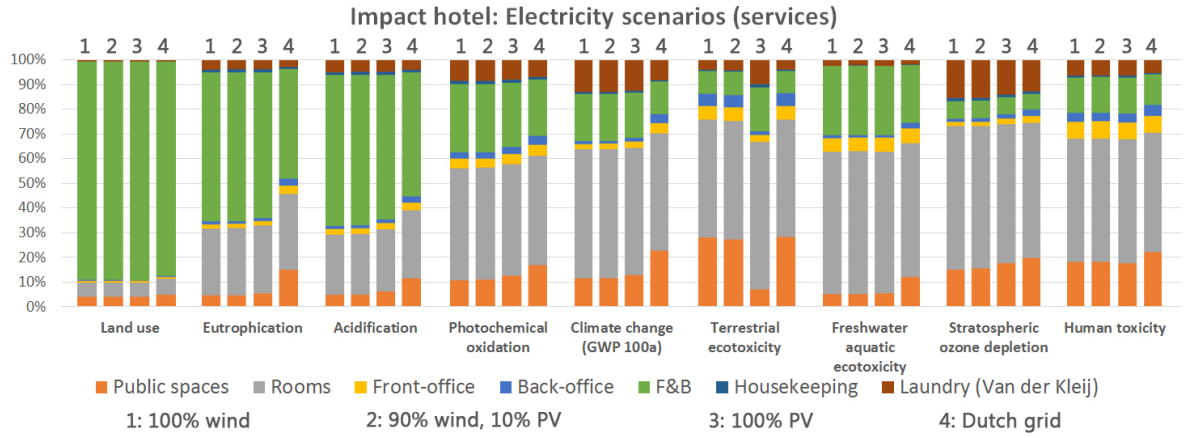

Figure 8.7: Origin environmental impact Conscious Vondelpark hotel services, with different electricity sources, per impact category

The use of wind electricity does appear to have resulted in a significant reduction of the environmental impact of the hotel on most impact categories, when compared to electricity from the Dutch grid. Replacing part of this electricity with electricity from PV-panels seems to slightly increase the impact of the hotel on most impact categories within this study, however. Installing PV-panels also increases the share of renewable electricity in the Dutch electricity mix, as the wind energy can be used elsewhere, and may therefore still be related to a net-positive effect.

8.3.2. LAUNDRY

The hotel currently makes use of the laundry service at Van der Kleij in Utrecht. This company has taken many efforts to reduce their environmental impacts, but also requires textile to be transported to and from the hotel. As such, the second scenario is focused on investigating what the effects of these efforts have been, by creating a hypothetical alternative laundry facility right in front of the hotel, which has not taken any of the efforts to reduce its environmental impact.
The laundry service at Van der Kleij has been investigated in detail, while the alternative laundry service is an adapted version of the Van der Kleij service. The difference between the two alternatives is investigated first, after which three scenarios are created for the Conscious Vondelpark hotel.

The first scenario represents the use of the alternative hypothetical laundry service which has been adapted from Van der Kleij. The third scenario is associated with the laundry service at Van der Kleij with transport that is 50% more efficient, while in the final scenario the laundry service at Van der Kleij makes use of wind electricity, based on electricity from wind park de Hondtocht.

CONTRIBUTION INDIVIDUAL LAUNDRY ALTERNATIVES

The impact of the laundry alternative appears to be higher than the impact of Van der Kleij in all impact categories, even though transport of textile to and from Utrecht is no longer necessary (figure 8.8). The increased use of gas and washing agents and chemicals in particular appears to be responsible for the higher impact, while the increased consumption of electricity also contributes to a higher impact for most impact categories. The lack of transport does lower the impact of the alternative laundry service to some extent, but not enough to compensate for the increased consumption.

At Van der Kleij the main contributing processes are the ironing and folding of linen, and the drying of towels. For the alternative, however, the main contributing process for almost all impact categories is the washing process, as the use of washing products, water/sewage and especially gas has increased dramatically for this

process. This is largely due to the less efficient use of water, and consequent washing products, and due to the use of natural gas for heat rather than waste-heat from the ironing of linen. The drying and ironing processes also require more natural gas, albeit less dramatically so, while the drying and shaking processes are associated with a slightly higher use of electricity due to the colder temperature of inflowing water and the lack of infrared technology.

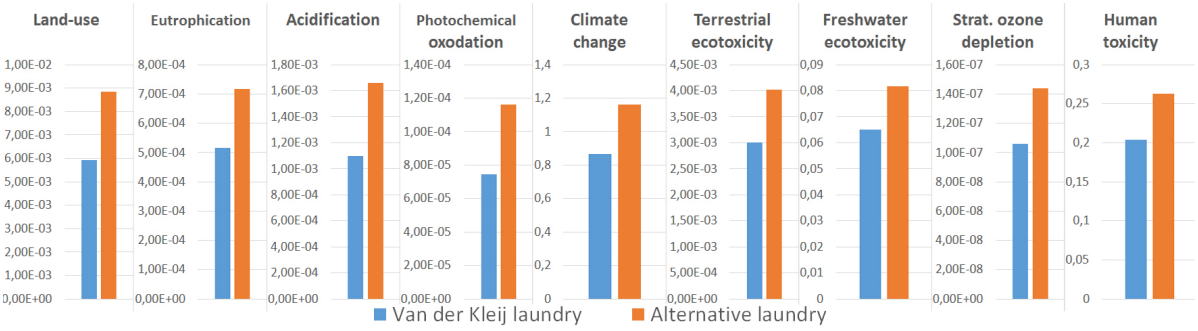

Figure 8.8: Comparison laundry services per 1 guest per day, per impact category

For most impact categories the use of natural gas for the various processes is still the main contributor, with a significant impact from electricity as well. The washing agents show a much larger influence, however, especially with regards to land use, acidification, photochemical oxidation, terrestrial ecotoxicity, freshwater ecotoxicity and human toxicity, while the impact on sewage treatment on eutrophication and terrestrial ecotoxicity is significantly higher.

LAUNDRY AT CONSCIOUS

For the impact of Conscious it appears the influence of the laundry scenarios is only minor, as the contribution of the laundry service on the environmental impact of the hotel is relatively small for most impact categories to begin with (figure 8.9). Still, the impact of laundry is noticeable, and the efforts of Van der Kleij do result in a lower impact of the hotel for all impact categories, especially photochemical oxidation, climate change and stratospheric ozone depletion.
More efficient transport of textile to and from Conscious is associated with little to no change in the hotel's impact, but changing electricity sources does appear to result in small reductions of the hotel's impact on most impact categories.

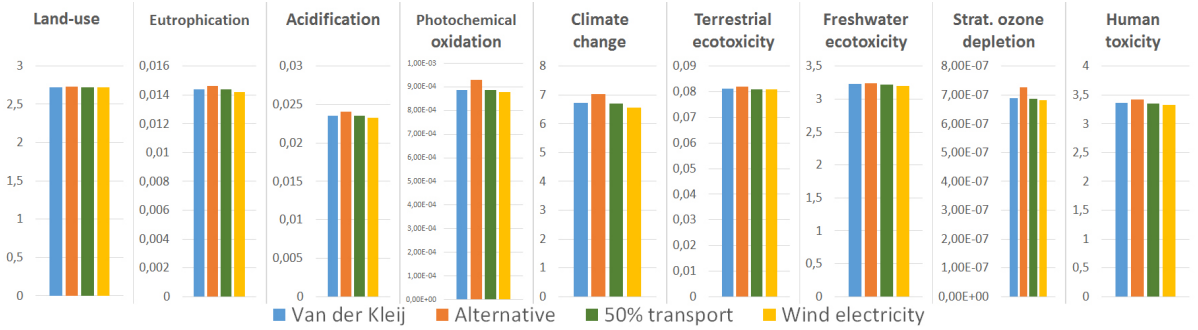

Figure 8.9: Environmental impact Conscious Vondelpark hotel, with different laundry scenarios per 1 day per average guest, per impact category

When perceiving the impact of the alternative laundry service and the impact of the laundry service at Van der Kleij with electricity from wind individually, the impact of the scenarios becomes more apparent (figure 8.10). As stated earlier the influence of gas and washing chemicals in particular appears to be higher for the alternative than for Van der Kleij. The washing agents chemicals show a particularly high increase for land use, eutrophication, acidification, terrestrial ecotoxicity and freshwater ecotoxicity, while the impact of natural gas is related to a significant increase for climate change, stratospheric ozone depletion and human toxicity, and a somewhat smaller increase for eutrophication, acidification and photochemical oxidation. For most impact categories the difference is reduced slightly due to the impact of transport.

Using electricity from wind instead of the Dutch grid is also associated with drastic reductions of the service's impact, especially with regards to land use, eutrophication and freshwater ecotoxicity. A smaller reduction is visible for the service's impact on acidification, photochemical oxidation, climate change, stratospheric ozone depletion and human toxicity. Only for terrestrial ecotoxicity very little difference is present, as the contribution of electricity to this impact category is almost entirely related to its distribution, not the source.

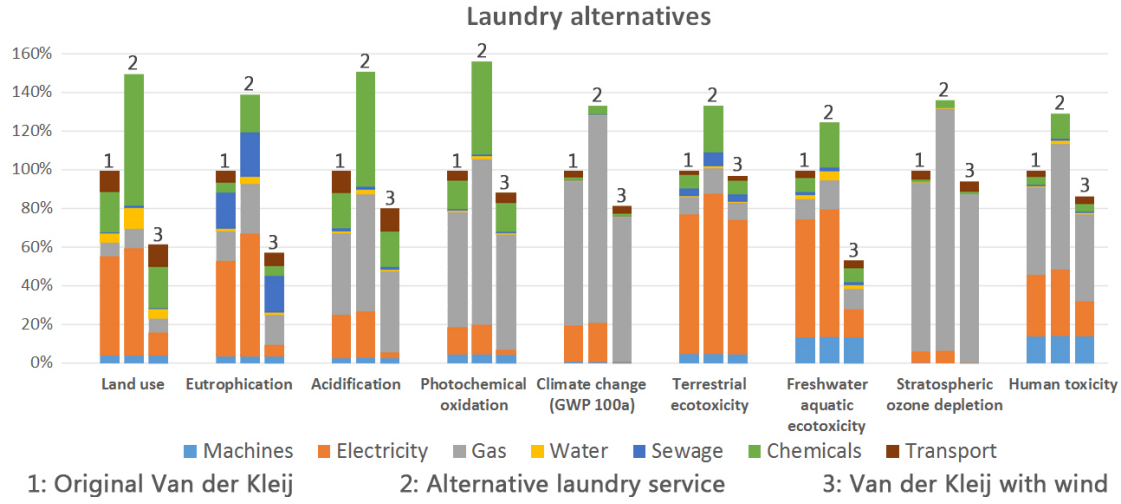

Figure 8.10: Origin and relative height environmental impact different laundry scenarios, per impact category

As such, it appears that even though the laundry service only represents a small contribution to the hotel's impact on most impact categories, the measures taken by Van der Kleij are still noticeable in its impact. When perceived outside of the hotel's scope, however, the potential influence of these efforts becomes more apparent. Changing the source of electricity from the Dutch mix to wind could further decrease the impact of the laundry service for almost all impact categories. The use of this electricity would result in a slight decrease of the hotel's impact on most impact categories as well.

8.3.3. BOILER INSULATION

Gas is one of the major contributors to the environmental impact of the hotel on some impact categories, which is partly due to its high use. According to Mr. Kropman at Conscious, this high impact can also partly be attributed to the loss of heat from boilers and piping. Currently options are examined to better insulate these boilers and pipes in order to lower consumption by roughly 9%.

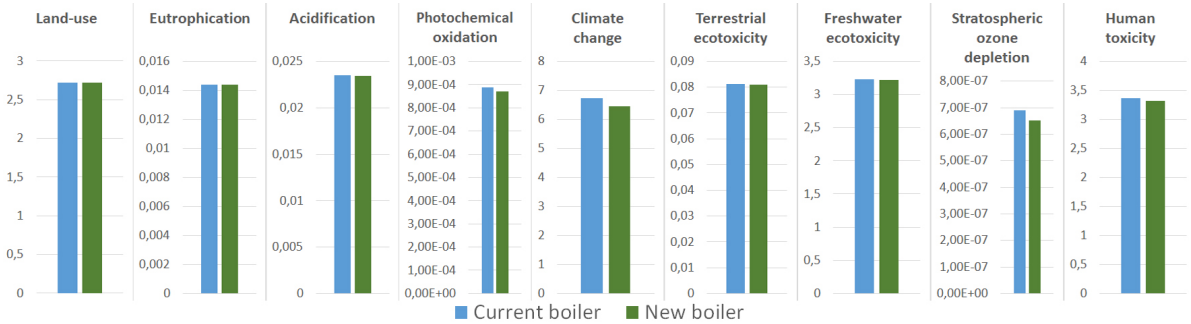

Figure 8.11: Environmental impact Conscious Vondelpark hotel, with different boiler insulation scenarios per 1 day per guest, per impact category

A simple scenario has therefore been set-up to assess the potential of this insulation to reduce the impact of gas on the hotel's impact. This scenario makes use of far less detailed data than the detailed studies, and is therefore useful to assess the potential influence of the insulation only. Materials are taken directly from the Ecoinvent 2.2 database as either exact or surrogate materials, while the application of the materials and possible other processes are disregarded.

In order to investigate the influence of such savings on the environmental impact of the hotel, the forecasted savings are projected onto the hotel, and the production of the insulation materials is added, essentially creating a new hotel which includes an insulated boiler system. The environmental impact of the hotel with boiler insulation is consequently compared with the current situation (figure 8.11). As the avoided losses also result in a reduced use of the boilers their lifetime could potentially increase, and as such use is reduced proportionally. This is done by adding the insulation and its disposal to the hotel, and by simply lowering the output of the boilers in CMLCA which automatically results in a lower use of gas.

As gas is related to a dominant contribution to the hotel's impact on climate change and stratospheric ozone depletion, the most significant changes related to the insulation can be seen here, with apparent reductions of approximately 4,00% and 5,50%, respectively. The influence of the reduces gas use appears to be much smaller for the remaining impact categories, however. With boiler insulation the hotel's impact on photochemical oxidation shows a reduction of roughly 2,00%, its impact on human toxicity 1,20%, its impact on acidification 0,40% and its impact on freshwater ecotoxicity 0,30%. Reductions to land use, eutrophication, terrestrial ecotoxicity are virtually non-existent.

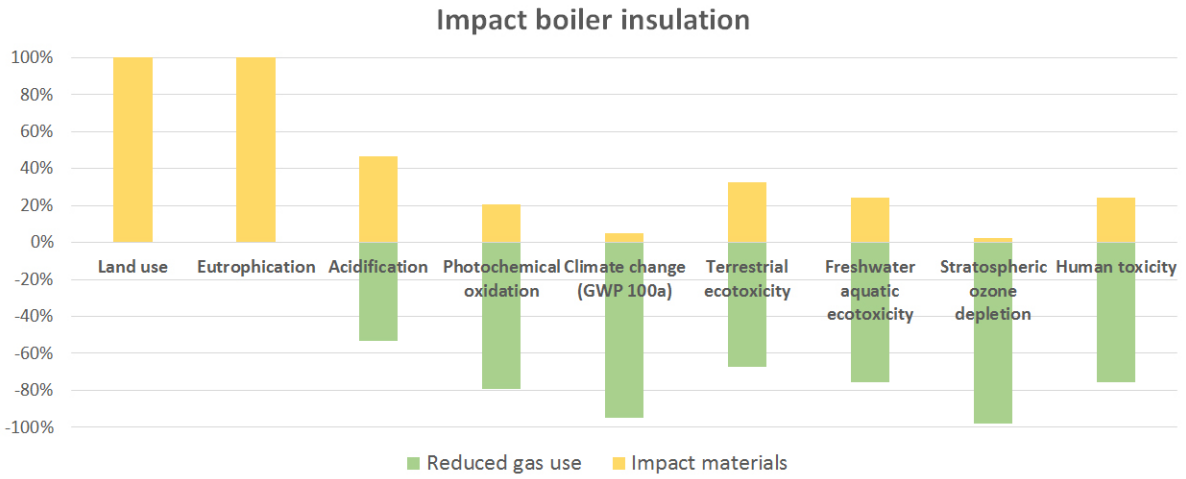

Figure 8.12: Environmental impact insulation materials and reduced gas consumption at the hotel, per impact category

In figure 8.12 the relative impact of the production and disposal of the insulating materials is visible. Only for land use and eutrophication these result in a higher impact, but relative to the hotel's impact this contribution is negligible. The materials additionally even out the reduced impact related to less gas consumption slightly on acidification, while they lower the reduced impact slightly for all remaining impact categories. The relatively low impact of the materials can partly be attributed by their relatively long lifetime of 25 years, reducing their impact to near-negligible proportions.

The impact of the materials is almost entirely related to the production of glass fibre and rock wool. For eutrophication the mining of lignite and coal for the electricity requirements of glass fibre and rock wool is the main contributor, while the impact on acidification and photochemical oxidation is directly related to the production of rock wool. The impact on terrestrial ecotoxicity and human toxicity are predominantly related to the production of glass fibre. For terrestrial ecotoxicity the impact is also partly related the production of the materials for rock wool and distribution of electricity for the production of both these products. Stratospheric ozone depletion, finally, is mainly influenced by the transport of natural gas for electricity, and to a slighter extent to the production of the materials for rock wool.

It therefore appears that the addition of insulation to the boiler system results in a slightly lower impact of the hotel, in particular with regards to climate change and stratospheric ozone depletion, and to a lesser extent photochemical oxidation and human toxicity as well. The material requirements only result in a higher impact for land use and eutrophication, but their contribution to the hotel's impact is negligible for all impact categories. As such, the overall impact of the hotel would likely go down when adding insulation.

8.3.4. SUMMARY SCENARIOS AT CONSCIOUS

The use of both the PV-panels and alternative laundry service both appear to generally increase the hotel's impact, while the addition of insulation to the boiler system seems to have the potential to reduce the impact to some impact categories (figure 8.13).

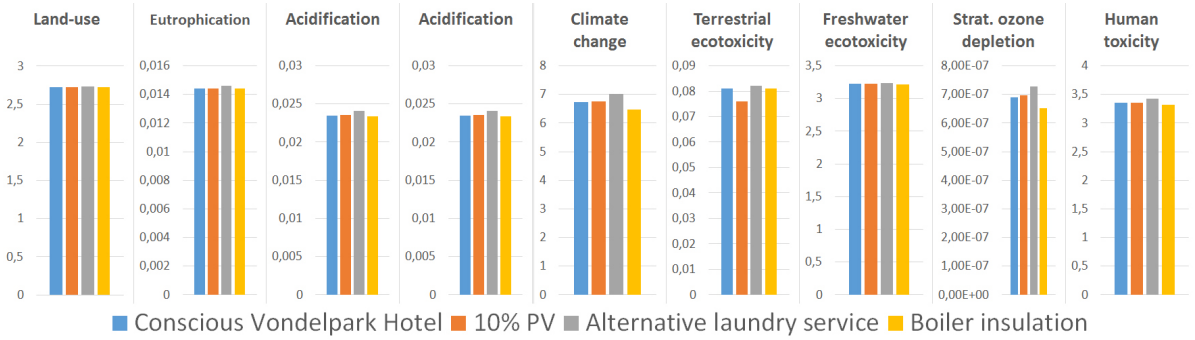

Figure 8.13: Environmental impact of different Conscious Vondelpark hotel scenarios, per 1 day per average guest, per impact category

The use of PV-panels to supply 10% of the yearly electricity requirements at Conscious appears to slightly increase the hotel's impact on most impact categories, especially with regards to acidification, photochemical oxidation, climate change and stratospheric ozone depletion. This increase is predominantly related to the fact that PV-panels require a higher materials and energy investment per kilowatt-hour they generate over their lifetime, which is mostly associated with the production of silicon, and to a lesser extent also to the production of electronic components and metals such as copper. The hotel's impact on land use does not differ, however, as this impact is almost entirely related to the food and beverages. The impact on freshwater ecotoxicity is also related to virtually no change, as the impact from both electricity sources to this impact category is nearly identical. Only the hotel's impact on terrestrial ecotoxicity decreases significantly when PV-panels are used to supply 10% of the yearly electricity requirements, as less electricity has to be distributed to the hotel in this scenario. The hotel's impact of human toxicity is additionally related to a very slight decrease, which is also related to the decreased electricity distribution.
The differences between electricity from wind park De Hondtocht and PV-panels are small, however, and both options are still associated with an impact that is drastically lower than of electricity from the Dutch grid.

The use of an alternative laundry facility appears to have increased the impact of the hotel in all impact categories. In particular the hotel's impact on climate change and stratospheric ozone depletion has increased, while smaller increases are visible for acidification, photochemical oxidation and human toxicity. The increased use of gas and washing agents and chemicals in particular appears to be responsible for the higher impact, while the increased consumption of electricity also contributes to a higher impact for most impact categories. The increase is much more noticeable between the individual laundry services, but as the contribution of this service to the hotel's impact is relatively small, this difference is diminished for the hotel. Even so, the efforts made by Van der Kleij appear to have visibly lowered the impact of the hotel, even though transport to and from Utrecht is required. The impact could potentially be reduced even more, however, when Van der Kleij would make use of electricity from wind.

The addition of insulation to the boiler system, finally, will likely lead to a reduction of the hotel's impact on the impact categories related to gas, according to the simple assessment within this study. In particular the impact on climate change and stratospheric ozone depletion could decrease, with smaller but noticeable decreases for acidification, photochemical oxidation and human toxicity. The impact of the insulation material appears to be negligible, which is partly due to its long lifetime, but also related to the relative low impact of the materials that are used.

8.4. SUMMARY CONTRIBUTION ANALYSIS

It appears the rooms are associated with the highest contribution to the hotel's impact for most impact categories, which is mostly associated with its gas consumption and the high amount of products present in the 81 rooms. For land use, eutrophication and acidification, however, the F&B service provides the highest contribution, which is predominantly associated to its use of food and beverages. The contribution of the public spaces and laundry service is considerably smaller. For the public spaces the impact is predominantly related to its consumption of gas and electricity, and the products present, while the impact of the laundry service largely derives from its consumption of gas and electricity. The impact of the front- and back-office is smaller still, and is mostly associated with the production of the products present, and to their use of gas and electricity. A large share of both offices, but mostly the back-office, is also associated with the commute of employees. The slightest contribution appears to derive from the housekeeping service, which is almost entirely related to the commute of housekeeping employees.

As such, the impact of the services and pseudo-services is related to different origins. Neither the products, utilities or activities are responsible for a high contribution to the hotel's impact on all impact categories, however. Gas and food are associated with very high contributions to some impact categories, and combined they appear to be responsible for the majority of the impact in most impact categories, with the exception of terrestrial ecotoxicity, freshwater ecotoxicity and human toxicity. The products seem to be responsible for a small contribution to all impact categories, while it looks like the laundry service and employee commute are responsible for small contribution to all impact categories except land use. The contribution of electricity and trash are generally only slight for most impact categories, except for electricity on terrestrial ecotoxicity and the impact of waste on freshwater ecotoxicity, where their contribution appears to be very high. The impact of water seems to be negligible, finally, but wastewater treatment is associated with a small contribution to eutrophication and a slight impact to terrestrial ecotoxicity.
The impact of gas is predominantly related to its combustion at Conscious, but also to its production and transport. The impact of food is almost entirely related to the production of food and beverages, mainly animal products and oranges. The impact of products is associated with the production of their materials, mainly metals, and the electricity consumption of the production processes. The highest contributing products are the mattress and electronic devices such as LED TVs, with slightly lower contributions deriving from the plastic room tables and Yumeko blankets. The impact of the laundry service is mainly related to its use of gas and electricity, while the impact of employee commute is almost entirely associated with the use of trains and cars. The impact of electricity is predominantly related to the production of the wind turbines and distribution network, which is mainly related to the production of metals, while the impact of trash is almost entirely associated with the incineration of municipal solid waste. Only for terrestrial ecotoxicity the processing of organic waste is the main contribution for trash. The negligible impact of water, finally, derives from the use of electricity, while the impact of its treatment is directly associated with the treatment process and effluents.

The impact of the hotel on most impact categories appears to increase when 10% of its yearly electricity requirements are replaced with PV-panels, although only slightly. This impact is predominantly related with the increased use of materials, and increased use of high-impact materials such as silicon per kWh output of the PV-panels, compared to the wind turbines. Only for terrestrial ecotoxicity and human toxicity does the impact decrease, which is associated with the reduced electricity distribution to the hotel. Electricity from both wind and PV is associated with considerably lower impacts than electricity from the standard Dutch electricity mix, however.
When using an alternative laundry service in Amsterdam which has not taken efforts to reduce its environmental impacts, the impact of the hotel increases visibly for most impact categories. This increase in impact seems to be predominantly related to the increased use of gas, electricity and washing products at the alternative laundry service. The reduced impact of transport is only slight compared to the increases impact from the facility, and as such the efforts made by Van der Kleij appear to have visibly lowered the impact of the hotel, even though transport to and from Utrecht is required. The impact could be reduced further for some impact categories when wind energy would be used, however.
The addition of insulation to the boiler system appears to be related to a decrease of the hotel's impact on the impact categories which are related with natural gas. It looks like the impact of the insulation material is relatively low, and is nearly negligible due to the long lifetime of the insulation.

9

INTERPRETATION - CONSISTENCY & COMPLETENESS CHECK

In order to assess the validity of the results, the consistency and completeness of the study must be analysed. Both were taken into account during the entire study, as every choice had to be consistent with other choices. The Handbook on Life Cycle Assessment recommends to carry out the consistency check before performing the contribution analysis. This was done during this study, but to separate LCA results from the further analysis into the effect of streamlining, the contribution analysis has been documented before the consistency check in this paper.
During a consistency check it is determined whether assumptions, methods, models and data are consistent with the goal and scope of the study. A completeness check is carried out as well, during which it is determined if all relevant information and data necessary for the interpretation is present and complete. As streamlining efforts have been applied during the study, there are inherent inconsistencies and completeness errors. As such, the influence of the assumptions, data and processes used will be further analysed during the sensitivity analysis.

9.1. CONSISTENCY CHECK

As many different processes, products and activities are taken into account, it is important that the parameters, assumptions and data between them are similar. Due to the streamlined nature of this study, however, some inconsistencies have emerged, which are discussed here.

First functional consistency of the products and activities present is explored, after which the consistency and accuracy of data, processes and assumptions used is investigated. The technical and temporal consistency of both data and processes are also taken into account, as is their geographic consistency. The influence of any inconsistencies found will be investigated during the sensitivity analysis further on in this report.

9.1.1. FUNCTIONAL CONSISTENCY

All products, services, activities and processes within the study follow the same function, which is based on the daily use in the Conscious Vondelpark hotel by one average guest. The production, use and disposal stages are not directly linked to each other, but are all combined within the services. As such all life-cycle stages are present and based on the same function in a consistent manner, and the entire life-cycles of all products and services are taken into account. Only for the windmills, PV-panels, air handling unit surrogates and boilers the disposal is combined in the production process, as these units are part of general facilitating services, rather than being directly associated with a specific service.
A distinction is additionally made between primary foreground, secondary foreground and background processes, predominantly based on the use by guests. For the vast majority of services this distinction is clear, but for the food and beverages, tableware and cutlery, and bicycles this is not as clear. These products both facilitate a service, rendering them secondary foreground processes, and are directly used by guests, rendering them primary foreground processes. As the use of guests is decisive, their use is treated as a primary foreground process, while their production is treated as a secondary foreground process.

9.1.2. CONSISTENCY AND ACCURACY OF DATA, PROCESSES & ASSUMPTIONS

A basic set of assumptions has been applied to all products, services, activities and processes in this study whenever relevant. At the basis of all foreground processes lie background processes from Ecoinvent, ensuring that all results are principally based on the same database and on equally extensive life-cycles. Packaging is never taken into account in foreground processes, and capital goods only when information is available. Recycling background processes are modelled quick-and-dirty and based on the avoided burden approach, while its multifunctional allocation takes place at the sorting process. Re-use of products is allocated to the new use, except for the transport to the new destination, which is allocated 50/50 to the disposal and new use. The transport of all materials and products to and from foreground processes is also taken into account, and based on production locations or European standards when locations are unknown. Direct transport to Conscious from the final production facility is assumed for all products, while most transport is assumed to take place with >16 ton lorries. All disposal at Conscious is assumed to be processed by Milieuservice Nederland, all boilers are >100 kW condensing modulating boilers, and all industrial furnaces are >100 kW low-NOx furnaces.
There are some inconsistencies present in the data, however, especially with regards to background processes from Ecoinvent. These background processes take packaging and capital goods into account, where this information is omitted for foreground processes, while recycling is based on the cut-off approach, rather than the avoided burden approach. As these inconsistencies are related to the database itself, however, it is very difficult to avoid them. The sporadic inclusion of capital goods is an additional inconsistency with regards to the foreground processes, but as data regarding the capital goods is often lacking it is difficult to include these for all processes. Additionally, the packaging of food and all other products has not been taken into account, but the disposal of paper from packaging is present in the F&B service, resulting in an inconsistent mass balance for this material.
An apparent deviation of the recycling approach is additionally present for the Auping mattress, as recycled plastics derive from an external source. This choice has been made consciously, however, as the plastics in the mattress are composites which cannot be recycled, and are therefore always incinerated. This incineration must therefore be taken into accounts, while the plastic is modelled to derive from an external source who's impact is still partly allocated to the disposal of plastics outside of the study boundaries. As such the same principle is applied, although the impact is partly allocated to external processes.

Regarding the data sources themselves, a strict hierarchy is pursued for all foreground processes, as explained in chapter 6. This hierarchy is consistently followed, but as not all products and services are associated with the same amount and detail of primary and surrogate data, differences between them are present. Primary foreground processes are almost entirely based on primary data, but secondary foreground processes are associated with four levels of detail, from highly detailed to crudely detailed. Accurate background processes were also missing for some products and services, resulting in the use of surrogate data from either Ecoinvent, the US LCI database or (non-)scientific literature, respectively. In order to use such surrogate data, further assumptions are necessary which affect the accuracy of the results. When Ecoinvent processes are adapted linear scaling of processes is assumed and when data from the US LCI database or literature is used surrogate Ecoinvent processes and materials are chosen to represent this data. This inconsistency in data accuracy is difficult to solve, however, as it cannot easily be avoided unless the same amount and detail of primary data and background processes from Ecoinvent are available for all of them. As this is very unlikely, the inconsistency is accepted and the influence of the assumptions and data sources will be investigated during the sensitivity analysis.

Between the individual alternatives of the electricity source and laundry service high consistency is present. Both electricity alternatives are based on extensive Ecoinvent processes which have been adapted to fit the situation of Conscious under the same basic assumptions and estimations, while the laundry alternative is based on the original laundry service at Van der Kleij which has been adapted. The contribution of services within the hotel is partly subjective, however, as the utility distribution for the services has been largely based on literature research and calculated estimations.

9.1.3. GEOGRAPHIC, TECHNICAL & TEMPORAL CONSISTENCY

The Dutch environment is always assumed for foreground processes, except in the case of production processes, which are based on their specific production locations. When processes from other locations are used, such as Ecoinvent processes or data from literature, they are adapted to fit their respective location, which is predominantly focused on changing the electricity mix and transport distances. Background processes from Ecoinvent are often not adapted, however, and as such all processes are essentially based on European and Swiss data, rather than Dutch. Additionally, even though processes are adapted to fit their respective environment, they are principally still based on processes from other locations. Some differences in the exact consumption and type of processes might therefore exist. Even though surrogate data is used, however, all processes are still based on existing large-scale technologies, whether they derive from Ecoinvent or other literature sources.

The primary and secondary foreground processes with regards to use at the hotel, either by guests or employees, are based on data from 2015/2016, as this is the period they are used. The primary foreground processes with regards to production are based on the year products were produced, as these represent the production of the products used at Conscious. In some cases production facilities have moved or shut down since delivering the products, for example, and as such their former locations and processes are used for this research. Background are largely based on the Ecoinvent database, however. This means their year of reference is often 10-20 years old, as more recent production data is rarely available. Surrogate data is also often based on varying reference years, which is usually 1-10 years for literature, and 5-10 years for the US LCI database. Most temporal inconsistencies are therefore associated with the background processes. The utility use at Conscious could be more specific, however, as data from before 2015 is often incomplete. As there are difference in consumption throughout the years, the inclusion of consumption data from more years would result in a higher accuracy of data.

9.1.4. SUMMARY CONSISTENCY

The function of all products and services is consistently based on the use of one average hotel guests during one day, and all life-cycle stages are consistently considered, but there is a difference between the level of detail of secondary foreground processes. The levels of detail are based on a strict hierarchy for all secondary foreground processes, however. Additionally, a general set of assumptions is present for all foreground processes, but these assumptions are not always consistent with background processes from the Ecoinvent 2.2 database. Packaging and capital goods are present in background processes, but packaging is never taken into account for foreground processes, and capital goods are often omitted for secondary foreground processes as well. Additionally, Ecoinvent cuts-off recycled materials, while these are taken into account for foreground processes through the avoided burden approach.
The Dutch environment in 2015/2016 is assumed for all foreground processes at the hotel, while external foreground processes are based on their respective locations and production periods. All foreground processes make use of Ecoinvent background processes, however, and some secondary foreground processes are based on processes from Ecoinvent as well. As this database is predominantly based on the Swiss environment, the geographical consistency is reduced, in particular between foreground and background processes. Additionally, there is a temporal inconsistency between the literature sources, as primary data is very recent, data from literature is 1-10 years old, data from the US LCI database is 5-10 years old, and data from the Ecoinvent database is 10-20 years old. All fore- and background processes are based on existing large-scale technologies, however.

9.2. COMPLETENESS CHECK

As streamlining efforts have been applied the study is inherently incomplete, but information regarding the completeness of data can still be useful during the sensitivity analysis to explore their influence on the results.

First the boundaries of the study are discussed, and missing processes and flows identified and accounted for. The completeness of the process tree and mass balances is also examined, after which the included impact categories are shortly discussed.

9.2.1. BOUNDARIES & MISSING PROCESS/FLOWS

The study is principally based on products and services related to the hotel service which are associated with high use, high mass/energy, or are deemed important by the hotel itself. As such a somewhat subjective selection has been made which enables the study to take place. Additionally, surrogate data is used in many cases to fill in data-gaps, especially for secondary foreground production processes. This data is often less accurate than primary data, and accompanied by assumptions. Finally many processes are treated as background processes, and packaging and capital goods are not taken into account, as the collection of data beyond the use stage and its facilitating stage is not possible for the myriad of products and services present at the hotel. This partly has to do with time limitations, but is also largely due to the inaccessibility of primary data due to secrecy and lack of specific knowledge by the suppliers.

This selection of processes and use of data has essentially made the study incomplete. Some products and activities in the hotel are missing, in particular those deemed less important due to their mass/energy, quantity or environmental relevance. Some products are additionally left out due to the focus of the study, which is related to the hotel service rather than the building. In some cases this has introduced a somewhat subjective division of what belongs to the service, and what belongs to the hotel. In this study all products, services, activities and processes directly related to providing some kind of service to hotel guests, or facilitating this provision, are assumed to be related to the hotel service. All products which make up the basic components of the building, such as walls, windows and doors, therefore fall out of the scope, as do the activities of guests outside of the hotel. Some ambiguity is present in this definition, however. Floors coverings, for example, are included in the hotel service, as are the air handling units and boilers, but ceilings and piping are left out. As with the selection of products and services within the hotel service, the selection of ambiguous products and services is also based on data and time constraints. Some floor coverings, for example, were associated with a high amount of primary data availability, while data for the ceilings was barely available. As such, rather than subjectively deciding which products and services are not a part of the hotel service, the availability of data and time is used to make this decision. This additional selection also ensures that the life-cycles of all processes are equally extensive, as a lack of data would result in the omission of a product or service. The inclusion of more products is possible, however, such as ceilings, wallpaper and radiators. Pinpointing exactly where the line between service and building lies is associated with subjectivity, however, and some ambiguity will therefore always be present.

9.2.2. PROCESS TREE & MASS BALANCE

The process-tree is considered to be complete for the gathered data. The production, use and disposal stages of the different products, services and activities are separated from each other, but combined in the services. Only the use stage and its facilitating process are treated as foreground processes, while the remaining processes, such as material production and disposal, are treated as background processes. As such most extensions are allocated to background processes, and often represented by service processes within the foreground processes. Additionally, it appears that no processes are cut-off within the boundaries of the process tree, with the notable exception of recycling within background processes, which is difficult to avoid as this cut-off is an inherent part of the Ecoinvent database.

The mass balance of the study adds up to zero for nearly all products, activities and services. An exception is present for the recycling activities within Ecoinvent background processes as stated before, as recycled products are cut-off. The trash produced at Conscious is also generally not in line with the inflow of materials into the hotel, which has several causes. First of all, the hotel is not a closed system, since guests can bring products in and out of the hotel. Secondly, a large portion of the products brought into the hotel on a daily basis are food and beverages, which are consumed rather than disposed of. Finally, the packaging of food and all other products has not been taken into account, but the disposal of paper from packaging is present in the F&B service nevertheless. For all individual products, the use of water, adapted recycling processes and all other processes the mass balances do add up to zero. The magnitude of emissions between alternatives, finally, is in line with each other without high outliers, and differences are generally where they would be expected.

9.2.3. METHOD

Impact categories from the CML-IA midpoint method 'CML 2001' are included, with the addition of land use. Abiotic resource depletion is lacking, however, even though this is considered a baseline impact category within the CML 2001 method. As a result 917 interventions are not associated with characterisation factors, which would have been 812 if abiotic resource depletion would have been included as well. As stated in chapter 7, however, including more a plethora of other impact categories would not be in line with the streamlining efforts of this study.

9.2.4. SUMMARY COMPLETENESS

The study is incomplete, as only a selection of products and services related to the hotel service have been included, while the hotel building has not been taken into account. Additionally, surrogate data is used to fill-in data-gaps, and all processes except the use and use-facilitating ones are treated as background processes. As such the hotel building, low-mass/energy, low quantity and low-importance products have been omitted, and part of the supply chain is generic. This has additionally introduced a somewhat subjective division between processes which are associated to the service and to the hotel building. The process-tree of this study is considered to be complete, however, as all stages are included and no processes are cut-off within the system boundaries. Only background processes are related to a cut-off of recycling, which is difficult to avoid. The mass balance for the study adds up to zero in most cases, although there are exceptions. These exceptions are caused by the consumption of food, disposal of trash food packaging, and the aforementioned cut-off of recycled materials in background processes. Food and trash flow in- and out of the system boundaries with the guests, and can therefore not add up to zero, while packaging is thrown away by the F&B service but not produced in accordance with the general assumption that packaging is never included. All other materials, products and utilities present in the system add up to zero, however.
The impact assessment method used, finally, has resulted in the use of nine baseline characterisation categories. As such some interventions are not associated with characterisation factors, but adding a plethora of other impact categories would not be in line with the streamlining efforts of this study.

10

INTERPRETATION - SENSITIVITY ANALYSIS

To enable a quick and extensive assessment of the environmental impact of the hotel service, many assumptions have been made and surrogate data from different sources has been used. The use of assumptions and surrogate, however, increases the uncertainty margins of LCA studies (de Koning, Schowanek, Dewaele, Weisbrod, & Guinée, 2010). As such the sensitivity of the study results has to be explored in order investigate the influence of assumptions and data on the environmental impact of the hotel and its services, and uncover their sensitivity. This will be done by performing a sensitivity analysis, during which specific parameters will be deliberately changed for a selection of processes within the study. This can provide insight into the influence of different life-cycle stages, processes, data sources and types, assumptions, and streamlining efforts. The sensitivity analysis is partly subjective, however, as a threshold for the significance of changes has not been set beforehand.
Within this study the environmental impact of some products and processes is additionally compared with existing literature in order to investigate if results from this study coincide with earlier studies. Comparing results with literature is challenging, however, as the exact assumptions, methods and input data is often not known.

In this section the sensitivity of the impact assessment method and characterisation is explored, after which the sensitivity of the data and assumptions used during the LCA is investigated. First the influence of the impact assessment method on the contribution of services within the hotel is examined, as is the influence of impact categories. After this a selection of individual products and processes is examined, during which sensitivities are identified and investigated. In cases where similar studies are present, results are additionally compared to see if similar results have been reached in the past. The influence of the product and service sensitivities to the hotel results are also explored, as is the sensitivity of the utilities and other activities within the hotel.
An extensive account of the sensitivity analysis can be found in appendix J, while calculations are present in appendix I.

10.1. METHOD

There seems to be no significant differences of the contribution of the services between the impact assessment methods of CML2001, IMPACT 2002+ and eco-indicator 99, although the impact of the food and beverages appears to be higher for IMPACT 2002+, while eco-indicator 99 is associated with negative impacts as well. The negative contributions actually relate to positive impacts, as the impact of the F&B service on some impact categories within ecosystem quality appears to be negative for the eco-indicator 99 method. This can be attributed to differences between the methods, while the remaining contribution still appears to be in line with the contribution used in this study. As was pointed out in chapter 7, however, not all interventions are related to characterisation factors. Including more impact categories would likely solve this issue at least in part, as was shown by the addition of the baseline impact category depletion of abiotic resources. Adding this impact category reduced the amount of interventions without characterisation factors by roughly 11%, but did not change the general observation of either the services or of the products, utilities and activities within the hotel. Adding more impact categories would likely reduce the amount of interventions without charac-

terisation factors even further, and could even provide completely new insights, as is also the case for land use. Adding more impact categories besides the baseline categories would not coincide with the objective of the streamlining efforts which were focused on speed, however, as this would likely require a higher time investment during the LCIA and interpretation phases.

10.2. INDIVIDUAL PRODUCTS AND SERVICES

In this section the sensitivity of the data, processes and assumptions used for a selection of products, utilities and activities will been investigated. Additionally, the influence of the product and service sensitivities to the hotel results have will be explored, after which all sensitivities of the study will be reviewed.

10.2.1. ELECTRICITY FROM WIND & PV

For wind the influence of the transport, electricity distribution, steel and concrete for the tower, losses during distribution and lifetime were investigated, while for PV the influence of transport distance, lorry type, supporting structure and installation, electricity source, lifetime/efficiency and packaging were investigated. The most important results are summarised in figures 10.1 and 10.2.

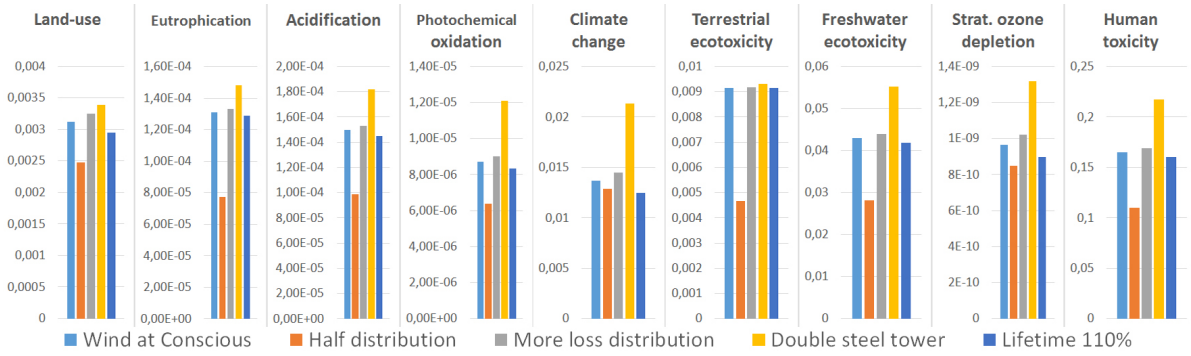

Figure 10.1: Influence of a selection of assumptions and materials for electricity from wind, per impact category

It appears that the wind turbine-related assumption that the material and utility requirements of the generator and especially the tower can be linearly scaled to changes in their size and lifetime introduces a sensitivity of their impact. Doubling the amount of steel is related to a fairly significant increase of the impact of nearly all impact categories, while reducing of increasing the lifetime by 10% also shows a noticeable impact. The influence of transport of the parts, as well as the cement used for the tower seems to be negligible, however, while the distribution of electricity has a high influence on nearly all impact categories. The influence of distribution on terrestrial ecotoxicity is uncertain, however, as this is almost entirely related to the use of wooden poles for distribution which are barely used in the Netherlands. This is due to the fact that the Ecoinvent 2.2 database is primarily based on Swiss or European data, not on Dutch data.

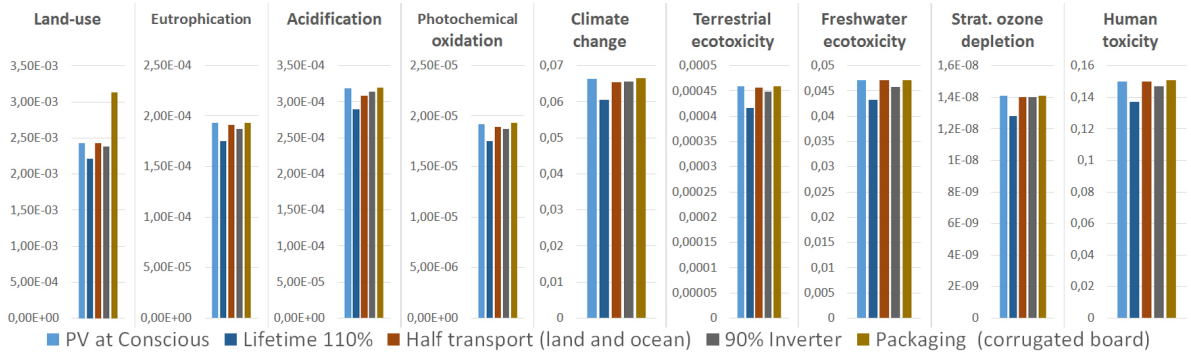

Figure 10.2: Influence of selection of assumptions and materials for electricity from PV, per impact category

For the PV system the efficiency introduces a fairly significant sensitivity, as a myriad of external factors could increase or decrease its environmental impact. Transport distances, which are partly assumed, don't seem to

be associated with a significant influence, however, and halving the transport distance only shows a noticeable effect on the impact of acidification. The type and lifetime of the inverters does how a relatively high influence to all impact categories, with a slightly smaller impact from the type and size of rooftop construction, and a slight impact to some impact categories by the electrical installation. As these are based on Ecoinvent standards rather than the hotel, they introduce a sensitivity which can have influenced the results. Packaging materials only influences the impact on land use, and quite significantly so, while the use of Chinese instead of CENTREL electricity shows a slight influence on all impact categories, and has therefore introduced a small but unnecessary sensitivity. The production location of the PV-panels in China is additionally sensitive to the technology used, as the Ecoinvent process is based on European technologies. Both electricity systems are therefore likely related to more sensitivity than initially thought.

10.2.2. LAUNDRY SERVICE

The validity of the impact of the laundry service, and especially the impact distribution among its services, were explored. The efficiency of washing, boiler type and gas consumption, towel and linen distribution, electricity source, transport of machines, transport distance and mode for textile, consumption of water and washing products, and sewage treatment were investigated for the Van der Kleij laundry service (figure 10.3).

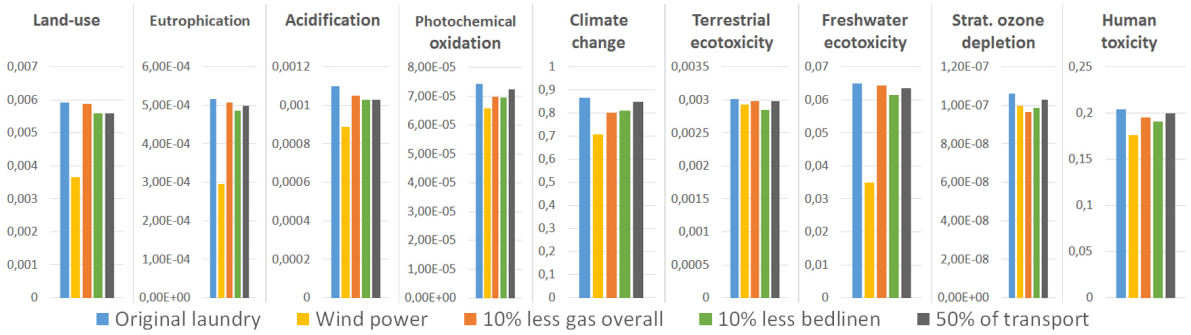

Figure 10.3: Influence of a selection of different assumptions and processes for the laundry service, per impact category

The influence of these aspects on the contribution of the different activities within the laundry service has been investigated as well 10.4. Additionally, the influence of the gas calculation and consumption of water and washing products for the alternative washing service were examined. The alternative is associated with an inherent sensitivity, however, as it is hypothetical and therefore highly influenced by assumptions.

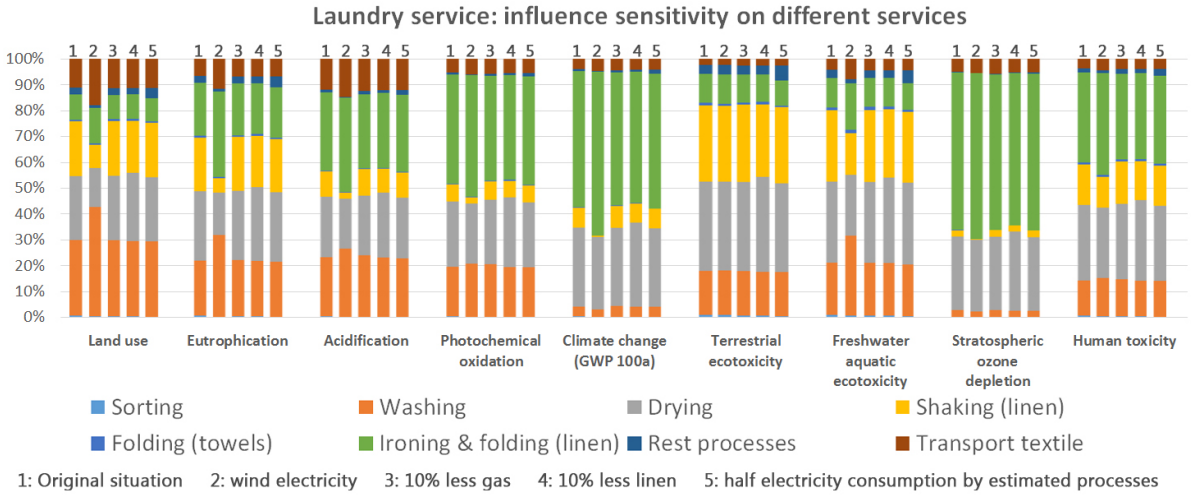

Figure 10.4: Influence of a selection of different assumptions and processes for the contribution of different processes at the total impact of the laundry service, per impact category

It appears the amount of textile washed per cycle especially has a large influence on the results, showing a near-proportional influence to all impact categories. This sensitivity does not lead to a possible sensitivity

however, as the yearly consumption and throughput at Van der Kleij has been supplied directly by the company and is therefore fairly certain. Gas consumption also seems to be related to some influence, while the impact of electricity only appears to result in large differences when fossil resources are switched with electricity from wind. As the consumption of gas and electricity are based on measurements, they are relatively certain, but the assumption that the distribution of Conscious's textile can be projected on the textile of Van der Kleij introduces some sensitivity nevertheless. The consumption requirements of restaurant textile could be removed according to accounts from Van der Kleij, but the remaining consumption of the facility has been divided over the towels and linen according to the textile distribution of Conscious. The proportion of towels and linen might be different at the laundry facility, however, which could alter the consumption of both electricity and gas related to the drying and ironing processes. The contribution of the linen ironing process is especially sensitive, as its consumption of electricity and gas has been based on assumptions related to the facility's total consumption. For this study this could not have been done differently, but the effect on the gas assumption especially might have altered the impact of the service to some extent. The influence of gas does not seem to be significantly influenced by type of >100 kW boiler, but this of course could be different for boilers other than the ones in Ecoinvent, and also depends on the burning efficiency of gas. The burning efficiency has a larger influence on the alternative, as this facility makes use of more gas. This gas consumption has been based on a relatively ideal situation, however, and is therefore also somewhat sensitive to change.
The impact of machines is inherently sensitive, as they are mostly based on assumptions and estimations. Their impact seems to be relatively low, however, and within this study is almost entirely caused by their production. The influence of the textile transport is small, but the estimated distance is sensitive, as the exact route of the lorries is unknown. The influence of the washing products, chemicals and wastewater treatment, finally, does not appear to be high, but due to the assumptions underlining these products and processes they are associated with sensitivity, as is their impact. The influence of washing products is considerably higher for the alternative, however, as this facility consumes roughly four times more. The impact of the washing products is further investigated in section subsection 10.2.8.

10.2.3. INTERFACE CARPET TILES

The validity of the impact of the Interface carpet tile on the different impact categories were investigated by examining the influence of transport, materials, energy sources and recycling processes, both for its production (figure 10.5) and disposal (figure 10.6). The production processes and disposal process, both of which include transport, are separated from each other.

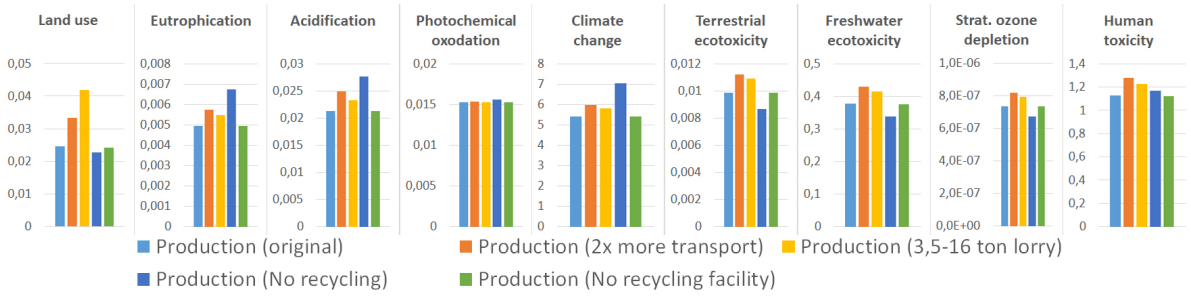

Figure 10.5: Influence of a selection of different assumptions for the production of the Interface Unity carpet tile, per impact category

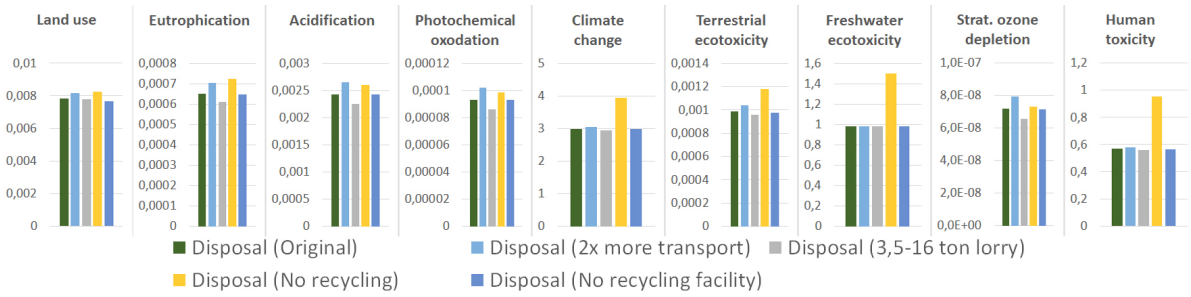

Figure 10.6: Influence of a selection of different assumptions for the disposal of the Interface Unity carpet tile, per impact category

The recycling process in particular appears to be associated with some sensitivity, as changing this process or its infrastructure could result in different results. Additionally, the choice of avoided burden allocation appears to have resulted in a higher impact of the carpet tiles compared to cut-off allocation possibilities. The use of recycling processes is associated with transport and energy consumption which outweighs the impact of virgin material production, although this is not the case for the high-impact material of nylon. Even though the recycled content of this material represents slightly more than 6% of the tile weight, its high production impact outweighs the avoided impact of recycling processes. As such, it appears the avoided burden approach is mostly useful for high-impact materials, almost regardless of their weight.
The lorries used for transport of the materials in particular also poses a slight sensitivity, as it is based on assumptions which do appear to influence the results. The transport distances are based on data from Interface, however, and as such are more certain. The biomass combustion process can also influence the results, especially with regards to photochemical oxidation, while the use of biogas is not very different from natural gas, but as it is not combusted its impact could be higher.

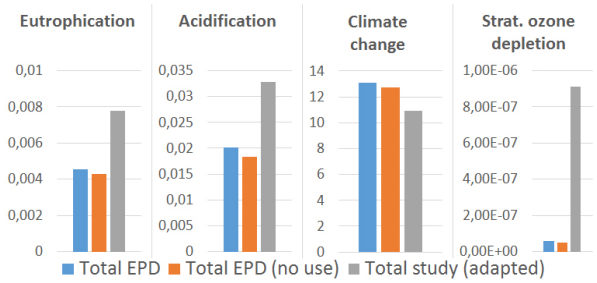

Figure 10.7: Comparison of impact carpet tile from EPD (with and without use) and adapted study tile for similar impact categories

When comparing the impact of an adapted, less detailed form of the Unity carpet tile to a carpet tile investigated in an EPD of Interface, it looks like the impact of both tiles is different, but in the same order of magnitude for climate change, acidification and eutrophication (figure 10.7). These differences can be associated with differences in characterisation and the databases used, but also to differences in assumptions and specificity of the materials. This is lightly suggested by the fact that transport and bitumen appear to be associated with very different impacts between the studies with regards to stratospheric ozone depletion. The fact that climate change, acidification and eutrophication appears to be relatively equally affected by the production of especially nylon and plastics for the tiles within this study, while these impact categories show very different results in the EPD, also suggests that these production processes are different between the databases used. The recycling processes might also influence the impact, although its impact on climate change, acidification and eutrophication is particularly small within this study.

10.2.4. AUPING MATTRESS

As with the Interface carpet tiles, the Auping mattress contains recycled content. These recycled materials have been taken into account with the avoided burden approach, which has introduced several recycling processes which are all associated with environmental impacts.

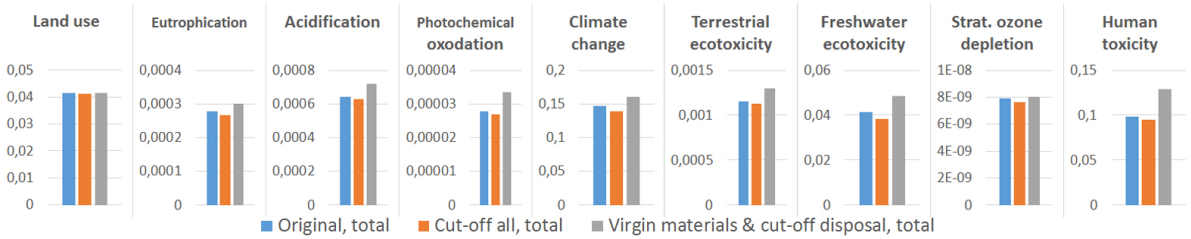

Figure 10.8: Impact Auping Inzinio mattress with different recycling allocations, per impact category

As stated before, however, cut-off approaches could also have been used. When both the in- and output or recycled materials would have been cut-off, the impact of the Auping mattress would have been slightly lower, predominantly due to the omission of the energy and transport related to the recycling processes (figure 10.8). When only the waste materials are cut-off, while the recycled content during production is replaced by virgin

materials, the impact of the mattress is noticeably higher for almost all impact categories, however. This is due to the increased production of the high-impact materials of steel and polyurethane foam. As with the Interface carpet, it therefore appears that the avoided burden approach is mainly mostly useful when dealing with high-impact materials. In the case of the mattress, however, the weight of the recycled materials also plays an important role. Recycled steel represents more than 28% of the total weight of the mattress, while recycled foam represents almost 19%. As these materials are also related to a high impact, there is a significant difference between their production from virgin and recycled sources.

10.2.5. LED TV

The validity of the LED TV was investigated by investigating the influence of different production processes and efforts, transport, and disposal (figure 10.9). The alteration from LCD to LED screen appears to be in line with literature, and does not involve a large change in the environmental impact (figure 10.10). As little other literature is available to confirm this, though, the assumption is still somewhat sensitive.

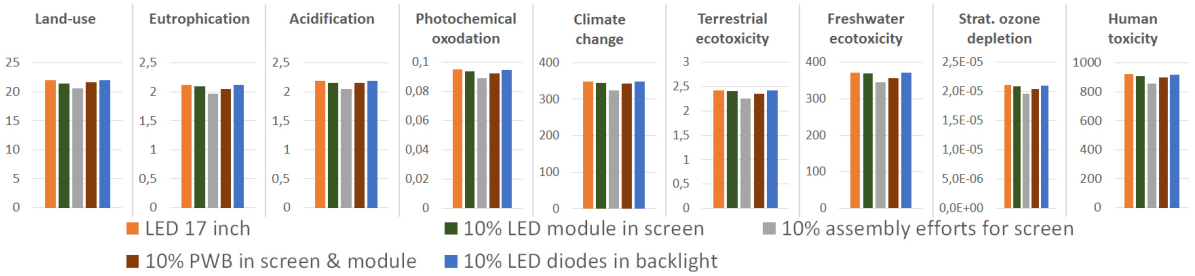

Figure 10.9: Influence different processes on the impact of the LED TV, per impact category

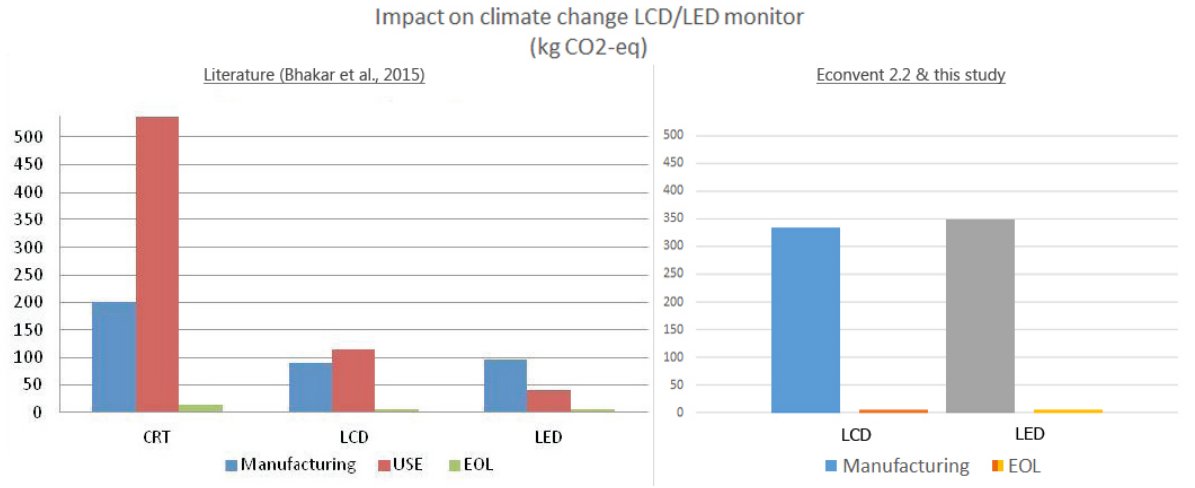

Figure 10.10: Relative impact on climate change of LCD and LED monitors from Bhakar et al. (2015) and this study

A larger sensitivity, however, derives from the fact that the TV is based on a computer monitor, rather than a TV. Possible additional requirements of PWBs or other materials and processes associated with a more extensive product therefore introduces an inherent sensitivity of this product which can only be dealt with by gathering more detailed data. The impact of transport is not related to sensitivity for this products, as the production process is associated with far higher impacts, while the disposal of the LED TV only introduces a small sensitivity for freshwater ecotoxicity, as it is based on the disposal of an LCD screen.

10.2.6. BICYCLES AT FRONT-OFFICE

The validity of the impact of the bicycles were explored by investigating the influence of weight, metals and their related processes, electricity mix, transport and possible maintenance (figure 10.11).
It looks like the amount of aluminium present in the bicycle is associated with some sensitivity, as the exact composition of the Van Moof bicycle is not known and its weight is roughly 10% lower than of the bicycle

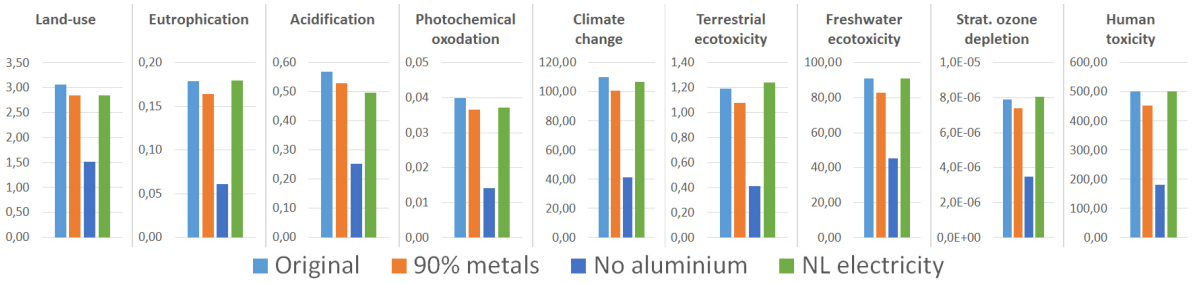

Figure 10.11: Influence selection of assumptions for one bicycle, per impact category

in Ecoinvent. The process of bicycle production appears to be associated with an impact lower than of the combined metals, but its use of electricity can still influence the results to some extent. As Chinese electricity is used to represent Taiwan, however, the sensitivity is assumed to be only slight. Transport is not associated with a high sensitivity, as the impact is predominantly based on transoceanic transport and relatively small, but the omission of bicycle maintenance does introduce an inaccuracy which results in less reliable data.

10.2.7. YUMEKO PRODUCTS

The validity of the impact of the blankets was explored by investigating the influence of the feathers, cotton and electricity (figure 10.12).

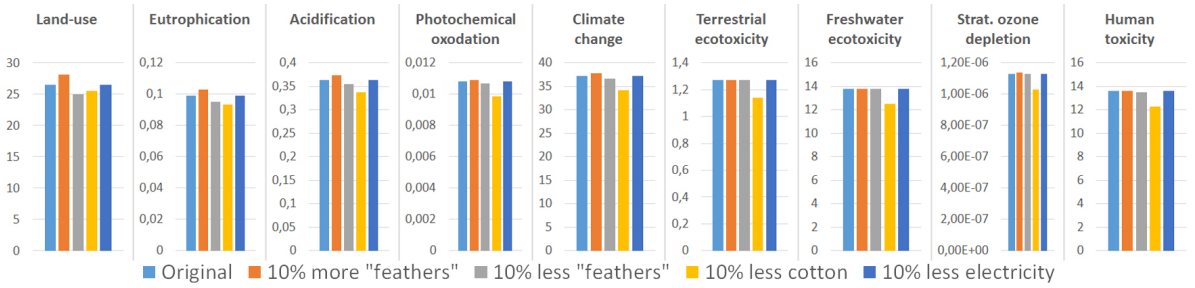

Figure 10.12: Influence different assumptions on the impact of the Yumeko blanket, per impact category

The sensitivity of the Yumeko blanket appears to be lower than expected, as nearly all impact categories are predominantly influenced by the production of cotton textile, of which the production process and quantity is fairly certain. The highly sensitivity feather surrogate appears to mainly influence the blanket's impact on land use, eutrophication and acidification, with a minor influence on photochemical oxidation, climate change and stratospheric ozone depletion. The impact of the sheep used to represent the feathers is assumed to be higher than of ducks, as they are far larger, but this cannot be stated with certainty. The Yumeko products are therefore still associated with sensitivity related to the feather filling.

10.2.8. DHARMAZONE IN HOTEL & WASHING AGENTS VAN DER KLEIJ

The analysis of the Dharmazone products and washing agents at Van der Kleij is predominantly focused on the impact of constituents. Different surrogate options from Ecoinvent for sodium levulinate, emulsifiers, ethoxylated alcohol and organic products for Dharmazone were reviewed, while the chosen constituents used for the Select Detergent were investigated as well (figure 10.13). The Dharmazone products have been partly combined for review as both products are very similar, while Select Detergent has been chosen as this washing product is the most extensive of the three, and contains roughly the same amount of water as the Dharmazone products.

The constituents and production process of the Dharmazone products are responsible for most of the impact of these products for nearly all impact categories. They are, however, associated with a high level of sensitivity, and changing some constituents could result in a different impact with regards to all impact categories. The validity of their environmental impact therefore appears to be low. This sensitivity is further emphasised by the fact that mistakes can be easily made in the choice of surrogate constituents, due to the lack of chemical knowledge present in this study.

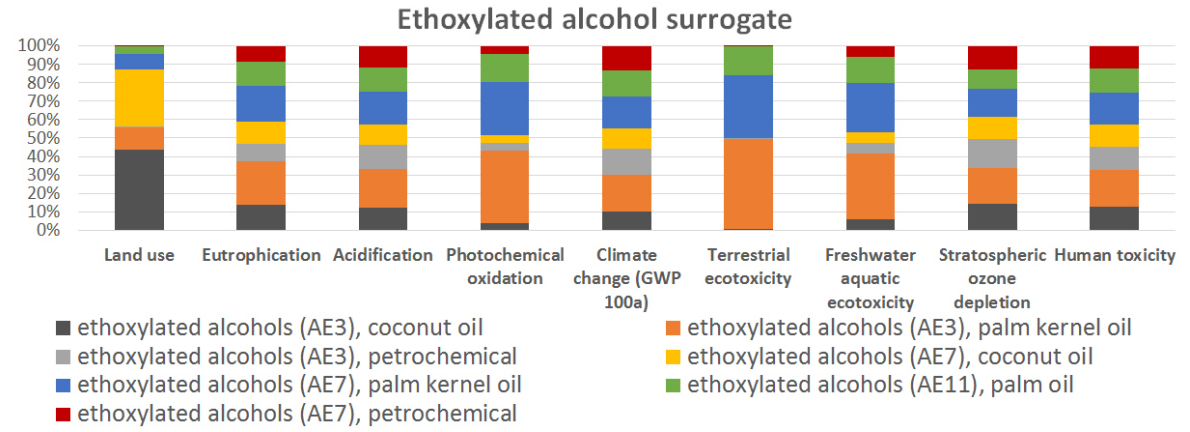

Figure 10.13: Influence different surrogate options for ethoxylated alcohol per kg, relative to each other, per impact category

The impact of these products can therefore barely function as a rough estimation of the possible contribution to the hotel's impact. Fortunately, as their contribution on this impact is low for all impact categories the influence of these sensitive products on the final results is relatively low. Including packaging for the Dharmazone products, which could be deliverd in 400 mL bottles, would increase the impact of the products visibly for some impact categories (figure 10.14). The impact of packaging is likely to be minor for the hotel, however, as refillable containers are used instead of bottles.

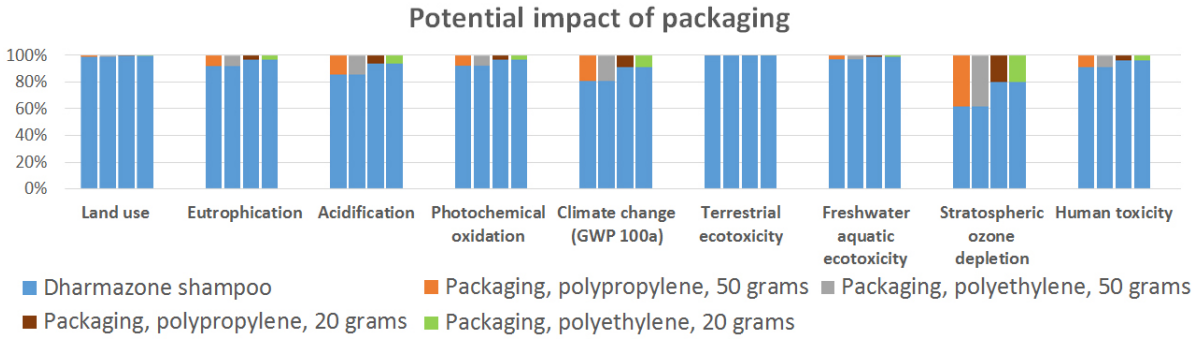

Figure 10.14: Influence different packaging options for Dharmazone shampoo per 400 mL bottle, relative to total impact, per impact category

The washing products used at Van der Kleij seem to be associated with less sensitivity, as the type and amount of constituents is based on more reliable data and expert estimations. The process of producing the products, however, is still sensitive, and can lead to different results for most impact categories, for example with regards to terrestrial ecotoxicity for Select Detergent. A more reliable production process could increase the validity of their environmental impact.

10.2.9. FOOD & BEVERAGES

The main activity at the F&B service is the serving of food and beverages. The validity of the results related to the different type of food and beverages present in the F&B service were examined. The difference in impact of the organic products that surrogate certain types of food, the influence of transport per food/beverage type, the influence of the use of sheep for animal products, and the potential altered influence of the dairy process were investigated. As was found earlier in chapter 8, the impact of the different foods and beverages

differs considerably , which is predominantly caused by their cultivation process, and to a lesser extent by their transport.

The impact of the foods and beverages is very sensitive, as they are based on average organic products from Ecoinvent, which do not represent exactly the same foods as present in the hotel. Additionally the impact of the different organic products differs between them (figure 10.15). The impact of the animal products is also very sensitive, as this is based on the cultivation of sheep meat alone, while the amount of useable products from this sheep is assumed. Changing this assumptions leads to significantly different impacts, as could the addition of other types of animal products. The dairy products are also very sensitive and likely far too low, as these are based on milking alone. The transport of products additionally appears to be influential mainly if the transport distances are large, although the mode of transport also plays a minor role, as does the relative impact of the product being transported. The assumed transport therefore also introduces a slight sensitive. The impact of the oranges, fruit/vegetables and animal products can still serve as an indication of what their impact could be, even when they are not exact. The impact of milking appears to be underestimated, however, and can therefore not serve as an indication of its potential impact.

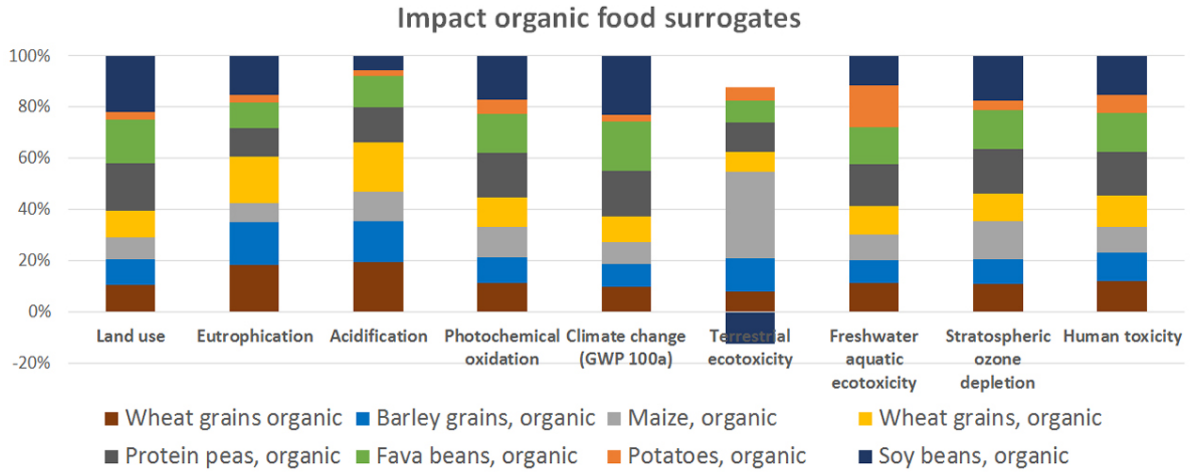

Figure 10.15: Influence different surrogate options for organic food surrogates per kg, relative to each other, per impact category

The representativeness of the surrogate organic cultivation processs could be further investigated by performing a literature research, both with regards to the difference in impact of fruit, vegetables and animal products, and also with regards to the influence of processing after cultivation, which has been omitted from most food and some beverages in this study, leading to further sensitivity. The wheat products and other beverages, finally, are also associated with less sensitivity, as they are based on a few literature sources. Expanding this literature could also give additional insight in the representativeness of the results, and could elucidate if the impact of some food products such as dairy products and coffee/tea are associated with too low of an impact to different impact categories. The fact that the menu changes throughout time, however, can make the results of a study outdated quickly, which is difficult to prevent in a single study.

10.3. HOTEL & UTILITIES

The influence of the products, utilities and activities on the hotel's impact is examined further in this section, while the influence of other services and activities present in the hotel were also investigated, both for the hotel (figure 10.16) and the contribution of its services (figure 10.17). The influence of the employee transport, trash transport at the hotel were studied, as was the influence of the assumptions regarding the gas used in and outside of the hotel within this study. The influence of the combined products on the hotel's environmental impact was also explored further by changing their lifetime and numbers at the hotel. The contribution of the services were additionally investigated, which was predominantly focused on the way in which electricity, gas and water are distributed.

There are some sensitivities present in the study, especially with regards to the sensitivity of products and food and beverages, but also with regards to other activities and utilities. In some cases these sensitivities are only noticeable for individual products and services, however, while their influence on the hotel's impact is difficult to assess.

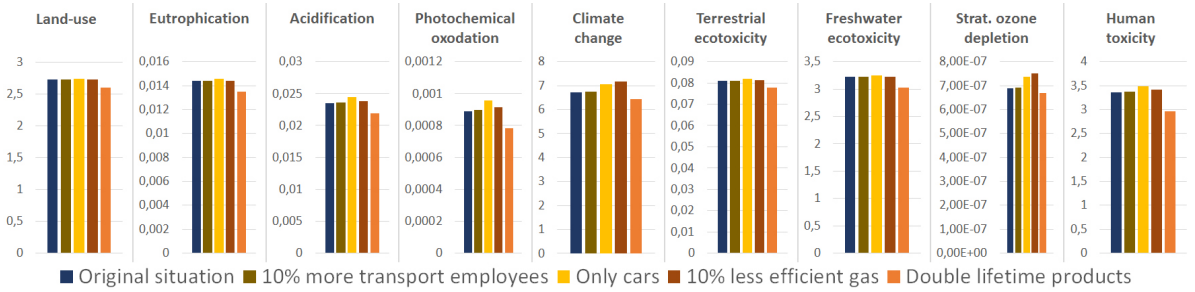

Figure 10.16: Influence of a selection of different assumptions for the hotel, per impact category

The sensitivities related to some individual products have a direct effect on the results of rooms and public spaces, especially those with are related to a high-impact such as the LED TVs. In most cases, however, the products only show a small contribution to the hotel's environmental impact when combined, and as such the sensitivity related to individual products is often not distinguishable. The assumed lifetime of products appears to be sensitive to change for both the impact of individual products and the hotel, however. Doubling their lifetime leads to significant reductions of their impact, and a noticeable reduction of the impact of the hotel on all impact categories. This is also reflected in the service contributions, as doubling the lifetime lowers the contribution of the rooms noticeably. Increasing the amount of food and beverages seems to be related to a change of the hotel's impact and contribution of the F&B service, but only to the impact on land use, and eutrophication, and to a lesser extent acidification, photochemical oxidation and climate change. The sensitivity of these impact categories is very high as a consequence, however.

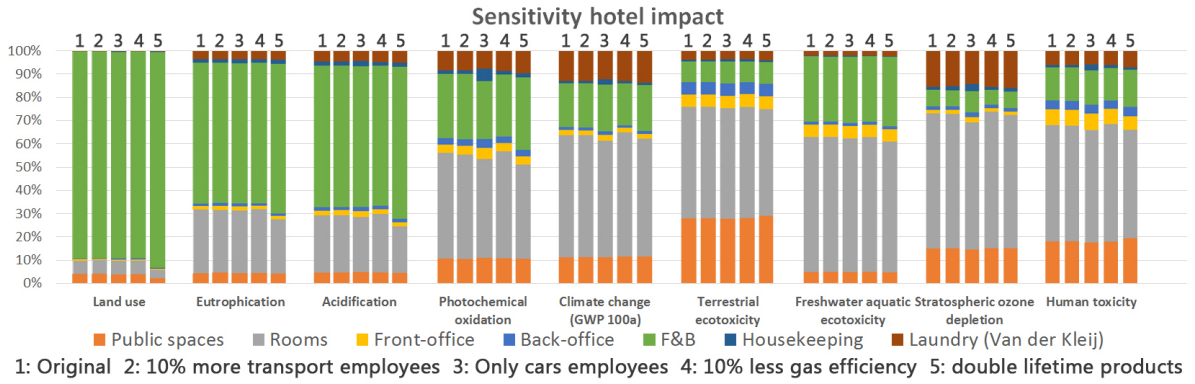

Figure 10.17: Influence of a selection of different assumptions for the hotel services, per impact category

The influence of disposal of both products and trash from Conscious to the hotel's impact is small for all impact categories except freshwater ecotoxicity. It is entirely based on Ecoinvent processes, while its transport shows very little influence overall, and as such does not seem to be not sensitive to change within this study.

The influence of gas consumption on the hotel's impact is high for some impact categories, especially climate change and stratospheric ozone depletion, and to a lesser extent photochemical oxidation and human toxicity. As such the assumed heat value is associated with some sensitivity, since changing this value results in small but noticeable changes in the aforementioned impact categories. The influence of this burning rate on the contribution of individual services to the hotel's impact appears to be trivial, however. It looks like the choice of boiler also does not lead to noticeable changes in the impact of the hotel.
The influence of electricity is slight, partly due to its renewable origin and consequent low impact, while sewage only shows a slight influence on the impact on eutrophication. Most of the sensitivity of these utilities appears to be related to the contribution of the rooms and public spaces, as these consume the highest

amount of the utilities. Water is related to a negligible influence on the hotel's impact.
All utilities are related to a sensitivity with regards to the (pseudo-)services, however, as they are distributed among these services in the hotel based on calculated assumptions. The rooms are the highest consumers of all utilities, but when proportionally allocating 10% of their consumption to the other services, no drastic changes with regards to the overall contribution of the services show up. The utility distribution is associated with some sensitivity, however, as it is not entirely based on measurements.

The commute of employees appears to be one of the main sources of sensitivity to the hotels impact on all impact categories, although its influence is rather small. Especially the impact categories of acidification, photochemical oxidation, climate change, stratospheric ozone depletion and human toxicity are influenced by the commute. This is associated with the employees themselves, as they can make different choices on modes of transportation, and staff changes can occur in relative short amounts of time and often. The use of cars especially seems to influence the results, which is also partly due to the fact that most transport currently takes place by public transport and bicycles. The commute mainly influences the front- and back-office and housekeeping, as these services are more heavily affected by employee commute, although the general order of contributing services remains the same. The transport of waste, however, barely influences the overall results or the relative contribution of services.

10.4. REVIEW OF SENSITIVITIES

A sensitivity analysis has been carried out for a selection of products, utilities and activities in use by Conscious, in order to investigate the influence of assumptions and data on the environmental impact of the hotel and its services, and uncover sensitivities. The sensitivity of the impact assessment method and characterisation, as well as the sensitivity of data and assumptions used are explored.

10.4.1. METHOD & IMPACT CATEGORIES

The use of different impact assessment methods does not appear to significantly alter the overall contribution of the different services, as rooms and the F&B service are still the main contributing services between impact categories. The fact that only a selection of baseline impact categories have been included, however, does increase the amount of interventions which are not related to characterisation factors. The inclusion of the baseline impact category depletion of abiotic resources did reduce these interventions by roughly 11%, but did not significantly change any of the observations made. More impact categories could be added, but this would not be in line with a streamlined LCA which is partly focused on speed.

SURROGATE PROCESSES AND DATA

The use of surrogate data appears to have introduced some inconsistencies, and has led to a somewhat incomplete LCA study. As a consequence some of the results are sensitive to changing assumptions, making them sensitive to some extent. These sensitivities are predominantly related to the impact of products present in the hotel, but also influence the results of the services and hotel.

When using surrogate processes, it appears sensitivities can arise when these processes have to be scaled in order to better represent the products or services under investigation. These sensitivities are related to the fact that not all activities and materials within a process are affected equally by scaling, and to the fact that these activities and materials are associated to varying degrees of impact. As such the impact of a scaled process is sensitive to the scaling method applied. Within this study linear scaling is assumed, which means all activities and materials within a process are scaled equally, rendering the scaled processes particularly sensitive to the influence of high-impact activities and materials. An example of this is the scaling of the wind turbine towers, the impact of which has been shown to change to a slight extent when less or more steel is used. As the exact amount of steel is unknown, the actual impact might be somewhat lower or higher, leading to a small sensitivity.
Results based on surrogate processes are also sensitive to the geographic locations of these processes, as the technologies used are often focused on these locations. For most processes this can be minimised by adjusting the electricity source, transport and activities to fit the location of the products and services under investigation, as has been done in this study. The impact or processes is only slightly sensitive to the electricity source use, however, as the electricity mix of almost all countries is predominantly associated with electricity from fossil fuels. Differences between locations will still likely be present to some extent. As all processes are based on existing large-scale technologies, however, the sensitivity of these locations is likely

to be small for foreground processes. For some background processes, however, the process location has a very high influence on the results. An example of such a background process is the distribution of electricity, which in Ecoinvent is based on the Swiss environment where wooden poles are predominantly used. The use of these poles is associated with a high impact on terrestrial ecotoxicity in particular. In some countries such as the Netherlands, however, such wooden poles are barely used, and as such the validity of the impact on terrestrial ecotoxicity of any Dutch process using electricity is lowered substantially. The impact on terrestrial ecotoxicity of the Conscious Vondelpark hotel, for example, is largely associated with the distribution of electricity, which means this impact is likely considerably lower in reality.
The sensitivity of using surrogate processes is likely stronger when data from different sources is used, as the data input, assumptions, methods and system boundaries might differ between them. For the Interface carpet tiles, for example, the recycling processes are based on the US LCI database as these processes are not present in Ecoinvent. When another source would have been used for this process, the impact might have been different.

Materials used in foreground processes as well as materials used in background processes can introduce significant sensitivities for products, in particular when highly specific materials are surrogated. The impact of such materials is highly sensitive to assumptions, as seemingly similar materials might be associated to wholly different impacts. Especially when specialised knowledge is lacking, mistakes regarding surrogate materials are easily made, significantly reducing the validity of the results for some products. An example of this are the Dharmazone shampoo and body wash in the hotel, the composition of which is based on estimated surrogate ingredients. The choice of other suitable alternatives to ingredients would have significantly altered their impact, and as such their impact can only be used as a very rough approximation of what their contribution to the hotel's impact might be. For other products such as the Yumeko blankets this sensitivity is less severe, as these are only partly based on surrogate materials.

Surrogate data has been applied in varying degrees for different products and services, especially with regards to secondary foreground production processes of the products present in the hotel. This variation is caused by the fact that not all products and services have the same amount of primary data at their disposal, leading to four kinds of detail levels for secondary foreground processes. As a result of this, the sensitivity of the results of some products is higher than others. Dharmazone products, for example, are based on surrogate materials and are sensitive to changes of these processes and therefore relatively sensitive. The Interface carpet tiles, on the other hand, are largely based on primary data, and their results are therefore far more certain.

ASSUMPTIONS

In order to include a myriad of products and services some general assumptions have been implemented as well. These assumptions are also sensitive to changes, and thereby introduce some sensitivities for the results.
Besides using surrogate processes, some products and processes have been omitted from this study altogether. Capital goods have been omitted for many secondary foreground processes, while packaging has been omitted for all foreground processes. Leaving out capital goods only appears to have a very slight influence, as the capital goods for both the laundry service and entire hotel are only related to show slight contributions to the total impact. The capital goods used in the recycling processes are also responsible for only a slight part of the impact of this process.
The omission of packaging has introduced an inconsistency within the hotel, as food packaging is thrown away, but not produced. The influence of packaging is likely to be very small, but could be significant in cases of low-impact products which require a relative high amount of packaging materials, such as shampoo. For most products, however, the impact of packaging is likely to be insignificant in comparison to the production processes of the product, as is also the case for the PV-panels.

The exact transport distances or both products and materials are additionally estimated, either on their known production locations or on European standards, and the modes of transportation are generally assumed. The influence of transport on the total impact of products, services and the hotel appears to be only slight, however, and as such the sensitivities associated with this transport are minor. The results of transport appear to be sensitive only when very long distances over land are present, or when other processes besides transport are associated with low impacts. Small changes in the distance do not alter the impact of products

and services, however, and as such the influence of transport on the sensitivity of results is low.

The burning rate of gas is set at a specific unit, while this rate can vary to some extent. As such the impact of gas in both the (pseudo-)services and hotel is sensitive to this assumed burning rate. Changing the burning rate barely influences the results of the hotel and its services, however. Only for the laundry service at Van der Kleij some slight changes in the results are visible, as the environmental impact of this service to some impact categories is almost entirely influenced by its gas consumption. Changing the type of boiler or industrial furnace shows even less impact. As such the sensitivity of the results related to gas use is deemed to be fairly low.

All waste disposal from the hotel and its services is furthermore assumed to be processes by Milieuservice Nederland at Suez Amsterdam. The impact of both disposal and transport are only very slight, so these introduce little sensitivity of the results. The way in which materials are recycled, however, is sensitive to the assumptions made. This is partly caused by the fact that the recycling processes themselves are surrogate processes, and as such their impact can differ depending on the source used. The use of the avoided burden approach to allocate material recycling by weight also makes the results sensitive, however, as using cut-off approaches would have resulted in slightly different impacts of products containing recycled content. When all recycled material would have been cut-off, both during the production and disposal processes, the impact of products such as the Interface carpet tile and Auping mattress would have been lower compared to the avoided burden approach. This has to do with the fact that the impact of recycling would not be taken into account in this case. When only the disposal of recycled materials would have been cut-off, while the recycled content during production would have been replaced by virgin materials, the impact of the products could be either higher or lower compared to the avoided burden approach. The height of this impact seems to mainly depend on the relative impact of the virgin material which replaces the recycled content, and to a lesser extent on the amount of recycled material present in the product. As such, it appears the avoided burden approach is mostly useful for high-impact materials, almost regardless of their weight, while low-impact materials could potentially be cut-off altogether without significantly altering the results of products.

PRODUCTS, SERVICES AND COMPLEX SERVICES

For the impact of the (pseudo-)services and the hotel, the sensitivity related to products are not always distinguishable. This mostly has to do with the fact that the products are not associated with a large impact on any impact category, and with the fact that individual products have impacts that pale in comparison to the impact the utilities and activities at the hotel. As such there appears to be a difference between the sensitivities of products, (pseudo-)services and the complex hotel service.

Combined, the sensitivities related to the use of surrogate processes and materials for products results in a somewhat sensitive impact of these products. Most sensitivities are limited to slight alterations of the products' impact, however, and it is likely that changing assumptions will lead to a higher impact for some products but lower for others. Additionally, the contribution of the production to the hotel's impact is small. As such their combined contribution to the hotel's impact is likely to be less sensitive to changing assumptions, and hence introduce less sensitivity than for individual products alone. The exact sensitivity related to the combined products is difficult to assess, however, as the sensitivities differ per product.

Including more products will likely increase the contribution of the products in the hotel. However, as most high mass/energy and high-quantity products have already been included, and since the impact of individual products is barely noticeable on the total impact of the hotel, the increase of the products' contribution to the hotel's impact might only be minor. Their impact might be more significant for the (pseudo-)services, in particular the rooms, as these are more directly influenced by the products. Additionally, even though the lifetime is not associated with sensitivity as it is based on primary data, changing the lifetime of products does result in significant changes of their impact. Increasing the lifetime of products could therefore significantly lower their impact in the hotel.

Specifically for the hotel service, two factors make the results sensitive. The utility distribution at the hotel is associated with some sensitivity, as it is partly based on calculations. Changing the assumptions underlining these calculations does not appear to significantly alter the results, however, as the difference between the consumption of hotel rooms, public spaces and the remaining services in the hotel is very large. Small

changes in assumptions therefore still lead to the same general distribution of different services.
Additionally, the commute of transport is very sensitive to staff changes and employee preferences. The related sensitivity on the hotel results is only slight, however, as the commute of employees only represents a small fraction of the total hotel impact.

10.5. SUMMARY

It appears that using a different impact assessment method would still likely lead to the same conclusions regarding the contribution of services. Additionally, the addition of more impact categories such as abiotic resource depletion would reduce the amount of interventions lacking characterisation factors and could potentially provide new insights. Adding more impact categories would not be in line with an LCA application focused on speed, however.
main sensitivity related to the products in the hotel appear to be associated with the use of surrogate processes and materials for their production processes. Surrogate processes are sensitive to scaling, and to a lesser extent to changing geographical locations. This might increase the sensitivity of results, which is more likely when data from different sources is used. For background processes the geographic location can have a more significant influence, as these processes are used without alteration and could therefore represent impacts which are specific to certain regions only.
Surrogate materials are sensitive to assumptions, in particular when highly specific materials are surrogated. Seemingly similar materials might be associated to wholly different impacts, and mistakes can easily be made when specialised knowledge is lacking. These sensitivities are mostly present for products, but also influence utilities and activities which are associated with production processes.

The omission of packaging and capital goods has introduced a slight sensitivity, as their addition would only slightly increase the impact of products in particular. Transport also does not significantly influence the results, and is only sensitive to changes when large transport distances are present, or when particularly low-impact products are transported.
The impact of gas is slightly sensitive to the assumed burning rate, but changing this rate does not appear to significantly change the results of the hotel. For the laundry service the sensitivity related to this burning rate is slightly higher, as this service is more prominently affected by gas. The type of boiler, however, seems to barely influence the results.

The sensitivity of waste, finally, is mostly associated with the recycling processes, and introduces a small sensitivity for products containing recycled content. The recycling processes are surrogate processes from the US LCI database, and hence their impact is sensitive to the assumptions of this source. Additionally, the avoided burden approach has been applied rather than simply cutting-off materials. When recycled content would be cut-off during production and disposal, the impact of the products would naturally be lower, as the recycling processes would not have been taken into account. When all recycled content during the production is replaced by virgin materials, however, while the recycled content of waste is cut-off, the impact of products could be either higher or lower between impact categories compared to the avoided burden approach. The height of this impact is predominantly related to the relative impact of the recycled content. As such, the avoided burden approach appears to be mostly useful for high-impact materials, almost regardless of their weight, while low-impact materials could potentially be cut-off without significantly altering the results of products.

Between the products, (pseudo-)services and hotel service, the influence of process sensitivities also differs. The sensitivities related to products are less noticeable for services, in particular the rooms, and not distinguishable at all within the hotel. This has to do with the fact that the impact of products is only noticeable in the hotel when they are combined, and as such the impact of individual products and their related sensitivity is difficult to assess when combined. The omission of low-impact products has likely reduced the impact of both the services and the hotel, however, although this impact is likely minor, since most high-impact products and services are present.
Additionally, the sensitivity of the utility distribution among services can only be observed among the services themselves, while the sensitivity of employee commute only affects the services and hotel, but not the products. As such, it appears the influence of sensitivities can lead to varying levels of sensitivity between products, services and hotels.

11

Discussion

In order to investigate the environmental impact of the hotel branch with LCA, the application of LCA had to be streamlined to allow the incorporation of a myriad of products, utilities and activities in one study. This has affected both the speed of the study and the validity of its results.
The streamlining efforts and their effect will therefore be discussed first, during which both the speed of the LCA and the validity of its results are examined. Afterwards the results for the Conscious Vondelpark hotel are discussed as well, which will be focused on the findings for the hotel specifically.

11.1. Discussion streamlining efforts

An important aspect has been the speed with which the LCA can be carried out, as the incorporation of a high amount of processes will significantly increase the time requirements if no streamlining is performed. The LCA still had to represent the hotel service under study, however, and had to be able to provide valuable results. This meant results of the LCA had to be accurate enough to represent the specific hotel service under study, and had to provide detailed insight into the different origins of the impacts within its system.
The balance between speed and accuracy is therefore of high importance, and are discussed first to examined if the proposed LCA application can indeed deliver valuable results in a time-frame of roughly three to four months. The future perspective of this LCA is discussed as well, both for hotels and the tertiary sector.

11.1.1. Goal & scope definition

Most of the streamlining efforts during the goal and scope definition phase has been aimed at reducing the time required to include the high amount of products, utilities and activities. No time is gained during the goal and scope definition itself, but conditions are set to decrease the time investment during the LCI and other phases. By focusing the study on the hotel service rather than on the building, the selection of processes to include has decreased substantially in comparison to a study which includes the building as well. The data gathering process is simpler as well, as only data from the hotel itself and its suppliers is required, without the need of technical building data. This has therefore significantly reduced the time investment to gather data. Including the building would have made it possible to investigate the influence of aspects such as building construction, lifetime and materials as well, however, and leaving this building out has therefore resulted in a less complete study.
By excluding the building it is still possible to provide valuable results, as hotel services are often concepts which can be applied to several buildings. As such, the impact of the building itself is not necessarily inherently related to the impact of service. The building is associated with energy efficiency, of course, but this can be taken into account for the service without explicitly including the building itself.
The distinction between products related to the service or building has not always been clear, however, making the selection of products partly subjective. This has likely decreased the accuracy of the LCA results of products in particular, as the incorporation of more products would have led to a higher impact. Even when the building would have been included, however, this ambiguity between products related to the building and the services would still exist, as the building would have to be treated as a separate entity. Incorporating the building in the products would not be valuable, as this would not provide insight into the separate impacts of products and building.

The significance of this inaccuracy has been partly mitigated by involving the hotel in the choice of ambiguous products to include. This way the hotel can gain insight into the contribution of all product, utilities and activities explicitly related to the service, as well as into the contribution of products that might be related to the building as well which are of special interest to the hotel or which they have deemed as important for the hotel's functionality.

Including a selection of products, utilities and activities based on high mass/energy, high quantity and high importance has also appeared to significantly reduce the time required to gather data. Including low-impact quantity products, utilities and activities would likely drastically increase the time investment, while their impact on the results would likely only be minor or even negligible. This selection has made the study inherently incomplete, however, and as such exact measurements of the hotel impact are likely not possible. As the LCA is set-up to uncover hotspots and gain insight into the contribution of processes, this is deemed acceptable, as contributions can likely still be approached when only low-impact processes are lacking.
The selection of products, utilities and activities to include has been partly subjective, however, as it is difficult to assess beforehand which are associated with high impacts. The assumption has been made that those products, utilities and activities related to a high mass or high energy content, or are used in the hotel in high amounts, are associated with high impacts as well. Some perceived low-impact processes might have been underestimated, however, and by not including these in the study the impact of processes will have been visibly lower, influencing their perceived contribution to the hotel's impact.
Extensive knowledge is required to accurately assess the impact of processes beforehand, however, which would involve a lot of research. As this is an explorative research, this knowledge is still largely lacking and investigating all processes would therefore require an infeasible time investment. This possible error is therefore accepted for this particular study. By carrying out the LCA on more hotels, more knowledge might be gathered with regards to the likelihood of high impacts.

The focus on the use of products and services by hotel guests and use-facilitating processes appears to be justified as well, as it looks like the LCA results were most strongly influenced by changes in these processes. The use of specific surrogate data seems to be justified as well, which will be discussed in more detail in the LCI section of this discussion.
By combining all products, utilities and activities in simple (pseudo-)services in the hotel, it has additionally been possible to instantly link them to the dominant life-cycle stage of use. As such it has not been necessary to investigate the utility consumption of individual products, nor has it been required to estimate the use of activities for the whole hotel. Instead, all product, utility and activity use could be based on the known configurations of services, which could be determined relatively quickly by counting the products, measuring the utility use and speaking with hotel employees.
Creating these simple services has additionally ensured that the contribution of individual (pseudo-)services within the hotel could be investigated. When data is not present for specific services this can affect the accuracy of their contribution, however, which will be further discussed in the LCI section as well.

The incorporation of detailed studies within the attributional LCA, finally, has increased the time required to gather data. These studies require more detailed data to construct their processes, and the sensitivity of their results must be investigated in relative high detail as well during the interpretation phase. By including these studies to create scenarios, however, the value of the LCA has increased. Instead of just giving insight into the causes of the impact, scenarios can provide information with regards to the influence of possible alterations to the hotel system. This can support decisions and as such makes LCA directly useful for hotels. As detailed studies require a relatively high time investment, however, it can be interesting to assess the potential of alterations to the system. This has been done by creating simple scenarios without the use of detailed data, the result of which can indicate if a more detailed study is desirable. This would require a slight time investment as well, but significantly less than for detailed studies.

11.1.2. LCI

Most of the streamlining efforts during the LCI phase have been aimed at reducing the data and process detail by making use of specific surrogate data. As such a high amount of surrogate data has been used, which has significantly decreased the time required to gather data, but has also affected the results. Due to the streamlining efforts taken, it is estimated the LCI phase could be carried out in one to two months full-time work by one person.

As was stated during the goal and scope section of this discussion, only the use of products and services by hotel guests and use-facilitating stages have been regarded as foreground processes which make use of primary data. Changes in these stages directly influence the LCA results, and as such these had to be representative for the hotel under study.
If surrogate data would have been used for the use of products and services by guests, or primary foreground processes, the study would not have been representative for the hotel anymore. This use is highly specific for every individual hotel and can therefore not be replaced with surrogate data, but has to be supplied by the hotel itself. As such, cooperation of the hotel to supply this information appears to be of vital importance. Such cooperation can likely only occur when they are intrinsically interested to improve their environmental impact. Without this interest, hotels have little to gain from the investigation and might not be willing to accept critical results, or might just use LCA as a marketing tool. As such they might be less inclined to share information, and might even leave information behind if it could negatively influence their impact.
For use-facilitating processes, or secondary foreground processes, specific surrogate data has been used to some extent, although primary data was preferred. Additionally, a distinction has been made between secondary foreground processes of products and of services within the hotel. Use-facilitating processes of services entail the use of products, utilities and activities by these services and their related employees. Use-facilitating processes of products entail their production process. As products in pseudo-services are directly used by guests, only the use of utilities and activities are regarded as secondary foreground processes for these.

As both secondary foreground processes clearly facilitate either a product or service which is used by guests, the division is justified for this LCA. The use of utilities and activities within services, and products within non-pseudo-services, could have been treated as primary foreground processes as well, however. This way the level of detail of services would have been higher, potentially leading to more accurate results. For the use-facilitating processes of utilities and activities gathering primary data would not have been feasible within a short amount of time, however, as these entail highly complex processes. This would have required gathering data for gas distribution and production, for example, or measuring the impacts related to driving a car. Besides being complex these processes are also relatively generic, and therefore often present in high detail in databases such as the Ecoinvent 2.2 database. Using such specific surrogate data therefore has not only significantly reduced the time investment, but has likely also resulted in a higher level of detail than could have been acquired by hand.
The exact use of utilities and activities in (pseudo-)services can be more difficult to uncover than the use of these services themselves, and as such it is possible such data is not available for all involved processes. As with the primary foreground processes this use directly influences the results of their associated services, and as such it cannot be based on surrogate data. By combining known primary data with specific surrogate data, this use can be calculated specifically for the hotel, though. If this is not possible, seemingly similar processes from surrogate data could be used to represent the activity or utility at hand, but this would significantly reduce the accuracy of the results and should therefore be avoided.

The secondary foreground process of products used directly by guests, or products in pseudo-services, entails the production process of these products. These are often highly specific, and can therefore usually not be based on data from the Ecoinvent database alone. As the availability of primary data differed between products, variations in data detail between their production processes are allowed in the study. Even though this does reduce the consistency between them, it makes the study more comprehensive. These products could also have been omitted, but this would likely have reduced the impact of the combined products considerably, and as such a more comprehensive study has been deemed more desirable. Not all products could be included, however, as a minimum level of representativeness has to be guaranteed.
It appeared at least the material amounts and types had to derive from primary data, as materials were often responsible for the highest contribution of products. When utility consumption and transport distances were taken from primary data as well, it appeared production processes could already be represented in relatively high detail, even if the remaining data was taken from specific surrogate processes. As the utility consumption was often not available, however, this was usually also based on surrogate data. Even though this had reduced the accuracy of products, it allows a high amount of products to be taken into account which would otherwise had to be omitted altogether. As most of the impact is related to the material use, the even production processes without primary utility data were therefore still assumed to be representative for the products.

Contrary to the products in the pseudo-services, the production processes of products in the services have generally been treated as background processes. These products are not used by guests, but by employees, and their production was therefore not considered as a secondary foreground process. These products were often included due to their high importance for the hotel's functionality, as they were present in small numbers or related to low mass. The front-office, for example, could not have functioned without the use of computers, even though only two were present. As such their contribution to the total impact of services and the hotel was only minor. These products were additionally often relatively generic, and included computers, paper and cardboard boxes which could directly be based on Ecoinvent processes. Considerable time was therefore saved by treating these products as background processes, while the influence on the results was minimal.
Most primary data for production processes had to be acquired from the suppliers and partners of the hotel, and their cooperation was therefore of importance as well. As with the hotel, suppliers and partners were more willing to cooperate if they had something to gain from the research, which was often the case if the hotel actively supported the research and kept up good relationships with them, due to possible continued business in the future. A good relationship between them and the hotel additionally increased the ease of making contact, as previous contact and trust would have already been established. The use of surrogate data was often still required though, as suppliers often did not have all required data at their disposal.

The use of surrogate data for secondary foreground processes therefore appeared to have considerably reduced the time required to gather data, but has also resulted in a lower accuracy of the results. Surrogate data is associated with geographic, temporal and technical specificity, and is additionally often based on specific assumptions. Even when enough primary data was gathered, the background processes still influenced the results, as most impacts were indirectly caused by these background processes. The geographic specificity of the Ecoinvent 2.2 database in particular appeared to affect the results, as most processes in this database have been based on the Swiss rather than the Dutch environment. This was most noticeable for the impact of electricity on terrestrial ecotoxicity. This impact is almost entirely related to the distribution of electricity by wooden poles, and is caused by the leaching of chromium VI from these poles into the soil. Even though the use of these poles is the status-quo in Switzerland, however, they are barely used in the Netherlands. As such the impact of most if not all foreground processes based on the Dutch environment on terrestrial ecotoxicity is uncertain and likely incorrect. For the remaining background processes this effect did not appear to be as drastic, however, even though the specificity of the database likely still influenced the results.
Similarly, even though the assumption has been made all background processes could be based on the Ecoinvent database, this was not the case for highly specific background processes or materials of secondary foreground processes. When such highly specific processes or materials are not present in the Ecoinvent database, they have to be based on seemingly similar surrogates, which can potentially be related to entirely different impacts. As such, these processes have to be based on specific data, either from surrogate or primary sources. This increased the time investment during the LCI phase, but did results in more representative results.
In some cases specific data simply was not available, however, and products or activities have been based on seemingly similar surrogate data nevertheless. This has be done when specific processes are present in high amounts, for example, as even seemingly similar processes could still provide insight into the possible influence of processes, and the impact categories they are related to. This has resulted in less accurate results, though, which had to be taken into account when considering their impact.

For all foreground processes general assumptions have also been used, most of which were related to the use of surrogate data. These assumptions have ensured all foreground processes were relatively consistent with each other, even though differences in data detail existed between them. When these assumptions would not have been in place, different assumptions might have been used between foreground processes which would have reduced the consistency of the study. Some assumptions have also improved the speed of the LCI phase, as they allowed shortcuts to take place.

The assumption to omit packaging and capital goods in particular appears to be justified, as is the assumption that transport distances can be based on the location of the related process. Including packaging and capital goods for all foreground processes and investigating exact transport distances would have likely significantly increased the time required to perform the LCI, while the effects on the results are minimal. The omission of packaging and capital goods has introduced an inconsistency with the background processes, however, but

as almost all background processes are based on the Ecoinvent database, this inconsistency likely affects all processes in a similar manner.

Linear scaling of products has also been assumed for surrogate processes to better fit the process they represents. This has likely resulted in an inaccuracy of results, but investigating the exact impact of scaling would have required extensive literature research, and as such speed has been chosen over accuracy for this assumption. Additionally, material and chemical properties have been set at scientific values, but this has not appeared to significantly affect the results.

Recycled materials of foreground processes, finally, have been allocated according to the avoided burden approach, based on mass. Including this allocation has required the development of new background processes, which has taken time. Additionally, these processes have been based on a limited amount of data from one particular source, and as such the effect related to recycling cannot be guaranteed.
Recycling materials according to this approach only appeared to significantly affect the impact of products which would otherwise have had to make use of high-impact virgin materials, however. As such, for low-impact materials the cut-off approach for the disposal of these materials could have potentially been used as well. Choosing when to use the avoided burden or cut-off approach would have been somewhat arbitrary, though, as the effect of the avoided burden allocation differed per material and was therefore difficult to assess beforehand. Its effect was more strongly influenced by the relative impact of materials than their quantity, and the amount of recycled material was therefore not a guarantee that using the allocated burden approach would be preferred over the cut-off approach. Combining both allocation approaches in the foreground processes would therefore require more research in order to better assess their preferred application.
Including the avoided burden approach to allocate recycled materials has likely increased the accuracy of products, and has made it possible to represent recycled content in products. This is particularly interesting for suppliers, as this could showcase their lower environmental impact. It is likely predominantly useful for detailed studies, however, as these focus on the comparison between system alternatives, rather than on approximate contributions. It might therefore have been most useful to apply the avoided burden approach to detailed studies alone.

Due to the high use of surrogate data and assumptions for the products in the pseudo-services, their impact is more sensitive to change than the impact of products, activities and utilities in the non-pseudo-services, and therefore likely more sensitive. Their contribution to the hotel's impact is also lower than the contribution of utilities and activities, however. The contribution of individual products in particular is barely distinguishable, and only when combined the products are associated with a small contribution to the hotel's impact on all impact categories.
This small contribution is related to the high lifetime of the products. During their use most products are not associated to any impact, and as such the daily impact of the products is based on the impact of their production and disposal over their lifetime. The impact of the utilities and activities at the hotel is associated with their use, however, and as such these provide an impact every day. As a result the impact of utilities and activities in hotels is higher than the impact of the products. This also means that possible changes in the impact of products related to their sensitivity are small, as these are scaled relative to the small contribution of products. As such, the sensitivity of the products is relative, and its effect likely less severe than for individual products.

11.1.3. LCIA

During the LCIA phase the CML-IA midpoint method 'CML-2001' is necessary, which was already integrated into the CMLCA software and included baseline impact categories. The use of his impact assessment method prevented the need for further classification, reducing the time required to perform the LCIA phase to a simple click of a button. Performing this phase by hand would not have been feasible within the limited time frame, but the use of existing impact assessment methods is fairly standard procedure, even with full LCAs. The use of the baseline impact categories has further not only saved significant time, but has also ensured future comparisons with other studies is possible.

The baseline impact categories of land use, eutrophication, acidification, photochemical oxidation, climate change, terrestrial ecotoxicity, freshwater aquatic ecotoxicity, stratospheric ozone depletion and human toxicity have been taken into account, to gain comprehensive insight into the impact of the hotel and its services.

More impact categories could potentially have been added, however, such as the baseline impact category of abiotic resource depletion. This would have increased the insight, but would have additionally increased the time investment during the interpretation phase. Including abiotic resource depletion additionally did not appear to change the general observations, as it provided similar insights as other fossil-fuel related impact categories.
The omission of impact categories would have decreased the insight, but would have decreased the time investment during the interpretation phase. The choice could have been made to remove the toxicity-related impact categories, for example, as their characterisation is associated with higher uncertainty than other impact categories. Terrestrial ecotoxicity in particular could be omitted, as its impact is mostly caused by the geographic specificity of the Ecoinvent database, and does not represent the hotel under study. The incorporation of these toxicity-related impact categories does provide insights which differ from the remaining impact categories, and therefore including these impact categories provide a more holistic insight into the impact of the hotel.

11.1.4. INTERPRETATION

The interpretation phase had been limited to a consistency and completeness check, as well as streamlined contribution and sensitivity analyses. The consistency and completeness of the LCA were checked throughout the study, and as such their documentation required little time. Performing these checks ensured that preventable inconsistencies and incompleteness were avoided, while they simultaneously provided insight into part of the sensitivities of the study. The contribution and sensitivity analyses did require a significant time investment, however, as they had to cover the a high amount of products, utilities and activities present in the hotel. As such both the contribution and sensitivity analysis have been streamlined as well. The time investment for the interpretation phase is still estimated at one to one-and-a-half months, however.

By focusing the contribution analysis on high-impact contributions in the hotel it has not been necessary to investigate all involved processes. Additionally, the origin of impacts has been limited to high contributing elementary flows, although low-impact elementary flows which were associated with each other were taken into account as well. This has made the contribution analysis feasible, but has likely also reduced the accuracy of the observed contributions. Including all elementary flows would not have been possible for the vast amount of products, utilities and activities which are included, however, and as such this streamlined approach was all but necessary. Additionally, as all high contributing elementary flows have been included, comprehensive insight into the main contributing background processes was still obtained.
The contribution analysis could also have focused on the contribution of services and products, utilities and activities in the hotel alone, without going into the origin of the impact. This way vital information with regards to the cause of the impact would have been lost, however. It would not have been known why certain products, utilities or activities would be associated with high impacts, and neither would it be known why certain products, utilities and services would have a higher impact on some impact categories than others. As such the formulation of recommendations to reduce their impact would not have been possible. The analysis of the scenarios would still provide information with regards to their influence on the hotel impact, but here as well the explanation of why the hotel impact changed, and why there might be differences between the impact categories would have to be omitted.

The sensitivity analysis has been streamlined by only focusing on a selection of products, utilities and activities which combined covered all types of data and assumptions. This way general observations could be made with regards to the sensitivity of the study, leading to insight into the validity of the results. The uncovered sensitivities were not absolute, however, as they were based on subjective observations. Even so, the perceived sensitivities already gave valuable insight into the validity of the results, and exposed the sensitivities related to the use of specific assumptions and data for hotels.

The sensitivity analysis could possibly have been omitted altogether, which would have saved time. The results from the contribution analysis already provide insight into the impact of the hotel, and as such the investigation could have ended there. By omitting this analysis, however, insight would have been lost with regards to the validity of the results. Under these circumstances all results would have to be assumed as valid and correct, while in fact some results were highly sensitive. Additionally, possible errors in the data which were not uncovered by the contribution analysis would remain hidden, which could further distort the results. The validity of the results would therefore decrease, and no insight could be gained into how the LCA

application and streamlining efforts could be improved to increase this validity. As such recommendations to improve the complex service might be based on faulty data, and recommendations for future studies would not have been possible. Due to the limited selection of products, utilities and activities, some sensitivities might still not have been discovered, however, and as such more extensive investigation into the sensitivity and uncertainty caused by the streamlining efforts is still required.

The contribution and sensitivity analyses are therefore deemed vital to provide valuable results. The insight gained by investigating the origin of the impacts and performing a simple sensitivity analysis appears to be worth the additional time investment and further streamlining or exclusion of these analyses would likely reduce the relevance and value of the study. More research could be performed towards the effect of the streamlining efforts on the sensitivity and uncertainty of results, however.

11.1.5. CLOSING STATEMENTS

All LCA studies are inherently uncertain and incomplete, as boundaries can always be expanded, and estimations and assumptions are always necessary in order to perform an LCA. As was discussed in chapter 3, the LCA appears to be more detailed than highly streamlined and screening LCAs, but is less detailed than a full LCA. As such the study is less complete and consistent than a full LCA, and its results are less certain.
The actual gravity of the completeness, consistency and certainty, however, is related to the intended use of the results. The LCA developed in this study has mainly been aimed at identifying and exploring hotspots, and therefore had to give insight into where impacts in a hotel derive from. As such the processes should have represented the specific hotel service under study, while results had to provide comprehensive insight into the different origins of the impacts within the service. It was therefore not required to provide exact measurements of the impact of the hotel and its service, but rather accurate approximations were necessary. It additionally had to be possible to carry out the LCA in approximately three to four months full-time work by one person.

It does appear the LCA is able to represent the hotel service under study, as most if not all high-impact products, utilities and activities have been taken into account, while only those with low impacts were omitted. This selection has been partly subjective, however, but can be improved if the LCA is performed more times.
All products and services, as well as the utilities and activities in the services are based on those present at the hotel. The use of products and services by guests is directly based on primary data from the hotel, while the use of products, utilities and activities within services has been based on primary data from the hotel in combination with specifically calculated estimations. Only the production processes of products are partly based on specific surrogate data, although at least their material type and amount as well as their production locations are known. As such, even when surrogate data is used the products are specific for the hotel, albeit possibly less accurate.
The life-cycle processes of all products, utilities and activities predominantly derive from the Ecoinvent database, and are therefore affected by its specificity, but only for terrestrial ecotoxicity does this appear to lead to significantly altered results. The remaining processes are likely affected by the specificity of the database as well, but as all impacts are most directly affected by the use of products, utilities and activities in the hotel, they are still regarded as representative enough to provide insight into the impact of the hotel. This notion can be disputed, of course, and could be reason for further research into the use of background data. Only those background processes which were highly specific and could only be surrogated by seemingly similar Ecoinvent processes cannot represent the processes at hand, but can still provide insight into their possible impact on specific impact categories. These processes are rare, however.
By making use of the existing impact assessment method CML-2001 in combination with a selection of baseline impact categories, the LCA can provide comprehensive insight into the impact of the hotel as well, without the need of further classification. Performing a streamlined contribution analysis additionally provides insight into the contribution of (pseudo-)services, as well as the contribution of products, utilities and activities and the origin of their impacts. The incorporation of a streamlined sensitivity analysis, finally, ensures the sensitivity of the results can be assessed, although it cannot provide absolute uncertainties.
Due to the streamlining efforts the LCA cannot deliver exact measurements of the hotel impact, but as it can provide comprehensive insight into the different origins of the impact within the hotel, it can be used to uncover its approximate environmental impact. It is additionally expected that the LCA can be carried out within a time-frame of three to four months, although this does heavily rely on the availability of both primary and surrogate data for the LCI phase. Cooperation of the hotel and its partners and suppliers is therefore required.

The LCA could potentially be carried out in even less time if more researchers are involved. During the LCI phase data for both primary and secondary foreground processes could be gathered for different processes simultaneously, as these often involve individual products, utilities or activities. Especially for products this is the case, as these rely on specific primary and surrogate data. As such, data for several foreground processes could be carried out within a short time-span. Gathering data for both primary and secondary foreground processes in particular could easily be combined, as a significant amount of the time had to be spent waiting for replies from the hotel, suppliers and partners.

Regardless of how data is gathered, however, results only reflect a snapshot in time. This fact could reduce the value of these results for hotels, as activities in hotels are prone to changes in short amounts of time. The commute of employees, for example, is highly dependable on the current staff, while the impact of food and beverages depends on the menu. Both staff composition and menus can change rapidly, which would mean the results of the LCA do not represent the service anymore. As such it could be interesting to investigate how the LCA could incorporate such changes through time, for example by adding more detailed studies after the hotel system has been set-up.
In order to carry out the LCA and possibly add data later-on, expertise and specialised software is also still required. When hotels, or possibly other complex services want to make use of LCA to investigate their environmental impact, they therefore rely on external researchers to perform the LCA. Once a hotel system has been set-up, however, hotels would likely be interested in investigating the influence of future alternatives, such as a new source of electricity or new type of products, as quickly as possible. Commissioning an external researcher for every adaptation would take time, and it would therefore be more attractive for hotels if they could add and compare data themselves, once the hotel system has been set-up.
To enable changes to the system and allow hotels to investigate the influence of alternatives themselves once the hotel system has been set-up, an easy-to-use-tool could be developed specifically for hotels. This way hotel employees with little expertise could potentially perform comparisons within the hotel system themselves, while external expertise could be limited to problem solving. This could also allow reference situations to be added, which can be used to compare the impact of the hotel.

The attributional LCA could potentially be used to investigate the environmental impact of more than just hotels as well. It offers a scheme to include a myriad of products, utilities and activities in one study, and might therefore be of interest for other complex services within the tertiary sector. Complex services within this sector are not necessarily homogeneous, however, and as such directly applying this LCA to any given complex would likely not be possible. Some complex services, for example, might not make use of simple services such as a front-office, while others might be predominantly associated with the use of products. When no simple services are present within the complex service it can be more difficult to directly link utilities and activities to their use by guests, and when products are responsible for the main impact their accuracy might have to be increased. The relative inaccuracy of products in particular could pose a problem, as gathering primary data for them can be difficult.
In order to allow a more wide-spread use of the proposed LCA, the general effects of the streamlining efforts therefore has to be investigated further. This way the sensitivities of different products, utilities and activities could be known beforehand, which could guide initial research of complex services other than hotels to specifically reduce the sensitivity of those elements which are likely associated with a high contribution. Having more comprehensive insight into the sensitivities related to the streamlining effects can also indicate which complex services can be investigated with this LCA, and which cannot, based on their set-up.

For complex services which are associated with inhabitants which make daily use of services and pseudo-services the LCA might already be directly applicable, however. Examples of such services are hospitals, elderly homes and institutions for people with mental disabilities. The rules set for the LCI, LCIA and interpretation could likely be used for such complex services, as they too are based on the daily use of products and services by some form of inhabitants. The goal and scope definition phase would likely have to be unique for every complex service, however, as their exact set-up might still differ from hotels. For some of these complex services it might be interesting to include the building, for example, and the set-up of services and/or pseudo-services might differ between them. Overall, however, this LCA application could be interesting for these complex services in particular.

11.2. DISCUSSION OF RESULTS FOR THE CONSCIOUS VONDELPARK HOTEL

As the impact of the Conscious Vondelpark hotel is predominantly related to the rooms and F&B service, most reductions of the environmental impact can likely derive from these (pseudo-)services. In order to investigate where these reductions could derive from, however, the impact of the products, utilities and activities has to be considered first.

A significant share of the hotel's impact appeared to be associated with the use of natural gas, which is largely associated with the rooms. Adding insulation to the boiler seemed to result in a reduction of the gas consumption, and as such appears to be one option this gas consumption could be lowered. As most gas is consumed in the rooms, however, another solution could be to ensure a more controlled environment in the rooms to reduce gas losses. The hotel could also consider using biogas, although the impact of this type of gas should be investigated first to prevent problem shifting.

A high contribution for land use, eutrophication and acidification appears to derive from the cultivation of food and beverages for the F&B service. This impact could therefore be reduced by using food and beverages with a lower impact. The impact of the food and beverages could be overestimated, however, as they have been based on seemingly similar cultivation processes from Ecoinvent, rather than exact processes. As such, more research is required for the F&B service before decisions can be made.

The products appeared to be associated with a small impact to all impact categories, and as such the reduction of their impact might result in a small reduction of the entire hotel impact. This can be most effectively done by increasing the lifetime of the products. Using products which are associated with very small environmental impacts can decrease their combined impact as well. If they replace products which could have been used for a longer period of time, however, their environmental benefit can be diminished, as the average daily impact of the replaced product would have been higher during its shorter lifetime.

The choice of laundry service appears to have lowered the impact of the hotel. By using electricity from renewable sources, however, the impact of the laundry facility could decrease even more. PV-panels are likely no option due to the high investment costs, as electricity for large-scale companies such as laundry services is cheap. Electricity from large-scale wind parks could provide an alternative, however.

The commute of employees is additionally associated to a slight impact to all impact categories. Even though the impact of this commute was based on one moment in time, it still appears that the use of cars and scooters in particular can increase this impact. Ideally, every employee would walk or use the bicycle for commute, but demanding that of employees would likely not result in a positive work environment. The use of bicycles, trains and other forms of public transportation could be promoted, however.

The installation of PV-panels to cover 10% of the electricity demand of the hotel did appear to result in a slight increase of the hotel's impact on all impact categories. This impact is still considerably less than when electricity from the Dutch grid would have been used, however. Additionally, the 10% wind electricity does not disappear, but can be 'used' elsewhere, as the wind turbines still deliver this electricity. As such, installing PV-panels at Conscious does increase the amount of renewable energy sources in the Netherlands, thereby theoretically lowering the impact of the Dutch grid. Additionally, as there is no direct link between the wind turbines and the hotel, installing PV-panels would provide them with a direct source of renewable electricity, rather than one based on contracts. As such they can be even more confident their electricity is renewable.

The use of water does not appear to provide opportunities for significant reductions of the impact, as the contribution of its production is negligible, while the contribution of wastewater treatment is only slight for the hotel's impact on eutrophication and terrestrial ecotoxicity.

The impact of waste appears to be generally small, but is associated to a high contribution to the impact of freshwater ecotoxicity. This impact is predominantly associated with the incineration of municipal solid waste, however, and as such is difficult to avoid. Currently only paper, glass and organic waste are recycled, however, and as such recycling more products could decrease the amount of waste that is incinerated.

12

Conclusion LCA application

During this study an attempt has been made to uncover the holistic environmental impact of the hotel branch within the tertiary sector by using Life Cycle Assessment. For this a set of research questions has been set-up in chapter 2, which will be answered throughout this conclusion. The main research question which will be answered at the end of the conclusion has been formulated as: “How can the application of Life Cycle Assessment be adapted and applied to contribute to a better understanding of the holistic environmental impacts of hotels, as an example of complex services within the tertiary sector?”

12.1. Investigating the life cycle impacts of hotels

The first sub-question has been formulated as: “What adjustments can be made to the application of LCA to quickly measure the life cycle impacts of a complex hotel service, accurately uncover where this impact derives from, and investigate the influence of changes in the system?" The answer of this question is given by investigating several aspects. First the way in which the application of LCA can be streamlined to investigate the environmental impacts of a complex hotel service and accurately uncover their origin within the hotel in a limited time frame is explained. Then the way in which accurate comparisons within this system can take place for both (hypothetical) counterparts and proposed future alternatives is examined, as is the way in which the potential of proposed future alternatives can be assessed.

12.1.1. Streamlining LCA for a complex hotel service

A hotel can be regarded as a complex system which makes use of a myriad of products, utilities and activities, which are all related to their own life-cycle processes. As such, in order to use LCA to investigate the environmental impact of such a system, it has to be streamlined to allow the incorporation of this high amount of processes in the minimum amount of time, while still ending up with valuable results for the intended purpose.

The streamlining efforts have therefore predominantly been focused on reducing the requirements for the detail of life cycle stages and data requirements. To a lesser extent they also addressed the use of impact assessment methods and analysis of data. As such most streamlining efforts have taken place during the goal and scope and Life Cycle Inventory (LCI) phases, and to a lesser extent during the Life Cycle Impact Assessment (LCIA) and interpretation phases.

The exact streamlining efforts are discussed below, and can be regarded as a set of rules which enable the use of LCA to investigate the environmental impact of complex hotel services.

Goals & scope definition

In order to use LCA to investigate the environmental impact of hotels, it has been organised as an attributional LCA. This entails results of the LCA had to be accurate enough to represent the specific hotel service under study, and had to provide detailed insight into the different origins of the impacts within its system. The results were not meant to provide an exact measurement of the environmental impact of the hotel, however, as a detailed approximation was sufficient. This opened up the opportunity for further streamlining during the LCI phase, as the use of specific surrogate data is allowed, and products, utilities and activities which are associated with different levels of data detail can be included. All life-cycle processes have still been taken

into account, however, although not all are based on primary data.
The focus during the goal and scope has additionally been put on the hotel service itself, while the hotel building has been omitted, and only a selection of products, utilities and activities have been included. This selection has been limited to those which are associated with high mass/energy, high quantities and high importance for the hotel's functionality.
A dominant life-cycle has also been set, namely the use of products and services within the hotel. In order to make all products, utilities and activities tangible to use by guests, they have been combined in simple services which are used by guests, such as the front-office. These simple services are divided into 'services', which are directly used by guests, and 'pseudo-services', which contain the products directly used by guests.

LCI

During the LCI phase the use stages of products and services have been treated as foreground processes. These have additionally been divided into primary and secondary foreground processes, the distinction of which is primarily associated with the detail of the processes and the sources of data that are used. The use of both services and products has been regarded as primary foreground processes, which only made use of primary data. The use-facilitating processes have been regarded as secondary foreground processes, which make use of both primary and specific surrogate data. For products these use-facilitating processes encompass their production, while for services these encompass their use of activities, utilities and products. The exact strategies applied to mitigate data-gaps are treated in section section 12.2 of this conclusion, and are therefore omitted from this section.
General assumptions have also been in place for foreground processes. Packaging has been omitted from all foreground processes, while capital goods have only been included for primary foreground processes, and some secondary foreground processes when these were known. Transport distances have additionally been estimated based on the location of the hotel and the associated process. When surrogate processes had to be scaled to fit the process they represent this was done linearly, and material and chemical properties have been set at specific scientific values in order to allow primary data to fit surrogate data. Recycling of materials used in foreground processes, finally has been performed according to the avoided burden approach.

LCIA

During the LCIA phase the existing CML-IA midpoint method 'CML-2001' has been used, in combination with the baseline impact categories of land use, eutrophication, acidification, photochemical oxidation, climate change, terrestrial ecotoxicity, freshwater ecotoxicity, stratospheric ozone depletion and human toxicity. These impact categories provided a different insight into the environmental impact of the hotel, and as such a comprehensive holistic environmental profile could be achieved. The method and impact categories were already integrated in the CMLCA software, and as such further classification was not necessary.

INTERPRETATION

During the interpretation phase a consistency and completeness have been performed in order to avoid preventable inconsistencies and incompleteness of the study, and to gain insight into possible uncertainties of the study. Additionally, streamlined contribution and sensitivity analyses have been included, while other analyses have been omitted from the interpretation.
The contribution analysis has been focused on the contribution of services, and on those products, utilities and activities which were associated with high contributions to the services and hotel. The origin of the impact of individual products, utilities or activities related to a noticeable impact within a particular impact category have been investigated further to uncover the origin of their impact, which has been predominantly focused on high contributors, while low individual contributions will largely be disregarded.
The sensitivity analysis has been focused on assumed uncertainties which have been elucidated by the consistency and completeness checks as well as by observations during the LCI phase, while the sensitivities related to the detailed studies have been investigated as well.

12.1.2. COMPARING ALTERNATIVES

In order to investigate the influence of alterations to the hotel's system, scenarios have been added. With these scenarios the influence of hypothetical, past and future alternatives on the hotel's impact could be investigated. To ensure these scenarios delivered accurate results, they were based on studies which were associated with a higher level of detail than the remaining products and services at the hotel. These studies made use of more primary data than the other products and services in the hotel, for both fore- and background processes. In case highly complex but specific processes were present in the Ecoinvent 2.2 database, these processes could also be adapted with extensive use of primary data.
To quickly assess if detailed studies are necessary before carrying them out, simple scenarios been added as well. These were scenarios were based on less detailed studies, which were associated with the same use of data as the remaining products and services at the hotel.

12.2. APPLYING THE PROPOSED LCA

The second sub-question has been formulated as: "How can the proposed LCA application be implemented on a case-study hotel?" The answer of this question is given by investigating the requirements for the hotel's attitude towards sustainability and its relationship with suppliers. The answer is further given by uncovering the requirements for data availability, as well examining as strategies to gather data and mitigate data gaps.

12.2.1. REQUIREMENT OF THE HOTEL, PARTNERS AND SUPPLIERS

Intrinsic interest of the hotel to reduce its environmental impact, and their willingness to accept potentially critical results have has been vital to gather extensive and transparent data from the hotel. A good relationship between the hotel and its suppliers has also been of importance in order to establish contact, while the active support of the hotel has ensured many suppliers were willing to share data.

12.2.2. REQUIREMENTS FOR DATA AVAILABILITY & STRATEGIES TO MITIGATE DATA-GAPS

For primary foreground processes all data had to be delivered directly by the hotel, as this data provided the basic outline of the hotel system. For secondary foreground processes, however, not all data has been available from primary sources. Even though much data could be found online, the use of specific surrogate data has therefore been necessary. As the availability of data differed between products, utilities and activities, a strict hierarchy for the use of surrogate data was additionally necessary in order to reduce the loss of data and increase the consistency between them.
The secondary foreground processes of products encompassed their production process, and required primary data for the type and amount of materials as well as the production location. The utility consumption of the production process was important as well, but could often be based on specific surrogate processes. The remaining processes and emissions could usually also be based on specific surrogate data without significantly altering the results. Surrogate data would preferably derive from the Ecoinvent 2.2 database, but if needed could also be based on scientific literature, the US LCI database or non-scientific literature, respectively.
The secondary foreground processes of services encompassed their use of products, utilities and activities, and required primary data for all these uses. Data-gaps had to be avoided, but when these nevertheless did arise they could be solved by combining primary data with specific surrogate literature to calculate the use for the specific service.
Background processes, finally could largely be based on the Ecoinvent database. In case of specific background processes, however, specific primary or specific surrogate data was required.

12.3. EFFECTS OF THE STREAMLINING EFFORTS

The third sub-question has been formulated as: "What are the effects of streamlining the application of LCA to quickly assess the life cycle impacts of a hotel on the results?" The answer of this question is given by investigating the influence of the streamlining efforts on the speed of the LCA application, as well on the validity of the results. This will be done per LCA phase.

12.3.1. SPEED OF THE LCA APPLICATION

The streamlining efforts have predominantly been focused on the goal and scope definition and life cycle inventory (LCI) phases.

GOAL & SCOPE DEFINITION AND LCI

Most of the streamlining efforts during the goal and scope definition and LCI phases have been aimed at reducing the time required to include the myriad of products, utilities and activities. As such no time has been gained during the goal and scope definition itself, but conditions were set to decrease the time investment during the LCI and other phases.
By focusing the study on the hotel service rather than on the building, and including a selection of products, utilities and activities the time required to carry out the LCI phase has decreased significantly. The combination of all products, utilities and activities in (pseudo-)services has also ensured less time had to be invested in the LCI phase. The incorporation of detailed studies for scenarios did not result in time saving during the LCI, but did increase the validity, as is explained later on. By adding simple scenarios detailed studies could be avoided, however, as these could assess the potential of alternatives in the system beforehand in a fraction of the time.
Significant time has additionally been saved by limiting the use of primary data to the use of products and services by guests (primary foreground processes) and the processes directly facilitating this use (secondary foreground processes), while using background processes from the Ecoinvent 2.2 database for the remaining processes. By further allowing the use of some surrogate data from different sources for secondary foreground processes, and using even this surrogate data directly for the secondary foreground processes of products, time is saved as well.
The use of the general assumptions for foreground processes that packaging is always omitted and capital goods are often omitted has further decreased the time required to gather data, and the assumption that scaling of surrogate processes can be done linearly has ensured surrogate data could be used quickly. Recycling according to the avoided burden approach required additional time, however.

Gathering data for different products and services could often additionally be carried out simultaneously, especially with regards to the products, allowing the LCI phase to take place in roughly one to two months full-time work by one person, depending on the data availability.

LCIA

By using existing impact assessment methods during the life cycle impact assessment phase, The LCIA phase involved little more than running the model in CMLCA, and therefore did not require a notable time investment.

INTERPRETATION

The consistency and completeness check of the interpretation phase required little time, as these were carried out throughout the study. Time savings were partially lost during the interpretation phase due to the incorporation of contribution and sensitivity analyses, however. For the contribution analysis this time investment was partially mitigated by only focusing on high contributing products, utilities and activities within the hotel, and only taking high contributing (combined) elementary flows into account. For the sensitivity analysis significantly less time was required, since it was focused on a selection of products, utilities and activities which combined covered all types of data and assumptions. The time required for the interpretation phase is still estimated at 1-1,5 months full-time work by one person, however.

It is estimated the study could be performed in three to four months, although this does heavily depend on the availability of data during the LCI phase. This is associated with the requirements of the attitude of the hotel and its suppliers, which has been presented in section 12.2.

12.3.2. VALIDITY OF LCA RESULTS

The streamlining efforts during the goal and scope definition, LCI and LCIA phases have made the study somewhat incomplete, and have introduced some inconsistencies.

GOAL & SCOPE DEFINITION

The omission of the hotel building has resulted in an incomplete study, but has not necessarily reduced the value of the results for hotels as the building can be seen separately of the service. The selection of products has additionally decreased the completeness of the study, but has been necessary in order to perform the LCA. As most, if not all high-impact products, utilities and activities have been included, the incompleteness is likely only associated with minor effects on the impacts. As such it is still possible to approach the hotel

impact and investigate the contribution of services as well as of products, utilities and activities in the hotel, and provide valuable insight into the hotel impact.
By combining all products, utilities and activities in (pseudo-)services, some sensitivity has been introduced with regards to the utility distribution among services. This could partly be solved by using primary measurements in combination with specific literature to calculate this distribution. As such the distribution would not be exact, but still representative for the specific services within the hotel. By making use of these (pseudo-)services, insight could additionally be gained into their contribution to the hotel's impact, which is valuable information for hotels. The incorporation of detailed studies and less detailed studies for scenarios additionally increased the value of the LCA results, as these could provide comprehensive insight into the influence of possible alterations to the hotel system.

LCI

The use of surrogate data has reduced the completeness and consistency of the study, and has increased the sensitivity of the results. The results were meant to provide insight into the contribution of the different services as well as the different products, utilities and activities of the hotel, and the main origin of these impacts had to be uncovered. Exact measurements of the hotel impact were therefore not required, and as such some inaccuracy of the results was possible.
As primary data has been used for the use of products and services by guests, the study has been representative for the specific hotel under study. By further making use of primary data and specific calculated estimations for the use of products, utilities and activities in services, these were based on the specific situation at the hotel as well. The use of specific surrogate data for the secondary foreground processes of products has made their results less accurate, especially as several sources have been used, but as the material types and amounts were always based on primary data they were still considered representative. Products for which the production location and utility use were based on primary data as well were even more accurate, however, but this has not always been possible. The impact of the combined products therefore provides comprehensive insight in the contribution of most products, but this impact is not exact. As products in hotels were associated with smaller contributions than the utilities and activities due to their high lifetime, however, the inaccuracy of these products had less influence on the total results.

The use of background data for the remaining life-cycle stages has introduced inconsistencies with regards to the geographic, temporal and technical specificity between the fore- and background processes, which has made the results less accurate. Due to the use of the Swiss Ecoinvent 2.2 database this effect is mostly noticeable for the impact of electricity on terrestrial ecotoxicity, which is likely inaccurate. The effect of the database specificity on the remaining processes appeared to be less drastic, however, even though the specificity of the database likely still influenced the results.
When highly specific background processes were not present in the Ecoinvent 2.2 database, these could often not be surrogated by seemingly similar surrogate processes, however. Seemingly similar materials and processes could be associated with significantly different impacts, and as such these processes had to be based on more specific data from either primary or specific surrogate source. In case products, utilities or activities were based on seemingly similar surrogate data, they could only provide insight into their potential environmental impact on different impact categories, but this impact would be highly sensitive.

The use of general assumptions, finally, has allowed for more consistency between the foreground processes, and appeared to not have significantly altered the results. The omission of packaging and capital goods did not appear to result in noticeable changes of foreground processes. The estimation of transport distances also did not significantly alter the results, but linear scaling of surrogate data may have made these results less accurate. Setting material and chemical properties at specific scientific values also did not appear to affect the results, albeit a slight influence was noticeable when a process with a set value was used in relatively high amounts. The allocated burden approach used to recycle materials, finally, seemed to be mainly useful for materials associated with high virgin production. Most of these assumptions are predominantly related to the accuracy of the product result, who's contribution for hotels is small, as mentioned before.

LCIA

The use of the CML-2001 impact assessment method in combination with a selection of baseline impact categories has ensured comprehensive insight into the hotel's impact has been possible, and has additionally made comparisons with future studies possible.

INTERPRETATION

The consistency and completeness checks have ensured the LCA was as complete and consistent as possible, and have additionally provided insight into possible uncertainties of results. The addition of a contribution analysis had additionally made it possible to gain insight into the contribution of services as well as products, utilities and activities, and has ensured the origin of these impacts could be investigated as well. This had made it possible to uncover hotspots for change, based on which recommendations could be made. It has also allowed comprehensive insight into the differences between alternatives within scenarios.
The addition of a sensitivity analysis has increased the value of the results further, as it has provided insight into the sensitivities of these results, and have made it possible to uncover errors in the data. As such recommendations for hotels could be further improved by indicating the likelihood results represented reality, and recommendations for further improvement of the LCA application could be made as well. The sensitivities were based on subjective observations, however, and as such were not absolute. Further research into the sensitivities and uncertainties is therefore required.

The results of the LCA therefore appeared to represent the hotel, and could provide comprehensive insight into its impact. Some inaccuracy was present, but LCA results could still provide comprehensive insight into the environmental impact of a hotel, as contributions of services as well as products, utilities and activities could be constructed, and the origin of their impact could be investigated. By including detailed studies it was also possible to investigate the influence of different scenarios on the hotel, which could provide valuable information to hotels.

12.3.3. USE OF LCA FOR THE HOTEL BRANCH AND TERTIARY SECTOR

The fourth and final sub-question has been formulated as: "How could the proposed LCA application be used by the hotel branch and other services within the tertiary sector in the future?" The answer of this question is given by presenting the opportunities LCA provides to improve the environmental impact of hotels, and by examining the generalisability of the LCA application for the tertiary sector.

OPPORTUNITIES OF LCA FOR THE HOTEL BRANCH

By applying LCA on the hotel branch, hotels are given the opportunity to gain holistic insight into their environmental impact. This will allow them to better understand where impacts derive from within the hotel, and what the causes behind these impacts are. As such, hotspots can be found in the hotel system that indicate where changes are most effective to reduce the environmental impact of the hotel, which could support decision making processes. The incorporation of scenarios in the LCA in particular can provide valuable insight for hotels, as this allows them to investigate the effect of potential alternatives beforehand. This can prevent problem shifting, and can help guide investments to be as effective as possible.
The use of LCA by hotels can also be used as a marketing tool, as is shows the commitment of hotels for sustainability. This should not be the main objective of the LCA, however, as it is principally meant to support a better understanding of the holistic environmental impact of the hotel branch. This holistic insight LCA can offer can make hotels aware of the fact that sustainability is in fact complex, and covers more than just the emission of greenhouse gasses or deforestation.
LCA would be most useful for hotels if they could make use of it themselves to investigate the influences of alternatives, especially when this could be done instantly. This could be achieved by developing an easy-to-use tool for hotels which includes the inventory of the hotel system, and allows changes to be made to this system. The way in which such a tool can be developed is further touched upon during the recommendations, in chapter 14.

GENERALISABILITY OF THE PROPOSED APPLICATION TO THE HOTEL BRANCH AND TERTIARY SECTOR

As the attributional LCA allows a myriad of products, utilities and activities to be included in one study, the LCA provides an interesting application of LCA which could potentially be used for other complex services within the tertiary sector. Complex services in this sector are not necessarily homogeneous, however, and as such the LCA might not be applicable to all of them without alteration.
For complex services which are associated with a daily use by inhabitants, the LCA could already be used. These include hospitals, elderly homes and institutions for people with mental disabilities, for example. All these complex services are based on the same principles of facilitating the use of products and services by some form of inhabitants, as is also the case for hotels. As such a more wide-spread application of this LCA for the tertiary sector appears to already be possible.

12.3.4. A BETTER UNDERSTANDING OF THE ENVIRONMENTAL IMPACTS OF HOTELS

By answering the four sub-questions, the main question can be answered. As stated before, this question is formulated as: "How can the application of Life Cycle Assessment be adapted and applied to contribute to a better understanding of the holistic environmental impacts of hotels, as an example of complex services within the tertiary sector?"

By streamlining the LCA application, it has been possible to include a myriad of products, utilities and services in one study, within a limited time frame of three to four months. This has allowed LCA to be used to investigate the environmental impact of hotels.

Most streamlining efforts have been aimed at the goal and scope definition and LCI phases. The LCA has been set-up as an attributional LCA which is aimed at uncovering hotspots, rather than giving exact measurements of the impact, and the amount of processes to include has been reduced. Additionally, all products, utilities and activities have been combined in services which could be directly used by guests, and the application of primary data has been limited to this use and the process directly facilitating this use. For the use-facilitating processes, specific surrogate data could additionally be used, while all other processes have been treated as background processes. A set of general assumptions ensured all foreground processes were consistent, and data could be gathered quickly. By including a selection of detailed studies, finally, the influence of possible alternatives in the system could be investigated with scenarios, the potential of which could be assessed with a simple scenario beforehand.

As such, the processes were representative for the hotel, but could be constructed in roughly one to two months full-time work by one person. Intrinsic interest from the hotel to reduce its environmental impact was required to apply the LCA, however, and data had to be made available by its suppliers and partners.

During the LCIA phase the existing impact assessment method CML-2001 had been used in combination with a selection of baseline impact categories, ensuring comprehensive insight into the results could be gained. The interpretation phase, finally, has been limited to a consistency and completeness check as well as contribution and sensitivity analyses. By limiting the contribution analysis to high-impact contributions and elementary flows, comprehensive insight could be gained into the contribution of the services as well as the products, utilities and activities of the hotel, and the origin of their impact could be uncovered in roughly one month. By limiting the sensitivity analysis to a selection of processes sensitivities can be uncovered as well, which increases the value of the results.

As such, LCA could be applied to gain comprehensive insight into the environmental impact of the hotel branch, leading to a better understanding of the holistic environmental impacts of hotels. This insight could be used to support decision-making processes and guide investments to lower the environmental impact of hotels as effectively as possible.

The use of LCA could become even more attractive for hotels when this is incorporated in an easy-to-use tool which allows them to compare alternatives within the hotel system themselves. The LCA application additionally appears to provide the opportunity to investigate the environmental impact of other complex services within the tertiary sector as well, especially those which are also facilitate the use of products and services by a form of inhabitants.

13

Conclusion Conscious Vondelpark hotel

The attributional LCA has been applied to a specific case, namely the Conscious Vondelpark hotel. For this case four research-questions have been created, which have been based on the second and third sub-questions of the general thesis. All results have been are associated with residing in the Conscious Vondelpark hotel for one day and night, for one average guest, based on yearly hotel averages.

13.1. Approximate environmental impact of the Conscious Vondelpark hotel

The first research question for the case-study has been formulated as: "What approximate environmental impacts are related to residing in the Conscious Vondelpark hotel during one day and night for one average guest, and where do these impacts derive from?"

The approximate impact of the Conscious Vondelpark hotel has been presented in chapter 7. The rooms appeared to be associated with the highest contribution to most impact categories, while the F&B service was related to the highest contribution to land use, eutrophication and acidification, and lower contributions to the remaining impact categories (figure). The public spaces generally showed only a small contribution, with the exception of terrestrial ecotoxicity, while the laundry service showed a small contribution to photochemical oxidation, climate change and stratospheric ozone depletion, and a slight contribution to the remaining impact categories with the exception of land use. The front- and back-office seemed to be related to slight contributions to most impact categories except land use, while it looked like the housekeeping service was related to barely any contributions at all.

The differences of the service contributions derived from their use of products, utilities and activities, which differed between them. The impact of the rooms was mostly associated with their use of gas and products, but also derived from their high use of electricity, trash and to a lesser extent waste water, depending on the impact category. The impact of the public spaces was largely related with its consumption of electricity and gas, with smaller impacts associated with their use of products. For the front- and back-office the impact predominantly derived from their gas consumption as well as the commute of employees, and mainly for the front-office also to a small extend from the products this services was related to. The impact of the F&B services was almost entirely related to its use of food and beverages, and to a slight extend from its use of electricity and gas, while the impact of the housekeeping service was predominantly caused by the commute of employees.

The contribution of the products, resources and activities at Conscious were associated with varying impact to all impact categories, and as such general statements can only give an approximate insight. Only the products appeared to be associated with a contributions to all impact categories, although this contribution varied as well. This contribution seemed to be predominantly related to the Auping mattresses and electronic devices such as LED TVs, plastic tables and Yumeko blankets. The origin of the impact was mostly related with

the production of materials, especially metals, and energy consumption during production processes.
Overall, the impact of the use of gas and the food and beverages appeared to be was associated with the highest contributions, but they did not affect all impact categories. Gas was associated with a high contribution to climate change and terrestrial ecotoxicity, a smaller contribution to photochemical oxidation, and slight contributions to acidification and human toxicity. It looked like food and beverages were associated with high impacts to land use, eutrophication and pacification and slight impacts to photochemical oxidation and climate change. The impact of gas was related to its production, transport and combustion, depending on the impact category, while the impact of the food and beverages was almost entirely associated with their cultivation, especially animal products and oranges.
The impact of electricity appeared to be low for most impact categories, except for its impact to terrestrial ecotoxicity, which was very high, and its impact to human toxicity, which was relatively high. This impact was predominantly associated with the production of the windmills and distribution network, although the impact on terrestrial ecotoxicity was caused by the distribution itself.
It looked like the contribution of water was negligible, while the impact of sewage treatment only showed a slight contribution to eutrophication and terrestrial ecotoxicity.
The disposal of waste and products appeared to be associated to a high contribution to freshwater ecotoxicity and a small impact on climate change and human toxicity, but was not associated with high contributions to the other impact categories. Its impact was predominantly associated with the incineration of municipal solid waste, especially plastics.
It looked like the transport of employees and laundry service were both associated with small contributions to roughly half of the impact categories, although the impact of the laundry service generally appeared to be higher, with the exception of photochemical oxidation. The impact of the laundry service was mostly associated with its use of gas and electricity, while the impact of the employee commute was predominantly associated with the use of trains and cars by guests.

13.1.1. INFLUENCE OF USING PV-PANELS TO SUPPLY 10% OF THE YEARLY ELECTRICITY DEMAND AT CONSCIOUS

The second research question for the case-study has been formulated as: "What is the influence of using electricity from roof-based PV-panels to supply 10% of the yearly electricity demand on the environmental impact of the Conscious Vondelpark hotel for one average guest during one day and night, compared to the current use of electricity from wind from Windpark de Hondtocht?"

Replacing part of the electricity from wind park de Hondtocht by electricity from Canadian Solar PV-panels appears to be related to a slight increase of the hotel's impact on most impact categories, with the notable exception of terrestrial ecotoxicity, human toxicity, land use and freshwater ecotoxicity. This increase of impact seems to be predominantly associated with the production of energy-intensive silicon, but also with the higher material intensity per kWh electricity related to the PV-panels in comparison to the windmills, especially with regards to copper. In particular the impact categories of acidification, photochemical oxidation and climate change show an increase of the contribution from electricity, and the contribution to stratospheric ozone depletion is most noticeable, as this impact was practically non-existent for electricity from wind. This new contribution to stratospheric ozone depletion almost entirely be attributed to the production of multi-SI photovoltaic cells. The changes are generally only slight, however, as the impact of renewable electricity was slight to begin with.

For the two impact categories that were associated with the highest contribution from electricity to the hotel's impact the impact has actually decreased, especially with regards to the impact on terrestrial ecotoxicity. For both terrestrial ecotoxicity and human toxicity this appears to be related to the fact that less distribution of electricity is required when more PV-panels are used. The hotel's impact on freshwater ecotoxicity is associated with barely any difference, as the increased impact related to the silicon for PV appears to be almost exactly the same as the decreased impact related to the reduction of copper for distribution and steel for the windmills. For land use the impact of electricity from both sources is negligible when compared to the impact of the food, beverages and products, although the impact of wind appears to be slightly higher. The use of electricity from both PV and wind appeared to be associated with significantly lower impacts than the use of electricity from the Dutch electricity grid.

13.1.2. INFLUENCE OF USING AN ALTERNATIVE LAUNDRY SERVICE BY CONSCIOUS

The third research question for the case-study has been formulated as: "What is the influence of the laundry service by Van der Kleij in Utrecht on the environmental impact of the Conscious Vondelpark hotel for one average guest during one day and night, compared to a nearly identical hypothetical laundry service in Amsterdam which has not made efforts to lower its environmental impact?"

Replacing the laundry service at Van der Kleij in Utrecht with a hypothetical laundry service in Amsterdam which has not made efforts to lower its environmental impact results in a slight increase of the hotel's impact on all impact categories (figure). This increase is largely attributed to the increased use of gas and washing agents/chemicals, and to a lesser extent to the increased consumption of electricity. The highest increase is noticeable for photochemical oxidation, climate change and stratospheric ozone depletion, as these provided the highest contribution to the hotel's impact for Van der Kleij as well. The relative increase for photochemical oxidation is higher, as this impact category is heavily influenced by the transport of natural gas, while the hotel's impact on photochemical oxidation also shows an increase that is slightly higher than of climate change, as this impact category is also influenced by the increase of washing products and chemicals, especially sulphur dioxide. A slight decrease of the impact of transport is also noticeable for all impact categories, but this does not weigh up to the increased impact due to gas and washing products.

Besides the current efforts taken by the Van der Kleij company, a further reduction of the environmental impact of the laundry service can be achieved by replacing the fossil-based electricity mix by electricity from wind. This would drastically decrease the service's impact on land use, eutrophication and freshwater ecotoxicity. It would additionally be associated with a noticeable reduction to all other impact categories except for terrestrial ecotoxicity, as this category is predominantly influenced by electricity distribution, and stratospheric ozone depletion, as this impact category is predominantly influenced by the transport of gas to Van der Kleij.

13.1.3. INFLUENCE OF INSTALLING INSULATION TO THE BOILER SYSTEM AT CONSCIOUS

The third research question for the case-study has been formulated as: "What is the influence of adding Thermatras insulation to the boilers at the Conscious Vondelpark Hotel to its environmental impact for one average guest during one day and night, compared the current situation without such insulation?"

Adding insulation to the boiler system appeared to be associated with decreases of the impact of the Conscious Vondelpark hotel for the impact categories which are associated with the use of gas. As such, the decrease was most notable for climate change and stratospheric ozone depletion, and smaller for acidification, photochemical oxidation and human toxicity. Due to the high lifetime and relatively low production impacts of the materials used for the boiler insulation, their impact appeared to be negligible.

13.1.4. VALIDITY OF THE RESULTS FOR CONSCIOUS

The fourth research question for the case-study has been formulated as: “What are the effects of streamlining the application of LCA on the validity of the results for the Conscious Vondelpark hotel?”
As was explained in chapter 10 and in the discussion of the attributional LCA, the focus on the hotel services and selection of products, utilities and activities have made the study incomplete. Additionally, due the use of surrogate data and assumptions, inconsistencies and sensitivities have emerged as well. First the sensitivities related to the products and services are explained, after which the overall validity of the results are presented.

PRODUCTS

Many different products were present in the Conscious Vondelpark hotel, all of which were associated to some degree of sensitivity due to the use of surrogate data. The use and lifetime of all products has been based on primary data, either from Conscious or its suppliers and partners. Most production processes, however, were associated with limitedly detailed secondary foreground processes. As such the type and amount of materials of the products as well as their production location derived from primary data, while the remaining data for the production process derived from specific surrogate processes, either from the Ecoinvent database or literature. The production processes of the Auping Inzinio mattress and Interface carpet were associated with a relatively high level of detail, however, as these were based on extensive primary data, and made use of specially developed background processes for highly specific materials and processes. The production processes of the Mosa wall- and floor-tiles, LED TV and all lights were of medial detail, as these were based

on primary data or extensive literature, in combination with specific Ecoinvent production processes. Only the Dharmazone products, cleaning products and all tableware and pans were associated with a crude level of detail. Their production has been based on seemingly similar surrogate processes, with the use of only very limited primary data. As such their results were too sensitive to represent these products, but do give an indication of what their impact could possibly be, and which impact categories were most likely affected by them. Additionally, even though the production of Yumeko blankets and pillows was regarded as limitedly detailed, as their use of materials and utilities as well as their production location was based on primary data, they do contain a very rough approximation of the feather production, which was based on seemingly similar processes and literature. Their sensitivity was therefore likely higher than most products, although still lower than of the crudely detailed products.
As such, almost all products in the study were deemed representative for the products at Conscious, although some sensitivity of the results did exist. These products can therefore not represent the exact impact they were associated with in reality, but could serve as a detailed approximation of their contribution to the services and hotel, both individually and combined. The combined impact of products was likely too low, however, which was predominantly due to the fact that two products which were related to high quantities and possible high impacts could not be included, namely the bedframes and closets. Additionally, some high quantity products which were assumed to be associated with a low impact were also not included, such as the showerheads, lampshades and decorative soaps. The floors have been included, even though these might be regarded as being part of the hotel building, rather than the service. This choice has been made as primary data for these floors was available and relatively easy to acquire, while data for other indistinct products such as ceiling plates was not available. The hotel additionally indicated they were interested in the impact of the floors, while the impact of the ceiling and other building-related products was of less interest to them.

SERVICES

The use and configuration of most services in the hotel were relatively accurate. The Van der Kleij service in particular was associated with a high level accuracy, as this service was based on data from a detailed study within the attributional LCA. The front- and back-offices were also relatively accurate, as both their primary and secondary foreground processes were based on primary data from the hotel and its employees, while nearly all background processes were directly based on specific Ecoinvent processes. The F&B service was associated with higher sensitivity, however, as the impact of this service was predominantly associated with the cultivation of crops for food and beverages. All food and beverages have been grouped, however, and their cultivation has been based on seemingly similar Ecoinvent processes. As such their impact was sensitive, rendering the impact of the F&B service sensitive as well. The housekeeping service, in turn, was based on the same data as the front- and back-offices, but did not contain all products which were used due to their low quantity and high specificity, for example in the case of vacuum cleaners. As such the impact of the housekeeping service was incomplete, but was not expected to change significantly when the low-quantity products would be added. All other secondary foreground activities within services were based on primary data, however, and as such these were deemed representative approximations. The impact of activities was based on their use by employees, however, and as such changes of staff can quickly change their impact, making the results outdated. This was especially true for the impact of commute, as the modes and distances deliver the impact, which were highly related to staff choices.
The distribution of utility consumption among the (pseudo-)services was somewhat sensitive as well, as this distribution was based on calculated estimations. This exact consumption of the individual services was not measured, and as such generic hotel consumption data was combined with measurements of the hourly, monthly and yearly consumption of all utilities in the hotel. The distribution among services was therefore based on extensive research and highly specific for Conscious, but still associated with estimations and therefore more sensitive than actual measurements per service. Without the hourly and monthly data, however, the sensitivity of this distribution would have likely been significantly higher.

The impact of pseudo-services was deemed slightly more sensitive than the impact of the front- and back-office and housekeeping service, as these were also affected by the sensitivity of the products. The impact of the rooms in particular were affected by the products, as these contain most products in the hotel as well as those products related to the highest impact, such as the Auping mattresses and LED TVs. The pseudo-services were specifically based on the rooms and public spaces at Conscious, however, and as such their results were deemed to be representative approximations.

VALIDITY OF FINAL CONTRIBUTION TO CONSCIOUS VONDELPARK HOTEL

The contribution of the services to the hotel's impact differs per service, and as such the sensitivity of the services has varying influences on the final results. The rooms in particular were associated with high contributions, and partly influenced by the sensitivities related to products. The contribution of the F&B service was high for land use, eutrophication and acidification, and as such the impact of the hotel to these impact categories was highly influenced by the sensitivity of this service. The impact of the fairly accurate front-office, back-office and housekeeping was very low, while the impact of the slightly less accurate public spaces and most accurate laundry service was small to most impact categories.

When perceiving the separate impact of the products, utilities and activities to the hotel's impact, the highest contributions appeared to derive from the utilities and activities used by the (pseudo-)services. The sensitivity of the impact of products was relatively high when compared to the utilities and activities at the hotel. As the contribution of the products to the hotel's impact on all impact categories was small, however, the influence of the product sensitivity was likely significantly lower for the total hotel impact than for the impact of individual products. The contribution of the activities was also related to the use of computers, paper and other products in the services, but their impact was only very slight and dwarfed by the contribution of the products in the pseudo-services.
The impact of the food and beverages was associated with the hisgest sensitivity, as they were grouped and their cultivation was based on seemingly similar processes. This sensitivity only significantly influenced the hotel's impact on land use, eutrophication and acidification, however, as the food and beverages were only related to high impact to these categories. The impact on photochemical oxidation and climate change was also associated with a small contribution from the food and beverages, and were therefore also slightly influenced by their associated sensitivity. The remaining activities of (waste) disposal, sewage and employee commute only provided a small contribution and were based on primary data and Ecoinvent processes. As such these were likely not responsible for a high sensitivity of the results, which was also associated with the fact that their contribution to the hotel's impact on most impact categories was only small. The impact of the employee commute was sensitive to staff changes, however, and could therefore quickly become outdated. The laundry service, finally delivered the most accurate contribution, although the impact of its alternative was slightly less accurate, as it was based on a hypothetical situation.
The impact of utilities was based on their yearly consumption by the hotel, and as such was not affected by the sensitivity of their distribution among services. The impact of electricity from either wind or PV was most accurate, as this was based on a detailed study, although its high contribution to the hotel's impact on terrestrial ecotoxicity was highly influenced by the geographic specificity of the Ecoinvent database and likely significantly too high. The impact of the remaining utilities appeared to be less severely influenced by this specificity, however. Their impact was considered to be fairly accurate, as their consumption was based on primary data, while their background processes were entirely based on specific Ecoinvent processes.

It therefore appeared that only the impact of the F&B service and its related cultivation of food and beverages introduced a significant sensitivity, which could be improved by using more specific surrogate data and by avoiding food grouping. Its influence was largely limited to the hotel's impact on land use, eutrophication and acidification, however. This contribution did provide insight into the probable impact of the food and beverages, however, and indicates which impact categories were likely most affected.
The pseudo-services were also sensitive due to their use of products. Especially the Dharmazone and cleaning products, as well as the tableware were sensitive, but these products were not associated with high impacts to any impact category. More detailed primary data was likely not available for these products, and as such excluding these products might increase the accuracy of the product results, although it would slightly decrease their combined impact as well.
The impact on terrestrial ecotoxicity appeared to be uncertain, as it was influenced by the geographic specificity of the database and likely did not represent the correct impact for the distribution electricity. For the remaining impact categories, the impact appeared to be fairly accurate, however. As such, even though their exact impact was associated with some sensitivity, the contribution of almost all products, utilities and activities appeared to be representative for the Conscious Vondelpark hotel to most impact categories, and provided valuable insight into the environmental impact of the hotel.

14

RECOMMENDATIONS

The application of LCA has been streamlined and applied to contribute to a better understanding of the holistic environmental impacts of hotels, and appears to be applicable to other complex services within the tertiary sector as well. It has been successfully applied to the case-study of the Conscious Vondelpark hotel, but improvements to the LCA application are still possible, and further research could be conducted. Additional recommendations can be given for the Conscious Vondelpark hotel, based on the results of the LCA.
Recommendations are therefore given for the further development of the LCA application, its potential future application, and possible follow-up research based on this LCA. Recommendations will also be formulated for the Conscious Vondelpark hotel which are focused on opportunities to improve their environmental impact, and general recommendations with regards to the way in which sustainability can be regarded within the hotel sector.

14.1. RECOMMENDATIONS LCA APPLICATION

When applying the LCA to investigate the environmental impact of a hotel, it is recommended that special attention is paid to highly specific background processes. As was shown, these can often not be surrogated by seemingly similar processes, since their impact might be significantly different. When such specific background processes are not available in the Ecoinvent database, they should therefore be based on either primary or specific surrogate data. This might increase the time investment of the LCA, but will result in more valuable results. When no specific data is available, it is recommended to include only those utilities and activities which are deemed important for the functionality of the hotel, such as food and beverages, as this can still provide insight into their potential impact, which could be the basis for further results.

For products, it is further recommended that primary data is gathered for materials and the location of their production process, but also for the use of utilities during their production process. The omission of utilities appears to result in less accurate data, but is likely often known when suppliers are the manufacturers of products as well. Even when exact measurements per products have not been conducted, the utility use might still be based on the average utility use and output of facilities, which could further guide the choice of specific surrogate data processes. Including utilities will likely not be possible for all products, however, which is predominantly caused by the fact that there is currently no need to document such data. If LCA becomes more wide-spread among the tertiary sector, hotels and other complex services might be able to convince their suppliers and partners to document this data, as it could become part of the decision-making process. This cannot be done in little time, however, and as such should be regarded as a potential long-term recommendation if LCA would ever become a part of the decision-making process hotels.

The use of the avoided burden approach is further recommended for detailed studies in particular. The use of this approach increases the representativeness of products and other elements containing recycled content, but appeared to be mainly useful for materials which are associated with a high-impact virgin production process. The approach requires a higher time investment than the cut-off approach where the waste disposal is not taken into account, but did not appear to result in significant different results of products containing recycled content of low-impact materials. As the approach was based on one process from the

US-LCI database in particular, further research into this approach is recommended as well before it is decided whether it should be included or replaced by another allocation approach for this LCA.

As the LCA makes intensive use of background data from databases, it is also recommended to use databases which are up-to-data, geographically specific and extensive. Currently, the Ecoinvent databases are among the most extensive databases available, and as such this recommendation is likely difficult to implement. As the data specificity of databases does influence the results, however, further development of databases could increase the results in the future.

To increase the value of the results for hotels and allow a more wide-spread use of this LCA within the tertiary sector, it is further recommended that more research is conducted into the effect the streamlining efforts on the sensitivity of the results. More products, utilities and activities should also be included in the sensitivity analysis, as this analysis is currently limited to a small selection only.
It is also recommended to perform sensitivity studies of the streamlining efforts of this LCA separately, in order to allow for improvements of the sensitivity analysis which is performed when the impact of hotels is investigated. Currently, only subjective sensitivities have been uncovered, as no clear threshold has been set for the significance of sensitivities. In order to uncover more definite sensitivities, the sensitivity analysis should therefore be based on less subjective notions, for example by conducting research into the significance of changes in results. This sensitivity analysis should predominantly be focused on the LCI phase, as most sensitivities are related to the use of surrogate data and general assumptions.
A separate uncertainty analysis could be conducted as well to uncover the general uncertainties caused by the streamlining efforts of this LCA. The results of these uncertainty analyses could thereby provide insight into the likely uncertainties of streamlining efforts, which can be used as input for a general set of rules for the LCA with regards to the use of surrogate data.

In order to prevent the omission of important products, utilities and activities, it is recommended the LCA is carried out on more than one hotel in the future. This could provide insight into the validity of the selection criteria, which have currently been set on high energy/mass, high quantity and high importance for the hotel's functionality. The exact impact of the selection is difficult to assess beforehand, but by employing the same principle on several case-studies more insight might be gained into the probable impact of products, utilities and activities. Based on this new selection criteria might be created. Carrying out the LCA on several hotels could also provide a reference situation for comparison, which will increase the value of the LCA results for any hotel.

When the environmental impact of other hotels are investigated, it is recommended that the choice of hotels is based on those which are intrinsically interested to reduce their environmental impact and hold close relationships with their suppliers and partners. The acquirement of primary data for the use of products and services is of vital importance for the representativeness of the results, and as such only hotels which are willing to transparently share their data can collaborate in a comprehensive LCA. The collaboration of suppliers and partners is also important in order to prevent high time investments during the LCI phase. When hotels are not interested in lowering their environmental impact, information might be left out, as LCA might only be used as a marketing tool to attract guests. By speaking with the managers and hotel employees beforehand, discussing the way in which hotels want to use the results, and investigating beforehand how information could be gathered, the potential of the hotel to use LCA can be assessed.

For future application of the LCA the boundaries of the LCA could additionally be expanded by also including the building which houses the hotel service. This would require a significant additional time investment, and as such it should be seen as a recommendation for a possible extension of the attributional LCA, rather than a required improvement.
Including the building would provide additional insight, and could allow the investigation of alternatives to building-related products. As such this extension could be particularly valuable for hotels which are considering renovations of their building, as it could provide supporting information for the choice of alternatives. The hotel building would have to be included as a separate element, similar to the combined products, in order to provide a transparent overview of its insight. For hotel chains the addition of the hotel building could thereby also provide insight into the differences between the different locations, which might be valuable information if hotel chains are considering to establish new hotel locations.

When performing this LCA, it is further recommended to consider involving a team of researchers. The LCI phase in particular could be performed by several researchers simultaneously, as it encompasses a myriad of different products, utilities and activities. As such, one researcher could focus on gathering primary data from the hotel with regards to the use of products and services, while another could focus on gathering primary data from suppliers and partners. A third researcher could be included as well, who could focus on the development of detailed studies.
The contribution analysis during the interpretation phase could also be performed by several researchers at the same time. Every impact category could be investigated separately, after which the findings could be combined to represent the hotel.
By working in a team, the hotel system can therefore be set-up in considerably less time than is possible by only one researcher. This could make LCA more attractive for hotels, as the results could be presented in significantly less time.

In order to make LCA more attractive and valuable for the hotel branch it is further recommended future research is conducted into the development of an easy-to-use tool for hotels, based on the LCA developed in this thesis. Through such a tool, LCA could be used by hotels for longer periods of time, instead of being performed only once as has been done during this study.
Such a tool would require a simple interface where data can be added or picked from the Ecoinvent database. This interface could allow users with little expertise to add data, by indicating which information is required and guiding them through the process. Data would still have to be gathered by the users themselves, but this could be based on a checklist containing the possible vital, important and less important data requirements. In order to allow users to carry out the comparisons within the hotel system, the contribution analysis would have to be automated. This way insight could be provided into the contribution of services, products, resources and activities, and into the main origin of their impact. Additional reference situations with the hotel in previous years might also be recorded in order to investigate the impact of measurements throughout the years. The addition of data might make comparisons difficult, however, as a more complete inventory can lead to higher impacts. This should therefore be taken into account as well.
The sensitivity of results should also be given, which requires the development of an automated sensitivity analysis as well. This could potentially be achieved by allowing users to indicate what type of data they have put into the tool, and which assumptions were used on a checklist per data point. This checklist could include options such as the detail of data (based on measurements, primary data from suppliers, surrogate data, estimations, etc.), the age of the process, and the type of assumptions required to translate data to the Ecoinvent database (specific or seemingly similar surrogate), besides many other options.
Considerable time would have to be invested to set-up the inventory for the hotel system according to the LCA developed in this thesis, of course, but after this is done a comprehensive model of the hotel would be present. Adaptions could be made to this model to investigate the impact of certain processes, but also to add new primary data, or to compare newly proposed alternatives. As such the hotel would be able to explore the environmental impact of alternatives within relatively little time. A specialised employee would likely be required to gather the data and use the tool, however, and external expertise will likely always be necessary to solve problems and check the results. External companies would no longer be required to investigate all changes to the system, however, allowing hotels to investigate this themselves.
The development of this tool is likely highly challenging, but could allow LCA to become an inherent part of the decision process of hotels, and could thereby support a holistic approach towards sustainability within the hotel branch.

Future research is also recommended into the use of this LCA for other complex services which are associated with a daily use by some form of inhabitants. Currently, it appears complex services such as hospitals, elderly homes and institutions for people with mental disabilities could make use of this LCA. This could be investigated further by applying the LCA on these types of services, and uncovering if there are differences between them. As such LCA could be developed further for use in the tertiary sector, and might even become part of the decision-making process of complex services within the this sector.

14.2. RECOMMENDATIONS FOR CONSCIOUS

Based on the results of the LCA study, some recommendations can be made for the Conscious Vondelpark hotel and its partners. These recommendations should not be interpreted as wide-ranging solutions which will reduce the environmental impact of the hotel in all impact categories, as the products, utilities and activities at Conscious are often associated with different influences per impact category. Additionally, as some sensitivity is present in the impact results, further research is recommended before decisions are made.

A large share of the hotel's impact on some impact categories is associated with the consumption of natural gas, which is partly due to the relatively inefficient use of this utility. It is therefore recommended that measures are taken to reduce this consumption. The proposed insulation of boilers and piping already shows promise, and based on a simple assessment it is recommended this insulation is added in order to lower the gas consumption. As a large share of the gas is used in the rooms, however, it is also hypothesised that a more controlled environment can lead to reduced gas consumption. Currently guests are able to open windows and control radiators, while heat or cooling is also provided by the central air handling units. By limiting the influence of guests gas consumption can likely be decreased. It should be noted, however, that replacing radiators, air handling units or other components is associated with a detrimental influence on the environment. A replacement of gas with another source of heat is also possible, but here the holistic impact must be considered as well. As such it is recommended that both the benefits and draw-backs of measures to reduce the consumption of gas are taken into consideration to prevent problem shifting or even overall detrimental effects.

The impact of food and beverages might decrease when less animal products and more locally sources food and beverages are used. Locally sourced food is not necessarily better, however, as the impact of transport is often inferior to the impact of the actual cultivation. Attention therefore has to be paid to the impact of this cultivation in particular. The influence of food and beverages on the environmental impact of the hotel is sensitive, however, and as such more research is required to investigate the actual contribution of the food and beverages.

Improving the lifetime of products is also recommended, as this prevents the disposal of old and production of new products and thereby reduced their daily impact. It should also be noted that any environmental benefit of products is reduced when they are used for only short periods of time, as this increases their daily impact in the hotel. It is therefore additionally recommended that the disposal and lifetime of products is taken into consideration at the time of purchase. When products need to be replaced nevertheless, it is additionally recommended to reduce the use of high-impact products, such as TVs, and high-impact materials, such as metals. Ensuring new products contain recycled content and can be recycled themselves could additionally reduce their impact. This reduction of impacts cannot be assumed as a rule, however, as recycled content does not equal an environmental benefit in all cases or impact categories. The statement that the presence of recycled content is 'better for the environment' is therefore appealing, but might only relate to certain impact categories, while the impact of others might actually increase. Increasing the lifetime of products is therefore likely the best way to reduce the environmental impact of products, and when choosing new products their holistic impact should be considered.

For the laundry service used by the hotel the measures taken appear to have resulted in a noticeable decrease of the service's impact. The use of electricity from wind, however, could further reduce its impact on most impact categories, in particular with regards to land use, eutrophication, acidification, climate change and freshwater aquatic ecotoxicity. This reduction would also be noticeable on the impact of the hotel, in particular with regards to climate change and freshwater aquatic ecotoxicity. The feasibility of using electricity from wind is unknown, however, although it potentially could be an alternative to electricity from the Dutch grid. Large-scale companies like Pure Energie could provide a promising alternative, as these could possibly deliver electricity at competing prices compared to the cheap electricity from the Dutch grid.

Even though commute is only related to a small impact to some impact categories, its impact could still be decreased. It is therefore recommended that cars and scooters are used as little as possible, as the impact of bicycles, trains and other forms of transportation is lower than either cars or scooters for all impact categories, depending on the category. Public transportation and even electric scooters are also associated with an impact on the environment, of course, but these did appear to be significantly lower than the impact of

cars and scooters. As such promoting the use of bicycles and public transportation appears to be an interesting way to lower the impact of the employee commute. This could be done by providing monetary support for employees who make use of public transportation to lower their personal travel costs, or by providing small bonuses for employees who take the bicycle for short travel distances.

The installation of PV-panels to cover a part of the electricity requirements of the hotel is also recommended, even though they appear to be associated with an increased environmental impact compared to wind. Installing PV-panels still increases the amount of renewable electricity in the Netherlands, which theoretically reduced the requirement of fossil-fuel based electricity. The Dutch electricity grid will likely always be required to provide a base-load form of electricity to accommodate variations in wind and sun power, but on the basis of the hotel using renewable electricity reduced its environmental impact on all impact categories.

It is also recommended to recycle more of the waste in the hotel. This might not reduce the impact of the hotel significantly, but as the impact of the hotel on freshwater aquatic ecotoxicity is almost entirely caused by the incineration of municipal solid waste, reducing the amount of this waste could reduce this impact. Plastic in particular could be recycled fairly easy, as this is already been done in the Netherlands. Other types of waste, such as soda cans and juice packages could be recycled as well for the same reason.

To make a more detailed holistic investigation of the environmental impact of the hotel possible in the future, it is recommended that the consumption of the rooms, and preferably the public spaces and other services as well, is measured on an hourly basis. This is already done for the whole hotel, but calculated estimations are still necessary to distribute the utility consumption over the different (pseudo-)services. Additionally, it is recommended that at least material types and amount, production location and utility consumption of the production of products is known at the hotel, which could be requested from the suppliers when products are purchased. This way the basis for an possible future LCA research can be quickly constructed, which saves time and increases its accuracy.

Finally, the general message that this study tries to convey to Conscious is that ‘sustainability’ is ambiguous, and not limited to impact categories such as global warming alone. Whenever decisions are made to improve the environmental impact of the hotel, a holistic approach can help to uncover impact to other impact categories as well, which could prevent problem shifting. This makes it possible to make decisions with more certainty, and prevents good intentions and investments to result in unintentional detrimental effects to the environment.

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