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A CE Indicator Scorecard and Circular Economy Business Model Canvas for the Food and Beverage Industry

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A CE Indicator Scorecard and Circular Economy Business Model Canvas for the Food and Beverage Industry

With a pilot study at the La Trappe Brewery for circular and sustainable resource use.

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by

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Summary

A circular economy (CE) is seen as needed in all industry sectors to manage finite resources and to reduce the impact of production and consumption of goods on the planet. While the food and beverage industry has already many measurements in place to ensure cleaner production, a transition towards a CE requires a broader systems perspective. Most frameworks and indicators for CE focus on the technical loop of materials, whose measurements do not fully apply for consumable goods in the food and beverage sector. Insights from the field of Industrial Ecology (IE) are used to develop ways to measure CE. Based on the biological loop of the butterfly diagram of the Ellen MacArthur foundation, water, organic materials and especially nutrients were defined as core focus points for a CE in the food and beverage industry. A CE for this sector needs to include a systems perspective, minimizing losses of nutrients, water, and energy along the entire life-cycle of products starting from the production of raw materials until the management of waste streams at the end-of-life (EoL) of products. In contrast to the technical loop, it is significantly more challenging to achieve a closed loop as production is connected to natural processes (when growing the raw materials). In addition, the product is consumed and then ends in the municipal waste stream. However, companies can develop strategies to take into account best practice of resource use along their supply chain as well as actions towards re-using, sharing, and recovering material, energy and water at the EoL stage as well as within their own production facilities. To best support companies in developing strategies for business models for a CE a review of existing business models was performed. CE was explored within the overarching category of sustainable business models to ensure the development of a Circular Economy Business Model Canvas (CEBMC).

CE Indicator Scorecard

for Products Created from Biological Waste Streams

Value Proposition		Value Creation		Value Delivery		Value Capture		Value Anchoring	
Product(s)		Key activities		Partners		Costs		System Consideration	
Customers		Key resources		Channels & Technology (Packaging & Transportation)		Benefits		Long-term Impact	

Figure I-1 CEBM canvas.

Based on this CEBM canvas, a set of 14 CE indicators was developed in the form of a scorecard to measure the progress of companies in the food and beverage industry in terms of CE. These indicators are based on water, material, nutrients, energy, customer, supply, production (water & energy), employees, partners, transportation, packaging, profit, system consideration, and pollution prevention and were obtained by letting companies fill in a questionnaire with a set of 24 questions (see *appendix IV*). The indicator results are shown in a spiderweb and were presented as equal (thus not weighed) as CE is considered an equally important element in all aspects of the BM canvas. The CEBM canvas and the CE indicator scorecard are available for use in Microsoft Excel.

The developed canvas and indicator scorecard were reviewed and validated through a peer review session, experts from academia, consultancies and companies in the field. Based on the feedback received the scorecard was adapted and shortened to be as user-friendly as possible.

A thesis research project with SEMiLLA IPStar B.V., the technology transfer partner of the MELiSSA space program, and a pilot study of the BioMakery at the La Trappe brewery in Koningshoeven, Tilburg, showed the functioning of the framework in practice, including its strong and weak points. The framework and scorecard were tested in three test scenarios on the technology of SEMiLLA, on Biopolus, who are both providing parts of the water processing technology for La Trappe, and the entire BioMakery of La Trappe to determine their contribution towards a CE. The data was filled in both by the researcher as well as the company itself, which allowed to get a better understanding on the sensitivity of the data input regarding the obtained results.

[Due to sensitivity of the data used in the case studies, data that could impact the competitiveness of the company is not shown in the public version of this thesis. A full version of this thesis including company data can be requested upon approval by the companies involved in the case studies].

When comparing the self-score of the companies with the score obtained during the pilot study research, some deviations were found especially in the social indicators. This can be explained with a knowledge gap and not fully available data during the research. It is therefore suggested to whenever possible have the company fill out the scorecard to achieve highest accuracy but to require a proof for the rating given to ensure transparency and no higher rating than would be appropriate. When comparing the results of the research with the self-score, however, it was found that in most cases the research result offered a higher score than the company credited themselves in the self-score.

What was seen during the design process of the scorecard is that an additional CE framework is needed to ensure circularity along the supply chain particularly as this is where the majority of impacts occur. At current, such a framework does not exist but could be developed with a starting point based on the CE indicator scorecard developed in this thesis. This would allow to better focus on material, water, and energy losses along the life-cycle of the product.

At current, the scorecard is designed to accommodate companies in the food and beverage industry that focus on creating valuable products from their waste streams. It was specifically tested at a beer brewing facility. Further research is suggested in order to expand the applicability of the scorecard beyond this industry. In addition, updating the scorecard when industry standards change is recommended as well as conducting further research on how to expand the indicator set, by for instance, by adding more social and financial indicators.

Specific recommendations for the companies involved in the pilot study, as well as recommendations to industry, government and consultancies for developing a CE can be found in chapter 8.

Key words: Circular economy, industrial ecology, closed loops, brewery, industrial symbiosis, nutrient cycle, water cycle, technology transfer, La Trappe, MELiSSA

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List of Abbreviations

AD	Anaerobic digestion
ASP	Anaerobic sludge processes
BAT	Best available technology
BAU	Business-as-usual
BM	Business model
BOD	Biological oxygen demand
CE	Circular Economy
CEBM	Circular Economy Business Model
CH_4	Methane
CO_2	Carbon dioxide
COD	Chemical oxygen demand
EC	European Commission
EoL	End-of-life
EU	European Union
FOG	Fat, oil and grease
GHG	Greenhouse gas emissions
H_2SO_4	Sulfuric acid
IE	Industrial Ecology
K	Potassium
KPI	Key performance indicators
LCA	Life-cycle assessment
LCC	Life-cycle costing
LCSA	Life-cycle sustainability assessment
MCI	Material circularity indicator
MFA	Mass flow analysis
MLSS	Mixed liquor suspended solids
MNR	Metabolic network reactor
MOP	Muriate of Potash
N	Nitrogen
NH_3	Ammonia
NH_4	Ammonium
NO_x	Nitrogen oxides
N_2O	Dinitrogen monoxide
P	Phosphorus
PEF	Product Environmental Footprint
OEF	Organizational Environmental Footprint
SBM	Sustainable Business Model
s-LCA	Social life-cycle assessment
TN	Total nitrogen
TP	Total phosphorus
TS	Total solids
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket
WWT	Waste Water Treatment
WWTP	Waste Water Treatment Plant

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1. Introduction

1.1. A Circular Economy for the Food and Beverage Industry

A growing population and overexploitation of vital resources pose a challenge on future food and beverage production. A sustainable way of production and consumption is urgently needed to feed an expected 9 billion people of which more than half will live in densely populated urban areas by 2050 (FAO, 2011) without damaging the planet while doing so. The food system is responsible for 19-29% of global greenhouse gases, with large N_2O emissions from fertilizers in soils, methane emissions from cattle farming, rice cultivation, and manure processing and up to emissions from rotting food waste in landfills (Vermeulen, Campbell, & Ingram, 2012). While almost 80% of the emissions directly or indirectly stem from agriculture, ensuring efficient production and waste reduction in the further links of the value chain can help to ease these impacts. For this reason, the practices of the food and beverage processing industry play an important role in creating a more sustainable food system. Agricultural food production, which provides raw material resources for the food and beverage production industry, is connected to high water, energy and nutrient use. Wasting agricultural products in the production or consumption phase leads to a loss of all the nutrients, energy and water required to produce these goods. When nutrients are not fully recovered in waste water treatment processes they lead to pollution of rivers and soils. (Breure, Lijzen, & Maring, 2018) High energy and water demand in production processes, further increase the impact of the products.

With growing regional impacts of climate change and industrial or agricultural intensification, for instance on water availability and local draughts, creating food and beverage industries centred around sustainable resource management becomes vital. Cleaner production methods and higher efficiencies in the production processes have already been applied to reduce energy and resource uses in the processing industry. (Garza-Reyes, 2015; Maxime, Le Marcotte, & Arcand, 2005; Olajire, 2012; Tseng, Fung Chiu, Tan, & Bella Siriban-Manalang, 2013)

In the past few years the concept of 'circular economy' has received increasing attention. Circular economy (CE) is seen as a way to mimic natural ecosystems and their self-regulating loops that keep the system in balance while producing minimal amounts of waste (for instance, in the form of fossil fuels stored underground) (El-Haggar, 2007). The Ellen MacArthur Foundation (2015) defined the preservation of natural capital, optimization of resource yields and fostering of system efficiencies as core principles of the circular economy. It appears only logical to apply CE to the food production system and to expand existing practices with CE principles. A visualization of this concept can be seen in the butterfly diagram of the Ellen MacArthur Foundation for CE, highlighting the need to close technical and biological loops.

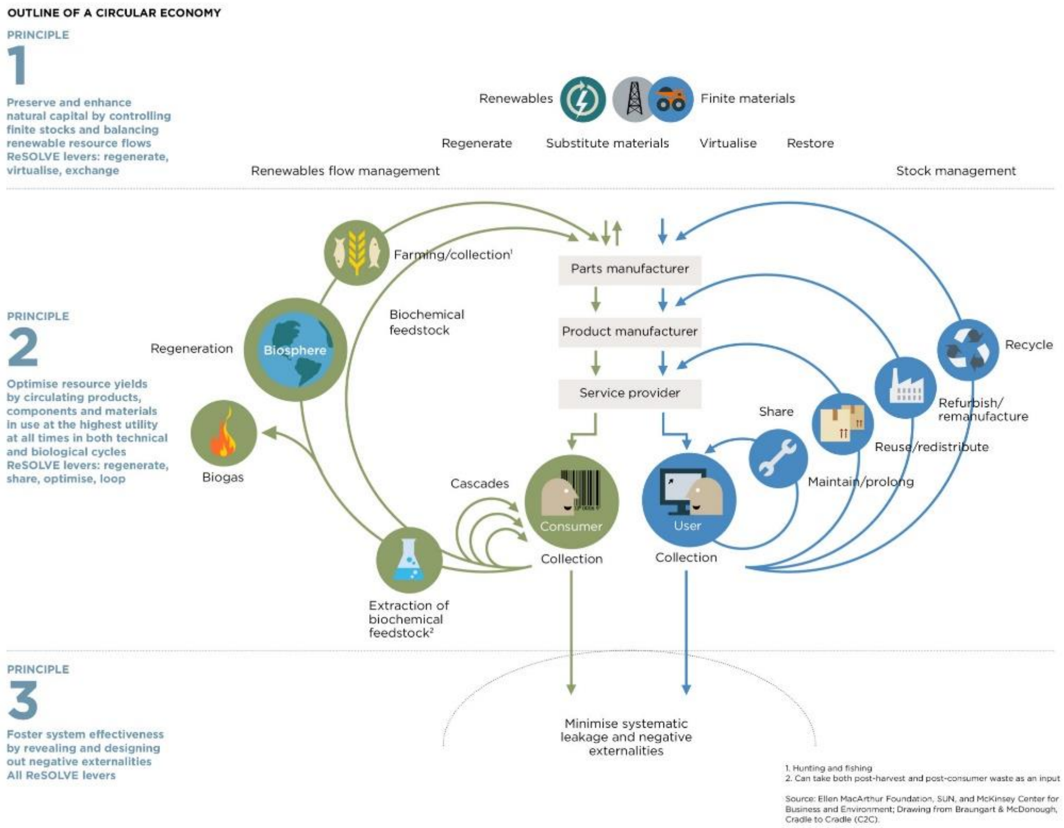

Figure 1-1 The Ellen MacArthur butterfly diagram representation of CE. *(Ellen MacArthur Foundation, 2017b)*

Whereas CE in other industrial sectors focusses mostly on closing cycles by recycling and reusing materials and extending product life-spans, this proves to be more challenging in the food and beverage industry as it concerns products that are inherently designed for consumption. The main challenge for the food and beverage industry is how to close biological material, nutrient and water cycles. (Breure et al., 2018; Olajire, 2012) While the food and beverage processing and production industry has been a frontrunner in cleaner production and eco-efficiency, a CE perspective will allow to give a systems perspective on biological loops and contribute to more efficiently reuse and repurpose waste streams through the establishment of industrial symbiosis networks.

New value creation strategies in the form of CE business models (CEBM) are needed to explore further in which way a food and beverage producing company can best contribute and profit from creating a closed loop. Based on these new strategies, a set of CE indicators is needed to support decision making and management of the transition towards a sustainable CE food and beverage industry on a company and on a product level.

Despite ongoing developments in the food production industry, agriculture and consumption are still majorly suffering from high energy usage, nutrient loss, water overconsumption and food waste. As the food and beverage industry is the central link between agricultural production and consumption, this might allow to tackle resource management issues along the entire production and consumption value chain and view CE from a systems perspective.

1.2. Aim of the Research Project

At current, no single framework exists that can be used for creating or measuring CEBM for the food and beverage industry. The goal of this research project is to offer a framework that provides individual businesses in the food and beverage processing sector with a support structure for their strategy towards a Circular Economy. The framework comprises of a CEBM canvas including building blocks specifically designed for companies in the food and beverage industry. This is accompanied by a CE indicator scorecard that allows to visualize the company's progress in striving towards creating a business model based on CE principles. The strategy used for the CEBM should not only be economically but also environmentally and socially sustainable. The CE indicator scorecard will be applied and tested with a case study of SEMiLLA's water processing system at the La Trappe brewery.

To develop a profitable strategy for improving CE in the food and beverage industry at a firm level, the following research question arises:

What circular economy business model (CEBM) framework and accompanying set of indicators are needed to support the development of CE strategies in the food and beverage industry?

To answer this research question, several sub-questions need to be addressed:

1. What constitutes a Circular Economy (CE) in the food and beverage industry and how can it be measured?
2. What is the state of Circular Economy Business Models (CEBM) for the food and beverage industry?
3. Which CEBM and accompanying set of indicators are needed to measure and develop a CE in the food and beverage industry?
4. How does this new framework perform in practice (when tested at La Trappe)?

To answer the research question and its four sub-questions several research methods will be applied. A comprehensive literature review will give an overview of the current state of CE and CEBM in the food and beverage industry as well as the most frequently used indicators in the field. Sub-question three requires a design approach to develop a new framework applicable for the food and beverage industry that will provide a strategy for a sustainable CEBM and an adjacent set of CE indicators. This developed framework will be tested with a case study at La Trappe.

1.3. Research Project and Case Study with SEMiLLA

The study builds on a thesis research internship at SEMiLLA IPStar B.V., or otherwise called SEMiLLA, within the NextGen Horizon 2020 project at the La Trappe brewery. SEMiLLA is ''the technology transfer member of MELiSSA, an international space research consortium run by the European Space Agency with the goal to develop a closed loop ecosystem for space missions. SEMiLLA is located in Amsterdam, in the Netherlands, and develops space technology for Earth based circular systems'' (SEMiLLA Circular Systems, 2019). The aim of the company is to use technology inspired by technology developed for manned life support in space to make earth more sustainable. For this project, SEMiLLA builds upon technology from the MELiSSA regenerative life support system of the European Space Agency to create a circular water and nutrient stream for a circular economy project within La Trappe, a Trappist brewery in Tilburg, in the Netherlands (La Trappe Trappist, n.d.). A part of the MELiSSA technology will be integrated into the 'BioMakery' of La Trappe, a waste water treatment system that aims at recovering and reusing all the waste streams from the brewery and associated production sites at the abbey grounds. SEMiLLA's installation will be added to the Metabolic Network Reactor based inside a greenhouse, that are used to treat the brewery waste stream, to treat municipal waste water stemming from the abbey grounds, especially the restaurant and the monks' quarters. The water will be cleaned and reused, and the nutrients and proteins extracted turned into a high-value product. The aim of the research internship is to contribute to the creation of a CE business model for the technology that SEMiLLA implements at La Trappe.

The project takes place within the larger Horizon2020 NextGen project that incorporates the entire BioMakery system for waste water treatment and bio-product creation at the La Trappe abbey grounds. The project was initiated by the abbey as La Trappe is a small Trappist brewery organized by 22 Trappist monks in a monastery in Tilburg, the Netherlands. (La Trappe Trappist, n.d.) Today, there are only 20 Trappist monasteries around the world. Trappists follow strict rules on living a simple life based on the Rule of Saint Benedict of Nursia dating back to the 7th century. Only 11 of the 20 monasteries brew Trappist beer. Strict guidelines need to be followed when applying for a Trappist label for a product. Values, such as socially responsible entrepreneurship, sustainable supplies, and concerns for the environment are deeply embedded into the guidelines of the Trappist community. To receive a label for the beer production, the monks have to actively supervise and be involved in the beer production process. All production has to take place in the immediate surroundings of the abbey, and the profits should be used for the monastery community as well as for charity and development projects. Method of production, quality and traceability of the products, as well as communication is controlled by the International Trappist Association. (ITA, n.d.) These values tie to all three aspects of a CE. The monastery in Tilburg aside from beer also produces cheese, chocolate, cookies, honey, and jams. (ITA, n.d.) The beer at La Trappe is co-produced with Swinkels Family Business (formerly known as Bavaria). Other stakeholders involved in the project are the European Commission who is providing a Horizon2020 grant to fund the pilot project, the water board of the Province De Dommel, and Biopolus, a Hungarian company building the greenhouse and micro-nutrient reactors for the brewery waste stream line (NextGen, 2019).

The case study aims to give an insight into a successful strategy for a CE business model at La Trappe. The application of the new CEBM framework and indicator set will offer insight into advantages and drawbacks of the developed framework and show its potential for use in additional cases in the food and beverage sector. It will also give insight on the performance of the MELiSSA based technology in terms of its contribution towards a Circular Economy.

1.4. Industrial Ecology for a Circular Economy in the Food and Beverage Industry

Connecting former water, energy or material waste streams, as is aimed for in this project, to create closed loops and circular system is an integral part of the interdisciplinary study of Industrial Ecology (IE). IE studies the flow of materials, water, and energy through society and aims at closing these loops. It does so by applying a systemic approach, and by integrating the three pillars of sustainability, people, planet, profit. Only by taking into account the economic, environmental, and social impacts of a circular economy, can it truly lead to sustainable development. For this reason, it is highly relevant to link CE, both in theory and in its practical application to the tools and approaches provided by IE. While IE studies societies metabolism in urban regions, it does so too, for industrial clusters and processes. Insight from IE can provide ways of incorporating CE into industrial sectors, and to combine and repurpose waste flows similar to natural ecosystems. (Ayres, Robert U, & Leslie, n.d.; Short, Bocken, Barlow, & Chertow, 2014) Industrial Symbiosis, connecting different industrial sectors to each sector's benefit, can, for instance allow sugar processing companies to raise their profits and reduce environmental impacts by growing tomatoes, and it might be used in the case of La Trappe to show the potential of a beer waste flow to be repurposed with technology designed for space to produce energy and grow fish to contribute to a more sustainable society.

The research project focusses on the valorisation of waste and the implementation of CEBMs within the food and beverage process industry. The focus will be put on the biological loops of materials, nutrients, water and will include energy, while not focussing on technical cycles of packaging materials or equipment needed for production. The study was performed by an individual MSc student in the time period from January to July 2019.

2. Literature Review

2.1. Selection Criteria and Literature Review Methodology

To understand the significance and the challenges of Circular Economy for the food and beverage industry, as well as the developments regarding CE business models and indicators in the field, a literature review was performed. The review of current literature on the topic allows to build upon existing knowledge in the field.

The literature review first addresses the components of a Circular Economy and its significance for the food and beverage industry within the bio-economy. In a second step, ways to measure CE in this sector are reviewed. Then, the review looks at CE from a company perspective and the development of CE business models and ways to measure CE performance. The literature review uses elements of a systematic literature review for structuring the search process. A systematic literature review is meant to give an objective and diverse overview of existing research in the field based on a keyword search. This form of review is meant to provide an explanation of the literature chosen as well as more transparency and replicability than classical reviews. (Denyer & Tranfield, 2009; Merli, Preziosi, & Acampora, 2018) The key word search has been used for collecting relevant literature in the field of CE. Similar to a systematic literature review, the search terms and scope were determined by the researcher. (Tranfield, Denyer, & Smart, 2003) This approach served as a starting point for the selection of literature and offered a way to make the search transparent and replicable. The quantitative analysis of the chosen articles, as can be seen in typical systematic literature review articles, however, was not deemed a needed step for the purpose of this research. For gaining an initial understanding on the current perspectives of CE in the food and beverage industry, in the first step, a keyword search was performed in Web of Science based on the terms "circular economy" AND ''business model'', ''sustainable business model'' AND ''framework'', ''sustainable business model'' AND ''food'' OR ''beverage'' as well as ''business model innovation'' AND ''bio-economy'' AND/OR ''circular economy'' AND/OR ''sustainability''. The resulting papers were then screened according to the number they were cited previously to gain an understanding of the most discussed papers in the field. For this purpose, 'highly-cited' papers representing the top 1% of the field and 'hot' papers, which were cited frequently in the recent months were selected. Then they were manually checked for eligibility based on their content. In addition, duplicates were removed. The papers acquired through these processes were published between 2010 and 2019 and can be assumed to represent the most up to date findings and research in the field. In addition, another search was conducted in Scopus to complement this literature based on the key word search ''circular economy'' AND ''food'' as well as ''circular economy'' AND ''beverage''. For this search, no time limit was defined. However, the selection was based on the top 20 cited papers, out of which eight were deemed relevant for this research topic.

In a second step, the literature review was expanded with snowballing through automatically recommended articles in Elsevier based on each article chosen from the above-mentioned search criteria. This allowed to identify further relevant articles, including papers outside of the time-frame chosen in the first step. This resulted in an additional 25 scientific articles that matched the topic.

While these two initial steps formed the basis of the research, additional literature was later acquired through recommendations from experts in the field, or follow-ups on footnotes and bibliographies in the literature reviewed at later stages of the research. In addition, several reports and notes from the companies involved in the case studies were used to complement the information obtained from the scientific papers.

The literature review focusses first on a definition of CE, especially when applied in the bio-economy, and ways to measure CE. In a second step, the focus is put on the micro, or firm level, and examines business model innovation for the creation of CE business models within the domain of sustainable business models. Based on the selected literature, a definition of CE for the food and beverage sector, as well as the connection between CE and sustainability is established. In the following step, major challenges were identified for this sector in developing a CE.

2.2. A Definition of CE

In the recent years, the Circular Economy (CE) has turned from a buzzword towards a goal in the policy agenda in many countries, and the centre of attention for many research projects in the area of sustainability. CE is seen as a way to incorporate sustainable development into the business level. (Kirchherr, Reike, & Hekkert, 2017a) To understand the significance of CE for the food and beverage sector it is important to understand the origins of the concept and its definition.

Despite a common notion of CE, there is no single clear-cut definition. Most CE approaches are focussed on closing material loops by implementing reverse supply chains and designing products for reuse or recycling. (Ellen MacArthur Foundation, 2017c; Kirchherr, Reike, & Hekkert, 2017b; Stindt & Sahamie, 2014) CE aims at redesigning the economy by turning it from its current linear state into a circular state. This design is meant to mimic biological ecosystems and their circular streams. What is a waste product of one plant is valuable fodder for another living being. The same concept is applied in CE to achieve higher economic benefits while reducing raw material usage and lowering environmental impacts (Lieder & Rashid, 2016). Material streams of one company are connected to other companies and former ‘’waste’’ streams are repurposed as valuable input and secondary raw materials and are used to form a closed-loop to avoid waste accumulation. (Iacovidou et al., 2017) This principle can to a certain extent be used for by-products within the food and beverage industry. In the food and beverage production sector, the focus lies in terms of CE lies on the recovery of organic materials, in particular nutrients, as visualized in the biological loop of the Ellen MacArthur foundation’s butterfly diagram. (Ellen MacArthur Foundation, 2017b)

The concept of CE has gained increased importance as it is seen as one way to create sustainable development and to reduce the burden on the planet. Principles, such as “systems thinking, stewardship, transparency, collaboration, innovation and value optimization” are oftentimes included in a definition of CE (Pauliuk, 2018). What these principles have in common is that they are aimed at turning economy from a linear into a circular system (Ellen MacArthur Foundation; McKinsey Center for Business and Environment; Sun, 2015).

2.3. CE and Sustainability

Circular Economy is seen as a business approach to sustainable development by focussing on waste valorisation. Sustainable development is defined in the Brundtland report as meeting ‘’the needs of the present without compromising the ability of future generations to meet their own needs’’ (UN, 1987, paragraph 27), and typically involves considerations both for the environment and society. This is expressed through the three pillars of sustainability: society, economy and the environment. Although CE has different origins from SD and a stronger focus on economic benefits, it is seen as a beneficial condition for sustainable development. (Geissdoerfer, Savaget, Bocken, & Hultink, 2017) However, this link is hardly ever explicitly stated in scientific literature, and CE definitions mostly focus on profitable resource re-usage. (Kirchherr et al., 2017a) Since the final aim of CE is to lead to sustainable development, sustainability of people, profit, and planet should play a central role in defining the CE and in assessing CE projects. (Elkington, 2004). These three pillars should and can be included in defining a (sustainable) CE. However, reviews of CE articles found that sustainable development and CE were oftentimes only weakly linked (Kirchherr et al., 2017a). A stronger focus on the underlying motivations for creating a CE need to become more dominant.

For a CE, the economic aspects tend to prevail, and a project will only be successful if value can be created from creating a product from a waste stream. This allows to embed the CE strategy in our current economic system even though system changes are needed in the way materials are mined, processed, and (re)used.

Environmental aspects form the underlying motivation for creating a CE. Reducing waste and using resources more efficiently implies a reduction of resources needed and connected to that less emissions and less climate change. A Circular Economy is therefore assumed to contribute to decoupling economic growth from (virgin) resource use and negative environmental impacts. For this to be the case consumer and user behaviour needs to be taken into consideration to avoid rebound effects that counteract improvements from circularity or resource efficiency. (Ghisellini, Cialani, & Ulgiati, 2016)

As the aim of a CE is to reduce the burden on the environment, its environmental performance at every step of the CE needs to be taken into account in addition to the resources that are being reused. This means, that energy requirements for the establishments of the closed loops, as well as potential negative effects, such as pollution, need to be accounted for. By creating a fully circular economy negative externalities, such as delayed costs from pollution, negative health effects or waste management will be reduced.

Social aspects are oftentimes not taken into consideration when defining and measuring CE. For instance, in a review of 114 papers on CE Kirchherr at al. (2017a) only detected view papers that took into consideration social equity or a customer perspective. Social value creation also needs to be more strongly incorporated in business models for a CE and the role of social business models needs to be explored (Bocken, Short, Rana, & Evans, 2014). A long-lasting circular economy requires not only a sustainable business model and sustainable resource and energy usage, but also sustainable management of social capital. This means, that people engaged in and impacted by the circular economy should be able to lead healthy lives, have access to healthcare and education and be included in the decision-making processes. This refers to all levels of the CE supply chain from production processes to consumption. Taking into consideration social aspects is considered particularly important for the bioeconomy, as food production and consumption is closely linked to basic needs. (Siebert, O'Keeffe, Bezama, Zeug, & Thrän, 2018).

However, a CE is not as such designed to lead to lower negative environmental and social impacts. Closing loops might be connected to higher energy usage, or might not decrease primary resource demand, but drive consumption. At the same time, ensuring consumer health when re-using waste and increased treatment is linked to increased energy demand. Moreover, only when the products created from waste valorisation truly substitute a product created from primary raw materials and having a similar or lower energy demand for its production will there be reduced negative environmental impact. (Figge & Thorpe, 2019; Zink & Geyer, 2017) For this reason, it is important to include economic, environmental and social considerations in designing and assessing CE projects. Then, a Circular Economy will provide additional financial value to a company's business and a national economy, reduced strain on the environment through circular resource use, and a healthier living and working environment for humans. At the same time, CE is expected to create more high-quality jobs and by alleviating pressure on the environment providing a healthier ecosystem, benefitting society locally and globally. Alongside other contemporary societal challenges in a globalized world, CE is thought to be reached by thinking 'glocally', thus, by acting locally and thinking globally (Kefalas, 1998).

By tying CE to sustainability, this allows to not only tackle climate change and the problem of sustainable resource management but also alleviate inequality in the economic system. This will allow for the creation of business models that truly form a sustainable CE over a long period. This perspective of CE applies to both the technical as well as the biological loop of circularity.

2.4. Challenges of CE in the Food and Beverage Industry

In addition to agreeing on an overall definition of CE, there have been debates about what constitutes a circular economy in the food and beverage industry. Considering the assumption that the underlying motivation for CE is to lead to sustainable development, the main challenges and waste flows of the food and beverage industry in this regard will be explored.

The food and beverage industry lies at the heart of food production and consumption and is seen as a central element in the bio-economy. The bio-economy is defined as covering ‘’all sectors and systems that rely on biological resources (animals, plants, micro-organisms and derived biomass, including organic waste), their functions and principles’’ including not only primary agriculture but also ‘’industrial sectors that use biological resources and processes to produce food, feed, bio-based products, energy and services’’ (European Commission, 2018)

The EC report on best available techniques (BAT) for the food, drink and milk (FDM) industries identified water usage, waste water, air pollution (including odour), waste production, and high energy usage for heating and cooling during processing stages as the main challenges of this sector. (European Commission, 2006) The EC stated in their communication paper on the efficient use of resources that for food and beverage production the focus should be put on reduction of the use of fossil fuels, better mineral and water usage and avoidance of pollution and eutrophication through fertilizers, reduction and re-use of biowaste, reduction of land-take and restoration of ecosystems as well as biodegradable or recyclable packaging. (European Commission, 2011). These policy points show a strong focus on the biological loop of the butterfly diagram of the Ellen MacArthur foundation. A definition of circular economy for the food and beverage sector can be based on the biological loop. To restore this loop and create a CE it is necessary to return resources (including water), nutrients and materials back to the planet in a restorative way, without causing damage. (Breure et al., 2018; Buckwell & Nadeu, 2016)

It needs to be pointed out that this assumption puts the focus on the main bio-based product and does not include the packaging which in most cases falls within the technical loop and requires different forms of re-use or recycling for closing the material loop. To focus on a CE based on the biological loop, mineral cycles, water use, land use, and energy use will be considered the main areas to study when aiming for a circular economy in the food and beverage industry.

Looking at the challenges of the food and beverage industry in creating a circular economy is not possible without a broader perspective on the entire bio-economy. As businesses in the food and beverage industry play a major role in the demand of agricultural products and the shaping of consumers’ demand taking more of a systems approach is needed to understand how to truly manage the challenges of this industrial sector beyond industrial processes. For every Euro spent on a food product, society is required to spend two euros for environmental and societal damage control (EllenMacArthur Foundation, 2019). These societal and environmental challenges mainly concern land use, water use, nutrient use and energy usage as well as human health, pollution and waste creation.

2.4.1. Land and Soil Use

Land and soil use have to be considered when speaking of a Circular Economy in the food and beverage industry. Soil is as a non-renewable resource at its recovery is slow. At the same time, it is vital in the provision of raw materials for food and biomass production as well as in the storage and transformation of water, minerals, and carbon. Unsustainable resource use leads to soil pollution, more land use and land use change. This impacts ecosystems and biodiversity and also competes with living space for humans. (Breure et al., 2018) Forms of urban farming or vertical farming are tackling increased land and soil use by using available spaces on roof tops or by growing food vertically. When linked to automatic water and nutrient circulation, either in the form of hydroponics or in the form of aquaponics they not only reduce land area required to grow vegetables and fruit, but also reduce water and nutrient losses. (Besten, 2019; Quagrainie, Flores, Kim, & McClain, 2018) This, however, comes at higher energy requirements and might not always be economically feasible as high upfront investments are needed. For a circular system based on the biological loop, sustainable use of land and soil should play a role in the selection of supplies in the food and beverage processing industry.[1] Promoting sustainable agriculture when choosing input material could be one way to help reducing land use change and soil degradation.

2.4.2. Water Use

Overexploitation of water sources increasingly becomes an issue, especially in the food and beverage sector, which heavily relies on agriculture and agricultural products as input (FAO, 2011). In addition, many production processes are highly water intensive. Local draughts, even in water-rich countries, such as the Netherlands, are increasingly common due to climate change and intense agricultural and industrial practices. Breure et al. (2018) suggest that taxes on natural resource usage, such as ground water, might be adopted in the future as incentives to develop more CE strategies.

Secondly, water pollution due to insufficient treatment of waste water has large impacts on human health and the environment. (Vermeulen et al., 2012) Therefore, waste water management plays an important role in a circular economy for the bioindustry. The focus here lies on treating the used water from agriculture, households, and industry in a way that it can be returned to the environment without causing any harm or stocks of poisonous chemicals to build up in the environment. EU-wide legislation, such as the Water Framework Directive (WFD), as well as many national legislations, lay the foundation for the minimum quality level of water that is returned to the environment (EU Commission, 2019). Removal of excess nutrients is not only needed to regain potential value and ensure food security but also to avoid environmental impacts, such as eutrophication of water bodies (Cornel & Schaum, 2009; Pandey, 2018; Withers et al., 2015). For a circular economy, reaching drinking water quality through removal of contaminants, especially antibiotics, will become increasingly important (Christou et al., 2017).

2.4.3. Mineral and Resource Use

Closing mineral cycles is one of the core concerns of CE in the food and beverage industry. Most minerals reach humans through the food they consume. These elements are absorbed by plants from the soil and water, and then consumed by humans directly (or indirectly through animal products). There are 18 essential elements that humans need for maintaining good health. They comprise of six macro-elements and twelve micro-elements. Macro-nutrients are needed in larger quantities, and micro-nutrients are sufficient in smaller nutrients to ensure a healthy life of humans, animals and plants. (PBL Netherlands Environmental Assessment Agency, 2017)

For plants to grow, the availability of phosphorus (P), nitrogen (N) and potassium (K) is particularly important. These are needed in the largest quantities. In addition, plants require calcium (Ca), magnesium (Mg), and sulphur (S). In addition to macro nutrients, micronutrients, such as iron (Fe), manganese (Ma), boron (B), chlorine (Cl), zinc (Zn), copper (Cu), nickel (Ni) and molybdenum (Mo) are needed for plant health. In a natural ecosystem, mineral cycles are closed as plants take up nutrients from the soil. When plants decay these nutrients re-enter the soil. (Pandey, 2018) In agriculture, where plants are harvested, these nutrients are displaced and have to be re-introduced artificially. Mineral streams are imported with fertilizers and exported with food product export. This leads to regional imbalances and to massive need for fertilizer purchasing for soils used for intensive agriculture. Many agriculture-intensive European countries suffer from oversaturated soils, and pollution of water bodies with nutrients or chemicals. The mineral losses from agriculture and industrial production cause severe environmental pollution. On a European level, 18-46% of mineral nitrogen, and 42% of mineral phosphorus are lost in the food production processes. (Buckwell & Nadeu, 2016) Sustainable and circular use of nutrients is also needed as mining of nutrients occurs in conflict areas, or is only possible in few countries which leads to a high risk of supply and geopolitical dependency. (Coppens, Meers, Boon, Buysse, & Vlaeminck, 2016; Pandey, 2018)

[1] For instance, different management styles or new ways of farming offer a way to reduce nutrient losses or accumulation in the soil (Buckwell & Nadeu, 2016).

Besides pollution reduction, recovering the nutrients with the most important concentrations in waste flows will be considered essential for a CE in the food and beverage processing sector. This will allow to recover valuable resources and at the same time limit pollution. The most important nutrients for plant growth are P, N, and K and their recovery will be looked at in more detail.

2.4.3.1. Phosphorus

Phosphorus (P) is an essential element needed for photosynthesis and plant growth. For humans, it is essential for the growth of cells, bones and teeth. Phosphorus, which is an essential part of fertilizers, is won by mining of phosphate rocks. (Buckwell & Nadeu, 2016; Linderholm, Tillman, & Mattsson, 2012)The mining from the open mines is highly energy-intensive, requires large amounts of water and produces large quantities of waste. For one ton of P, 21t of waste are assumed, of which one quarter is radioactive phosphorgypsum. In addition, 85% of phosphate rock stems from only, only Morocco and Western Sahara, China, and the US. (Cordell, Drangert, & White, 2009) For this reason, phosphate is a part of the list of the 20 Critical Raw Materials, based on the importance for European economy as well as the supply risk of the raw material. Better management of resources and a closed mineral cycle would reduce any geopolitical supply risks. (Buckwell & Nadeu, 2016; Malhotra, Vandana, Sharma, & Pandey, 2018)

In addition, P is often traded indirectly, across the entire globe, through food and fertilizer imports and exports. Managing P cycles therefore needs to ensure a balanced distribution of P along the supply and consumption chain of products (see *figure 2-1*).

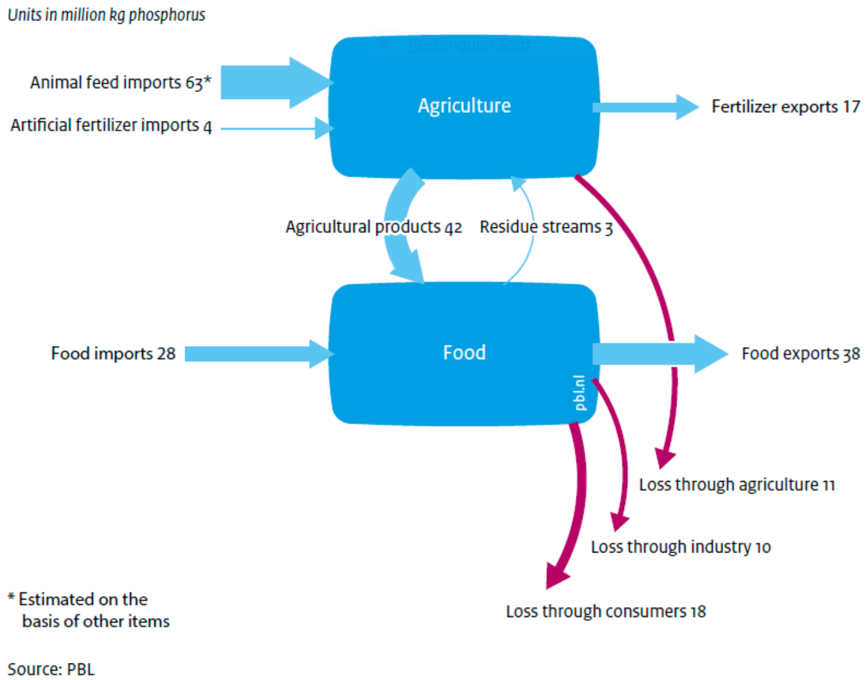

Figure 2-1 Phosphorus streams in the Netherlands. (PBL Netherlands Environmental Assessment Agency, 2017)

Displacement of P, as well as of other nutrients, could be reduced by employing more of a systems perspective. Existing policies, such as the Phosphate Cycle Agreement, limit the use of fertilizers to reduce soil and air pollution. At current, the nutrient use efficiency (NUE) of phosphorus is 30%, which signifies that less than a third of P input to agricultural production ends up in human consumption. (Buckwell & Nadeu, 2016) Measures to recover P include secondary phosphate use for animal feed and fertilizers as well as phosphate recovery from sewage sludge. (PBL Netherlands Environmental Assessment Agency, 2017)

2.4.3.2. Nitrogen

Nitrogen (N) is essential for growth and reproduction of all living organisms, and occurs in DNA and RNA, as well as in chlorophylls, which are responsible for photosynthesis in plants. 70% of fertilizer applications measured in volume stem from nitrogen applications. In large quantities, however, it is damaging to the environment, and in its varying forms can cause damage from algae blooms in lake (NO_3), over ground level ozone (N_2O) to respiratory problems in humans (NO_x). (Cox, Pradhan, & Vanderbeck, 2019; Mosier, Syers, & Freney, 2013)

Nitrogen is the only mineral that does not need to be mined but can be extracted from the air in the form of nitrogen gas (N_2) that then is transformed into ammonia (NH_3) or nitrate. N_2 makes up over 80% of the atmosphere. It is, however, an inert gas until it combines with other atoms. When it forms chemical compounds, it becomes 'reactive', and can be processed and taken up by plants. There are several forms of nitrogen, depending on its state of oxidation. Reactive nitrogen mainly occurs in four forms: Ammonia (NH_3), nitrates (NO_3), nitrous oxide (N_2O) and various nitrogen oxides relevant for air pollution (NO_x). Ammonia is generally found in manure and biomass and is a vital element in protein formation and plant growth. Nitrates are often used as fertilizer but due to their water solubility often end up polluting water streams through run-off or through untreated waste water. Nitrous oxide, which is formed in agriculture as well as industrial processes, is 300 times more potent GHG than CO_2. NO_x are mainly found in exhaust fumes and known to cause respiratory diseases. (Cox et al., 2019; Dodds, Burgin, Marcarelli, & Strauss, 2017; Metcalf & Eddy Inc., Tchobanoglous, Burton, & Stensel, 2003; Vermeulen et al., 2012)

Nitrogen can be taken up by plants in different chemical compounds, from the soil mostly in the form of either ammonium (NH_4+) or nitrate (NO_3-). In a closed ecosystem, bacteria or microorganisms typically transform nitrogen to reactive nitrogen that can be taken up by plants. Denitrification takes place and un-reactive nitrogen cycles back into the atmosphere. Nitrate leaching and denitrification due to use of nitrate fertilizers are the most prominent sources for N loss in Europe. (In other countries, due to the use of urea losses occur through volatilization of N in the form of ammonia.) (Mosier et al., 2013) To create fertilizer from nitrogen in the air nitrogen fixation is needed. One way of synthetic nitrogen fixation is the Haber-Bosch process. For nitrogen fixation from the atmosphere with the Haber-Bosch process energy is required to create high temperature and high pressure. This energy is most commonly supplied in the form of natural gas (CH_4). In this process N_2 is converted to ammonium (NH_4) which can be used as mineral fertilizer. This fixation process contributes to 1% of all global fossil fuel use. (Buckwell & Nadeu, 2016; Dodds et al., 2017; Lawlor, Lemaire, & Gastal, 2001)

Throughout the value chain in food and beverage production 87% of all nitrogen is lost. A way of recovering nitrogen from waste streams and returning it to where it is needed for plant growth is therefore important in the creation of a more closed nutrient cycle. (Breure et al., 2018; Buckwell & Nadeu, 2016) For the first time, a global resolution on nitrogen and its management was drafted in March 2019 in recognition of the importance to manage the nitrogen cycle. (Cox et al., 2019)

2.4.3.3. Potassium

Current recovery schemes focus mainly on phosphorus and nitrogen. However, potassium (K) is a vital macronutrient. Adequate potassium levels are needed to ensure the ripening of plants and were also found beneficial for soils in handling draughts and retaining water for a longer period of time. (Zörb, Senbayram, & Peiter, 2014)

Potassium is won by mining potash, which typically refers to salts containing potassium (Baset, 2015). 80% of potash stems from only five countries, which could lead to potential supply risks in the future. Potash is expected to deplete earlier than phosphorus rock. More potassium is used globally for fertilization of soil than phosphorus per annum (32 Mton of K, versus 21 Mton of P) (S. Johansson, Ruscalleda, Saerens, & Colprim, 2019). Potassium can be recovered from waste stream after the nitrogen removal step in the form of potassium struvite ($MgKPO_4 \cdot 6H_2O$, MPP) from centrate. The recovery rate depends on temperature and pH value of the fluid. At current, potassium recovery is still at a research stage. (Johansson et al., 2019)

2.4.3.4. Other Minerals

Other minerals accumulate in much smaller quantities. Research so far has not yet been focussed on nutrient usage in agriculture besides P, N and K. However, for plants to grow, sulphur, magnesium, and calcium are important for initial growth, photosynthesis, and life-span of the plant. (Yara, 2018) Their transport through the agricultural and economic system has been less closely monitored than for P, N, and K. However, lack of these micronutrients can limit nitrogen uptake, and hinder plant growth and development. (Mosier et al., 2013) The importance, use and application of other macro- and micronutrients should, be further studied to truly create closed nutrient cycles.

2.4.3.5. Organic components of waste water

Typical waste water streams also contain organic material that needs to be broken down by bacteria or through chemical reactions. Solids, contained in the waste streams can be measured as total solids (TS) after drying a sample taken from the WW stream, or total dissolved solids (TDS) and total suspended solids (TSS). The latter is obtained filtering the WW sample. The solid materials consist of fibres, and proteins as well as fats, oil and grease (FOG), that when removed from the water have the potential to be reused. To measure the organic pollution in water the biological oxygen demand (BOD) is used. This parameter represents the amount of oxygen needed to break down organic matter in the waste stream. (Metcalf & Eddy Inc. et al., 2003) A healthy river stream should have a BOD value of below 1mg/l water. Too high BOD levels harm microorganisms in water systems that rely on oxygen. Chemicals in the water that need to be broken down are normally measured via the chemical oxygen demand (COD), which includes both the oxygen demand for organic and inorganic material[2]. (Hopcroft, 2014; Metcalf & Eddy Inc. et al., 2003) While recovery of these organic components not only reduces pollution, it can also allow for value recovery. Depending on the quality and pollution of the waste, recovery from food products to biogas production is possible (Alsheyab & Kusch-Brandt, 2018).

2.4.4. Food Waste

In total, one third of all the food produced is wasted before it ever gets consumed and enters a waste water stream. In the NL alone, this represents a value loss of 4.4 billion €. With growing demand for food globally, reducing losses would offer economic potential for increased food exports (Dolman, Jukema, & Ramaekers, 2019). While half of food waste occurs at the customer level, significant amounts of waste occur due to inefficiencies or residue streams during processing. (PBL Netherlands Environmental Assessment Agency, 2017) Waste re-use and reuse of residue streams of products is already taking place in most countries. However, obstacles in legislation, lack of knowledge or of financial incentives lead to re-use with lower value than its potential. Conflicting goals, such as promotion of sustainable energy from biomass or food safety standards add additional hurdles to optimize re-use of waste. (D'Odorico et al., 2018; EC, 2019; PBL Netherlands Environmental Assessment Agency, 2017) Supply chain and partnership management is therefore needed to ensure that losses are minimized during food processing and distribution.

2.4.5. Energy Usage

Food production, processing and waste treatment processes are energy intensive and to a large degree still rely on the use of fossil fuels. The FDM sector requires 45% of its energy use for process heating and cooling, making it the fifth most energy intensive industry. For instance, for Germany in 2006, more than 75% of the energy used stemmed from fossil fuels (European Commission, 2006; Vermeulen et al., 2012)

[2] Volatile organic compounds, sulphur, disinfection by-products and other components in wastewater that need to be considered when returning water to the environment in ensuring no negative impact on the health of the ecosystem as well as of humans.

The food and beverage industry therefore has a significant impact on GHG emissions and global warming. Re-using waste heat and switching to non-fossil forms of energy generation as a sub-element of creating circularity is needed. Re-using materials from waste streams, such as through nutrient recovery, is oftentimes connected with energy-intensive extraction processes. Heating or cooling of water streams, or adding electricity, might be required in order to extract material. (Seneviratne, 2016; Sun et al., 2018) In many cases, a trade-off and full assessment of the impact of the product in terms of energy demand and environmental and social impact will be needed.

In addition, circular economy and CO_2 emission reduction policies might conflict as current subsidies for sustainable energy from biomass promote the creation of biofuels from residue streams and discourage companies for exploring alternative solutions that are located higher up on the value pyramid. This causes not fully closed loops and losses in potential value to be recovered. (Banja, Sikkema, Jégard, Motola, & Dallemand, 2019; Massara, Komesli, Sozudogru, Komesli, & Katsou, 2017; PBL Netherlands Environmental Assessment Agency, 2017) A truly CE will need to explore the circularity option with the highest value and lowest energy requirements and losses.

2.5. The Significance of CE in the Food and Beverage Industry

To sum up, the main challenges involved in the production of food and beverage products are the high usage of water, energy, and nutrients throughout the supply chain and during production. Nutrient pollution from agriculture and wastewaters lead to deterioration of water quality, air and soil quality, ecosystems, and as a consequence human health (Dri, Antonopoulos, Canfora, & Gaudillat, 2018). A holistic approach is needed to reduce nutrient losses (Sutton & Billen, 2011). A systems thinking approach forms the basis of creating CE projects at company level in the food and beverage industry. In addition, no circular system can be 100% circular as there will always be inefficiencies. Furthermore, trade-offs between increased circularity and pollution control and energy usage will be needed. While more waste materials can be extracted, this oftentimes comes at higher economic and environmental costs (Dri et al., 2018).

While the term circular economy was applied only in recent years for the bio-based economy sector, efficient use of resources has been practiced already during the last decades. Policies for sustainability, green growth, resource efficiency and bio-economy have already been focused on reducing waste and closing loops. (PBL Netherlands Environmental Assessment Agency, 2017) A circular food and beverage industry can be based on these terms as it needs to have at its basis a circular material and water flow within its industrial processes and should use its all by-products and waste products. Energy used for these processes should come from renewable sources. However, its focus lies on repurposing waste streams in the best way possible by considering the entire cycle of the product. For this reason, a systems perspective needs to be applied by managing the supply chain with regards to sustainable practices of suppliers and ensuring reduction of losses of material and energy on consumer sides through education, and investment and support of nutrient recovery projects where possible. As a link between production and consumption the food and beverage industry is a lever in creating a circular system in the entire bioeconomy.

Thus, for defining a CE for the food and beverage industry, circularity within the entire production and consumption system is needed. This requires a systems thinking approach. This idea is already found in the EC's guidelines on BAT where ''BAT are to seek collaboration with upstream and downstream partners, to create a chain of environmental responsibility, to minimise pollution and to protect the environment as a whole'' (European Commission, 2006, vi). When creating a circular system of nutrient and water flows, the entire supply and consumption chain needs to be taken into consideration. It is in agriculture where most nutrients are removed and used and transported through production processes to customers for consumption. From a company perspective at a processing level, an overview of the impacts of their products at a production level might allow for measures reducing these impacts, such as education on ore sustainable farming techniques, or returning nutrients recovered from waste streams to the production sites to agricultural fields in the form of fertilizers. In addition, water needs to be seen as valuable resource in this sector. High water usage and accumulation of nutrients or other forms of pollutants in the used water, occur throughout the entire supply chain and the production processes. Water leaving production and consumption stages still needs to undergo energy-intense treatment. (Metcalf & Eddy Inc. et al., 2003; Seneviratne, 2016)

In addition, collaboration between industries by forming industrial symbiosis systems as based on concepts found in the field of Industrial Ecology can be sued to better share resources, repurpose and use waste and close water, energy and material loops. Mirabella et al. (2014) offer an overview of how to repurpose various waste streams in the food and beverage industry. By cooperating with industries from different sectors innovative ways of re-using waste as secondary raw material could be found.

Thus, striving for more circular and efficient nutrient and water use, and supporting sustainable and circular agricultural practices as well as investing into research and innovation to regain nutrients at the end of the life cycle, be it in production or consumer waste streams, allows individual companies in the food and beverage industry to create and foster CE practices. Based on this, a CE for the food and beverage industry can therefore be defined as a system that minimizes nutrient displacement and resource depletion, and maximizes water, nutrient and material circularity by re-using waste steams with regards to energy consumption and the impacts on environment, economy, and societal well-being based on a systems perspective. After having chosen the key elements constituting a CE in the food and beverage industry, ways of measuring the progress of the industry and its individual companies in terms of CE have to be identified.

2.6. CE Indicators for the Food and Beverage Industry

To measure economic performance, typically a set of indicators is developed. This is also the case for measuring the performance of an industry in terms of CE. For CE, many different indicators exist, with a focus on many of the different aspects of circularity. The following chapter will give a short overview over the state of CE indicators in academia and provide guidelines on the selection of indicators for the food and beverage process industry.

2.6.1. Important Underlying Concepts for Measuring CE

To understand how to measure CE, especially with a focus on the production sector, it is important to know the historical development of the term and the indicators it builds on. Circular Economy builds upon prior existing industry practices for more efficient and cleaner production (Ghisellini et al., 2016). Cleaner Production (CP), or pollution prevention, refers to the reduction of waste and emissions, with maximization of production and was first coined by the UN in 1990. It was later expanded to Resource Efficiency and Cleaner Production (RECP) to better include optimization of production processes and their impact on human lives and ecosystems. (El-Haggar, 2007; UNEP DTIE, n.d.) Cleaner production aims at creating higher efficiencies within a linear system. These production improvements are important within a CE. (Sousa-Zomer, Magalhães, Zancul, Campos, & Cauchick-Miguel, 2018) CE, too, focusses on recyclability and extended life-spans of products but its ultimate goal is to remove waste as an output of the system and create circularity. Concepts of cleaner production were later integrated into the term *eco-efficiency*. Eco-efficiency is understood as the value of the product divided by the environmental impact that the product causes. (Widheden & Ringström, 2007) While CE goes beyond eco-efficiency, some of its key indicators can be used in understanding the impact an industrial process has on the environment and on human life and in the development of circularity within industrial processes. In a perfect CE, eco-efficiency would equal 100%, meaning that all cycles are perfectly closed. With perfectly closed cycles there would be no more pollution as outflow, and no more primary raw materials needed as input (assuming constant demand of the product) (UNEP et al., 2011) This, in practice, is however, not attainable, as there will always be losses.

The degree of eco-efficiency is measured by a set of key indicators. The key indicators for eco-efficiency (EEI) were designed by the World Business Council for Sustainable Development (WBCSD) and are based on a reduction of material and intensity of goods and services, reduction of the spreading of toxic material, extension of a product's life-span and better recyclability, maximum sustainable use of renewable resources. They examine the intensity of land, water, material and energy use as well as the amount of pollution created in production processes. (United Nations ESCAP, 2009) Concepts of cleaner production and eco-efficiency, however, can be incorporated in measuring production processes and their environmental impact within a CE.

Ultimately, CE is based on the school of thought of Industrial Ecology. Industrial Ecology (IE) studies the flow of materials, water, and energy through society and through industrial processes. It aims at mapping these flows and minimizing waste flows by creating closed loops (Lüdeke-Freund, Gold, & Bocken, 2019). Tools and methods of IE are highly suitable in understanding the environmental impact of products and services throughout their entire life-cycle. They allow to analyse flows within the circular economy and design new systems. IE aims at providing a scientific understanding of 'sustainability' and provides the tools needed to measure CE. Typically, tools like Life-Cycle Assessment, or Mass Flow Analysis, or Environmental Input-Output Analysis can be taken into account when measuring CE (Ayres et al., n.d.; El-Haggar, 2007; Guinée et al., 2001; Udo de Haes, 2002). However, while they are suitable for pointing out the environmental impacts of products or sectors, they are less suited to point at social or financial impacts. For this reason, additional tools and indicators need to be chosen to receive a complete picture of the impacts that CE has.

There are several approaches to measuring the progress in achieving a circular economy. Circular Economy can be viewed from a macro, meso, and micro perspective. While the macro level measures CE on a global or national level, the meso level focusses on specific regions, and the micro level on companies or individual products. (Saidani, Yannou, Leroy, Cluzel, & Kendall, 2019) For the purpose of this research, only the micro level will be looked at in more detail. Viewing CE in the food and beverage sector from a micro level is particularly challenging if a closed loop is not seen as something that can be achieved within a business but that involves nutrient transportation throughout the supply and consumption chain and back to nature.

2.6.2. Existing CE Indicators

To identify suitable indicators to measure CE within the food and beverage sector an overview of existing CE indicators will be performed to offer an overview. The focus will be put on micro-level indicators that can be used on a business level.

An abundant source of indicators can be found that aim to measure the circular economy. (Ellen MacArthur Foundation; Granta Design, 2015; Griffiths & Cayzer, 2016; Linder, Sarasini, & van Loon, 2017; Mayer et al., 2019; Moriguchi, 2007; Vercalsteren, Christis, & Van Hoof, 2017) Several taxonomies have been created to categorize and offer an overview over existing CE indicators on the macro, meso, and micro level. Saidani et al. (2019) reviewed existing papers on CE indicators and highlight the most commonly cited ones. Based on this review of 55 circular economy indicators, all the indicators mentioned were reviewed for their applicability for the food and beverage industry. For this research, only indicators on the micro and meso level, relating to products and companies or industrial symbiosis-based circularity, were considered. This resulted in 18 indicators[3] that were identified (see *table 2-1* and *table 2-2*). Their suitability for the food and beverage sector was examined by checking whether they included or were based on the biological loop (to focus on organic material and nutrients). In a next step, it was tested whether aside from material recovery, the indicators also measured economic, environmental and social impact. This was followed by reviewing

[3] For two indicator sets, data was unavailable once due to a broken link and once due to privacy regulations of the consultancy developing the indicator. As the two indicator sets were based on the technical loop, this did not limit the research.

whether the set of indicators was developed for a broader application or for a specific industry sector. Then, final comments on the suitability for the indicator set for the food and beverage industry were given.

Of all product-based circularity indicators, only the C2C certification takes into account the biological loop which is essential for the food and beverage industry. In addition, it considers environmental and social impacts of the product assessed (leaving out economic aspects). However, as the C2C is based on an LCA, and requires external assessment it does not offer perfectly suitable indicators for use by companies.

Several of circularity indicators for the technical loop are based on the MCI of the Ellen MacArthur foundation. Due to its frequent use and familiarity, this indicator could be considered for supplementary use, for instance, for packaging material in the food and beverage sector.

Table 2-1 Micro level-based CE. (Based on the selection tool from Saidani et al., (2019)*)*

Circularity Indicator Abbrev.	Circularity Indicator Name	Loop	Pillars	Target	Source	Comments/Suitability	Suitable for F&B Industry
BCI	Building Circularity Indicator	Technical	-	Building material recycling	(Verberne, 2016)	Building on the MCI (see below), this indicator was developed for the technical loop, specifically building materials, and is therefore not taken as central element for the food and beverage industry.	X
C2C	Cradle to Cradle (or Material Reutilization Part)	Technical & Biological	Environmental, Social	Single Products - Certification	(C2C, 2019)	To gain an understanding of the environmental impacts of a product throughout its life-cycle a common indicator used is the Cradle2Cradle (C2C) indicator. This approach is based on life-cycle assessment (LCA) as a means of assessing the environmental impact over the entire life-cycle of the product. While some of the elements comprising the indicator, such as usage or renewable energy forms, health and social fairness along the supply chain, are relevant for the indicators to be developed for the food and beverage industry, this set of indicators is designed for products that are not consumed. In addition, the certification scheme is highly time-consuming and needs to be done by an external assessor. While C2C contains many useful elements for indicators for a CE in the food and beverage industry, they are not fully suitable for application for consumable goods or company-wide assessments.	~
CEI	CE Index	Technical	Economic	EOL recycling	(Di Maio et al., 2017)	It calculates the recycling rate of materials based on their value but does not include products based on the biological loop.	X
CEPI	CE Performance Index	Technical		Plastic Waste	(Huysman et al., 2017)	This indicator was designed for circularity of plastic waste, and thus, not relevant for the scope of the research.	X
CEIT	Circular Economy Indicator Prototype (CEIT)	Technical			(Griffiths & Cayzer, 2016)	This indicator is based on the MCI. (see below) Similar to the MCI, it focusses on the technical cycle and material durability, which makes its application not applicable for the main elements of the food and beverage industry.	X
CI	Circularity Index	Technical	Economic/ Environmental (energy)	EOL recycling	(Cullen, 2017)	This indicator gives a value to different recycling options at the EOL stage. Due to focussing only on the technical loop it will not be considered a suitable indicator.	X
EoL-RRs	End-of-life recycling rates	Technical	-	Metal recycling	(Graedel et al., 2011)	As the focus lies on metal recycling, this indicator set is not applicable for the food and beverage industry.	X
EVR	Eco-efficient value ratio	Product-Service System (Technical)	Economic, Environmental, Social	Circular business models for PSS	(Scheepens et al., 2016)	Based on LCA and economic data, the CE of a product-service system is assessed. It does not focus on creating value from waste.	X

IOBS	Input-Output Balance Sheet				Not available		X
MCI	Material Circularity Indicator					The indicator assesses how restorative the material flow within a company is, e.g. what percentage of the material will be reused or recycled. It takes into account the length and the intensity of use of the product as well as its end-of-life. However, material losses in the supply chain are not taken into consideration. The indicator comes with a sub-set of complementary indicators that measure risk based on material scarcity and toxicity, based on variations to the Herfindahl-Hirschman Index (HHI) measuring the monopoly of supply of a product's constituent. (Ellen MacArthur Foundation; Granta Design, 2015) It was designed for technical loops rather than biological loops. It could, however, be used for the packaging material used by the food and beverage industry.	x
PCM	Product-Level Circularity Metrix	Technical	Economic	Product design	(Linder et al., 2017)	The indicator focusses on economic aspects of a CE for the technical loop only.	X
RIs	Recycling Indices for the CE	Technical	-	Metal recycling	(Reuter & Van Schaik, 2016)	The indicator is in essence a recycling indicator for metals, and thus, not applicable.	X
RRs	Recycling rates	Technical	-		(Haupt et al., 2017)	The indicator looks at the recycling rates of materials at municipal waste plants but excludes organic materials and is therefore not very suited for the biological loop.	X

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Table 2-2 Meso-level based CE indicators (based on the selection tool of Saidani et al. (2019)*)*

Circularity Indicator Abbrev.	Circularity Indicator Name	Loop	Pillars	Target	Source	Comments	Suitable for F&B Industry
CETUS	CE Toolbox US	Technical	Economic, environmental (waste production)	Generic	(U.S. Chamber of Commerce Foundation, 2017)	Generic set of indicators for either companies or products focussing on recovered content as well as the form of energy used for production. It does not focus on environmental impacts or recycling/reuse or social impacts.	x
HLCAM	Hybrid LCA Model	Biological	Environmental	Chemical industry & Food industry	(Genovese et al., 2017)	While studying the food industry from a systems perspective, the focus lies mainly on the environmental aspects, particularly on GHG emissions. For this, a highly specific and data-intensive LCA study is needed. Other aspects of a CE are not incorporated in the indicator set.	~
EISCE	Evaluation Indicator System of CE				Not available		
FCIM	Five Category Index Method	Biological	Economic, environmental	Chemical Industry and wastewater flows	(Li & Su, 2012)	The focus was put on the economic and environmental aspects of waste usage and reduction as well as production efficiencies. This was ranked into four categories from 0-1 depending on the progress towards a CE. The indicators are specifically designed for the chemical industry, focus rather on reduction of impacts rather than waste valorisation and do not take into considerations social elements of a CE.	x
IPCEIS	Industrial Park CE Indicator System	Technical	Economic, environmental	National and regional indicators for IS	(Geng, Fu, Sarkis, & Xue, 2012)	Set of indicators measuring the rate of resource consumption, waste production and pollution. The focus is less on waste valorisation, or social aspects of a CE, and neither waste streams relating to biological cycles.	x
RP	Resource Productivity	Technical	Waste reduction	Industrial Symbiosis system	(Wen & Meng, 2015)	The focus lies mainly on resource use efficiency in an industrial symbiosis system.	x
SCI	Sustainable Circular Index	Technical (recycling & life-time)	Economic, Environmental, Social	Manufacturing industry	(Azevedo, Godina, & Matias, 2017)	A set of indicators was developed for all three pillars of sustainability as a basis for a manufacturing industry based on CE.	x
VRE	Value-based	Technical	Economic	Generic	(Di Maio et	This indicator measures the resource efficiency of process or product by	~

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resource efficiency		al., 2017)	looking based on the value of materials used and recovered. While aimed at the technical loop it could also be used for estimating resource efficiency of, for instance, nutrients in a biological loop.

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What can be seen from the overview on the available CE indicators on a meso-level is that similar to product level indicators most are aimed at the technical cycle. While the FCIM was developed for the food industry it does not look at valorisation of waste (but rather its reduction) and was for this reason not considered as truly suitable indicator for a CE in this sector. In addition, only two sets of indicators in both tables take into consideration all three pillars of sustainability, while most focus on recycling. Overall, social impacts are only considered in three of the indicators. Typically, circularity, and not economic, environmental or social performance is in the centre of most indicators. In addition, measuring production processes, water, or energy usage are oftentimes excluded (Moraga et al., 2019).

Linder et al. (2017) suggest the use of typical tools core to the field of Industrial Ecology for assessing the CE. Tools, such as life-cycle assessments (LCAs), mass flow analysis (MFA), or analysis of industrial symbiosis are oftentimes used to expand existing indicator metrics with a focus on environmental impact assessment. Especially when aiming at integrating a systems perspective, LCA is oftentimes used as a basis. Existing product and organisational environmental footprint indicators (PEF and OEF) are equally based on LCA. (Niero & Kalbar, 2019). However, LCAs are highly time consuming and highly sensitive to the data input. They require experts and a high degree of detailed knowledge on emissions throughout the life-cycle of the product. In addition, financial and social aspects are typically not considered in LCAs. Life Cycle Sustainability Assessment (LCSA) combines LCA, life-cycle costing (LCC) and social aspects via social LCA (s-LCA) to allow for choices between products and to add social and environmental aspects to measuring the impact of the product. (UNEP; SETAC, 2011) However, LCC and SLCA are currently not fully developed. As LCAs require expert knowledge and highly detailed information on sensitive data both company-internally and along the entire supply chain and consumption, indicators based on LCA data could be highly challenging for companies to use. For this reason, for the indicator development of this study, indicators not based on a full LCA will be selected and developed.

In addition, as most of the CE indicators identified in *table 2-1* and *table 2-2* focus on circularity or only on some elements of economic, environmental or social impact, some indicators from existing sustainability measurements could be used as a supplement. A frequently used sustainability indicator is the Global Reporting Initiative (GRI) Standards. The GRI Standards comprise of a thorough set of sustainability standards, divided into economic, environmental and social standards developed for organizations. While not all of them are applicable for CE, they can be used as an input, particularly concerning the social impact standards. The GRI social standards offer indicators on quality of life, health (physical and mental well-being), job creation and satisfaction (fair wage, support of company values), as well as benefits for local community & education. (GRI, n.d.) These are elements that are also relevant when implementing new CE solutions and could also be applied to companies in the food and beverage industry. Famous sustainability indicators, such as the ecological footprint, Environmental Sustainability Index and the Environmental Performance Index focus only on the environmental aspects and fail to create a connection between the economic performance and growth and environmental impact reduction. (United Nations ESCAP, 2009) While their focus lies on sustainable use of resources, they do not all take a circular economy into consideration. However, they could offer a useful set of complementary indicators.

To sum up, most indicators on CE mentioned in the literature focus on the material and its recycling or reusability qualities. While these could be used as complementary indicators for packaging material, they are not applicable for measuring CE of the food and beverage industries and their biological cycles. At current, there is no overarching set of indicators that could be applied for the food and beverage indicators. An indicator for the food and beverage industry and the bio-economy as a whole should take into account the reuse and cascading of nutrients and organic material as well as the reuse of water. In addition, a broader view than in other sectors will be needed to also take into consideration, circulation of nutrients between production, processing and waste water treatment. Overall, (supplementary) indicators should account for all economic, environmental and social impacts of a circular project. There are existing indicators that address one of these three pillars. Some indicators are used to identify the environmental performance of the products over their life-cycle. Only few indicators measure biological loops, financial aspects of CE (apart from LCC), or even social-aspects. LCC and S-LCA deal with social and financial aspects of product cycles but are not yet fully developed and are highly complex. Specific indicators measuring the closing of the biological loop in terms of nutrients, and water are still missing. Therefore, further research is needed to identify a set of indicators that can be used in the food and beverage processing industry. Such a set of indicators can then be connected to the CEBM of a company to measure the performance of business models for developing a sustainable CE.

2.7. Strategies for CEBM in the Food and Beverage Industry

New business models and strategies are needed to create a circular economy in the food and beverage industry on a company level. The following chapter explores what circular economy strategies businesses need in the food and beverage industry and how business models can be used to realize these strategies. There are several ways to achieve a transition towards a circular economy. At the heart of CE lies the reuse of waste from waste streams and their revalorization at its highest potential.

It is important to determine the potential value of the waste streams that can be re-used. In the bio-economy the term 'cascading' is used for describing the stock available for re-use, but also to reflect upon the quality of the material available for reuse. or products obtained from the biological loop a hierarchy exists for the order of their re-use depending on the economic value (and the lowest environmental damage) that can be created by doing so. In this hierarchy, fine chemicals rank highest, with humans and animal feed, for instance in the form of proteins, followed. Incineration for energy generation is seen as the last resort, as this depletes the material and allows for no more cascading. (Bezama, 2016; Gontard et al., 2018)

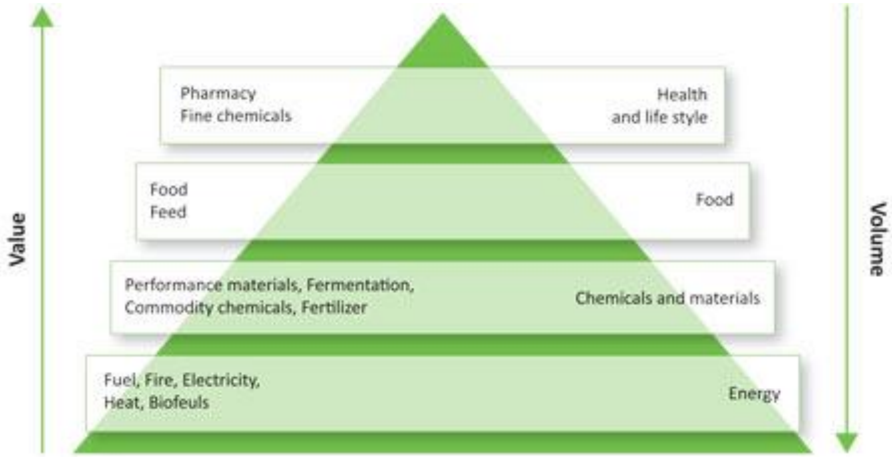

Figure 2-2 The bio-economy value pyramid. (betaprocess bioenergy, 2012)

Figure 2-2 shows the bio-economy value pyramid, highlighting the relationship between attainable volume and value of the product. Generally, when estimating the value of the bio-stream, the highest value can be created with pharmaceutical products and chemicals, followed by human food and animal fodder. This is followed by various material and fertilizers. The lowest value per volume is obtained from using waste streams for energy generation, such as biomass. For this reason, if possible, a higher value application should be sought.

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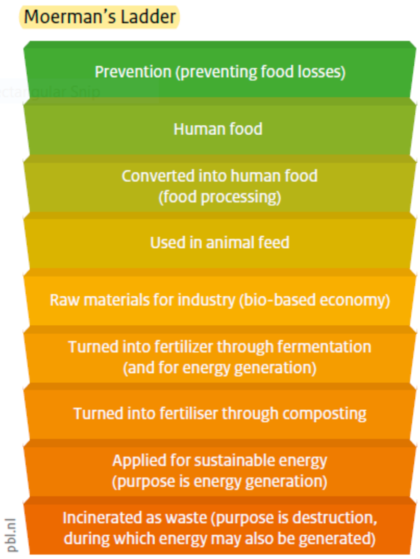

*Figure 2-3 Moerman's Ladder. (*PBL Netherlands Environmental Assessment Agency, 2018)

This is similar to Moerman's Ladder (see *figure 2-3*) which estimates the value of the re-use stream (PBL Netherlands Environmental Assessment Agency, 2018; Waarts, Sluis, & Timmermans, 2011). What is different from the value pyramid is that in Moerman's ladder prevention of waste is seen as the highest step of the ladder. While this is supported in the production steps in a circular economy, prevention cannot be used as a measurement point as no waste would mean not input for new products and would therefore make the strategy of revalorizing waste futile. However, it is assumed that the wastes revalorized, typically stem from side-production and cannot be decreased even through better production techniques. Moerman's ladder is similar to the value pyramid in that it offers a ranking of different ways to reuse biological waste streams. The potential for re-use, however, depends also on available technology, regulations, the amount of energy needed and the market potential of the new product. Health concerns, for instance, for human solid waste and waste water, or bone tissue from animals are oftentimes the reason for inability to re-use material as they could carry diseases or hormone traces. Nutrients can typically be recovered from animal manure, food waste, or sewage sludge either from industrial or municipal waste water. (Lipińska, 2018; Sun et al., 2018)

Bezama (2016) points out that the spatial dimension of cascading needs to be taken into consideration when trying to implement ideal re-use situations. The production facility needs to be seen within its regional landscape where it cooperates or competes with other companies and has an environmental, social and socio-economic impact in that region. He defines the need to measure the impact on this geographical level and include indicators on the quality of the re-use stream. While the re-use of residue streams has already been common for long periods of time, an approach for innovative use of residue streams based on the value pyramid to increase its value is suggested. (PBL Netherlands Environmental Assessment Agency, 2017)

The strategy of cascading as described with Moerman's ladder focusses mainly on the re-use of nutrients (Waarts et al., 2011). However, water usage is becoming more and more important and water as a resource needs to receive a more central place in business modelling strategies. This is something currently not considered in CE business model strategies. With increasing awareness on water as a scarce resource, circular water management can be expected to play a major role in the upcoming years. A similar value pyramid as existing for nutrients can be developed for the re-use of water based on the quality of the water

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after treatment (and potentially type and impact of treatment). Incorporating water usage into a business strategy can be done by either focussing on resource efficiency within industrial processes and industrial cleaning processes or on re-using water at the end of its use phase, thus at the point of municipal water treatment stations.

Optimizing energy usage and re-using waste energy during production processes can be an additional strategy to reduce the impact and resources needed by companies. This can be done company internal or in the form of industrial partnerships or symbiosis. Combining waste treatment systems, such as anaerobic digestors and compost creation is seen as a way to more efficiently use the waste product stream. (De Schoenmakere, Hoogeveen, Gillabel, & Manshoven, 2018)

In an industrial symbiosis system, companies create partnerships to share resources, such as materials, water, or energy, oftentimes across industries. The most well-known case of Industrial Symbiosis is the Kalundborg Symbiosis which is connecting 25 different streams of energy, material, and water between various companies. (Ellen MacArthur Foundation, 2017a; Kalundborg Symbiosis, n.d.) Cooperation between different companies or even industries allows to better use and share resources, from production sites, to waste products or waste energy streams, to potentially even knowledge to jointly create higher values for their (side) products. In the effort to become more circular, another strategy is to create an internal symbiosis, which refers to links between different production processes of different products to share resources internally. (Short et al., 2014) In an internal symbiosis, a company combines different waste streams with different product lines or even creates new products to diversify their business strategy.

Circular Economy requires different approaches, business models and organisational measures depending on the industry or system under study. Often this requires including systems thinking for creating new business strategies and business models Once a strategy is deemed well chosen, it can be executed with the help of a business model. The same order can be performed for CE strategies within the food and beverage industry.

2.8. Practical Examples of CE Strategies in the Food and Beverage Industry

Opportunities for CE exist in closing internal cycles and in engaging in cross-company or cross-sector partnerships via industrial symbiosis. For cross-sector partnerships, for high-value residue stream re-use, agricultural producers can cooperate with chemical or biotech industries. For innovation, combining different sectors and thinking out of the box is needed. This happens already in cases such as in flax seed production, where the seeds are used for food and the fibres for the textile and chemical industry. Internal closing of loops can, for instance, can be done with waste water or nutrients. These companies are sometimes referred to as ecological recycling businesses (PBL Netherlands Environmental Assessment Agency, 2017) For instance, aquaponics, a combination of fish and plants grown together in a closed system, is one example of trying to create a closed internal loop without the need for fertilizer application. Cross sector business cooperation or expansion of production to cover by-streams require a rethinking of the traditional business model. Revaluing waste streams not only has to offer a profitable business case but should also benefit workers and society as well as reduce the burden of the production on the environment to truly reach a sustainable production. Innovative business model approaches and strategies are needed to adequately capture the value of these new add-ons.

One example for a successful redesign of a business model comes from Short et al. (2014) in their analysis of the British Sugar Wissington factory. Due to quotas and low sugar prices the company shifted to business model innovation and internal industrial symbiosis to create value from their (previous) waste by-products.

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Innovation initially started with improvements of internal processes and efficiencies and remained initially within the company. Over the decades and outward expansion with partnerships to create liquefied CO_2, biofuel and animal feed production, took place. In addition, the company built a greenhouse at their premises to use their waste heat, rain water and fertilizer to grow over 140 million tomatoes per year. Their product diversification not only allowed them to expand and find ways to create additional revenue but also enabled them to perform in a more sustainable manner. Communication, learning and active innovation within the company was needed to achieve this transition.

Circular Economy developments can also be found in the beer industry. Heineken employed a new CE business models for its brewery in Meoqui, Mexico together with the Ellen MacArthur Innovation Programme. Their projects at the factory include an e-learning tool on CE and innovation for all 2000 employees as well as a CE campaign with a Circular Entrepreneur Challenge, inspiring the development of CE business ideas. They recycle waste water and reuse the brewer's grain for cattle feed. In addition, they built an industrial symbiosis with a glass factory reusing their waste heat for the brewery process. They also tried to extend the concept of circularity to their worker's garments which they produce from recycled clothes from their employees. Their innovations are based on the ReSOLVE self-assessment tool. (Heineken, 2018) This is based on the Ellen MacArthur ReSOLVE framework consisting of five pillars: regenerate, share, optimize, loop, virtualize. (Ellen MacArthur Foundation, 2015)

Industrial Symbiosis for energy efficiency is also applied in the Heineken brewery in Puntigam and Schwechat, Austria where the heat from the brewing process is used to provide heat to houses (which initially had to be cooled down by cold well water). The cooled water is returned to the brewery and reused. (Heineken, 2018)

These new strategies require different business models. Business models for CE have to be apt to highlight the main values that circular economy brings to the food and beverage industry and show the structure that a company needs in order to do so. While a strategy is needed to show how a business can outcompete a competitor, a business model is essential to best execute this strategy (Richardson, 2008). Economic as well as environmental and social impacts should be considered in this BM.

2.9. Business Models for a CE in the Food and Beverage Industry

To create value within a circular economy and to execute CE strategies, new types of business models are needed. Returning to the assumption, that CE can be seen as an economic approach to sustainable development and sustainability, its relation to existing sustainable business models will be explored in this chapter. To understand CEBM as well as SBMs, first, more clarity is needed on what a business model entails. In a second step, developments in the area of CEBMs will be explored.

2.9.1. The Traditional Business Model

Business models are intended as a blueprint of how an organization works and creates revenue, oftentimes by offering several pre-defined components and their relationship between each other (Geissdoerfer, Morioka, de Carvalho, & Evans, 2018; Teece, 2010). Many different business model frameworks exist that aim at offering guidelines on how to execute strategies for value creation. They can, for instance, focus on creating a competitive advantage based on quality of the product, pricing, their customer service or customer retention, or their way of distributing their product or managing their supplies.

A business model should not be confused with the terms 'business case' and 'business plan'. A business case highlights the benefits of the project to be implemented, either in terms of financial value or in terms of advantageous service it will bring. Main questions to be answered in a business case are the reason for

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doing the project, the deliverables, costs, main risks, stakeholders, the timeline, success factors, quality standards and key performance indicators. This document is generally submitted to the board of directors before financial commitment is made within the company. (Lester, 2014) What makes the business case different from the business model is that the business case is dominantly focussed on the feasibility of the project while the business model is focussed on the value (and revenue) that is created through the project. A 'business plan', on the other hand, is a detailed description of the growth of the business for the upcoming one to three years. While this can be useful for existing companies with a lot of data on similar projects, for innovative projects, it is less and less frequently applied due to the large amount of data that is required and that is hard to estimate beforehand. (Organizing4Innovation, 2018) This research focusses on the organizational structure and the value proposition of the company, and thus, looks at business models.

Using BM design tools can help to clearly map out the business model used. One of the most dominant design tools applied in a traditional business model is the Business Model Canvas by Ostenwalder and Pigneur (2010). It highlights the main building blocks of a business. The Business Model Canvas is structured into 9 sections that depict how a company aims to make profit. These sections consist of customer segments, value proposition, channels, revenue stream, key resources, key activities, key partners and stakeholders as well as the cost structure of the business. The value proposition is central to this more content-based design of a business model. A tool that is frequently used to visualize the value proposition in a business model of a company is the Value Proposition Canvas. (Osterwalder, Pigneur, Smith, Bernarda, & Papadakos, 2014) It highlights the pains that a customer has and the gains that he or she expects and shows how the developed service or product caters the needs of the customer. This allows to develop a product or service that is tailored to the needs of the targeted audience. A more compact approach on how to map the way a business generates value, is Richardson's (2008) business model framework focussing on value proposition, value creation and delivery and value capture. The value proposition shows why customers are willing to pay and what they will receive, similar to the value proposition canvas. The value creation and delivery building block refers to the network, resources and organizational structure the business needs. Value capture focuses on how the company creates revenue and its cost structure. Frameworks for sustainable and for CEBM are oftentimes based on one of these two design frameworks.

2.9.2. Circular and Sustainable Business Models

Circular economy business models aim at integrating the principles of CE into business model design. Similar to the definition of CE, there is often a lack of a clear distinction between sustainable business models and circular economy business models (Kirchherr et al., 2017b; Ranta, Aarikka-Stenroos, & Mäkinen, 2018). Circular economy business models focus on closing resource loops and making them more efficient and apply principle of reuse, reduce, recycle (Bocken, de Pauw, & van der Grinten, 2016; Geissdoerfer et al., 2018). Sustainable business models incorporate the triple bottom line of environment, economy and society (Geissdoerfer, Bocken, & Hultink, 2016). However, as CE is intended to be a solution to sustainability problems and lead to sustainable development, the three-pillar approach will be integrated in this research to truly create a sustainable CE. For this reason, CEBM can be places within SBM as one possible sub-category on how to create sustainability, in this case by focussing on reusing and revalorizing waste.

A BM canvas that includes social, environmental and economic impacts is Joyce and Paquin's (2016) extension of Osterwalder's and Pigneur's BM canvas (see *figure 2-4*).

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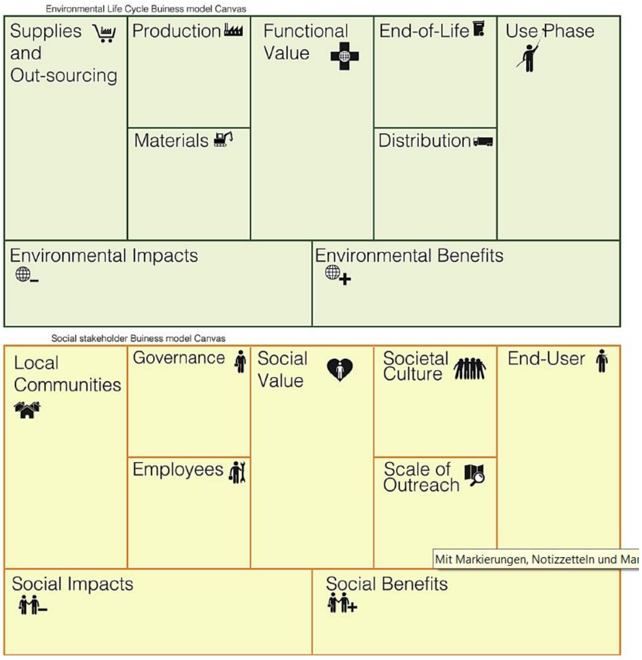

Figure 2-4 Environmental and social extension to the traditional business model canvas. (Joyce & Paquin, 2016b)

With the three layers approach, Joyce et al. aim at achieving horizontal and vertical coherence in the business model design. However, while this offers a thorough qualitative approach for sustainable business models, it does not specify how to quantify the value gained through circular and sustainable measures taken. The BM is generic and does not focus on waste valorisation or the food and beverage industry in particular. For this reason, it is not directly addressing the needs of the industry in developing CEBM strategies.

Lewandowski (2016) suggests the creation of a circular economy business model canvas (CBMC), which expands the traditional business model canvas with two additional sections: take-back systems and adoption factors. The author considers a take-back system vital in the success of a circular system. External and internal factors for adoption of the new business model need to be taken into consideration when implementing it. The framework allows to incorporate CE principles into the business model canvas. However, it was not tested in practice and adds complexity to the existing model. Lewandowski's model seems suitable for the technical loop that builds upon re-use, re-collection and recycling after the end of a product's life-span. This, however, does not translate directly to CE requirements in the food and beverage industry.

Bocken et al. (2014) redeveloped Richardson's BM framework (2008) for a CE based on value proposition, value delivery, value creation, and value capture (see *figure 2-5*).

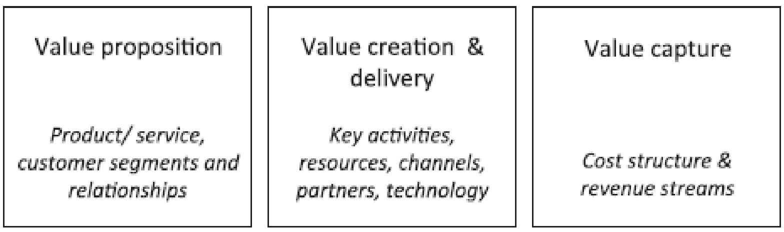

Figure 2-5 Business model dimensions. (Bocken et al., 2014)

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The framework by Bocken et al. offers a useful and compact overview of potential CEBM design options. In comparison to Joyce and Paquin's triple bottom layer BM canvas, it allows to integrate all elements of a CE within one canvas. Its focus on products, key activities and partners as well as costs, allows to use it for designing CE strategies and incorporating social and environmental elements. While the framework is generic and needs to be further developed, it offers a suitable basis for further evolving it for the food and beverage industry.

Bocken et al. (2014) developed sustainable business model archetypes which were later expanded by Ritala, Huotari, Bocken, Albareda, & Puumalainen (2018). Here, CE can be seen as a sub-category of SBM archetypes, as CE focusses on closing resource loops. Value is created through reduction of environmental and economic costs through repurposing of waste. The reduced waste and virgin material use has a positive impact on society. Geissdoerfer, Morioka, de Carvalho, & Evans (2018, 713), too, define CEBM as sub-category of SBM that aims at "closing, narrowing, slowing, intensifying, and dematerializing loops" to minimize waste and improve sustainability performance. This CEBM archetype can be found in some successful business model innovation cases in the food and beverage industry. It provides a useful basis for a more detailed business model for the food and beverage industry. However, its placement within the environmental innovation-based SBM archetype can be criticized as CEBM, while interested in reducing environmental impact and resource use, have a large focus on economic considerations for repurposing waste. In addition, CE incorporates all three pillars which makes a representation in an archetype addressing only one of these pillars incomplete. In addition, a more specific design is needed for the food and beverage sector.

Lüdeke-Freund, Gold, & Bocken (2019, p. 47) offer an additional step to Bocken et al. (2014)'s archetype framework. They define six patterns for developing CEBMs: ''1. repair and maintenance, 2. reuse and redistribution, 3. refurbishment and remanufacturing, 4. recycling, 5. cascading and repurposing'', and ''6. biological feedstock''. While the first four are focussed on closing the technical loop and extending the life-span of products, the latter two can be applied to the biological loop and are therefore more suitable for the food and beverage sector. Cascading and repurposing CEBM patterns are based on CEBM centred around multiple cash flows and creating additional products from waste. Creating value by extracting nutrients and reusing waste for other industrial processes via industrial symbiosis are part of the strategies within this CEBM pattern. Organic feedstock CEBM patterns focus on recovering resources, industrial symbiosis, and closed loops in supply chains. In essence, this pattern is applied when other options for cascading are exhausted and bio-based wastes are repurposed into biofuels. The cascading CEBM pattern should therefore be the preferred pattern if applicable. Design options based on the CEBM pattern selected are added by the authors to provide a general framework. The design options are based on Bocken et al.'s (2014, p. 43) Conceptual Business Model Framework.

Overall, there is no mention on how the performance of these CEBM are later measured and the BM frameworks remains rather vague. For this reason, in the next chapter, a more detailed framework will be developed for this sector, that will then be linked to a set of circular economy indicators that measure the impact of the company's CE strategy in all three areas of sustainability.

To conclude, initially a choice of a business model framework to build on was needed. Two frequently used existing traditional BM frameworks and their SBM and CE expansion were assessed for their suitability as a CEBM framework for the food and beverage industry. They were chosen as their usage is common and the frameworks are well known. Joyce and Paquin's triple bottom layer-based BM canvas, while being very thorough, was considered slightly less apt as it divides the BM canvas into three separate layers. It was seen as important, however, to develop an easy to use and compact BM framework incorporating all elements.

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For this reason, Bocken et al. (2014)'s conceptual BM framework will be chosen as a basis for developing a CEBM for the food and beverage sector. A focus will be put on incorporating all three pillars of sustainability. In addition, it can draw on elements of existing archetypes on closing loops, cascading and biological loops in the developing of the framework targeting the closing of loops in the food and beverage processing sector. By further developing the framework with new research insides from Lewandowski (2016) and Lüdeke-Freund et al. (2019), a basis for developing a framework specifically targeting the food and beverage industry and offering a more detailed business model framework with regards to all three pillars of sustainability can be developed. This will allow to best implement and plan strategies for a CE.

2.10. Conclusion: How to Define and Measure CE

To answer the first research sub-question ''*1. What constitutes a Circular Economy (CE) in the food and beverage industry and how can it be measured?*'' a literature review was conducted. The literature review showed that there are various different approaches towards measuring and defining a circular economy, especially in the food and beverage sector. There is no truly singular measurement system for a CE, particularly when assessing the biological loop. A definition of CE was found when assessing the key challenges of the sector. These were obtained to be nutrients (and organic materials), water, and energy usage. Closing the material and nutrient, as well as the water cycle and reducing fossil fuel usage are the main aspects in creating a CE. CE for the food and beverage industry is therefore the closing of nutrient, material and water cycles, as well as the optimal use of non-fossil fuel energy to reduce pollution and to create a sustainable food system that takes into account the well-being of employees and consumers. For this, a systems perspective is needed as circular nutrient and water flows that are defining for this sector stretch over the entire life-cycle of the products created, and thus, include agricultural production and supply, as well as consumption. Companies play a central linking element and have the power to exert influence both on suppliers and consumers. Current business models still mostly focus on the company level and tend to not take into account the impact occurring at other stages of the system. Therefore, creating a circular system needs to be incorporated in the business model of a company and includes a company's own production processes as well as the life-cycle of their product. This view needs to expand to the social perspective and on the impact of the product on current and future generations. Circular sourcing and circular consumption should be integrated into the business model.

In a second step, existing CE indicators were reviewed and assessed to identify their suitability for measuring process in terms of a CE for the food and beverage industry. The review of existing CE indicators highlighted the lack of a specific set of CE indicators targeting the biological cycle, in particular, the re-use of nutrients, organic materials, water and energy at a micro-and meso level as most indicators developed focus on the technical loop of the CE. Most indicators focus on recycling or recirculation rate as well as waste reduction, but less on value maximization from waste. In addition, only few indicators take into consideration all three pillars of sustainability. When a systems approach was included this was done in the form of an LCA as a basis for the indicator calculation, requiring an expert and detailed data throughout the life-cycle of the product. No existing indicator set suitable for or targeted at the food and beverage industry was discovered during the research step. For this reason, a new set of indicators needs to be discovered that takes into account a systems perspective, as well as the three pillars of sustainability, while focussing on the biological loop and the challenges of the food and beverage industry. Some of the existing indicators, such as the MCI for packaging, or social indicators of the C2C certification for rights of workers in the supply chain could be used as sub-set or as complementary indicators. To fully answer the second part of this sub-question, a specific set of indicators needs to be designed that target the food and beverage processing industry.

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To answer sub-question 2 *''What is the state of Circular Economy Business Models (CEBM) for the food and beverage industry?''* existing frameworks for CEBMs within the domain of SBMs were analysed. First, different CE strategies for the food and beverage sector where looked at in more depth to understand the needs of the sector with regards to business modelling frameworks and tools. While a possible strategy for the food and beverage industry could be built upon high levels of cascading nutrients, using waste flows for energy production should not be seen as a separate strategy. This is said as this would oftentimes lead to policy incentives focussing on creating biomass and thereby overlooking the potential for innovative solutions that would allow a higher value re-use of the product. While energy creation can be a sub-category of cascading it should not become a separate strategy.

Then the most common existing BM frameworks were analysed. The BM framework of Bocken et al. (2014) focussing on the value proposition, value creation, value delivery and value capture was seen as most apt for developing a targeted CEBM for the food and beverage industry due to its compactness and the ability to easily fit all three pillars of sustainability into the framework. However, an expansion to encompass a systems perspective will be needed. Elements of the SBM archetypes for CE can be used in the design of the framework, especially when based on cascading and the biological loop.

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3. Methodology for a CEBM and CE Indicators

3.1. Design Considerations

While research sub-question one and two were solved using a literature review, a design approach is needed to answer sub-question three: *Which CEBM and accompanying set of indicators is needed to measure and develop a CE in the food and beverage industry?*

Based on findings from the literature review and desk study conducted in chapter 2, a suitable CEBM canvas as well as a set of indicators to measure CE in the food and beverage industry were developed. The design of the framework and the indicators were done in the steps shown in *figure 3-1*.

Testing the scorecard during a research internship at SEMiLLA at a pilot study with the brewery La Trappe allowed to give recommendations for the further development of the scorecard as well as recommendations on how to improve the CE at the companies involved in the case studies.

The following chapters elaborate on the choices and content of the design steps shown in *figure 3-1*.

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Figure 3-1 Design steps for the CEBM Canvas and CE Indicator Scorecard.

3.2. Building on the Literature Review

The following choices will be incorporated based on the results from the literature review:

Table 3-1 Design considerations. Basis for CEBM Canvas & indicator selection from the literature review.

CEBM canvas	
Value proposition, value creation, value delivery, value capture	Based on Bocken et al. (2014) and taking into consideration the triple-bottom line
Importance of life-cycle and systems thinking	Adding additional element based on systems thinking

CE Indicator Selection	
Focus on biological loop and value creation strategies	Incorporating Moerman's Ladder (PBL Netherlands Environmental Assessment Agency, 2018) Taking into consideration GHG emissions similar, to, for instance, in the HLCAM indicators (Genovese et al., 2017) C2C indicators as potential input, for instance, for additional social indicators (C2C, 2019)
Elements of a CE relating to the technical loop, such as packaging material	Can be calculated with the MCI (Ellen Macarthur Foundation, 2015)
Based on the definition of CE for the food and beverage industry: Selecting indicators for nutrient, organic material, water, and energy recovery and cycling	Essential macro-nutrients identified in chapter 2. Water cycling and energy recovery potential from literature & interviews with De Dommel during research internship (Interview Istvan Koller)
Format of indicator scorecard	Expert consultation

3.3. Choice and Re-Design CEBM Canvas

For truly integrating principles of a CE into a business model for the food and beverage industry, a new business model canvas was created. First, the CE business model was embedded within the overarching topology of sustainable business models. Selection and re-design criteria for the new framework were: easy applicability, compactness and a specific fit for the challenges of the food and beverage industry in creating a product or service based on CE, for achieving economic, environmental and social sustainability for their company. To return to the original definition of a business model, that includes the value that a business creates as well as the business structure, several aspects were taken from the existing CEBM found in the literature and transformed to fit as a model for the food and beverage industry. This business model is meant to incorporate the transformative nature of the CE and maintain an option to change or adapt the business model or relevant partners. This was done by basing the CEBM on the CEBM framework proposed by Bocken et al. (2014) with an expanded focus on the stakeholder and partner network and the various product streams to be created from the waste products. Elements of Lüdeke-Freund et al.'s (2019) CEBM

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patterns were incorporated into Bocken's framework (2014) where applicable for the food and beverage industry.

To emphasize the importance of systems thinking and a life-cycle approach to CE, an additional building block was designed. Based on this CEBM canvas, a set of indicators was defined to highlight the progress made within the various building blocks of the canvas in terms of CE.

3.4. Expert Pre-Consultation

To ensure all relevant aspects of a CE for the food and beverage industry are incorporated, expert consultation both in person and via skype took place within the research internship with SEMiLLA. An interview with Istvan Koller, from the Waterschap De Dommel highlighted the different steps of recycling water in industrial processes as well as the different levels of water quality. Consultations with Dr. Clara Plata, Manager for Technology & Operations at SEMiLLA, added additional input in the form of suggestions and literature to ensure all elements of a CE are included in the indicator selection.

In addition, a consultation session with Olivier Benz, consultant for CE at Sustainalize, a consultancy company in Utrecht, the Netherlands, highlighted the challenges and opportunities for developing indicators for the biological loop within the CE. The session led to further literature input, and testing of existing software and indicator tools for the technical loops of the CE (WeSustain, MVO Nederland, & ecopreneur, 2019). Based on these tools, a similar approach for the biological loop in the form of a CE indicator scorecard was chosen.

3.5. Design of the CEBM Indicator Scorecard

The final aim of the indicator selection was to make the indicator tool as simple and yet accurate as possible to be interesting for companies to fill in. For this reason, a CEBM scorecard was developed to allow filling in the indicators with the help of a questionnaire. This method is based on similar tools that measure circularity for the technical loop, such as for instance, the Circularity Check developed by ecopreneur and WeSustain (ten Wolde & Kunert, 2019). The reasons for choosing a scorecard was to provide a company with an easy way of measuring their circularity. This will be possible even in the absence of precise data. While it incorporates elements of systems thinking from LCA, it does not include an LCA for this reason. The scorecard design was picked after a feedback session on the framework with the consultancy Sustainalize. While similar tools were designed for the technical loop of the CE, no scorecard as of now was developed to measure the biological loop. Some elements of existing scorecards, for instance by WeSustain (ten Wolde & Kunert, 2019), were taken as an input. This allowed to get a more coherent cross- industry way of assessing CE projects.

The developed CEBM scorecard is based on the building blocks of the CEBM canvas. The scorecard was created in order to provide a measurement method that would allow quantification of the indicators and to provide a justification for the rating system. Companies have to fill out a set of questions with a range of possible answers for each of the questions. The final result shows their development in terms of CE for the product chosen for each of the building blocks of the BM. The rating was based on a numbering system from 0-6 for each category, where 0 represents no circular economy considerations and 6 would refer to all CE options fulfilled within this category of the business model. The results will be shown in a performance spiderweb.

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The indicators selected are specific as they are designed to specifically address the individual building blocks of the CEBM for the food and beverage industry. By giving them a rating from 0 to 6 even more social-related elements of CE will become measurable. To ensure that the objectives are both achievable and realistic, a validation step with industry and experts from the field was undertaken after the development phase. They are time-based in the sense that they take the CEBM as a starting point and measure the performance of the company at the point at which the scorecard is filled out. This is compared with business as usual (BAU) implementations occurring at the industry at that given moment to allow to compare the system or product developed to non-circular solutions.

Indicators are meant to measure the most important objectives for a company. This set of indicators is based on the most important elements constituting a circular economy in the food and beverage processing industry. The indicators will focus on re-use of waste streams, with regards to its financial feasibility as well as the degree of nutrient and bio-material reuse, water reuse, energy re-use and use from non-fossil sources, as well as pollution and social impact. The focus was put on adding indicators measuring the progress in terms of CE. Supplementary indicators relating to other aspects of the BM, as well as already existing indicators suitable for these areas, will be mentioned below, but are covered in less depth, due to the scope of the study.

The CE indicator scorecard was designed to be filled out by companies. User-friendliness was therefore one of the main priorities. The questionnaire, on which the indicators are based, was therefore offered as an Excel data sheet that could be easily filled out.

3.6. Expert Validation Sessions

After having developed a first framework prototype, in a first step, the framework and indicator set were validated through a peer review session, conducted with four graduate students from the master programme Industrial Ecology. For this validation session, a one hour long physical meeting was held with four students from the master programme. After a short introduction to the topic, all students received the CEBM canvas as well as the scorecard questions. Then they were asked to give feedback on the design and selection. Based on the feedback some changes were made to the initial design.

In a second validation round, the scorecard was presented to Dr.ir. Gijbert Korevaar, professor at the TU Delft and specialist in Industrial Symbiosis systems to validate the scorecard in terms of sharing of resources within a CE and industrial symbiosis between industries. Based on this feedback, small changes to the indicator set were made.

In a third round, the scorecard and CEBM canvas were presented to external experts working in the field of CE, and the food and beverage industry. These experts included: Astrid Carl, an advisor on Circular and Economy and Sustainability with a focus on food and beverage industries and CEO of Green Moves, in Copenhagen, Denmark. Paul Tuinenberg, director of Impacter, an innovation-supporting company in Utrecht, the NL, is a specialist in innovation and technology transfer and was able to give insight into aspects of maximizing impact of research projects and innovation on society. Olivier Benz is a sustainability consultant at Sustainalize, a consultancy in Utrecht, the Netherlands and is specialized in the development of CE indicators. The results of these validation sessions were then used to give suggestions for future adaptations of the scorecard and the CEBM canvas.

Based on the three validation rounds, the CE indicator scorecard was adapted, with some questions being changed or removed to better accommodate the needs of the industry. This led to a final version, that was

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then used for testing in the pilot study as part of the research internship at SEMiLLA in the NextGen Horizon2020 project at La Trappe.

3.7. Pilot Study (Three Scenarios) and Research Internship

To test the developed framework and indicator set, a pilot study within the food and beverage industry was chosen. The pilot study was performed during a research internship with SEMiLLA IPStar B.V. from February to July 2019. The research internship allowed to get insight into the motivations underlying decision-making, (waste) product development and technical feasibility of the proposed CE project. Access to data relevant for economic, environmental, and social aspects of the production processes allowed to test the CEBM canvas and CE indicator scorecard with the companies involved in the NextGen project at La Trappe.

Several sources were used for data collection. These sources include work documents from SEMiLLA, such as a feasibility study, conducted at an earlier point in time, as well as company data from La Trappe on their BioMakery system. This is supplemented by direct observations and practical insights into their methods on quality assessment, testing of the waste water and their by-product production processes as well as innovation and research groups. A written report of the company visits as well as semi-structured interviews with experts on and off-site are added to give structure to the data gathered. There are several ways of conducting interviews. They can either be performed in an unstructured, semi-structured, or structured manner. In a structured interview, a questionnaire with pre-formulated questions is designed that is then administered verbally. There is only little room for spontaneous changes. In an unstructured interview, on the contrary, the questions are developed ad-hoc during the interview, which allows for more flexibility. Semi-structured interviews lie in between and are based on several pre-formulated key questions. However, they allow to adapt and add questions during the interview and follow the flow of the interview. This allows to capture the most information while directing the interviewee in the needed direction to collect information necessary for the topic. (Gill, Stewart, Treasure, & Chadwick, 2008) To achieve maximum information uptake as well as allowing for flexibility in the interviews, a semi-structured interview approach was chosen for the case study research. To ensure credibility and transparency of the research method and of the data gathered, a research protocol was made for site visits at La Trappe (see appendix II-a). The results of the semi-structured interview based on a questionnaire of pre-formulated questions can be found in the appendix as well.

For this pilot study, the CEBM canvas and the CE indicator scorecard was tested in three different scenarios. three cases were analysed. Scenario one looked at the performance of the treatment system and products developed using only SEMiLLA technology, which is based on technology from the MELiSSA space program. Scenario two applied only technology from the partner company Biopolus, providing the greenhouse structure for the BioMakery and the Metabolic Network Reactors (MNRs). Scenario three looked at the combined technology of both companies within the BioMakery of La Trappe. The CEBM canvas and CE indicator scorecard was filled out as a part of the research internship with the data collected.

3.8. Self-Score Sensitivity Check and Feedback Session with Pilot Study Participants

To check whether the developed framework could be used in practice to see how sensitive the results depending on the party that fills in the scorecard, the CEBM canvas and CE indicator scorecard was then given to the participating companies to be filled out by one of their representatives themselves. In addition, the companies were asked for their feedback and experience they had when filling out the scorecard.

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Final feedback on the scorecard was received by one representative of Biopolus, one representative of the BioMakery and two representatives of SEMiLLA offering feedback on the scorecard and canvas application. The feedback and the hands-on experience to test the user-friendliness of the scorecard allowed to give further suggestions on improving and adapting the developed framework.

3.9. Discussion

The discussion section in chapter 6 takes into consideration the final recommendations and insights of the expert and feedback sessions. The chapter highlights insights on how to further develop the CE Indicator Scorecard and will be complemented with recommendations for the pilot study participants in chapter 8.

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4. Results

4.1. A CEBM Canvas for the Food and Beverage Industry

Bocken et al.'s framework is built on value proposition, value creation, value delivery and value capture. (Bocken et al., 2014). These four building blocks were further analysed to fit the food and beverage industry while incorporating the three pillars of sustainability.

4.1.1. Value Proposition

The value proposition (VP) shows the reason or the unique selling proposition for the product as well as the target customer. For a CEBM, the VP has to show the contribution of the product in terms of circularity and the type of customer interested in and aware of a CE based product. (Richardson, 2008)The VP is based upon providing a service or product. In a CE, this typically comprises of a product based on a waste flow as a resource. Services could include facilitating collaboration, providing material input (for instance, from waste), waste management and treatment or additional tasks, such as education. (Lüdeke-Freund et al., 2019) The positive impact of the product in terms of economic, environmental, or social value can be highlighted.

In addition, this section defines the target customer. Target customers are seen in the B2B sector as well within green customers (Lüdeke-Freund et al., 2019). For a CE, involving the customer in the closing of the resource loop is an essential element.

4.1.2. Value Creation

Value creation includes the key value creation processes and key resources (Richardson 2008). Collecting, reselling and winning back components, or waste, are the core value creation processes in a CE (Lüdeke-Freund et al., 2019). In addition, Schenkel, Caniëls, Krikke, & van der Laan (2015) point out various (non-technical) processes of adding value to products based on circularity. The main ways identified are through increased economic value, environmental value, customer value and information value. Additional economic value is seen as one of the key elements of value creation, for instance through reduced operational costs, resource and raw material costs, lower risks in supply, and increased revenue from expansions of products and market segments. Environmental value can be seen in reduced costs for energy, a green image and corporate social responsibility and through that increased customer satisfaction, anticipation of environmental legislation that saves costs, lower costs for landfilling and waste production. Similarly, customer value can be created, for instance through higher customer satisfaction and brand image. It can be argued that higher levels of trust through transparency of a company in terms of emissions of production processes and supply chains can be linked to this category and improve customer value. Schenkel et al. (2015) also identify information value as another potential element of value creation. By closing loops companies are able to receive feedback and gain life-cycle information about the product. While this is more challenging for biological than for technical loops, it still allows to gain better insight into, for instance, the uptake of nutrients by plants, soils, or even the human body and might allow to better design products, such as fertilizers or foods.

Key resources in the food and beverage industry comprise of waste flows, which are used as production input for creating new products. These waste flows contain valuable nutrients, or other organic materials that can be extracted and re-used. Water and energy, in addition, are essential resources for this sector.

4.1.3. Value Delivery

Value delivery looks at core partners and important channels and technology. Valuable partners for a CE in the food and beverage industry are the providers of raw materials, in most cases, retailers, or farmers, for

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raw vegetables, fruit, grains, fuel, or other forms of bio-based products. Awareness and transparency in terms of the input materials and their quality, production conditions in terms of social and environmental impact, need to be taken into account. For the production process, partners in re-using the waste streams play a central role, as well as research in developing high-value and sustainable re-use options. (Lüdeke-Freund et al., 2019) In a further step, awareness and involvement in the waste stream treatment processes (ideally also after the consumption step), are needed. Thus, WWT partners need to be included in this network of partners. For the food and beverage, collaboration in the form of industrial symbiosis to share inputs, or reuse waste streams plays an important role to create and deliver value.

Modes of transportation and distances within supply chains and partners in re-using waste play an important role in the channels used for distributing the product. For a circular economy, the entire supply chain as well as the reverse supply chain is important. (Schenkel et al., 2015) Shorter distances in most cases should be given priority for a better control of the value delivery process and avoidance of energy and material losses. (Especially, when considering the products are perishable.) Potential take-back systems or involvement in waste collection and treatment needs to be pointed out at this point.

4.1.4. Value Capture

The value capture covers the economic aspects of the business model by focussing on potential costs and benefits of the product in question. (Richardson, 2008) Value capture is based on revenues and costs. For the cascading CEBM, revenues can be created through additional products that are sold based on reusing waste. Costs are associated with respective waste handling as well as potential additional transport and logistics. With material cycles the value strategy is to maintain the value of the materials used. Lüdeke-Freund et al.'s framework shows the importance of avoiding contamination of the materials for being able to fully close the loops (Lüdeke-Freund et al., 2019) One aim of a CEBM is the integration of potential negative externalities to account for all costs, for instance by creating zero pollution.

4.1.5. Framework Expansion to Integrate a Systems Perspective - Value Anchoring

Bocken's framework allowed for integration of all three pillars of sustainability while focussing on the food and beverage industry. However, the four building blocks did not really allow to view the product and waste valorisation from a systems perspective.

Material, water, and energy flows often cross boundaries and need to be regarded from a systems perspective to avoid problem shifting, for instance, by avoiding the end-of-life phase or potential pollution at a certain step of supply or production. While the production process occurs locally, the impacts occur globally. Temporal and spatial boundaries are for this reason seen as a limitation of CE. (Korhonen, Honkasalo, & Seppälä, 2018) To overcome this limitation, the impact of the product based on the geographical location of the production company as well as the global impact, the life-time and long-term impact of the product and its production need to be incorporated in the business model. This requires an expansion of the currently known business model.

For this reason, the existing framework was expanded with an additional building block, named *VALUE ANCHORING* was added. This block takes into consideration global impact, local impact and long-time impact of the created product. It aims at answering questions such as ''How will the product impact the local challenges and the local environment?'' Or, for instance, ''What is the impact of the supply chain, and production in a certain area in regard to water, nutrient, energy stresses, or social impacts?'' And, ''Are all steps of the product taken into consideration, from production to recycling or disposal? What is the impact of the product over a longer period of time?'' This column offers space to answer these questions. It allows to already include a long-term vision into the business model while also address the local challenges.

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The name ''value anchoring'' was chosen to compare the nature of a business company with the anchor of a boat. An anchor grounds the boat and allows to place it in a certain location to stop it from floating away. At the same time the anchor is connected to the entire boat. It is similar with the product of a company. The location of where the production is places is of high importance, however, its connection to the entire life cycle of the product and its global impact (comparable to a boat that should not float of or sink) needs to be incorporated.

4.1.6. A CEBM Framework for the Food and Beverage Industry

Based on all the points mentioned, a CEBM canvas was developed for the food and beverage industry, which can be seen in table 4-1.

Table 4-1 A canvas for a CEBM framework for the food and beverage processing industry.

CEBM framework for the food and beverage industry	Value Proposition	Value Creation & Recovery	Value Delivery	Value Capture	Value Anchoring
Building Blocks	Product or Service based on waste streams CE Value: Economic value, Environmental value, Social value, Informational value	Key activities & Organisation: Acquisition and Production	Partners Involvement in circularity	Costs Including external costs	System value System Impact (life-cycle)
	Target Customers Inclusion of customers	Key resources: Waste, processing equipment	Channels and Technology Transport along the life-cycle	Revenues from reusing or eliminating (and treating) waste	Long-term Impact Accumulation, GHG emissions

Using a canvas as a BM creation tool allows to easily add multiple product categories below each other to account for and give an overview of the variety of products that can be created or extracted from one waste stream. The advantage of this canvas is that it incorporates all elements needed for a sustainable CEBM, comparable to the triple business model layer canvas, but with a focus on the value proposition and the condensed representation and connection of elements within just one instead of three tables. This CEBM was designed in a way to be applicable for all CEBM strategies in the food and beverage industry.

This canvas includes a systems perspective with the new added building block called ''value anchoring'' focussing on local and system impacts as well as temporal embedding of the CE project. The CEBM canvas was designed in a way to fit all the strategies needed for CE in the food and beverage industry.

To get a clearer understanding on the implementation of the CEBM in the company and the performance in terms of CE relative to all areas of the business model a set of CE indicators will be defined and connected to the CEBM. By linking indicators to the basic CEBM framework, the strengths of the company in certain building blocks can be highlighted. This allows investors to better understand the company's value at an early stage. At the same time, it allows the company to plan on the basis of which building block they can innovate, expand or change their business model in the future. The right set of indicators is needed that

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can be connected to a business model framework. The following chapter will discuss existing CE indicators and will explore their potential of being integrated into the CEBM framework.

4.2. Circular Economy Indicator Selection for the Food and Beverage Industry

4.2.1. Scope

The developed scorecard is based on the general CEBM framework for products created from waste streams within the food & beverage processing industry (see *table 3-2*). It is based on a business model that re-uses (and treats) organic waste streams within an existing company. The scorecard measures the performance in terms of CE for all building blocks of the business model, namely: value proposition, value creation, value delivery, value and value system anchoring. To create a CE in the production facilities of a beverage or processed food producer, circularity of water, material and nutrients, sustainable use of energy as well as a systems perspective, and social and environmental sustainability were seen as central elements.

4.2.2. Indicator Set-Up

In order for a company to understand their performance based on the various elements building towards a CEBM, as identified in the previous chapter, a scorecard was designed to measure progress towards a CE for each of these stepping stones, based on value proposition, value creation, value delivery, value capture and value anchoring.

The scorecard is meant to be filled out by a representative of the company. To ensure correct and honest responses, a statement or document of proof has to be added for each of the questions answered. This allows to check the accuracy of the responses, should the results of the indicator scorecard be used for communication with the public. There are indicators for each building block of the CEBM. The building blocks are numbered alphabetically from A-K.

The rating of the score card follows a numbering scheme from 0 to 6. 0 representing zero considerations for certain aspects of a CE while 6 represents high development towards a CE in that area of the CEBM. This was done to allow for a way to compare indicators relating to economic, environmental and social impacts of the product. While social impacts are oftentimes expressed in qualitative terms, environmental and economic impacts can be expressed more easily in quantitative terms. To allow for a framework that combines these two ways of measurement, a scorecard was built that combines both measurement systems. While quantitative responses were grouped based on percentages or values along the 0 to 6 grading scheme, qualitative responses were graded according to the level of impact or degree of citizen involvement on a level from 0 to 6 (based on pre-defined categories found in literature).

The indicators are linked connect to the value proposition, value creation, value delivery and value capture and value anchoring to allow an easy monitoring of the strengths of the business model strategy in terms of CE and potential room for further development for the company's resource management strategy. This builds on the notion of a business model as a dynamic tool with room for adaptation in the future. The indicators should be fit to highlight the value of the business in terms of CE and in terms of the development of the business structure needed for circularity. They need to represent the specific challenges and requirements for the food and beverage industry based on closing biological loops.

4.2.3. Indicator Types

To determine circularity within the food and beverage processing industry two approaches are required. The first looks at recycling rate of nutrients, waste products, energy, and water, and its quality, within the

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company or within an industrial system. The second looks at the impact of the company within the biological cycle encompassing the ecosystem and the entire bioeconomy. As the latter is highly dependent on networks of cooperation and transparency within the supply chain and consumer side, this too, will be taken into account for the indicator selection.

In addition, indicators for CE normally also touch upon the expansion of the life-span of the product. This is controversial in the food and beverage industry. It could be argued that extending the life-span of consumer goods could decrease food waste as most occurs due to deterioration of the food before its consumption. However, artificially prolonging the life of the food or beverage would have negative impacts on human health and/or the environment if chemicals are used. It would also have negative environmental and in consequence societal impacts if achieved through additional packaging. For this reason, product life-span will not be considered a suitable indicator for CE in the food and beverage industry. The value of the product created will, however, be taken into consideration. Implicitly, higher value products, are also assumed to be more apt for cascading. For instance, food products, can still be re-used for energy usage when entering the waste stream, while once a product is burned it is essentially leaving the cascading loop. Instead amount of cascading, the level the product has on Moerman's ladder is used as an indicator, as it will be assumed that these might also be more likely to be re-used another time. For instance, if reused for human or animal fodder, this will most likely end as sewage sludge, where nutrients can still be extracted, or in any case energy created at a later stage.

To develop a set of indicators to measure the performance of the company in terms of their CEBM, elements of reasoning for the choice of key performance indicators that are frequently used in businesses can be taken. For the selection of such KPI's it is important to ensure that only relevant information is highlighted. (Parmenter, 2015) In addition, indicators should be chosen in order to best align with the company strategy and in a way to not reinforce detrimental behaviour. The same applies to the CE indicators that will be determined. The progress in terms of CE will only be measurable if there is agreement on the usefulness of the selected indicators within the organisation. To define indicators, it needs to be distinguished between performance and result-oriented indicators. Performance indicators can be used to follow the performance of a certain working team or group. An example for a performance indicator is, for instance, the number of innovations implemented by a research team in a year. Result-oriented indicators, on the other hand, measure the outcome, and can be the result of several different actions. They are very useful in looking at the combined results but make it more challenging to look at individual actions. Oftentimes, they are focussed on financial measurements. Examples for result-based indicators, are, for instance, net profit before taxes or customer satisfaction development per group over one year (Parmenter, 2015). To measure CE indicators based on a strategy chosen for a CEBM, a choice had to be made between focussing on performance or result-based indicators. CE indicators typically are result-based indicators, as they describe the environmental, economic, and social performance of a product or business when assessed on a micro level. To be able to visualize progress towards a certain goal, result-based indicators are needed. For this reason, using a result-based indicator also in the case of CE indicators for the food and beverage industry as based on a CEBM is therefore the more logical choice to have a clear understanding on whether the expected goals were achieved. However, adding a sub-set of performance-based indicators will allow to measure the reason for achieving certain goals. They look at all areas and aspects of a company, from customers, employee learning to organizational environment (Marchand, 2014). They might offer a more fruitful way of learning how to improve company performance. The indicators were developed following the S.M.A.R.T. methodology: Indicators measuring a company's objectives should be specific, measurable, achievable, realistic, and time-based (Bogue, 2005).

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The indicators were developed based on the CEBM canvas designed in the previous chapter and following initial talks with experts in the food and beverage industry and CE indicators. A scorecard design was selected based on a similar concept for CE indicators for the technical loop designed by WeSustain (WeSustain et al., 2019). After the initial set-up of the CE indicator scorecard, peer review and expert validation sessions were used to adapt and finalize the scorecard.

4.3. Validation of the CEBM Framework: Canvas and Scorecard

4.3.1. Peer Review Session

The peer review session took place with four graduate students from the MSc Industrial Ecology, on July 10, 2019, in the Hague, the Netherlands. After a brief introduction to the topic, the participants were given the CEBM canvas as well as the scorecard and were asked to give critical feedback on each of the sections. The main recommendations stemming from the peer review with graduate students from the Master programme MSc Industrial Ecology can be seen in *table 4-8*.

Table 4-2 Peer review results of CEBM and scorecard development 10-07-2019.

Peer Review Session 10. July 2019	
Comments received	**How the comments are implemented**
Will the % response address impact companies with only a few suppliers negatively?	Still adequate – allows small companies to better manage their supply chain
More clarity needed on the fact that it is about a waste stream & waste product. – Maybe it should be renamed circular waste management.	The elements in question will be rephrased.
More clearly state that the resource utilization ration concerns the percentage of the waste stream that will be re-used.	The phrasing of the questions regarding the RUR will be adapted.
It might be useful to add a co-efficient to weigh the different elements.	It will be clearly phrased that all the scores cannot be directly compared to each other. Questions relating to one score will indeed be weighed. However, a weighing between the different building blocks of the CEBM will not be undertaken as it is up to the company to make a decision on which area to focus on.
Questions regarding transportation might be negligible due to the low overall impact of transportation in terms of environmental impact.	As distances and modes of transportation vary considerably depending on the product created by a company and the focus is put on the creation of products from the waste streams rather than the raw material input

4.3.2. Interview Validation with Experts

Several experts from academia, consultancies, and the food and beverage sector were invited to give feedback on the finalized CEBM canvas and CE indicator scorecard. They were sent the CEBM canvas as well as the CE indicator scorecard and were asked to prepare questions and comments during a physical or Skype meeting.

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4.3.2.1. Validation session with SEMiLLA IPStar B.V. (Clara Plata & Angelo Vermeulen)

This validation took place in an informal setting during the course of the research internship. The framework consisting of the CEBM canvas as well as the scorecard was discussed both with Clara Plata, responsible for the development of a CE strategy for SEMiLLA, as well as Angelo Vermeulen. The discussion led to suggestions for further literature on CE business models, as well as a focus on user-friendliness and simplification of the scorecard for to be more easily filled out by companies in practice. The sessions included a series of Skype conversations and e-mails with Clara Plata, as well as a physical meeting with Angelo Vermeulen, on July 16, 2019.

4.3.2.2. Validation Dr.ir. Gijsbert Korevaar

Another feedback session via Skype took place on July 25, 2019, with Dr.ir. Gijsbert Korevaar, who is specialized in design methods and tools for IS in industrial regions and networks as well as business model development for industrial clusters. A one-hour long discussion of the CE Indicator Scorecard provided useful practical insights and feedback on the developed tool. The recorded audio file can be found in the supplementary document folder.

4.3.2.3. Validation Paul Tuinenburg, Director and founder of IDfuse

This was followed by a validation feedback session with an expert in business innovation. The feedback session with Paul Tuinenburg, director of IDfuse/Impacter, a company supporting start-ups and companies with grant applications for new business models. The feedback session took place on August 2, 2019.

4.3.2.4. Validation Olivier Benz, Consultant at Sustainalize

Another validation session was conducted together with Olivier Benz, consultant and expert for CE indicators, at the consultancy company Sustainalize in Utrecht, the Netherlands. The 1.5h long feedback session took place August 8, 2019.

4.3.2.5. Validation Astrid Carl, CEO Green Moves

The final validation session took place August 15, 2019, with Astrid Carl, an expert on CE in the food and beverage industry, and CEO of the consultancy company Green Moves.

The overall results of these validation sessions can be found in *table 4-9*. For a more detailed transcription of the interview the author of this paper can be contacted.

Table 4-3 Results from expert validation feedback meetings.

	Suggestions for change or discussion	Other comments or positive feedback
General	Generally, the scorecard was considered too long and too time-consuming and too complex. A selection of core indicators and shortening of the scorecard was suggested. (For this reason, the scorecard was reduced to 24 instead of 30 questions.)	The layout and the visualization of the results were seen as clear and appealing.
Scope and limitation	Initially it was considered not fully clear who the target of the scorecard was meant to be. (This was clarified. It now states that is meant for the biological waste stream of a company and product creation from it.) Sometimes the switch from product to company focus was seen as confusing. (The excel scorecard design was meant to clarify	

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	this.)	
Score distribution from 0-6	One expert was critical on limited grading potential as percentages were limited to a score between 0 to 6 and a one percent difference could lead to a full point deduction or addition.	This was viewed differently by another respondent who considered this a standard way of rating within sustainability measurements. It offers a simplified view and a common way of measurement and was not seen as problematic.
Objectivity		
Weighing	Some experts were requiring whether weighing of the indicators took place as this was not specified previously.	
Percentages used for the questions	More explanation on the distribution of the percentages was needed. (This was added after the discussion sessions.) One expert would have preferred the same percentages for all questions to reduce complexity. However, other respondents were asking for more detailed differentiation in percentages based on literature or achievable values in practice. (The latter was done whenever data was available.)	
Individual scorecard questions		It was seen as positive that the scorecard also included social aspects of a CE.
	Some questions were considered as either too complex and/or vague. The previously included question on resource recovery ratio (RRR) was eventually not seen as necessary as the same information was already conveyed through question A.1 and A.2. as well as through H.23.	
Buildings and production equipment	While buildings and production equipment originally were a part of the scorecard, they were considered too complex and negligible for the purpose of the scorecard. For this reason, it was suggested to leave the circularity of the materials from building and production equipment, as well as office buildings, out of the scope of the research and scorecard.	
Transportation	For distances, it was suggested by one expert to adapt the distance scheme of WeSustain.	
Energy	A definition of renewable energy forms was suggested to be added to be clearer. (This was done after the interview session and includes second and third generation biomass while excluding first generation biomass.)	

Based on the feedback received during the various feedback session, the framework received its final version (as seen in chapter 4.4). It was shortened to contain 24 questions, and indicators were more balanced with a minimum of one question, a maximum of three questions, but on average two questions per indicator. The indicator scorecard was redesigned in Microsoft Excel and was made more visually

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appealing. In addition, it was made more user-friendly, including some automatic calculations, to reduce the time needed for filling out the scorecard. After filling in the questions, the result can be seen automatically in the radar (or ‘’spiderweb’’) integrated in the excel file.

4.4. A CE Indicator Scorecard for the Food and Beverage Processing Industry

The CE Indicator Scorecard consists of 24 questions that lead to 14 indicators. The indicator questions are numbered from 1-24, plus contain a letter A-H to signify which building block of the CEBM canvas they relate to. An explanation for all scorecard questions is given in the following chapters. Calculations, detailed explanations as well as changes made after the peer review and validation step can be found in the appendix. The full scorecard can be found in the appendix and in an additional Excel file.

4.4.1. Value Proposition

For *Building Block A,* the circularity of a product(s) in the food and beverage industry is measured according to the level of revalorization that the waste receives, as well as the circularity of nutrients, water and energy. Including a waste hierarchy is considered an important element in creating CE indicators (Kirchherr et al., 2017a). This is taken into consideration in question A.1, which is based on Moerman’s Ladder (see chapter 2).

A.1.Which level does the waste-based product have in terms of value creation?

0	treatment but not reused (e.g. landfilled or burned)
1	energy production
2	compost
3	bio-based materials or fertilizer from fermentation, or combinations of anaerobic digestion and compost
4	animal feed
5	human food
6	medicines and fine chemicals

A.2. What is the percentage of this product from all the products created from the waste stream?
________ (weight) %

The rating for the value of the re-used waste is based on both Moerman’s ladder and the bio-economy value pyramid. Waste reduction and avoidance, which scores highest on Moerman’s ladder, was not taken into consideration in this scorecard as it would make the business case void. Fine chemicals and medicines were assumed to be at the highest level, receiving a grading of 6, as these products have the highest economic value and are indirectly used for human consumption (as they are either consumed or applied to the human body). The rest of the rating overlaps with both approaches, with animal feed following human food and bio-based materials, coming before fermentation and fertilizer applications. As a combination of anaerobic digestion and composting is seen as the most efficient way to create fertilizer and use waste heat, this was also given an equal ranking as production of bio-based materials. (De Schoenmakere et al., 2018) The lowest level is formed by energy production.

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If the company creates more than one product from the waste stream(s), an average will be calculated based on the amounts of products created (and based on their weight in %). This is meant to balance out and take into consideration the trade-off between re-using a large quantity at a lower value level or a smaller quantity at a higher level (see appendix I for more details on the calculation).

Additional questions (A.3 to A.7) were chosen based on the core focus points of nutrients, energy, and water cycling, needed for creating a CE in the food and beverage industry. A waste stream was considered circular when the water leaving the company premises was cleaned from nutrients and organic materials that could be re-used. The concentrations used as reference values can be found in the appendix.

For question A.3. the legally required discharge quality in Western European nations for phosphorus was used to award 1 point if achieved and 2 points if done on-site. To look at reliable P removal and recovery data, German pollution regulations were taken as a basis as they are considered leading in the European Union and regulation is actively changed to support the development of a CE. 80% of P have to be recovered from German sewage sludge (Pollution Control Service, 2019). This was taken as a minimum requirement for 3 or 4 points depending on whether the treatment was on or off-site. Recovery rates of up to 87-99% of P from waste streams (including the sludge) are considered possible depending on the method used (Cornel & Schaum, 2009; Sengupta, Nawaz, & Beaudry, 2015).

A.3. What amount of P do you recover from your waste stream?	
0	We do not remove or recover P.
1	We do not remove or recover P. However, the WWTP we discharge our waste stream to removes the P and meets legal requirements.
2	We treat out waste stream and remove P and meet legal requirements.
3	We do not remove or recover P. However, the WWTP we discharge our waste stream to removes the P and recovers 80% or more.
4	We recover more than 80% of the P in our waste stream.
5	We recover more than 90% of our P in our waste stream and re-use the sludge as fertilizer or compost.
6	We use BAT and recover more than 90% of our P from waste streams and sludge.

For question A.4. the nitrogen directive of the EU chose a TN level of <10mg/l as the legal requirement for discharge (EC, 2010). This reference value is in line with the expected concentration after BAT usage for WWT (European Commission, 2006). This will be used as a basis for measurement for the developed scorecard question on N. For maximum N recovery, estimates from literature were taken. For waste streams, targeted recovery of N could allow for recovery of up to 100% (Sengupta et al., 2015). However, it was suggested, that of the nutrients in the created sludge, 33-47% of N can get lost to the air if sludge is dried for nutrient extraction (Deviatkin et al., 2019). It is recommended to double-check these values in accordance with real life performances of companies.

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A.4. What amount of N do you recover from your waste stream?

0 We do not remove or recover N.
1 We do not remove or recover N. However, the WWTP we discharge our waste stream to removes the N and meets legal requirements (<10mg/l).
2 We treat out waste stream and remove N and meet legal requirements (<10mg/l).
3 We do not remove or recover N. However, the WWTP we discharge our waste stream to removes the N at legal requirements and recovers 80% or more.
4 We recover more than 80% of the N in our waste stream.
5 We recover more than 90% of our N in our waste stream and re-use the nutrients in the sludges (e.g. in the form of fertilizer).
6 We recover more than 90% of our N from waste streams and sludges. In addition, the removal is based on the highest removal using BAT (with higher removal rates than legally required).

A nutrient that has received less attention is K. As there are fewer guidelines or best practices available on K recovery, the scorecard has a less strict rating for this nutrient as compared to P and N (Johansson et al., 2019). The focus is put mainly on the innovativeness of the company in dealing with this nutrient and in their active approach to research.

A.5. What amount of K do you recover from your waste stream?

0 We do not remove or recover K.
1 We do not remove or recover K. However, the WWTP we discharge our waste stream to removes the K.
2 We no do not yet remove or recover K. However, we support research on K removal and recovery.
3 We no do not yet remove or recover K. However, we are conducting research on K removal and recovery on-site.
4 We remove K from our wastewater and conduct research on K recovery.
5 We remove K from our wastewater and recover it partially.
6 We fully (>80%) recover K from our wastewater and sludge.

In addition to the resources, the amount of energy being recovered as well as water being recovered (for instance, through cleaning it or re-using it) is included in the value proposition, in question A.6. and A.7.

A.6. How much energy is saved through the production of the new product from waste as compared to production in a non-circular manner?

0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85%

A.7. How much water is saved through the production of the new product from waste as compared to production in a non-circular manner?

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0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85%

The scores based on these questions aim at giving inside into the focus of the value proposition and the potential in terms of circularity of the product.

The most important indicator for the *Customer* building block is the degree of awareness on the importance of CE as well as the level of involvement from the customers of the product. (This will also impact the type of marketing the company might have to do.) This led to the development of question B.8.

B.8. The Level of Customer Awareness and Inclusion: How are customers involved in the circularity of the product?

0 There is no direct interaction with customers.
1 The company knows whether their customers are interested in the circularity and/or sustainability of their product. (For instance, through conducting surveys.)
2 Customers are informed about the content of the product and its impacts on their health and the environment, for instance through labels on the package.
3 The customer side of circularity is taken into consideration when designing the product.
4 Customers have access to all data on where their product comes, its production processes, and impact on the environment and society, for instance, through following a QR code or a link to a website.
5 Customers have the opportunity to visit the production processes and have insight into the processes or get into contact with the company. They are able to give critical feedback and share their ideas on CE.
6 Customers are invited to join for ideation on new product design or improvements in terms of CE. Critical feedback is used for improving the product or supply chain.

The Level of Customer Awareness and Inclusion is meant to give an insight in how well-informed customers are about the product they are purchasing and its contribution to a CE. The idea behind this measurement is that customers will choose a product they can trust and that they can have an influence on. The more involved customers are, and the higher the transparency, the more sales the company will have. It also indirectly shows the system impact that the company can have, as word-of-mouth will lead more customers to buy a sustainable product. Merlo et al. (2014) recommend embedding customer participation in the strategy of the company, as this has the potential to create a higher revenue than standard marketing or word-to-mouth. This is the case as the customer involvement and feedback allows to identify elements of the products or production steps that customers disagree with. It creates more room to cater to the needs of the customers (Merlo et al., 2014).

4.4.2. Value Creation

To measure circularity within the key activities and key resources, a look at the supply chain is needed and the degree of CE within the raw material extraction and transportation. For this reason, an indicator would be the knowledge and transparency on CE practices within the supply chain.

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Table 4-4 Indicators for the value creation of the CEBM.

Indicators Value Creation	
C. Key activities and organisation:	Supply Production: Energy & Water
D. Key resources	Employees

The key activities for CE production principles for the food and beverage industry are focussed on acquisition of supply and the production processes of the company.

Question C.9. and C.10. focus on the supply of raw materials. In a first step, the transparency of the supply chain is evaluated. In a second step, the knowledge on CE of the supply chain, and the actual implementation of CE is tested. These questions aim at raising awareness and supporting the implementation of CE principles along the supply chain. As with previous building blocks the percentages used are based on average distribution and a linear progression.

C.9. Supply: For what percentage of the supplied inputs do you know the exact origin e.g. the farmer producing the raw material?

0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85%

C.10. Supply: What percentage of your suppliers work with a certification scheme for CE are rated as circular (using a metric based on energy, nutrients and water usage or a different certification)?

0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85%

For production processes, the focus is put on the re-use and efficient usage of energy, water, and material, in this case nutrients. The indicators are therefore based on these categories.

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Questions C.11. and C.12. focus on the energy use during the production of the product. For an ideal production process, cleaner and efficient energy usage as well as non-fossil energy sources need to be implemented. Ideally, surplus energy from some processes can be reused for other processes. The questions try to incorporate all elements from energy efficiency, energy source to energy circularity.

C.11.Production – Energy requirements: What % of the energy input for the product creation comes from a waste stream or from renewable energy sources?

0 0% The product is only built from fossil fuels
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85% The majority of the energy needed for the production for the product stems from either re-used heat, or renewable energy

C.12. Production – Energy requirement: What percentage of the energy used in the company is being re-used, e.g. as waste heat?

0	No waste energy is being recovered
1	>1%
2	>4%
3	>8%
4	>12%
5	>16%
6	>20% of waste energy is recovered

Question C.12. is based on findings on heat usage and waste in industrial processes. Only data for the UK was found but was assumed similar in other developed countries. 72% of industrial energy is needed for thermal processes, of which 31% is low temperature heat. Even more, 20% of it could potentially be recovered and reused. (Jouhara et al., 2018) The rating is loosely based on this finding. It has to be taken into account, however, that the recovery rate depends on the specific processes at the company level. Generally, energy efficiency should be given priority over waste heat reuse. The two sub-questions are combined to a final score on energy within the scorecard, by taking the average.

Question C.13. measures the recycling rate of the output, thus, recycled output divided by the total output. Ideally, in the case of 100% of the output being recycled this would lead to a rating of 1 or 100%.

C.13. Production: Water - What % of the water used in the waste product recovery process is being re-used afterwards?

0 0%
1 up to 20%
2 up to 40%
3 up to 60%
4 up to 80%

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5 up to 96%
6 96-100%

Question C.14. focusses on the quality of the water stream when returned to the company processes. The rating is based on an interview with Istvan Koller, from the Waterschap De Dommel, on re-use options for water depending on the quality of the stream.

C.14. Production – Water: What is the water quality after the production (& cleaning) process?

0 Polluted water
1 Meets standards to be sent to WWT
2 Meets standards to be used for irrigation of decorative plants
3 Meets standards to be discharged
4 Meets standards to be re-used for irrigation of edible plants, animal feed
5 Meets standards to be re-used for production processes
6 Meets standards to be used as drinking water

Based on the two sub-questions on water one final indicator for water circularity at the company level can be created by combining the score of these three questions into one average final score.

For *Building Block D,* employees were chosen as a key resource for transition towards a CE.

D.15. How do you involve your employees in your vision of creating a CE?

0 They are not involved.
1 Employees are informed about what a Circular Economy is and what the company contributes to it.
2 Employees are aware of the economic benefit of a CE strategy of the company and support the company vision towards a CE.
3 The company focusses on education and knowledge building on CE. There are trainings, work-shops and courses on CE available for employees that allow them to build expertise.
4 Employees are enabled to connect their personal goals with the CE goals of the company and work on areas of their personal interests.
5 Employees are invited to co-creation sessions (and can express their ideas within a healthy competition).
6 Results of the progress on CE (as well as the contributions of employees) are shared internally and externally. For instance, by sharing the results of performance indicators on CE. In addition, employees are aware of the system impact of the company and/or product.

To understand the involvement of the employees towards creating a CE, the level of involvement is tested with this question. This is based on research on aligning sustainability between corporate and personal values (Polman & Bhattacharya, 2016). A detailed explanation on the scores can be found in the appendix.

4.4.3. Value Delivery

Value delivery can be shown in terms of the partnership network integrated in the production of additional products from waste products and the level of connectedness between the partners. Sharing of technology

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and knowledge between the partners could be an additional element pointing towards successful value delivery. Indicators based on collaborative government theory, measuring the progress of the collaboration, as well as circularity of the partner institutions and supply chain members could provide a useful basis for measuring value delivery in terms of a CE.

Table 4-5 Indicators for the value delivery of the CEBM.

Value Delivery	
E. Partners	Circularity of Partners
F. Channels & Technology	CE in Transportation & Packaging

E. Partners

The indicator for the building block of partners measures the level of collaboration regarding a CE through the question E.16.

E.16. At what stage is the collaboration between you and your partners on creating a CE?

0 We do not have any partners.
1 We have partners. Our exchanges are mainly based on the profits to be gained from our products.
2 We share and discuss ideas with our partners.
3 We exchange information beyond financial details and have a shared code of conduct in terms of CE. Our partners are actively involved in deciding on a CE strategy.
4 All partners use some sort of certification scheme for CE and/or sustainability.
5 All partners use the same certification scheme for CE and/or sustainability as a basis or actively work together to improve their certification schemes.
6 All partners use the same certification scheme for CE and/or sustainability as a basis or actively work together to improve their certification schemes PLUS aim at sharing these best practices industry-wide and/or support legislative changes that foster a CE.

Question E.16. is based on Glasbergen's Ladder of Partnership Activity (2011), that defines several steps of collaboration towards management practices for sustainable development. The While this in theory was based on collaborative efforts between civil society, market and state actors, it can also be applied, with slight variation, to industrial partnerships, such as in industrial symbiosis. It studies collaborative partnerships and their influence on societal change and rule-systems. Companies within large collaborative networks can have a similar influence on society. The levels defined by Glasbergen are: ''Building trust, creating collaborative advantage, constituting a rule system, changing a market'', and ''changing a political system''. (Glasbergen, 2011, 4) The first step of the question is to identify whether there are partnerships and whether they are purely financial in nature. Building trust was mirrored in a shared understanding of CE and a shared code of conduct. A certification scheme for CE was seen as a way of constituting a rule system, that could expand beyond the partnership if applied also by other companies. This would then link to changing a market. ''Changing a political system'' was added after the validation interview with Sustainalize as this was identified as a way for companies to contribute to a systems change regarding CE.

Question F.17. and F.18. try to incorporate the environmental impact of transportation between production and processing and production steps of the products. Here, the focus is specifically on raw materials used initially to take into account more of a systems approach. These two questions only apply

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when looked at CE from the company perspective rather than a single product perspective. In addition, these questions were not quantifiable, as travel distance and production vary greatly between the type of production industry and their supply chosen. For instance, a chocolate producing company in Western Europe will be incapable to acquire its entire raw material input from local suppliers. However, the transportation mode chosen, especially when airplanes are involved, plays an important role on the impact on the overall product and company footprint.

F.17. What mode of transportation is used to transport the raw materials to the company?

0 Mostly airplanes
1 Mostly heavy trucks.
2 Mixture of trucks and shipping.
3 Mostly vehicles running on biomass.
4 Mostly transportation via low-emitting ships and short distances with non-fossil fuelled trucks.
5 Mostly electric powered vehicles or hydrogen vehicles running on clean energy.
6 Only railway or other modes of transport based on non-fossil fuels, or pipelines.

F.18. Transportation: What distance is involved in the transportation process until the raw materials reach (and leave) the production facility of the company?
0 Global supply chain and production steps around the world
1 Global supply chain but production steps EU wide.
2 EU wide supply and production
3 Supply EU wide, and production regionally (within 150km).
4 All supply and production within 150km of production site
5 Local or regional supply (within 150km) and local production (within 25km)
6 Only local suppliers and materials as well as local production (within 25km)

To provide a basic and fast understanding of the impact the mode of transportation and the distance from the raw material supplier was taken to give a rough interpretation of the impression of the impact of transportation. Local supply and production distance were defined as below 25km, and regional supply and production distance was defined within a 150km range. The ranges that were chosen in alignment with the existing CE scorecard designed by WeSustain for the technical loop in CE (WeSustain, MVO Nederland, & ecopreneur, 2019; Interview Sustainalize). This allows for a better cross-sector coherence.

While the food and beverage industry production processes are not concerned with the technical loop, this becomes relevant in case there is packaging involved between the different transportation steps, or for the sale of the product. For question F.19, the Material Circularity Indicator (MCI) – developed by the Ellen MacArthur Foundation – is used to calculate the circularity or the packaging material. In case of multiple packaging, the average will be used. To calculate the MCI, a tool can be used, developed by the Ellen Mac Arthur Foundation for Microsoft Excel. (Ellen MacArthur Foundation; Granta Design, 2015) The MCI focusses on the restoring of materials and the return of them after their end-of-life phase, for instance, through remanufacturing, reuse, or recycling. The indicator is constructed from the virgin feedstock, the amount of unrecoverable waste, and the length and intensity of use of the material (the latter two leading to the linear flow index. The calculation of the MCI can be found in appendix I.

F.19. What is the material circularity indicator score for potential packaging of the material?

0 0.00-0.1 No recycled or reused materials used and no collection after use.

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1 0.1-0.25 A small amount of materials that are being reused or recycled after its use phase.
2 MCI > 0.25 At least 50% of the materials either stem from recycling or reuse or will be recycled or reused at the end of their life.
3 MCI > 0.5 At least 50% of the materials either stem from recycling or reuse AND will be recycled or reused at the end of their life.
5 MCI > 0.8 Most building materials are sustainably sourced
5 MCI > 0.85 & Most packaging materials are sustainably sourced, non-toxic, and either reused or recycled after their life-span. Life-span is extended as much as possible.
6 Our product(s) do(es) not require packaging. OR Packaging is 95-100% circular and energy-neutral.

There needs to be awareness on the fact that this indicator does not take into consideration losses of the material throughout the supply chain.

4.4.4. Value Capture

Typical financial indicators measuring the costs and benefits, or profits generated, can be used for this section. The typical financial indicators were not included due to the limitations in scope of the research but can be added at a later point.

Table 4-6 Indicators for the value capture of the CEBM.

Value Capture	
G. Costs & Revenues	Profit

However, a basic question on the profitability of the established CE design is needed. For this reason, a focus on the degree of profit when taking into account externalities was chosen. This leads to the following question.

G.20. Is there a net profit from creating a CE based on the waste streams used?

0 It will cost us money (excluding including the negative externalities we are substituting).
1 It will cost us money, but we gain additional value (such as informational or customer value).
2 It will cost money; however, we will gain money considering current negative externalities we have to pay for (or reputation that costs us money).
3 The value is roughly comparable to a non-closed system.
4 We are making a small benefit.
5 We are making considerable profits from the closed system.
6 We are making considerable profits and make use of the additional value (informational, customer).

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4.4.5. Value Anchoring

To measure the system impact and the long-term impact of a product, the indicators system as well as pollution (including GHG emissions) were chosen. Each comprises of two questions.

Table 4-7 Indicators for value anchoring within a CEBM.

Value Anchoring		
H.	**Local & System impact**	System Consideration
I.	**Long-term impact**	Pollution (nutrient accumulation & GHG emissions)

Question H.21 and H.22 look at the integration of the entire life-cycle of the product into the CEBM.

H.21. Systems Perspective: Our company is actively involved in creating a CE within (tick if applicable)

a. Our suppliers
b. Our partners
c. Our production
d. Our production facilities and equipment
e. Our logistics
f. Our consumers

For question H.21 the company receives a point for each of the potential answers mentioned. Based on the incorporation of all elements of the value chain, the company or product receives a score of 0 to 6. This could be further elaborated for each of the elements of the system to also show their degree of circularity, e.g. of the supply with a grade from 0 to 6. The rating is applied in a similar manner for question H.22. Based on the activities of the company to promote and enhance CE a score between 0 and 6 is given.

H.22. Systems Perforation: Our company was active in:

a. Promoting CE to consumers through education (e.g. tours through the company, educational centre, labelling of product…)
b. Promoting CE to partners (e.g. seminars, meetings on CE strategies, …)
c. Promoting CE to supply chains (e.g. trainings, implementation of labelling schemes, support and education, financial support)
d. Promoting CE within the company's workforce (e.g. through training days, information sessions)
e. Promoting CE through research on-site from own R&D team and/or university research groups
f. Incorporating CE into our vision and business model

The long-term impact was measured by including the waste reduction per year in % as well as the GHG emissions (in CO_2eq.) of the production of the product in comparison to a BAU scenario and avoided pollution. Both are important indicators on keeping a balanced ecosystem in balance and allow for a food and beverage industry that can continue in the future. (EC, 2019)

I.23. How much waste was avoided (stock building) in % as compared to the BAU production of the company?

0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%

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4 up to 68%
5 up to 85%
6 more than 85%

I.24. What is the net reduction of CO_{2eq} emissions of the product created from the waste stream in comparison to the business as usual (BAU)?

0 negative or 0%
1 up to 17%
2 up to 34%
3 up to 51%
4 up to 68%
5 up to 85%
6 more than 85%

For the BAU scenario a non-circular production based on primary raw materials and resources was assumed. As more and more citizens are concerned about their contribution towards global warming, transparency with regards to greenhouse gas emissions (GHGs) (in CO_2eq.) adds additional value for the customer if the result of this indicator is shared. It also increases transparency and trust in a project aiming for a sustainable CE. There are several ways of calculating the CO_2eq. emissions associated with the production of the product. To calculate the full carbon footprint, as would be the ideal case, a life-cycle assessment is recommended. This, however, is time-intensive and sensitive to data availability. Alternatively, there are companies offering footprint calculations for a product, such as the Swedish company CarbonCloud (CarbonCloud, n.d.). However, the scope of the study needs to always be carefully taken into consideration when choosing the calculation method. Multiple ways of determining the GHG emissions of the production are possible, however, it is important that the company is transparent on how they obtained the result. Calculating these emissions is unavoidable if a company truly wants to contribute to sustainable development with their CE based product.

4.4.6. The CE Indicator Scorecard Results

Table 4-7 shows how the individual indicators are calculated. Unless otherwise stated, this is done by taking the average of the questions belonging to one indicator.

Each indicator comprises of between one and maximum three questions. All social indicators typically comprise of only one (qualitative) question. Indicators, involving quantitative questions usually comprised of two or more to be able to include all relevant information (mostly in combination with a recycling and efficiency of use stream).

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Table 4-8 Final scorecard based on the CEBM building blocks.

Scorecard Final Score per Building Block	Building Blocks	Questions per indicator (Score: 0-6)
Value Proposition	A Product:	
	Products	*Based on questions A.1 & A.2.*
	Nutrients	*Based on questions A.3-A.5.*
	Water	*Based on question A.6.*
	Energy	*Based on question A.7.*
	B Customer	*Based on question B.8.*
Value Creation	C Supply	*Based on question C.9 & C.10.*
	D Production: Energy	*Based on D.11-D.12*
	Production: Water	*Based on D.13-D.14*
Value Delivery	E Employees	*Based on question E.15.*
	F Partners	*Based on question F.16*
	Transportation	*Based on question F.17 & F.18*
	Packaging	*Based on question F.19.*
Value Capture	G Profit	*Based on question G.20.*
Value Anchoring	H System Consideration	*Based on question H.21 & H.22.*
	I Pollution Reduction	*Based on questions I.23. & I.24.*

No weighting of the indicators took place as this was considered too subjective to be possible. The indicators are listed individually in the form of a radar, rather than forming one aggregate indicator. This was done as it is impossible to achieve the highest rating in all the scores presented as some areas might be conflicting with each other. For instance, the highest nutrient extraction rate or waste-reuse might come at higher energy costs. Trade-offs have to be made depending on which areas are chosen as a priority. One joint indicator would therefore not properly display these trade-offs.

The scorecard does not offer an exhaustive list of indicators but aims at allowing companies to pinpoint in which areas they are performing the strongest and showing the areas in which improvement might be needed or still possible.

The results of the questions filled in will be visible in the form of radars highlighting the performance of the company for each building block.

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5. Research Internship and Pilot Study

The developed CEBM framework and the accompanying scorecard were developed during a research internship with SEMiLLA IPStar B.V. the technology transfer partner of the MELiSSA consortium and the European Space Agency (ESA) with the aim to develop a CE framework that can be used for CE projects related to the MELiSSA technology. The developed CEBM canvas and CE indicator scorecard were then tested with a pilot study on a CE at the La Trappe brewery within the NextGen Horizon2020 project. The framework was tested at a company level for the BioMakery, the CE production platform of the La Trappe brewery by applying it to SEMiLLA technology, as well as to the full technology used at the BioMakery and the technology partner Biopolus. The BioMakery treats brewery waste as well as the waste stream of the onsite cheese makery. Information on the project was collected during a five months research internship at SEMiLLA. Data on the BioMakery was collected during site-visits, and interviews with experts from the Waterschap De Dommel, the monastery and the brewery company.

This chapter gives an overview of the collected information needed to fill out the CEBM canvas as well as the scorecard. In addition, it examines the main impacts of the brewery industry on (local) ecosystems and their challenges and opportunities in terms of a circular economy. Options for creating circular solutions and reducing the environmental, social and economic impact based on circular water, nutrient and energy usage will be reviewed.

5.1. Waste and Nutrient Recovery for Beer Breweries

The following section describes the general situation in breweries and is not specific for the La Trappe situation. Waste streams in the beer producing sector have large potential as they are high in organic carbon , and low in chemicals or pollutants that would make recycling or treatment difficult. Since treatment of the waste is required by law, this provides an additional incentive to re-use the waste material at the highest economic benefits (and lowest negative impact on society and the environment).

5.1.1. Properties of Brewery Waste Streams

Beer is produced through various processes involving water, barley, hops and yeast. (Bojidarka & Spiteller, 2016) Every litre of beer produced produces between 3-12 litres of waste water. Typically, brewery waste water consists of a mixture of residues from the raw materials used for beer production, in this case, sugars, yeasts, ethanol, inorganic salts, and other solids. In addition, chemicals used for cleaning of pipes, containers and bottles enter the waste stream. (Bojidarka & Spiteller, 2016; Rao et al., 2007) *Table 5-1* shows the characteristics of a typical brewery waste stream. Variations depend on the dilution of the wastewater.

Table 1
Characteristics of brewery wastewater

Parameter[a]	Brewery wastewater
pH	3–12
Temperature	18–40 °C
COD	2000–6000
BOD	1200–3600
VFA	1000–2500
Phosphates as PO_4	10–50
TKN	25–80
TS	5100–8750
TSS	2901–3000
TDS	2020–5940

[a] All parameters except pH and temperature are in mg/l.

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Table 5-1 Typical composition of a beer brewery wastewater stream. (Rao et al., 2007)

In addition, the brewery wastewater has different properties depending on the production step. Waste water from the brewery production could be acidic, while waste water from caustic operations (which make up two thirds of the waste water) is alkaline. As a part of the pre-treatment, the different streams are homogenized in a buffer tank, where the pH is equalized. Normally, the waste water stream remains alkaline after mixing. Acids are used to return the pH value to about 7 or 7.5 before the anaerobic digestion treatment step. However, adding sulphuric acid could lead to formation of sulfide, which could treatment costlier, due to extra required safety measures. Alternatively …. can be used to balance out the pH, making treatment easier and more economical as CO_2 is already needed for the beer production process or can be gained from the anaerobic digestion process. (Rao et al., 2007) Cheese production waste water has similar properties as brewery waste water, with more total nitrogen (TN) and fats. (Suters et al., 2016)

5.1.2. Brewery Wastewater Treatment

Traditionally, brewery waste water is treated either on or off-site and then the water is returned to the environment. Water coming from industrial processes to WWTPs, such as from brewery processes involving chemicals or pollutants, is required to be pre-treated before it is discharged into municipal waste water lines. (Klijnhout & Van Eerde, 1986)

5.1.2.1. Wastewater Treatment Off-Site

The treatment steps at the municipal treatment level are similar to the treatment directly performed at (beer) production facilities. In typical waste water treatment systems, the cleaned water is discharged into rivers or streams, and what remains is sewage sludge. Sewage sludge comprises of the organic and inorganic materials remaining after cleaning the water stream. In waste water treatment plants (WWTPs) the waste stream is first pre-treated to remove larger solid objects, such as paper or bottles, and grit and sand. The first treatment step normally involves flotation or sedimentation and removes approximately half of the solid organic and inorganic materials, which is referred to as primary sludge. In a second treatment microorganisms are used that break down dissolved organic material leading to CO_2 emissions to the environment and microbial cell mass that needs to be filtered out in a further process step. This material is referred to as secondary sludge. If in a third step nutrients are removed, or the BOD is reduced, this creates a tertiary sludge. In a final step, pathogens in the water need to be destroyed before the water can be re-used or discharged. The sewage sludge types are then combined for further processing. Unprocessed, they form a health and an environmental hazard as they contain pathogens and are unstable. Treatment options include thickening, dewatering or filtration (which however, results in loss of nutrients), anaerobic digestion (requiring a temperature between 20-55 degrees Celsius and resulting in CO_2 and methane production), aerobic digestion (resulting in CO_2 production), alkaline stabilization or composting (together with saw dust at temperatures of at least 55 degrees Celsius). Sewage sludge is sometimes also landfilled, leading to methane emissions into the atmosphere, and leakages and environmental damage as it can contaminate groundwater of local environments. Incineration is another form of disposing of sludge, producing CO_2, emitting potential health-affecting pollutants, and fly ash. If sewage sludge underwent treatment to reduce pathogen content and stabilize it, it can be applied as fertilizer to land. In this case sludge is oftentimes named 'biosolid'. (Stehouwer, 2010) In the Netherlands, two-thirds of all sludge produced is burned and about 10% is used for electricity generation. (Arantes, Jos E Alves, Sequinel, Ant, & Onio Da Silva, 2017; Geertjes, Baas, Verschuren, Kaashoek, & Graveland, 2016; Klijnhout & Van Eerde, 1986)

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5.1.2.2. Regulation on waste water quality

Dutch law requires to produce the least amount of waste water possible and re-use as much as possible, and separate waste water streams unless they can be treated together without problems. The water discharge quality levels are based on the European REACH-regulation. It assesses the biodegradability of the material, its toxicity for humans and the environment, and its quantity. (Dutch Ministry of Infrastructure and the Environment, 2016) Discharge regulations depend on the area of discharge and the responsible waterboard of this area. For instance, for the waterboard of De Dommel, requirements for discharge and treatment with the local WWTP depend on the grade of pollution, the quantity of the discharge and the impact on the WWTP, the ability to treat it on-site, and the potential to close water usage loops. (Waterschap De Dommel, 2004) Discharge parameters might vary from location to location. The upper limit for phosphorus concentration in brewery (and most other) waste waters is set at 2mg/litre of discharged water. For nitrates this is set at 50mg/litre in accordance with the European regulation on nitrates. (EC, 2010) However, the discharge of total N (from ammonium, nitrate, and nitrite) cannot exceed 18 mg/litre. The pH needs to be 7 before discharge of any industrial waters. COD is required to be below 110ml/litre and BOD below 25ml/litre for brewery waste water. (Stein, n.d.) Benchmarks exist for all 25 regional water authorities in the Netherlands for their waste water treatment and the quality of the water that is discharged. Benchmarks include phosphorus and nitrogen content of the waste water stream as well as the net costs per pollutant that is treated and the volume of the stream. (OECD, 2014)

5.1.2.3. Choice for off- or on-site treatment of wastewater

The choice for on-site wastewater treatment is influenced by discharge legislation. When quality requirements are high for production facilities, it might be more cost-effective and from a logistical and technical perspective the only option for treating the waste stream. In addition, costs saved by treating the waste on-site rather than paying for treatment at a WWTP is another factor. (Klijnhout & Van Eerde, 1986) In 2011, public waste water treatment expenditures amounted to 1293 million Euros (OECD, 2014). On-site treatment would contribute to a reduction of stress on the budget of regional water authorities and for this and reasons of higher water quality discharge levels and increased circularity is the option supported by public authorities. With increased awareness of Circular Economy principles, such as high-end re-use of waste products and by-products, installing treatment options and creating additional value from waste products has become increasingly interesting to companies in the food and beverage processing industry. (Arantes et al., 2017; Simate et al., 2011)

5.1.2.4. Options for on-site wastewater treatment

Treatment of brewery wastewater on-site can either occur aerobically or anaerobically. While aerobic treatment requires O2, anaerobic treatment is used to remove organic material with bacteria without O2. Anaerobic digesters in comparison to aerobic treatment are seen as the preferred treatment option as they do not require energy input in the form of fossil fuels to run the process, produce only little excess sludge, can handle organic shock loads, have low costs and use simple technology. In addition, energy is won in the form of biogas and their high efficiency allows for closing loops more easily. (Grant et al., 2002; Van Lier, Mahmoud, & Zeeman, 2008) Efficiencies of removing COD from the brewery waste water in anaerobic digestion are up to 98% (Arantes et al., 2017). Efficiencies for other waste flows in the food and beverage industry, such as cheese or distillery waste streams are comparable to brewery waste water efficiencies (Grant et al., 2002). This makes anaerobic digestion a financially viable option for companies, particularly as it allows to re-use the created biogas for energy production. The sludge created could as well be turned into a new product. However, most of the traditional treatment options focus on sludge as a problematic waste, or as a means to create energy, but do not take into account possible nutrient recovery. To, combine WWT with CE, potential ways of extracting and re-using the nutrients at their highest potential value level need to be explored.

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5.1.2.5. CE Challenges of the food and beverage industry in beer production

For re-using waste streams in the food and beverage industry, pollution and energy consumption are two major challenges.

A challenge in creating a CE is posed by the pollution of the waste stream. In addition to nutrients, other chemicals needed for cleaning, or potential pathogens need to be filtered out from the waste stream, especially if the components are to be re-used for consumption, which requires additional treatment steps, costs and energy. However, overall, brewery waste streams are very low in pollution in comparison to other industrial waste streams, which makes them very suitable for re-use (Olajire, 2012; Simate et al., 2011).

Another challenge in creating a circular production system is reducing the energy usage to close the loop and ensure that non-fossil fuels are out-phased and excess energy is re-used. Beer production is an energy intensive process requiring heat for the different brewing steps. A heat exchanger network is recommended for efficient use of energy for cooling and heating. With the use of pinch analysis, the potential for re-using waste heat can be identified. (Muster-Slawitsch, Weiss, Schnitzer, & Brunner, 2011) Furthermore, energy usage is closely connected to the waste treatment and re-use of waste materials. By applying anaerobic digestion, more energy can be created than is used. The generated biogas can be considered a renewable form of energy as it stems from waste materials. (Banja et al., 2019; Venkata Mohan et al., 2016; Zeeman et al., n.d.) The produced biogas typically contains approximately 55-70% methane, 30-40% carbon dioxide and on average 1% of nitrogen. In addition, it contains small amounts of hydrogen sulphide (H_2S), and other gases. After a purification step to remove moisture, or potentially H_2S, the biogas can be used for electricity generation and after a processing step also for use in combustion engines, gas turbines and fuel cells, such as solid oxide fuel cells (SOFCs). (Arantes et al., 2017; Saadabadi et al., 2019) A recently discussed alternative to biogas production from anaerobic digestion could be the production of hydrogen. To produce hydrogen, the wastewater is used as a basis for fermentation. Through various chemical reactions, hydrogen can be created with low energy requirements (lower than by comparison through electrolysis). At the same time H_2 production contributes to waste water treatment as it reduces the amount of organic material in the waste water stream. Special bacteria, such as *Bacillus amyloliquefaciens*, can be used to produce H_2 and degrade carbons to fatty acids. This can also be used for similar industrial waste streams in the food and beverage industry, such as for the treatment of whey from cheese makeries. (Arantes et al., 2017) Since H_2 could offer a fuel source that produces H_2O in place of traditional CO_2 emissions it is often considered an ideal fuel. However, the challenges in producing and storing it, as well as its costs currently do not make it a feasible option (Saadabadi et al., 2019). In addition, the concept of energy generation from waste, needs to be seen critical, as it eventually still leads to emission into the environment, even if it replaces fossil fuel emissions. Moreover, precious nutrients and the potential for higher end re-use might be lost by doing so. Energy requirements and emission production thus needs to be closely monitored when choosing a treatment and re-use option for a circular economy.

Water is another important aspect of CE for the beer industry, and also in the case of La Trappe in Tilburg. Sustainable and circular water use is becoming increasingly important for companies but also the regions in which they operate. Climate change is resulting in increasing water shortages in certain regions of countries and droughts in agricultural lands. This particularly affects the South of the Netherlands due to the sandy grounds. Harvests of agricultural products highly depend on moisture in the root zone of the plants. Due to water shortage, plants grow slower or die and financial losses for farmers are expected to rise up to 140 million € in the upcoming years. At the same time industries typically discharge their waste water streams in to rivers or streams where they flow to the sea. (Bartholomeus, 2018) By creating more circular water

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flows these local water shortages could be re-sued. Closing water loops and ensuring high quality water that can be re-used after the production processes is an important step in addressing these challenges. For instance, Bavaria has started working together with farmers surrounding their breweries to re-use the effluent water for irrigation of land using a drainage system to counter draughts. Re-using water instead of discharging it also leads to improvements in water quality both of the re-used stream as well as the rivers and streams normally used for discharge. (Bartholomeus, 2018) However, increased water quality oftentimes goes hand in hand with increased costs, due to additional need for treatment. Some of these costs can be balanced out by the products created from the nutrients and minerals extracted in the treatment process.

5.1.2.6. CE for the brewing industry: Aims towards closing loops for nutrients, water, and energy

To create a circular system at a brewery facility, nutrient and material loops as well as water and energy loops need to be taken into consideration. For achieving this, on-site treatment of brewery wastewater is paramount as it allows to locally re-use water, waste heat and allows to use the potential of the nutrients and biomaterials that can be extracted from the waste stream. For a true CE the treatment needs to go beyond anaerobic digestion and energy production. The MELiSSA technology and its CEBM will be studied in light of these requirements. The same will be done in a second step for the entire BioMakery of the La Trappe brewery.

5.2. MELiSSA Technology for Water Processing and Nutrient Re-Use

The MELiSSA closed system technology implemented by SEMiLLA at the La Trappe brewery is based on the MELiSSA programme of the European Space Agency (ESA). The aim is to use the highly developed technology to improve the circular economy in various projects in Europe. As use in space and spaceships requires perfectly closed loops, this system is suited to advance the circularity of nutrient streams in the food and beverage industry. It is tested and installed in a pilot project with the brewery La Trappe. The MELiSSA separation technology is co-implemented together with a water processing system based on Metabolic Network Reactors (MNRs) created by the Hungarian start-up Biopolus at the BioMakery of La Trappe. The system designed by Biopolus aims at filtering and cleaning the waste water stream with a bio-film reactor within a greenhouse. [ex] The technology can either be used to improve the quality of the effluent stream from the beer production and can even include the domestic waste water lines of the brewery, abbey, visitor centre and restaurant, and treat both grey water (domestic water excluding toilets) and black water (waste streams stemming from toilets that could contain pathogens). The technology allows to extract nutrients from the waste water streams that can be used for a second greenhouse where high-value plants or algae may be grown. Part of the system can potentially also be used to filter the whey from the cheese waste stream at the abbey grounds. (Suters et al., 2016)

The designed separation system is based on the MELiSSA closed loop system (see *figure 5-1*). It creates a closed nutrient and water cycle based on the cycling of nutrients in aquatic ecosystems. For this it uses five compartments comprising of interconnected bioreactors. Compartment I consists of thermophilic anoxygenic bacteria that degrade the solid waste and liquefy it. It assumes human waste and organic waste as its input. Three main processes occur in this compartment: Proteolysis, or breaking down of protein structures, saccharolysis, or breaking down of sugar structures, and cellulolysis, the breaking down of cellulose into polysaccharides. During these processes, CO_2, as well as volatile fatty acids and ammonia are produced. This, in essence, is a similar process as the anaerobic digestion seen in industrial waste treatment systems. In the second compartment the products created in compartment I are treated, and the organic carbon compounds are removed in the water stream and transferred into inorganic carbon compounds by photoheterotrophic bacteria. Photoheterotrophic bacteria require organic carbon compounds to meet their carbon requirements and use light as a source of energy. One example for such bacteria are purple non-sulfur bacteria. (Bryant & Frigaard, 2006) Compartment II creates ammonia (NH_4^+) that will be treated in compartment III with the help of nitrifying bacteria. This compartment is a fixed bed reactor. The aim of this compartment is to transform NH_4^+ into NO_2^- and subsequently into NO_3^-, as in this form nitrogen can be taken up by plants. NO_3^- then enters compartment IV which consists of an algae growing part (containing cyanobacteria) and a higher plant part. The CO_2 from compartment I is used together with nitrogen for plant growth. At the same time the plants serve as a cleaning mechanism for the wastewater stream and the outflow of compartment four are then plants for human consumption, drinking water and oxygen. This can then be used by compartment V, the crew. Their wastes as well as non-edible plant parts are re-introduced to compartment I forming a closed loop. (ESA, 2015)

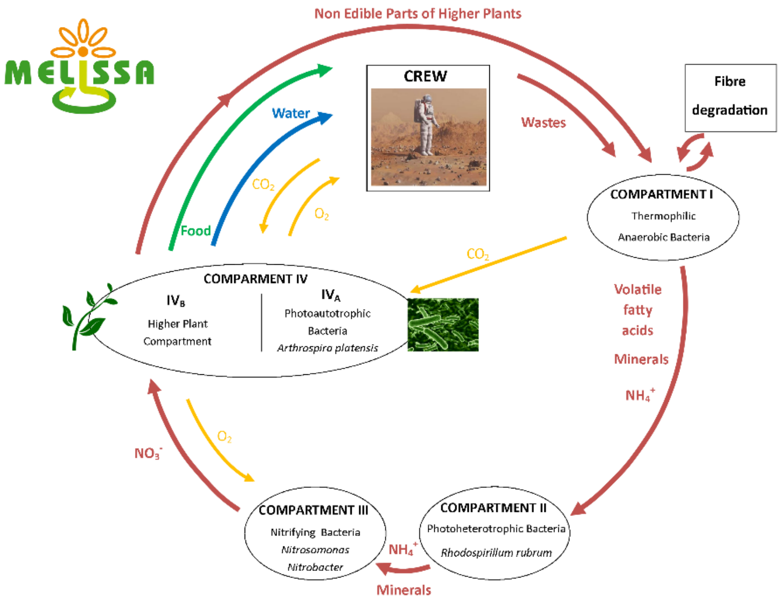

Figure 5-1 MELiSSA closed loop system. (ESA, 2015)

The technology of this closed loop system can be transferred to similar production systems in the food and beverage industry to allow for the closing of loops without (or with only small) losses. This makes it a highly attractive option for scale-up in industry. To use it in industrial applications, the system was slightly adapted. The MELiSSA treatment system consists of four departments. Compartment C-I and C-III will be used for the project at La Trappe and looked at in more detail. A feasibility study was performed by SEMiLLA on the performance of these two compartments at the brewery site. [Details of the feasibility are excluded from the public version of this study as the company and its technology are still under development. This parts are marked with [ex]]

C-I Anaerobic digestion [ex.]

5.2.1. C-III Nitrification Compartment

Compartment III is suitable for both the beer waste stream and also for municipal waste streams. This compartment also allows for future treatment of highly nutrient-dense urine stemming from the on-site restaurant, monks' quarters and the bathrooms at the production facilities. [ex.]

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5.2.2. Future Expansion Options for Enhancing CE

[For more details on the technology used and planned in the future, please consult with SEMiLLA IPStar b.v.]

5.3. Systems Approach: BioMakery at La Trappe

The La Trappe brewery at Our Lady of Koningshoeven Abbey in Tilburg belongs to one of the only 11 Trappist breweries in the world. The monks living at the abbey are involved in producing beer, chocolates, organic cheese, honey, and bread. (International Trappist Association, n.d.; La Trappe Trappist, n.d.)

5.3.1. Beer Production

At the beer brewery of the Koningshoeven Abbey, 90.000 hectolitre beer are produced per year. The daily production varies strongly, with production-free weekends. The average waste stream produced at the production site is 320 m^3 of wastewater. This can reach a maximum of 430m^3.

At current, the produced wastewater is buffered and then discharged to the municipal water treatment facility in Tilburg. The discharge costs amount to [ex.]. For the production of beer 90.000 m^3 of ground water are drawn per year. The ingredients used for making the Trappist beer are sourced sustainably. (Questionnaire Istvan Koller, 2019)

5.3.2. Why Sustainable

Sustainability is one of the core concerns of the abbey when it comes to the beer brewing process as well as their life-style. The monks pray seven times per day, including prayers for a healthy, thriving Earth and people living on it. The monk's beliefs are based on the encyclical letter of Pope Francis on the earth as god's house, which in its essence is an ecological story of how to treat and protect the Earth and forms the base considerations of sustainability (Pope Francis, 2015). This is what could be defined as a stewardship approach to sustainability and CE (Ritala, Huotari, Bocken, Albareda, & Puumalainen 2018). Istvan Koller, who is managing the BioMakery as a part of the Waterschap De Dommel, added that for a CE, more than just re-use of waste materials needs to be taken into consideration. To transfer these beliefs into practice it is of the abbey's core interest to ensure that the brewery is 100% sustainable. This is to be achieved with circular economy, to stop over-exploitation of resources, land and water and to stop pollution. The abbey implemented and funded a step by step approach to becoming circular with their 'BioMakery'. (Interview Istvan Koller and Father Isaac, 2019)

In addition, fresh water consumption is growing faster making it more important to find sustainable ways of using and consuming water. For the Waterschap De Dommel, this project offers a testing ground, a form of living lab, that allows for innovation and learning over time. Insights from this project can then be used for decision-making on water management and circularity for the region. (Questionnaire Istvan Koller, 2019)

As a frontrunner in circularity at their abbey and brewery, the monastery holds meetings on sustainability to share the gained knowledge with the other 20 Trappist communities around the world. (International Trappist Association, n.d.)

5.3.3. The Three Steps to Sustainability

The 'BioMakery' received a 500.000€ subsidy from the province of Noord-Brabant after winning the first prize in all categories of a tender within the Deltaplan Hoge Zandgronden to reduce fresh water shortage in the region. The province is working on a plan to adapt to increasing draughts due to climate change and to ensure the water taken from the ground and the water returned to the province are in balance and form a sustainable water cycle. (Wing, ZON, & DHZ, 2016) By managing their waste water and returning it to the local ground water supply in a clean and safe form, or reusing it, allows to reduce water losses in the region. Within the BioMakery, La Trappe has a three-step plan. (Interview with Istvan Koller) The first and beginning step is to clean the water and introduce it to a canal that leads to a reservoir that can be used for agriculture and therefore reduces the need of farmers to draw water from the ground for watering their fields. Before the water is discharged, it also flows through the plant nursery of the abbey therefore replacing previous ground water drawing for the growing of these plants.

The second step at a later point once cleaning techniques are explored and tested further is to reuse the water within the production processes for bottle cleaning. At the current moment, the production of 1 litre beer requires 7 litres of water, of which 3.5 litres are needed simply for cleaning processes. The water used for bottle cleaning needs to fulfil high quality standards and is for this reason drawn from ground water. By being able to circulate and reuse treated waste water, the water requirement for 1l beer can be reduced by 50%.

The third and final step is to expand the reuse of water to make it 100% circular, so that ideally, it could be possible to even reuse it for beer production itself. For this reason, many research projects are taking place at La Trappe, such as SEMiLLA's, Biopolus' and ESA's MELiSSA project to reuse municipal waste water and ESA and InVitro's Belissima project to reduce micro-pollutants, for instance, by removing medicines and other chemicals from the waste water stream.

5.3.4. The BioMakery

T All the materials for the BioMakery have a material pass (Madaster) and can be re-used or recycled at the end of their life-span and will still maintain a certain amount of economic value. The life-span of the building components is estimated at 30 years. The buildings will not require any fossil energy, as electricity is provided by solar panels and the heat for the greenhouse will be taken from the beer brewery waste heat. (Questionnaire Istvan Koller)

The BioMakery is built within a greenhouse containing 16 tanks for the water cleaning processes. It is designed based on modules to be expanded with modular tanks in order to be expanded in the future for further treatment, material and energy recovery, or increased capacity. There are, at current, 14 biofilm reactors for the brewery water and 2 tanks for the municipal water to which the MELiSSA technology may be added.

The brewery waste line processes normally around 320m^3 of waste water per day. It is typically running 24 hours per day on 7 days per week. This equals a flow of approximately 13m^3 per hour. The water cleaning cycle takes approximately 7 hours. Two water buffer tanks were installed to provide a back-up during hours of no beer production (as there is no production activity at night times or at weekends) and a storage capacity in times of over-production.

The capacity of the current system with the buffer is 150 000 hectolitres per year. The actual flow rate is currently around 90 000 hectolitres per year but expected to increase to about 125 000 hectolitres. As of April 2019, it has been running for 3 months without major problems. The MELiSSA expansion will be tested at smaller pilot scale at a later point in the project. The Waterschap (water board) De Dommel is responsible for the installation of the industrial waste water treatment system. In total, around 0.2 fte, which are about 8h of work per week by one additional person, are required to run the installation.

While some heat blowers were needed in the initial stage, the system does not require any outside energy inputs to run the greenhouse. This is due to the fact that the brewery waste water enters the cleaning process with about 20-25 degrees °C. The waste heat can be used to heat both the greenhouse and the on-site restaurant. The cleaned water leaves the greenhouse complex with 20 degrees °C, which is warm

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enough to allow fish growing in the collection basin outside of the greenhouse all year round, including winter months. The basin could at in the future be suitable to grow fish, like for example catfish Potentially, if the quality allows the fish may be served in the on-site restaurant.

Two separate tanks are used for the municipal waste water treatment using MELiSSA technology. This stream at current processes around 2-3m3 a day and is expected to process up to 18m3/day. For this system, COD and CSS testing is performed as well as an online monitoring of the microorganisms using Ayyeka, which is an industrial internet of things (IoT) remote monitoring solution.

[ex.]

The treatment process of the brewery waste water involves several steps:

a. Metabolic Network Reactors (MNR) as the core element.
   The metabolic network reactors are based on 3-5mm thick biofilms. [ex.] The MNR is foreseen to have a footprint of 40% compared to ASP, requiring only 70% of the energy of an ASP as well as having a lower CAPEX and OPEX than all comparable systems. Also, it is expected that less sludge is produced that has to go into follow-up treatment. (Interview Istvan Koller, 2019 and Site-Visit La Trappe)
b. Dissolved air flotation with a separate line for the brewery and the municipal waste which consists of a compression tank that adds CO_2 to the waste water stream. Sludge is removed and transferred to a sludge tank where it is further treated through aeration.
c. Microfiltration takes place with the influent coming from the dissolved air flotation. This step which removes additional sludge from the industrial waste water line that is also transferred to the sludge tank. At current, this sludge is dried and used as compost on the territory of the monastery. For the use of the compost on the monastery lands, they work together with the Diamant group that employs mentally disabled people and offers them a stable environment to work in. To improve the watering of the sludge chemical polyelectrolytes are added. There have been several studies performed on the potential of sludge to create higher value from it than just using it for compost. The effluent water leaves the greenhouse and is collected in a basin that is used to grow fish.

In case of over-production of waste water, the brewery has a contract with the municipal WWT facility of Tilburg to discharge their wastewater with them. Dairy acid is used to prevent rotting within the tanks as well as Sodium hydroxide (H_2SO_4), which is used for the cleaning of the tanks. This can on occasions cause a relatively high pH value, which poses challenges for a healthy fish population in the outside water basin. Also, the nitrogen content is measured, as well as BOD, COD, TSS, TOC, NO_3, DBS, before the water is released. *[ex.]*. [Private company data that could not be shown in this public version was excluded and marked [ex.]]

The MNRs are said to produce only 40% of the sludge of a conventional ASP. A conventional system is assumed to produce 0.7 kg of sludge per kg of BOD removed in the food processing industry. (Seneviratne, 2016) It is estimated that for this reason, only 0.28 kg of sludge per kg of removed BOD are produced. This would lead to 0,53 kg of sludge per litre of brewery waste stream.

5.3.5. Biopolus Technology within the BioMakery

The Biopolus Metabolic Network Reactor consists of a series of processing steps for the brewery waste water built inside a greenhouse. It uses a biofilm reactor for aerobic treatment in which the aim is that plants will provide the needed O_2 thus reducing the energy requirements of conventional aerobic treatments. It includes a tank where nitrification and denitrification take place and the nitrogen is taken up by the plants grown in the greenhouse. Phosphates are then chemically removed. The effluent is treated [ex.] before the water is stored and then re-used for irrigation water. (Biopolus, 2019; Suters et al., 2016)

5.3.6. Waste Products Created

There are several waste streams coming from the brewery production and the on-site cheese makery. Solid parts of the hop and malt waste are compressed and used for animal feed. The yeast waste is used as animal feed but also for other purposes. The sludge from the waste water stream is currently used for compost for on-site use together with the Diamant group. Whey is filtered from the cheese makery waste stream to be sold for protein. The existing products are planned to be expanded for a more optimal use of the waste streams that are available.

The BioMakery aims at maximizing the creation of fresh water, energy from waste and production processes, nutrients and usage for a variety of products including high value crops, and protein production from algae and cheese whey. They characterize these categories as ‘water factory’, ‘plant factory’, ‘protein factory’, and ‘energy factory’ (see *figure 5-2*).

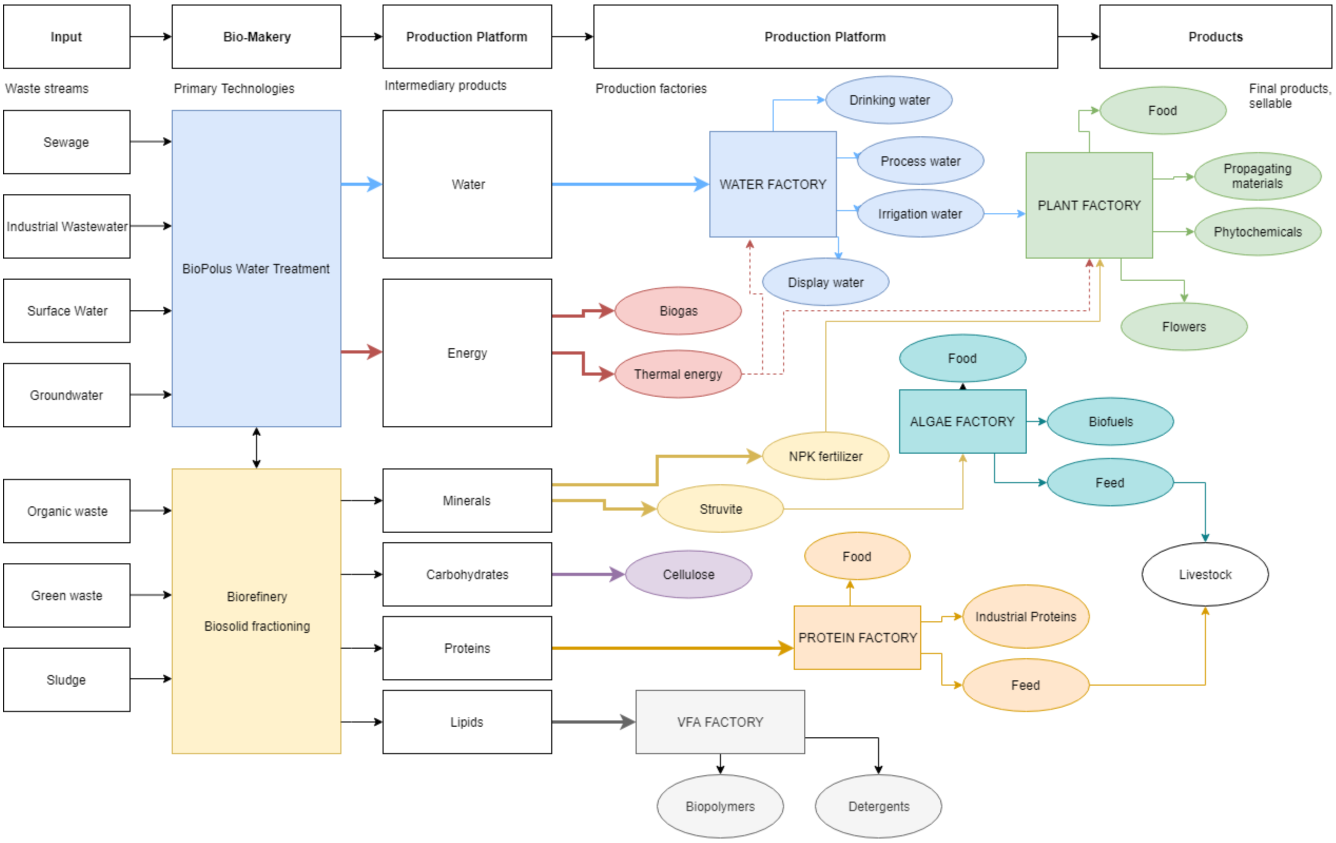

Figure 5-2 The BioMakery as a circular production platform of the future. (Guided Tour and info board La Trappe)

The heat of the brewery waste stream is intended to be used to heat the greenhouse as well as the on-site restaurant. A further option would be to expand the heat network to the on-site church that is currently heated with gas. Another option currently under investigation for higher value application for sludge is to use it for shrimp feed. Growing purple non-sulphur bacteria from compost would allow to feed shrimp or fish. This could be done by integrating the C-II compartment of the MELiSSA technology with the Biopolus system. It could offer a direct application for brewery waste water and a secondary application for municipality waste water after pathogen removal. For the latter, treatments for micro-pollutant and heavy metal pollution removal need to be added.

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5.4. Pilot Study Application of CEBM and Scorecard

The CEBM as well as the developed CE Indicator Scorecard were tested with a pilot study at SEMiLLA and La Trappe. The CEBM and the CE indicator scorecard were applied to the MELiSSA technology on a product level with use at La Trappe as well as to the BioMakery of La Trappe on company level. This created three application scenarios.

Scenario I: MELiSSA technology use only (for the beer brewery waste line)

Scenario II: Biopolus technology only

Scenario III: MELiSSA and Biopolus technology integrated and use at current potential

Considering that the projects are still ongoing, and that some of the data was not fully available, the results of the scorecard and CEBM need to be viewed with caution. However, this allows insight in how the framework could be applied and highlights the potential for more detailed use once more data is available.

5.4.1. Scenario I. SEMiLLA's MELiSSA Technology

The CEBM in scenario I assumes that the MELiSSA technology is fully implemented and used to treat the beer waste stream at the La Trappe brewery. Considering that C-II and C-IV are still at a test stage (and in addition, C-IV is considered post-treatment), these are not integrated into the following CEBM (This is a theoretical scenario assuming only MELiSSA technology is used and no other treatment technology.)

The system boundary chosen in this case is the production of products from waste streams stemming from La Trappe. In supply, it includes considerations on how sustainably La Trappe is sourcing and transporting its primary input material. For transportation of materials, the input materials, in this case, only the secondary raw materials were considered.

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Table 5-2 CEBM Scenario I.

Waste stream revalorizing at La Trappe	Value Proposition	Value Creation & Recovery	Value Delivery	Value Capture	Value Anchoring
Building Blocks	**Product** Water at drinking quality Nutrients for re-use	**Key activities + Organisation** - **Acquisition of Supply:** 320 m3 Beer and Waste Stream per day La Trappe - **Production: 18** reactor tanks needed to process the streams (if 1 for 18m3)	**Partners & supply chain** - Involvement in circularity – water, energy, nutrients, pollution, social impact	**Costs** including hidden/external costs	**System value**: Environmental, Social and Economic Impact on system (food & beverage sector) Long-term impact
	Customer Awareness on CE	**Key resources** Waste streams Technology & equipment Packaging Human capital Investment	Channels and Technology - Sustainable transportation methods - Circular design	Revenues including cost avoidance from reusing or eliminating waste	**Local Impact** – local challenge (water, energy, or nutrients – stocks)

Based on the CEBM design and available data the CE scorecard was filled in for SEMiLLA. The detailed scorecard results as well as the calculations performed can be seen in appendix II.

The following total output was obtained:

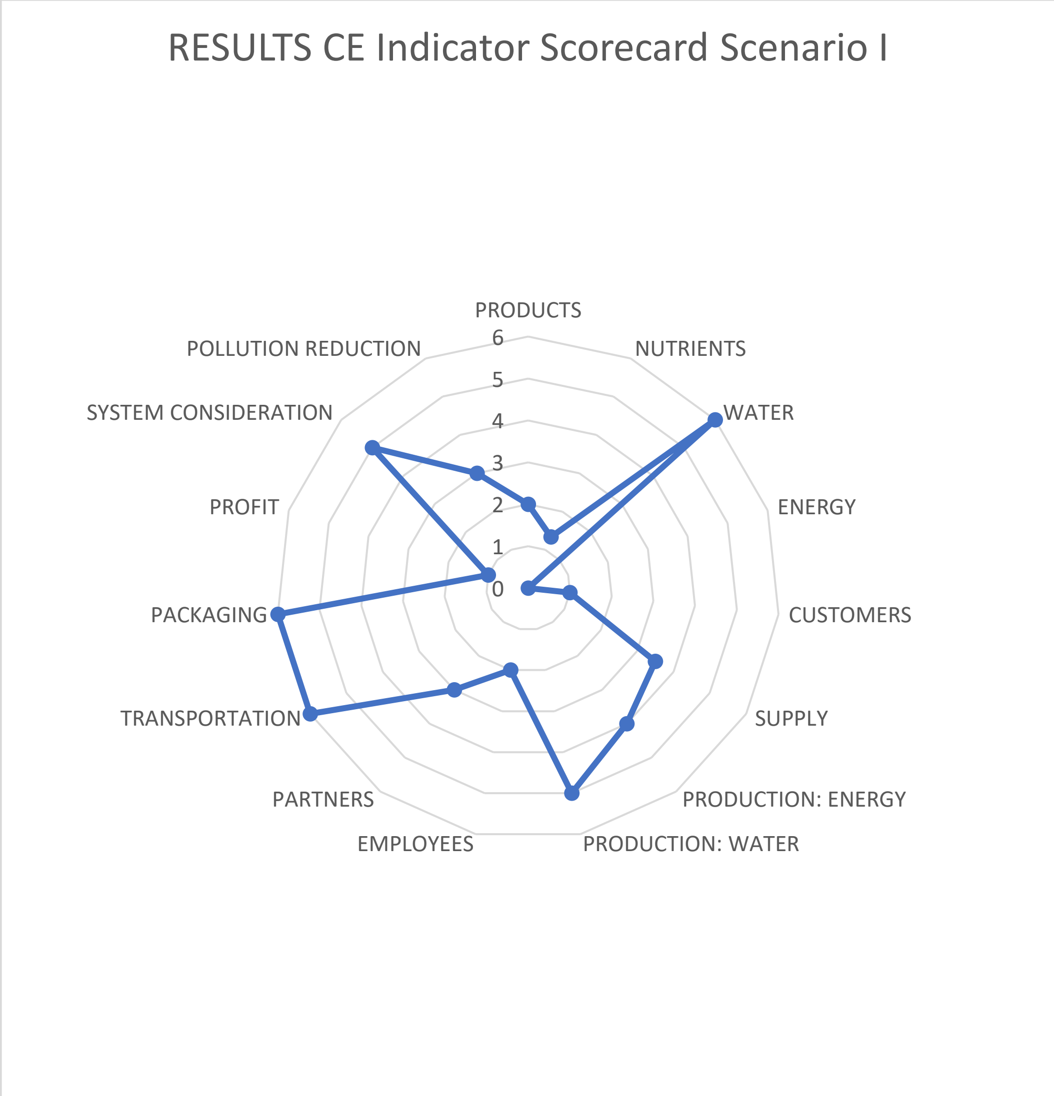

Figure 5-3 Scenario I for La Trappe's beer waste stream.

What can be seen is a high rating for water in terms of circularity, as water treatment and recirculation is the main objective for SEMiLLA. As no packaging is used and the treatment occurs locally, a high score was reached in this category.

High scores in water and transportation as well as packaging were reached. This is due to the assumption that all the water from production processes will be re-used at least at a level that allows for plant irrigation. The scorecard also manages to capture the focus of the company on water circulation. It scores well in terms of packaging and transportation, as all raw materials are assumed to be produced locally transported only locally and in the form of pipelines, and no packaging material is assumed to be needed for the products produced as they will be directly used locally. In addition, the creation of hubs reduces the need for transportation, and online meetings reduce employee transportation. The company scores 3 or above on energy efficiency and re-use, due to re-using waste heat of the main La Trappe process and because biogas is produced during AD. A score of 3 or up was also reached in the indicator category nutrients, due to the recycling and recovering of N and P, but not K, and in the category partners (project partners and fellow Trappist communities), due to sharing knowledge on CE with partners through seminars and meetings.

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5.4.2. Scenario II. Biopolus Technology

This scenario is looking at the performance of the basic Biopolus installation at La Trappe without taking into consideration the SEMiLLA add-on or future developments on the treatment site. It looks at the 14 MNRs used to treat the beer waste stream.

Table 5-3 CEBM Canvas Scenario II.

	Value Proposition	Value Creation & Recovery	Value Delivery	Value Capture	Value Anchoring
Building Blocks	**Product** MNR: Treated water to be used for irrigation – 320m3 per day Greenhouse – optics 165t of sludge annually as compost	**Key activities + Organisation** - **Acquisition of Supply:** Waste Stream - **Production:** Circular and sustainable production system (nutrients, water, energy)	**Partners & supply chain** - Involvement in circularity – water, energy, nutrients, pollution, social impact	**Costs** Installed as part of a 3,5 mio € grant for WWT (including the MELiSSA technology)	**System value**: Local challenge: water shortage addressed – creates water for agricultural usage Local challenge: nutrient over-accumulation – extracts nutrients to a high extend
	Customer Awareness on CE Tours through greenhouse	**Key resources** MNRs Plants and artificial roots Waste heat from brewery	**Channels and Technology** - Sustainable transportation methods - Circular design	**Revenues** Waste treatment costs of 250k € Marketing & customer value through possibility of visits	**Long-term Impact** Lower environmental footprint of treatment; reduces accumulation of nutrients in the environment Awareness raised, on-site research & innovation projects Expansion of system over time

Based on this CEBM, the CE indicator scorecard was filled out. The detailed scorecard with explanations can be found in the appendix.

What can be seen, that since in this application the focus is on water, as compared to energy and nutrient circulation, the performance in this area is significantly higher than in terms of nutrient or energy recovery. Hardly any nutrients are recovered to be re-used aside from some nutrients recovered in the compost created from the dried sludge. However, the creation of a greenhouse with biomass adds customer and informational value as it allows to visualize water treatment in an appealing way. A focus on reduction of energy usage for the treatment of the waste water stream was chosen for the MNR. [ex.]

The following total output was obtained:

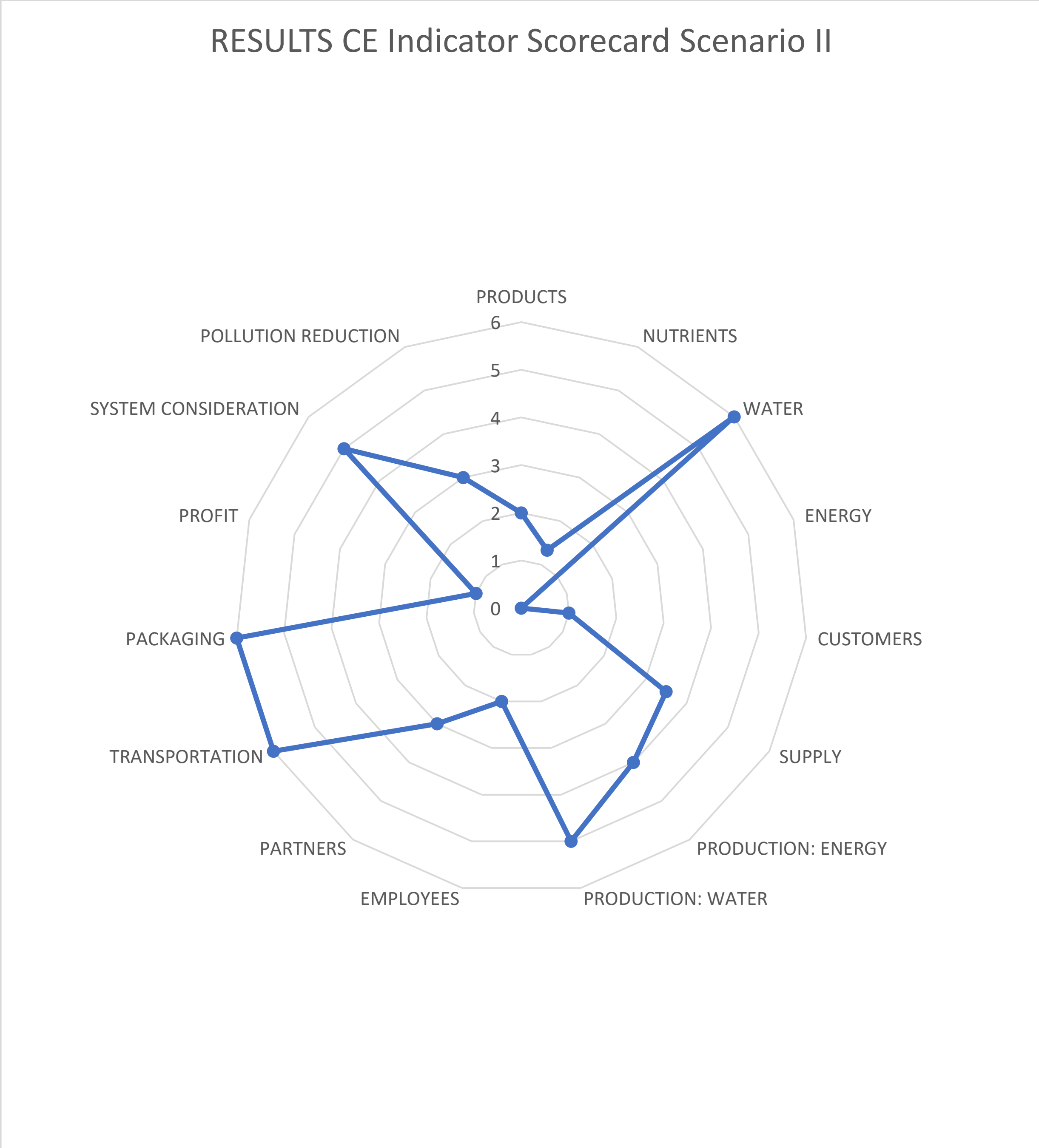

Figure 5-4 Scenario II for La Trappe's beer waste stream.

These scores are at based on the data provided by the company but include estimations where values were not as precisely available and therefore gives only an approximate result. Biopolus creates compost from 165 tons of sludge per year. For this reason, they receive a 2 in product creation, as well as in N and P recovery as they fulfil all standards but to not specifically recover them. K recovery is not considered and therefore a 0 was given. As they did not have data on their energy consumption and recovery a 0 was given as well. The main aim of the Biopolus treatment system is to clean the water stream. Without further add-ons for nutrient extraction and re-use, it reaches only a low grading in terms of product creation. However, due to its low environmental impact and the focus on sustainable construction materials as well as production processes the score of the system overall is high. Due to the lack of data, some of the values filled in were based on estimates. Thus, the results need to be seen critically. In addition, the numbers are expected to shift with changing activities of the companies over time.

5.4.3. Scenario III. La Trappe's BioMakery

The BioMakery scenario assumes a combination of Biopolus and SEMiLLA technology as seen in the previous chapters. In addition, it is assumed that catfish can be raised in the water retention basin. Considering that the water retention basin of the brewery could provide ideal conditions for raising catfish, the single cell protein could be used as feed for the fish. Catfish only require 2kg of feed per 1kg of body weight. (Brown, 2006) Thus, it is assumed that with 12500kg of feed, 6250kg of fish can be raised. Catfish can gain 1.5kg after 8 to 12 months of life. Thus, the feed would suffice for 4200 fish. (FAO, 2019; Veltman Vis Service B.V., 2013) The market price per kg of catfish (whole, without head) is quite high, with 4€ in the European market. (FAO, 2018) Thus, it is estimated that approximately 16 000€ of annual revenue could be made from fish production. Using the waste heat from the effluent water (at 25 degrees C) and considering that there is already a continuous water flow in the basin as part of the water is transported to canals used for agricultural irrigation, this would allow to grow fish with minimal energy input needed, minimal resources needed and low environmental impact.

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Table 5-4 CEBM Canvas for Scenario III.

	Value Proposition	Value Creation & Recovery	Value Delivery	Value Capture	Value Anchoring
Building Blocks	**Product from waste stream** Biogas 640kg N Fish	**Key activities + Organisation** **Acquisition of Supply:** Beer waste stream Municipal waste stream Food waste from restaurant, and abbey Further down the line: raw materials from local farmers – all input origins are known, and all farmers have a sustainability certificate **Production:** Re-use of waste heat from brewery production Re-use of waste heat from wastewater stream for growing fish (future: Solar PV panels for electricity generation)	**Partners & supply chain** Partners: Sharing of knowledge on circular production with other Trappist breweries Allowing for research on-site by universities, research institutes Projects with multiple partners to develop a CE	**Costs** Initial investment costs (partially covered by funding) + additional energy costs (off-set through initial instalment of solar PV panels and energy production on-site)	**System value**: Local Challenge: Water Shortage – after all treatment steps are implemented, the resulting water will have drinking quality; all water sources at the production facility and adjacent buildings are taken into consideration for re-use Nutrient accumulation – BioMakery filters nutrients from water and allows the created fertilizer to be re-used, and technically, also re-applied on other locations Growing plants in a greenhouse with aquaponics on-site also reduces the leaching of nutrients into the environment, and would allow to directly re-use the water after treatment
	Customer Awareness on CE	**Key resources** Waste streams Technology & equipment Packaging Human capital Investment	**Channels and Technology** Low impact from transportation as local raw materials are used, and waste streams are being re-used and re-purposed locally For this reason, also low usage of packaging material	**Revenues** Grants for pilot projects Media attention, and marketing value, positive public image; no clean-up or environmental pollution costs Cost avoidance (250 000€) from waste handling Sales of fish at restaurant Use of nutrients for on-site gardens Biogas sale	**Long-term Impact** Production of high-quality water, reduction on strain of local water bodies Higher awareness on pollutants in waste streams Increased investment in research allows for novel and up-scalable solutions, e.g. protein from algae, filtering of micro-plastics with positive impact on society and the environment

The CEBM was used as a basis for filling out the scorecard for La Trappe's BioMakery. The following result was obtained. Detailed explanations on how it was calculated can be found with the full scorecard in the appendix.

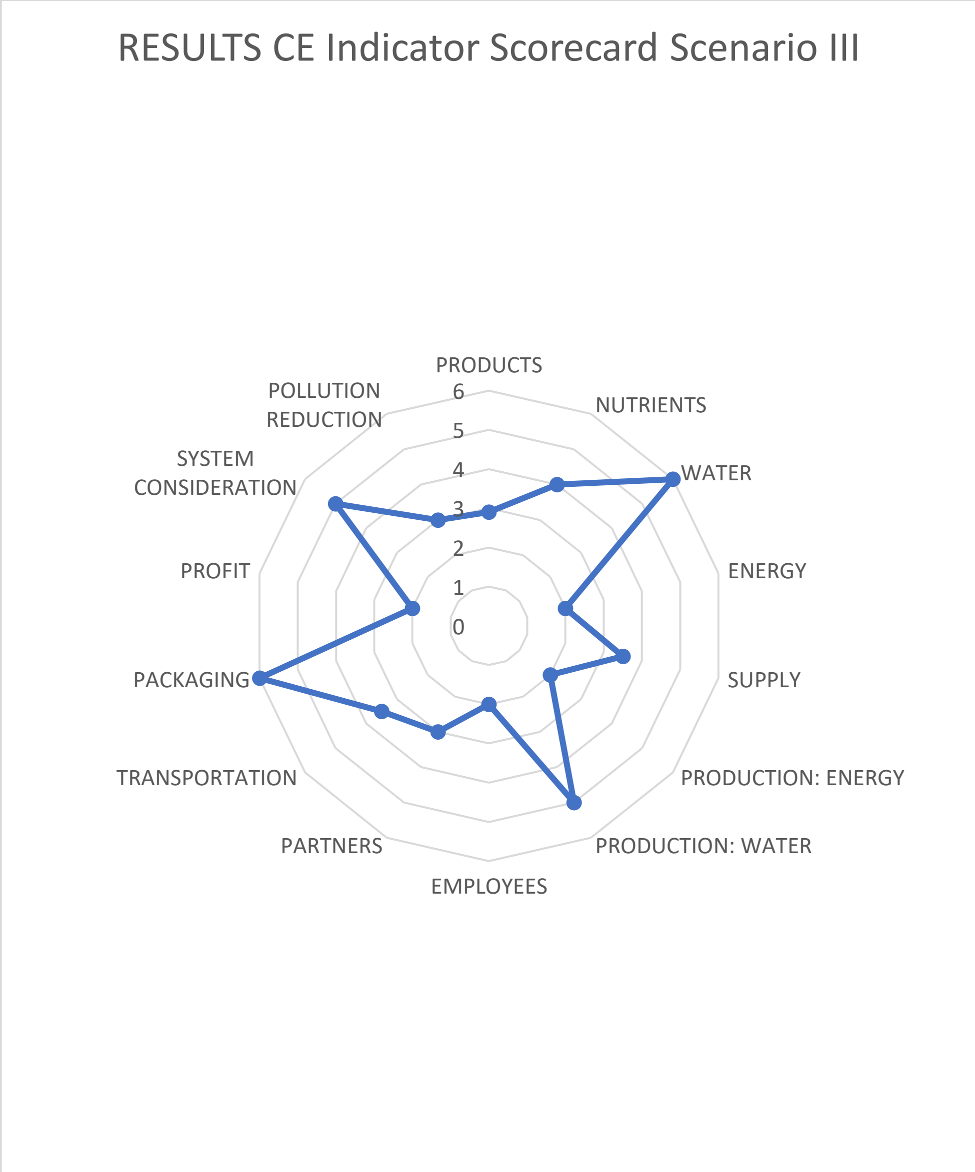

Figure 5-5 Scenario III for La Trappe's BioMakery.

The BioMakery was assumed to create biogas, grow fish (using extracted organic material as feedstock) and extract nitrogen for fertilizer use. This led to an overall rating of 3 in terms of product creation, with a lower value for biogas and a higher value for fish according to Moerman's ladder. Water recovery and efficiency in the production processes are high and received high ratings.

5.4.4. Results

The scorecard highlights the aspects of a CE that the companies put a focus point on, in the case of the pilot studies this was water (and partially nutrient and organic component) recovery. Values for profit and energy recovery, as well as employee and partner engagement were relatively low, which resulted from the fact that not a lot of information was given on financial details of the company (as they were still in the building phase) and CE strategies within or between the companies. However, it is expected that these areas can easily receive a higher rating once more data is available, or it is filled out company internally.

What can be noted furthermore is that 100% circularity is practically impossible, as there will always be small losses as no process is 100% efficient. This concerns energy use, and transformation, as well as product manufacturing, re-use and recycling. (Korhonen, Nuur, Feldmann, & Birkie, 2018) For this reason, the scorecard also emphasized the inclusion of energy, water, and nutrient efficiency of the processes used for closing loops. A CE will only be beneficial in economic, environmental and social terms if the closing of the loop does not lead to higher resource use through additional energy sources or infrastructures needed for the closing of the loop. To avoid phenomena, such as rebound effects (Figge & Thorpe, 2019), a comparison between the (economic) output and the needed raw material input had to be incorporated to ensure less negative impact of the company.

5.4.5. Evaluation Sessions for the three different scenarios

After filling out the scorecard based on the three different scenarios, the companies themselves were asked to fill out the scorecard and the results were compared and discussed in an evaluation session.

When regarding the quantities of the products and the values for energy consumption and emissions, it is assumed that the values directly obtained by the company (assuming their best practice) are more accurate than the one's estimated from the research. This is due to the fact that the companies have the ability to directly measure these values, and do not necessarily share them in the same level of detail with the researcher. To ensure the correctness of the values given by the company, a proof is suggested to be uploaded together with the filled-out scorecard (especially if to be used for public communication purposes), which at current has not been the case.

5.4.5.1. Scenario I

While values for nutrients, production, and packaging were aligned between the research results and the self-score, other values varied considerably. Especially, the more social-related indicators, in particular, customer and employee indicators saw a large divergence in the score result, with the research result being significantly lower than the self-score.

In the more quantitative indicators, water, energy, transportation, system impact and pollution the research results led to a higher score than the self-score. This is surprising, as it was implicitly assumed that companies would show a tendency to use a higher rating when possible. However, the divergence can be explained by the fact that the companies have better insights in their own energy consumption, production processes, and pollution and can therefore obtain more accurate results. In addition, some of the production processes and product developments were still not finalized which was taken into consideration differently by the research and the company, resulting in diverging scores. This shows the importance of clarifying which point in time as well as which data input was used when filling out the scorecard.

Scores for water, packaging, supply, customers and production steps were almost identical between the research results and the company self-score.

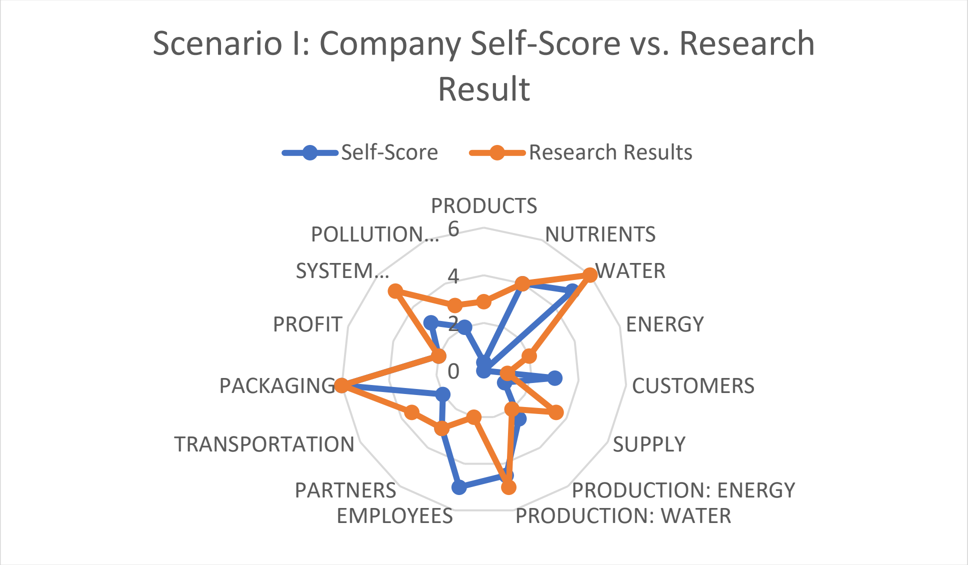

Figure 5-6 Scenario I: Company self-score and research result scorecard comparison.

5.4.5.2. Scenario II

When comparing the self-score with the research results it could be seen that the values obtained for nutrient, products and water were identical between the research results and the self-score. Also, packaging, transportation, partner and employees ratings were in line with the rating given during the research project.

System impact and supply was given a slightly lower rating than estimated during the research project. This is due to the fact that up to 85% of the inputs of the supply is known (and more was assumed to be the case by the researcher), and no certification schemes are in place. This resulted in a supply indicator value of 2.5 as compared to 3.5 as shown in the research-based score. For supply, production and system consideration the company rated itself slightly lower in comparison to the research results.

No information was available on pollution or on the energy needed for the processes. For this reason, the company left the relating questions blank, receiving no score for these categories.

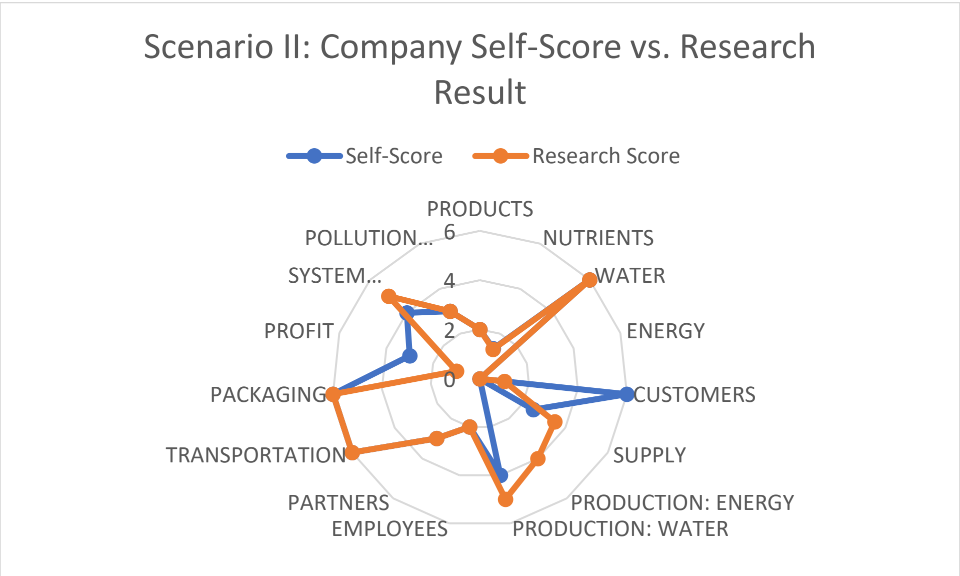

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Figure 5-7 Scenario II: Company self-score and research result scorecard comparison.

Similar to the assessment in scenario I, the research values given for customers was far lower than given by the company (with a rating of six, for including customers in the ideation process). This can be due to different interpretation of the potential responses or a lack of insight into the customer relationship that the company has. The values of the other indicators, however, to a large degree matched the values obtained by the researcher. This excludes energy data, for which the company did not fill out the scorecard.

5.4.5.3. Scenario III

As the BioMakery, using a combination of technologies, was not completed at the point of the final thesis presentation, there were no final company-internal measurements available for exact energy consumption, production processes, or waste production. In this case, only the research results, which offer an estimated value, based on combined data from scenario I and II. For this reason, variations towards the final company filled-in scorecard will be expected.

5.4.5.4. Conclusion Comparison of Self-Score and Research Score

To conclude, what could be noted overall was, that one implicit assumption, that companies would rate themselves higher when filling in the questionnaire in comparison to the researcher, was seen to not be the case. For most categories with deviations, the score given by the company was in fact lower than the estimated score given by the researcher (with the exemption of the customer indicator value).

The variable results, especially with the more social related indicators (customers and employees, in particular) shows the sensitivity of the scorecard to the data that is input, or the relationships that are assumed between the different stakeholders. The latter, due to their complexity, are also more challenging to measure. The results therefore need to be seen with caution and as a suggestion should always be supplemented with a document proving the statements made when filling out the scorecard.

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6. Discussion

6.1. Reflection on the Concept of CE

Circular Economy is seen as a way to reach sustainable development and to tackle the challenges set by a changing climate. However, CE needs to truly be integrated into the three-pillar approach of sustainability in order to do so. Oftentimes, CE solutions require a trade-off between environmental and social impact, energy usage, and financial profitability. For instance, the higher the water quality of the product achieved, in the case of WWT, the higher the treatment costs and energy requirements. CE needs to focus on solutions that favour low-impact technology, both in terms of the energy consumption, as well as the environmental impact.

6.2. Reflection on the Performance of the Pilot Studies

The intention of the scorecard is to be applied once the business model was implemented to test the circularity according to all building blocks. As for the pilot study, not the entire business model was implemented in practice yet, therefore, the results are only an indicator of the current moment. However, they give an impression on how the indicator system works and can be quite easily changed and adapted to future developments.

Testing the framework with three different scenarios allows to identify strengths and drawbacks of the CEBM and the scorecard. It also shows the focus point of the three companies in terms of a CE. What can be seen when comparing the different results of the separate and the joint technologies at the La Trappe BioMakery is that in this project, the two technologies of SEMiLLA and Biopolus complement each other, and allow for a more integrated approach to reach a circular economy. While any recovery technology will increase energy usage in comparison to BAU scenarios, this is 'offset' in the indicator results through the fact that SEMiLLA is creating bioenergy through their AD process, as well as the potential to re-use waste heat from the brewery and the waste stream. While Biopolus does not focus on nutrient or material recovery, this is brought in by the SEMiLLA technology. Overall, focussing on further development of product creation at a higher level of value (such as human food or medicines), will increase the rating of the BioMakery in terms of circularity. Adding, for instance, fish to the BioMakery system does not require increase in energy usage, nor additional material or land as an existing warmed water basin can be used, but provide a high-level product, that eventually also reduces environmental pressures (for instance, on fishing) as it can meet local fish demand (at the on-site restaurant) and generate additional income. By using the sludge to feed shrimps or algae to create protein, allows for internally upgrading the products a company can produce from its waste streams and thus not only increases its circularity but also its profit. However, while this is the ideal case scenario, this at the current stage is still in the planning, and its concept based on the brewery waste stream. Depending on the certification reached for the municipal waste stream, this stream could be added in the future.

What could be seen in the case applications was that there are typically high initial costs involved in turning towards CE, both in economic terms as well as in terms of the time it costs to re-design and implement a new system that aims to be spanning across the entire life-cycle of the product. However, a CE project can add various benefits to a company that can indirectly lead to additional profit. This can be, for instance, through increased customer value, and higher trust by customers interested in sustainable consumption, or higher informational value if there are higher transparency standards on the input of raw materials.

Figure 6-1 Comparison of scorecard results. [ex.]

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What can be seen in comparing the different results of the three cases tested is that overall, their performance is relatively alike in terms of water and system consideration. The technologies of the two different companies used for creating a CE at La Trappe individually score higher in transportation as only the transportation of the waste and the created products are considered which happens locally. This is not the case for the BioMakery, where technologies were combined. For the first scenario, SEMiLLA achieved higher rankings in its energy performance which is mainly due to the use of biogas production for energy use. However, the existing trade-off between energy and nutrient recovery can be seen in the scorecard results where higher level nutrient recovery is linked to lower energy performance (as no biogas is produced). Overall, it needs to be noted that due to insufficient data, some of the values might vary from actual results and input and feedback from the companies is needed to supplement the scorecard with potential data that was missing.

However, the comparison needs to be seen with caution, especially considering the large deviations that were found between the individual company results and the results obtained by the researcher. While this still allows for the scorecard to be used internally to improve performance, it shows that a direct comparison with other companies is not recommended, if the scorecard is filled out by different people.

6.3. Performance of the CEBM Canvas & Strategies

The main aim of the CEBM canvas was to offer companies an appealing way for creating a CEBM, while integrating all relevant aspects relating to CE in the food and beverage industry. Four strategies were suggested as an approach on how to create value in terms of a CE, and in terms of revalorizing waste streams in the food and beverage industry. By drawing on an existing framework, the CEBM canvas offers a familiar layout, with an additional column to take into consideration a systems perspective. In addition, it is addressing the needs of the food and beverage industry by allowing to focus on CE aspects relevant to this sector. The strengths of this canvas in comparison to the existing and dominant triple bottom layer BM canvas, it its focus on CE rather than more general sustainability, as well as the more simplistic design that combines the three canvasses of the triple bottom layer BM canvas into one by focussing on the CE-based value proposition. During the validation step it was seen as positive that the CEBM canvas builds on an existing framework as this will encourage companies familiar with the existing framework to fill it out. Further testing of the CEBM framework in practice is suggested to gain more insight on its usability.

6.4. Performance of the Scorecard

The application of the framework led to several points for discussion, such as the nutrients included in the scorecard, the inclusion of the supply chain, and the challenge of including social indicators.

To measure the degree to which the product or service, or company, contributes to the creation of a circular economy (as shown in the value proposition), the value of the product based on Moerman's ladder was chosen. This specifically looks at product's created. It can be argued that water, which is currently treated separately, could be considered a product that should then be integrated into these categories. However, considering the low market value of fresh water, and the fact that it is available as a natural resource led to the decision to treat it separately and put the focus on restoring this resource to its highest quality level.

Nutrient recovery was added as an individual indicator. It has to be mentioned, that the focus was put on nitrogen, phosphorus and potassium as these three nutrients are the key nutrients in agriculture. Additional nutrients, micronutrients or other chemicals were not included in this assessment. This was

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done as other nutrients at current are also not financially feasible to be extracted, either due to their small quantity or not sufficient value.

The value proposition aside from the creation of products also focusses on the re-use and recycling of nutrients and avoidance of nutrient pollution. What could be seen in the case studies was that much focus is put on the recovery of phosphorus and nitrogen (mainly due to their importance as a fertilizer but also due to legislation and their environmental impact). While the percentage used to assess the recovery of the nutrients is at the moment based on an equal distribution over the grading scheme (with the same % for each grade and above 85% recovery as the highest grade), research has shown that recovery rates above 90% are quite doable for N and P and was also easily achieved by the companies used for the case studies. Stricter grading could therefore be an option for these questions. It was found that overall, less focus was put by the companies on the recovery of potassium, also due to lack of research and technologies for recovery as compared to N and P. However, in most cases K is not even integrated in the tables measuring the content of waste streams. Considering the significance of the nutrient for the food and beverage industry and the considerable amount of this nutrient in fertilizer applications, it is suggested to add this as a potential nutrient to be recovered and turned into a product.

One point was whether to include the supply chain for the measuring of circularity. Including a supply chain perspective when regarding the produced products from waste from a company level, is highly relevant as it gives insight into the type of raw materials purchased by the company and their way of production. As they have leverage over the type of supply they select, focussing on suppliers with a high level of transparency and aims towards achieving a circular economy for the production part of the food and beverage sector is an important step in closing nutrient, water, and energy loops and in restoring and balancing of ecosystems. From a life-cycle perspective, integrating the various steps of the life cycle of the product and ensuring that each step is connected to the previous and the following one allows to exert control over the entire system, especially for companies that are important leverage points as they have the power to choose suppliers and to some extend guide their consumers.

In terms of supply, when regarded from a product level, as in the case of SEMiLLA and Biopolus, that designed technology for La Trappe to help La Trappe create a more circular system, their focus lies more on employing and selling their technology, and their source of supply consists mostly of the waste stream provided by La Trappe for their production. The raw material input of La Trappe is therefore of less interest to them. However, as SEMiLLA is emphasizing their role in terms of supporting companies in creating a CE, incorporating a systems perspective, when applying the technology at a company, to support and guide this company in the transition, might provide a useful addition to their business model. Thus, their business model can benefit from including a broader scope.

A final consideration was whether to keep the indicator on land use change. While it is an important indicator, it is highly time-consuming to get reliable results on the indirect impacts that your product has in this category and it requires in-depth knowledge both on the impacts of the company for which the scorecard is filled out as well as on comparable BAU scenarios.

The validation step of the framework and interviews with SEMiLLA representatives also highlighted the importance of user-friendliness of the scorecard and CEBM. The most important aspect identified was ''time needed to fill out the canvas and scorecard'' in order to make it appealing for companies and businesses to apply it. The CEBM canvas is therefore highly apt for application due to its compactness and its similarity to existing structures that make it easy to understand and use it, without too high time losses, whilst integrating all essential elements of CE for the food and beverage sector. The time needed to fill out the scorecard highly depends on the data available to the company. Calculations of emissions, recovery

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rates, or energy requirements of their production processes and collecting data from their suppliers or partners might require some time. However, it must be argued that if a company is truly interested in becoming circular (in a sustainable manner) they must be interested in investing the time to create knowledge in these areas.

Some design decisions were taken when selecting an indicator-based scorecard. It builds upon a simple quantification of responses from 0 to 6. This way eventually also makes it possible to compare scores, both within the company between different time periods, but also, for instance, between technologies or products to get an insight in which elements of a CE the planned project is strong at.

This type of indicator made the inclusion of non-quantitative indicators more challenging, such as the quality of the research performed or the degree of satisfaction of workers. Also, total values, such as the final revenue, or number of employees, etc. did not fit the evaluation frame, but could be added as a set of additional indicators if relevant to the company.

As all building blocks of the CEBM need to be regarded separately, and the number of questions to calculate scores per building block varies, no weighing was performed between the different building blocks, and thus no single value given. The decision for this was also based on the fact that circularity is a trade-off, with some areas scoring higher, some automatically scoring lower. A single indicator would not allow to show this trade-off and could not efficiently enough present the complexity of CE.

Finally, it is suggested that the scorecard will be completed by experts at the company as these already have the most detailed data available. To complement the scorecard, it is recommended that for each question filled in, proof needs to be added, in order to make the evaluation transparent and to avoid over-estimation of companies on their own achievements. The scorecard can then even be used for communication to the public, or for motivating employees in their goal to strive towards a Circular Economy. It also allows for management decisions on where to focus on in order to improve the CE strategies at the company.

6.5. Hurdles and Challenges in the Framework Implementation

What posed a major challenge in the course of the research and application of the framework was the availability of data. Collecting the amount of data needed from and outside perspective highly time-consuming and oftentimes connected with sensitive data, especially at initial stages of the business model implementation. What can be seen is, that while it is possible for outside consultancies to fill in the scorecard, due to the detailed level of data needed it is highly recommendable for companies to fill it out themselves, ideally by a specialist working in their SCR or sustainability department or the management of the CE project. Taking into consideration the entire life-span of the project would suggest the implementation (unless already added) of an additional position for managing the transition towards a Circular Economy both within the company but also alongside its supply and treatment system. This, in turn, might pose challenges, as data on crop and waste management on the side of the raw material producer might include sensitive information.

In addition, if the steps for filling in the scorecard based on detailed information is needed to be undertaken by companies, additional energy is needed from a management perspective. However, by avoiding too many calculation-based question sets, it was made easier for company representatives to fill in the data. Pre-answers are given from which they can select, thus cutting the time needed to fill out the questionnaire. Moreover, if a company truly aims at becoming circular, the data needed for the questionnaire will be needed in order to become circular.

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6.6. Limitations of the Study

The previous discussion chapters show the complexity of developing a CE indicator scorecard, especially when based on consumable goods.

The factor time posed a major limitation on the study results. To truly create a fully comprehensive scorecard, additional indicators, especially financial and social indicators should be added, but require more research. In addition, time constraints played a role in the acquisition of pilot study data, especially when working with data from ongoing projects, as delays are quite common, but difficult to manage in a tight thesis research timeframe.

Data availability poses a limitation on filling out the scorecard as there is a potential conflict of interest on offering sensitive data on economic, social or environmental performance between the company and the researcher and the public. In addition, in projects under development, not all data might be immediately available. This might lead to some section of the scorecard to not be fully filled out. However, it does not impede the functioning of the other sections of the scorecard and still allows to offer guidance on how to progress in terms of developing a CE on a company level.

The study is limited to the company and product level and does not specifically focus on the macro level of developing a CE.

A further limitation of the study is its current pilot application only in the beer brewing sector, particularly with a Trappist brewery, which typically follows strict standards in its brewing process. For a full applicability for all areas of the food and beverage industry, further pilot studies with different companies are needed.

Using a scorecard as a way to measure CE comes with certain limitations. In order to design the scorecard, some decisions had to be taken to facilitate the filling out and evaluation of the scorecard. This was especially challenging when attempting to combine qualitative and quantitative elements of the scorecard in a rating scheme from 0 to 6. In practice this means that when percentage rates were given as response to a question, a small percentage change could lead to a rating of a full point higher or lower. This is a common problem with rating schemes like this and was discussed during the validation sessions. While this poses a limitation, it was not considered problematic, as long as this is taken into consideration when looking at the scorecard results. In addition, a rating scheme such as this reduces the complexity of social interactions, or might exclude aspects from the rating, and for this reason cannot fully be independent from the perspective of the researcher. Finally, when companies fill out the scorecard themselves, different interpretations of the social-based questions might occur. Thus, these factors might limit the ability of the scorecard results to be directly compared between companies.

The recommendation section offers a range of suggestions for further development of the scorecard both by academia, as well as by consultants or the industry itself, to overcome the presented limitations. Despite the limitations of the study, new insights on measuring and developing a CE for the food and beverage industry were gained that add to the existing literature in the field.

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6.7. Theoretical and Practical Implications of the Research

At current, no uniform definition of a CE for the food and beverage industry exists. In addition, overall definitions of a CE oftentimes lack incorporation of social aspects of a CE or a clear link to sustainable development. This study aimed at adding a clearer view on what CE signifies for this sector by highlighting the importance of the biological loop, and in particular water, energy, and organic material as well as nutrients as central elements of a CE together with a triple bottom line approach. The research also adds to the existing body of literature on sustainable, and in particular, CE business models, and shows example of successful business strategies to reach circular solutions.

Similar to the definition of a CE, many indicators exist with the aim to measure CE on different levels. This paper reviewed the existing indicators and identified elements suitable for the biological loop of the food and beverage industry. Based on these elements, the first CE Indicator Scorecard developed for the food and beverage industry was designed and tested. While there is still the need to further develop it, it offers a first step towards measuring CE taking into consideration a systems perspective and basing the scorecard on a CE based business model of the company.

The developed framework offers companies a tool to highlight and communicate their development in terms of a CE by providing them with a CEBM canvas and the CE Indicator Scorecard based on this canvas. It offers a holistic approach taking into consideration economic, environmental, and social aspects of a CE and particularly tailors the canvas and indicators to the needs of the food and beverage industry. The research paper connects both to the literature on CEBMs and highlights the connection to SBMs as an overarching category. It also connects to the body of literature on CE indicators, and not only gives an overview on existing indicators but connects new ways of measuring CE based on a biological loop with existing tools for the technological loop. This is done by incorporating the MCI of the Ellen MacArthur Foundation, as well as by linking elements of the scorecard to ratings seen in other scorecards, such as WeSustain's scorecard (2019) on the technical loops of CE.

The research does not only add to the theoretical body of literature available on CE but also offers a practical tool that can be used by companies and consultancies and that will be publicly and freely available to use. The pilot study allowed to formulate practical recommendations for the companies involved, for the industry and governments as well as for further development of the scorecard.

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7. Conclusion

To answer the research question *What circular economy business model (CEBM) framework and accompanying set of indicators are needed to support the development of CE strategies in the food and beverage industry?* the research paper first examined the state of the art of CE to identify what elements it is constituted by. The CE in the bio-economy, and specifically the food and beverage industry, is focussed on closing the biological loop via re-using waste resources and cascading them to eventually return them to the ecosystem. The ideal result is a restoration of the system for a sustainable use. For this reason, the triple bottom line of sustainability, economy, environment, and society needs to be integrated in a definition and consequently a measurement tool for the performance of CE. Key challenges for CE in the food and beverage sector were identified as the closing of nutrient cycles, the water cycle, with regards to energy usage, pollution and land usage, and impacts on human quality of life. It is highlighted the need for a systems perspective, that takes into account the entire life-cycle of the product, including the supply chain, and the consumption, based on insights from the field of Industrial Ecology. Two address sub-question two, the literature review then also explored the state of the art of CE business models and indicators, which showed the gaps existing in measuring and supporting the development of a CE for the food and beverage industry based on a biological loop and a systems perspective.

To address these shortcomings and to answer sub-question three *Which CEBM and accompanying set of indicators are needed to measure and develop a CE in the food and beverage industry?* in a next step, the CEBM canvas, building on literature on SBMs, was developed. It specifically addresses the systems perspective, both geographically and temporally through the inclusion of the building blocks headed 'system anchoring'. Based on this CEBM framework, a set of CE indicators was developed in the set of a scorecard, to support companies in the measuring of their progress towards a CE in regard to all the important building blocks related to creating a sustainable business. It provides a way to highlight and rank the value of the waste streams and focusses on strategies to create additional value whilst reducing pollution and negative societal and environmental impacts. The framework was validated through peer reviews, and through validation session with experts from academia and the food and beverage sector. An important insight from the validation step was to focus on a user-friendly scorecard that could be filled in at a company level within a manageable time-frame. For this reason, the questionnaire for the CE indicator scorecard was realized in Microsoft Excel. A visualization was added to provide a quick and automatic overview of the result. A radar was chosen for the visualization, with each building block representing one corner of the radar. In an ideal scenario with high ratings in all building blocks the score will resemble a circle – thus visualizing having achieved a truly circular economy.

To answer the final research sub-question *How does this new framework perform in practice (when tested at La Trappe)?* the framework was applied using three different scenarios for the BioMakery at the La Trappe brewery. One scenario looked at the technology of SEMiLLA, one at Biopolus, and the third at their joint-implementation at the BioMakery of La Trappe. What could be seen during the application phase was that the scorecard is the most apt to be applied to the entire company level in the food and beverage industry to look at the improvements of its performance in terms of CE if they turn their (organic) waste streams into products. The research highlighted the potential for further expanding this framework with an indicator set for the agricultural production sector to better consider the impact of the supply chain for a CE in the food and beverage sector.

What resulted from the development of the scorecard and the application at the cases was the realization that CE projects will most likely always be subject to trade-offs as more circularity oftentimes goes hand in hand with higher energy requirements, and consequently, higher environmental impacts, and higher costs.

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It also shows the importance of the framework developed, as only if all aspects of circularity are being considered – environmental, social, and economic – can CE lead to a sustainable development of society with lower resource consumption and a reduced impact on the planet.

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8. Recommendations

The study led to several recommendations and focus points for the food and beverage industry, the companies participating in the pilot study, government and academia.

8.1. Recommendations for the Food and Beverage Industry Sector

Several overall recommendations were found for the food and beverage industry:

- It was found that at the current moment, the focus is mostly put on the re-use of the material and the recovery of it. But while re-using the nutrients and waste streams is already seen as a key element of a CE, the actual energy requirements and potential savings when establishing a closed loop are less considered in the cases studied. Similarly, the closing of the loop needs to be linked to an account of the GHG emissions caused through this production or recycling system, as eventually CE serves the purpose of decreasing the strains on the planet. Therefore, taking into consideration the impact in terms of resources needed for energy production, impacts on global warming and created pollution are crucial elements in assessing CE projects.
- It is recommended to ensure that economic, environmental as well as social aspects are taken into account for the creation of a CE, both within the supply chain (for instance, in the form of worker's rights and payment), and in the production processes and consumption (for instance, when regarding consumer health).
- To fully close the biological loop, the entire life cycle of the product needs to be taken into consideration. This includes the production of the raw materials and losses that occur at this stage. It is recommended to work together with the raw material producers on research to reduce losses, energy consumption and pollution at this stage, and to develop a certification scheme for circularity that allows to get better insights into the supplies whilst supporting circularity along the supply chain where possible.
- What could be seen in the pilot study was that, in order to achieve circularity, this oftentimes needs expansion outside of the initial production processes. For instance, in the case of La Trappe, waste energy is shared between buildings and different production processes, and products created from waste are re-used for new purposes or as input for different products, such as the planned fish breeding, which benefits the local restaurant. Some products, such as fertilizer and treated water, are used for new creation of agricultural products. Re-using products or energy locally also reduces losses of products and emissions due to transportation, and most of the time also reduces the need for packaging. It is therefore a recommendation, to map the potential partners or stakeholders in the region where the company is placed and to look together for new ways of creating value from the waste streams at hand.
- Sharing of best practices is suggested to find ways to re-use the most resources without increasing energy demand or emissions. One way of comparing performance would be to use an indicator system, as for instance the scorecard, as part of an industry-wide certification scheme, that takes into account water, energy and nutrient usage and losses along the entire supply chain and the end of life of the product (including, for instance, water stream treatment needed).
- To fully achieve a CE, the entire company needs to stand behind this mission. Engaging all employees in creating a Circular Economy is therefore important, by for instance, sharing the results of the CE Indicator Scorecard as a motivation, and by providing training sessions and ideation sessions that allow employees to have a more active role in creating innovative solutions for the circularity of the company.

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- The results of the scorecard can be used in highlighting achievements in creating a CE for communication with the public. It also offers a way of being more transparent, which could lead to increased trust and a better (and greener) image of the company.
- A final general suggestion is to take into consideration the end-of-life phase of the product, in this case, the consumption as well as the packaging and the impact on the consumer. Ensuring the safety and health of the consumer is, of course, the priority for the food and beverage industry. A circular economy offering transparency on the components of the products and their supply, can increase the quality of the product (for instance, by controlling and measuring the content of the product flows, or choosing raw materials with lower pollution concentration). In addition, cooperation with EoL managers and (municipal) waste treatment facilities are suggested for truly closing the resource and nutrient loop and ensuring that nutrients are not lost but recovered at the EoL phase.
- For the use of the scorecard, the following suggestions were made:
  It is highly important to add proof to the CE indicator scorecard as this will increase transparency of the company to outside investors, and/or customers and will help to build trust and support. In addition, it is suggested to apply and re-calculate the scores of the CE indicator scorecard when products or production processes change. Moreover, the results of the scorecard can be used for internal communication to motivate and engage employees to work towards a CE, or for external communication with partners, governments, or customers.

8.2. Recommendations for SEMiLLA

As SEMiLLA provides a technology that aims at increasing the circularity of a company, it is recommended to also share their expertise in CE in this sector to their customers and partners by providing guidance, training and support and by involving them in the ideation processes on how to create a CE. In this way, SEMiLLA does not offer the technology but also the expert knowledge on how to create a CE. For their technology, it is recommended to focus on the energy needed for production and processing, and to minimize the use of fossil fuel-based energy, and increase re-use of excess energy through, for instance, sharing waste heat with neighbouring production facilities, or greenhouses. In addition, an environmental assessment of the processes as well as the life-cycle of the product is recommended in order to understand the impact of the offered system, also with regards to resource usage. In addition, it might be useful to more clearly highlight the improvements offered in terms of economic and environmental performance of using space technology as compared to BAU treatment systems. Transparency over the processes, and potential emissions or energy usage will then also be a way to offer trust to customers, governments and civil society.

Similar recommendations, as offered for the food and beverage sector in general, apply. Taking into account environmental, and social impacts of the technology aside from the economic benefits is of high importance for projects relating to a CE. There needs to be awareness of the trade-off between a higher circularity and the connected energy usage as well as the impact the technology has along its entire life-cycle and throughout its life-span.

8.3. Recommendations for Biopolus

It is highly recommended to focus on a supply of non-fossil fuel-based energy (for instance, from solar panels on the roof of the greenhouse) for the production and running of the developed technology, and to use waste heat from other production processes if available or share its own. For this reason, symbiosis with other production processes or facilities would be highly useful. In addition, it is recommended to include an assessment of the environmental impact of the system with regards to GHG emissions, and

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potentially also other harm-causing environmental impacts. As the main aim at current is the water processing, and less the recovery of products, additional ways of re-using elements of the waste stream could be considered if a more circular system is desired. For instance, the greenhouse in which the MNRs are place could be used as a social hangout sphere or for future applications be integrated in a restaurant or café to engage customers and bring them closer to the project. In such a case, the plants of the MNRs could serve as air purification and alternative decoration of interior areas. Alternatively, research could be performed on harvesting some of the plants of the MNRs once they reached a certain size.

8.4. Recommendations for La Trappe

Overall, the pilot study showed the potential of the BioMakery as a frontrunner in Circular Economy. However, at current, a lot of the projects are still under development. For this reason, the main recommendation at current is to ensure a focus on including energy efficiency in the planning process and re-using waste heat wherever possible, including adjacent buildings. This would allow for optimal use of resources and available energy for instance, by usage of waste heat for neighbouring buildings on-site, such as the church to reduce emissions, and to reduce the costs for energy production.

In addition, it is recommended to put a focus on high value waste re-use options, to fully recover the highest potential of the materials from the waste streams. However, the trade-off between energy consumption and value creation and degree of product recovery should be taken into consideration when doing so. One way to internally upgrade waste products would be, for instance, by using it as feed to create a protein source, such as using the water basin as a breeding area for fish and feed them with fish food created from the beer waste stream.

When offering products created from the BioMakery, for instance, in the restaurant, highlighting the value of a CE to the customers is recommended. In addition, offering customers an input or way to add their ideas of how to create more circularity, for instance, in the form of a small 'letter box' or e-mail address they can write to, might help to more actively engage customers and get innovative propositions. The BioMakery could be more actively turned into a learning tool for customers and partners, and, for instance, by adding benches, become more inviting to actively spend time there and learn about CE. Especially in winter times or on rainy days, the greenhouse could serve as a place for (small) social gatherings, e.g. for workshops, or for the employees working at La Trappe or the monks living at the abbey.

It is important to point out the value of the knowledge on all different life stages of your product, their impacts, and emission for the company. This value can be created indirectly through engagement with customers and partners, trust through increased transparency, knowledge on which areas need to be managed more efficiently and a better understanding of the overall functioning of the system.

8.5. Recommendations for Governmental Institutions

It is recommended that governments offer more funding for research on CE projects as well as on their implementation, especially with regards to projects that prove to be not only economically but also environmentally and socially sustainable. Furthermore, it is recommended to develop and offer clearer guidelines on what a CE entails. These guidelines can then also be used for procurement.

In addition, it is highly important to work together with industry to overcome legislative hurdles for creating a circular economy and help support research ensuring safe CE solutions. Legislation that hinders circularity of nutrients, organic material and water needs to be re-assessed, to allow for re-use of ''waste'', for instance, the use of by-products as animal feed (while taking into consideration health concerns).

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A platform to exchange knowledge, and address challenges, between academia, governments, and industry needs to be implemented to ensure that companies can be ideally supported in creating sustainable CE projects. When implementing new legislation regarding CE in the food and beverage industry, all actors need to be involved.

In addition, a subsidy for products produced in a circular manner could be implemented to support customers in choosing (sustainable) CE based products.

Finally, support of the development of industrial symbiosis districts and planning of their geographical position to optimally share resources is recommended.

8.6. Recommendations for Academia and for Further Research

The development of the CE indicator scorecard revealed several points for further research:

- First and foremost, a more uniform definition of a CE for the food and beverage industry is needed that takes into account the three pillars of sustainability as well as a systems perspective. Only then can a burden shifting be avoided and the impact on the planet be reduced.
- More research on the recovery of nutrients or organic material and their valorisation or re-use, as well as their potential positive and negative environmental and social impacts is still needed. This allows to better visualize the trade-off between different product options or in some cases will help to decide whether circularity is truly the most sustainable option.
- It is important to ensure that CE eventually leads to sustainable development by evaluating the environmental and societal impact alongside the economic effects, and to avoid re-bound effects by taking into consideration consumer behaviour.
- In order to fully assess the circularity of the supply chain and the raw material production, an additional framework and scorecard indicator set is needed. This could be developed in further research, for instance, by another Master student or in the case of a PhD work. This CE supply chain scorecard should take into consideration the amount of nutrient waste (leakages, run-offs) occurs, as well as the amount of water and energy (and energy form used) per kg of product produced. By switching the type of fertilizer application sued, for instance using nitrogen injection instead of spraying fertilizer directly onto crops, by choosing fertilizer compositions that have less chemical reaction when applied to the field and produce lower levels of $N2O$, and by selecting transportation and harvesting equipment based on alternative fuel sources, losses from the nutrient and energy cycle can be reduced (Yara, 2018). In addition, closed production systems, such as aquaponic systems, could be studied and selected as a potential source for input.
- Approaches using big data for supply chain management could be tested for managing CE along the supply chain. In addition, a further expansion of the scorecard and reassessment of the scores and testing with further case studies would be advisable.
- Re-assessment of the percentages used to grade the performance of the companies in terms of nutrient or energy recovery could allow to adapt the scores in more detail to current achievable levels of recovery and should be updated whenever larger changes occur in the entire industry.
- As the currently developed scorecard is still at a basic level due to the limited time span available, an expansion especially on the social and financial indicators is recommended and could be done in the form of further research at universities or through usage by consultancies.

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- More case studies are suggested to test the framework on different food and beverage products, as the focus was so far mostly on beer production, which by itself does not allow to generalize the usability of the framework.
- For further development of the scorecard it would be useful to take into consideration more aspects of the impact of workforce and customers, for instance, their commute to work, or the energy demand of the adjacent office buildings belonging to the production sites to get a full image of the impact.
- An additional step in the scorecard development could be the connection of the final results of the scorecard with a list of recommendations on how to improve the rating in the various sections. These recommendations could vary depending on what score the company received, to help them improve step by step. Thus, once the company improved, and fills out the scorecard again (this time with a higher rating), a different suggestion or recommendation could be shown to help the company advance further.
- The study focussed on the company level. New insights into developing a CE could be gained by expanding or changing the scope to the meso or macro level.

8.7. Recommendations for Consultancies

Similar recommendations apply as can be seen in the recommendations for the overall industry. In addition, it is recommended to develop a cooperation between academia and the industry to develop a unified CE indicator system that is accepted and credited and includes all aspects of a CE. The developed CE indicator scorecard can be used as a first step. It is recommended to use the expertise and the network in the field to actively test and improve these indicators and to act as a link between academia and the industry sector.

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9. Bibliography

Alsheyab, M. A. T., & Kusch-Brandt, S. (2018). Potential recovery assessment of the embodied resources in Qatar's wastewater. *Sustainability*, *10*(9). https://doi.org/10.3390/su10093055

Arantes, M. K., Jos E Alves, H., Sequinel, R., Ant, E., & Onio Da Silva, ^. (2017). Treatment of brewery wastewater and its use for biological production of methane and hydrogen. https://doi.org/10.1016/j.ijhydene.2017.08.206

Ayres, Robert U, & Leslie. (n.d.). *A Handbook of Industrial Ecology*. Retrieved from http://pustaka.unp.ac.id/file/abstrak_kki/EBOOKS/A Handbook of Industrial Ecology.pdf#page=112

Azevedo, S., Godina, R., & Matias, J. (2017). Proposal of a Sustainable Circular Index for Manufacturing Companies. *Resources*. https://doi.org/10.3390/resources6040063

Banja, M., Sikkema, R., Jégard, M., Motola, V., & Dallemand, J. F. (2019). Biomass for energy in the EU – The support framework. *Energy Policy*. https://doi.org/10.1016/j.enpol.2019.04.038

Bartholomeus, R. (2018). Reuse of industrial residual water to meet agricultural water needs. Retrieved July 7, 2019, from https://www.kwrwater.nl/en/projecten/hergebruik-van-industrieel-restwater-voor-de-watervoorziening-van-de-landbouw/

Baset, M. M. D. (2015). *Nutrition of Crop Plants*. Hauppauge, New York: Nova Science Publishers. Retrieved from http://web.b.ebscohost.com.ezproxy.leidenuniv.nl:2048/ehost/detail?sid=d44eb0b5-faa9-40b3-be02-04b22464f99f@sessionmgr102&vid=0&format=EB&rid=1#AN=1049878&db=nlebk

Besten, J. Den. (2019). Vertical Farming Development ; the Dutch Approach. In M. Anpo, H. Fukuda, & T. Wada (Eds.), *Plant Factory using Artificial Light. Adapting to Environmental Discruption and Clues to Agricultural Innovation* (pp. 307–317). Amsterdam et al.: Elsevier. https://doi.org/10.1016/B978-0-12-813973-8.00027-0

betaprocess bioenergy. (2012). Towards value optimization. Retrieved May 1, 2019, from http://www.betaprocess.eu/the-value-pyramid.php

Bezama, A. (2016). Let us discuss how cascading can help implement the circular economy and the bio-economy strategies. *Waste Management & Research*, *34*(7), 593–594. https://doi.org/10.1177/0734242X16657973

Biopolus. (2019). Water-based Urban Circularity. Retrieved July 2, 2019, from https://www.biopolus.net/urban-circularity/

Bocken, N., de Pauw, I., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, *33*(5), 308–320. https://doi.org/10.1080/21681015.2016.1172124

Bocken, N., Short, S., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, *65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Bogue, R. L. (2005). Use S.M.A.R.T. goals to launch management by objectives plan. Retrieved from https://www.techrepublic.com/article/use-smart-goals-to-launch-management-by-objectives-plan/

Bojidarka, I., & Spiteller, M. (2016). Quantitative Analytical Methods of Organic Ingredients in the Quality Control Process for the Production of Beer. In W. H. Salazar (Ed.), *Food and Beverage Consumption and Health. Beer : Production, Consumption and Health Effects* (pp. 119–211). New York: Nova Publishers. Retrieved from http://web.b.ebscohost.com.ezproxy.leidenuniv.nl:2048/ehost/ebookviewer/ebook/bmxlYmtfXzEzODUzODdfX0FO0?sid=61ce7285-0fc7-498c-85db-4286855a5884@sessionmgr101&vid=0&format=EB&rid=1

Brabant Water. (2018). *Tarievenregeling Brabant Water 2018*. Retrieved from www.brabantwater.nl/tarieven

Breure, A. M., Lijzen, J. P. A., & Maring, L. (2018). Soil and land management in a circular economy. *Science of The Total Environment*, *624*, 1125–1130. https://doi.org/10.1016/J.SCITOTENV.2017.12.137

Brown, L. R. (2006). *Plan B 2.0: Rescuing a Planet Under Stress and a Civilization in Trouble.* Norton & Company. Retrieved from http://www.earth-policy.org/books/pb2/pb2ch9_ss4

Bryant, D. A., & Frigaard, N.-U. (2006). Prokaryotic photosynthesis and phototrophy illuminated. *Trends in Microbiology*, *14*(11), 488–496. https://doi.org/10.1016/J.TIM.2006.09.001

Buckwell, A., & Nadeu, E. (2016). *Nutrient Recovery and Reuse (NRR) in European agriculture. A review of the issues, opportunities, and actions*. Retrieved from www.risefoundation.eu

C2C. (2019). Product Certification. Retrieved July 26, 2019, from https://www.c2ccertified.org/get-certified/product-certification

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

CarbonCloud. (n.d.). Climate Footprints for Foods. Retrieved July 2, 2019, from https://www.carboncloud.io/

Christou, A., Agüera, A., Bayona, J. M., Cytryn, E., Fotopoulos, V., Lambropoulou, D., … Fatta-Kassinos, D. (2017). The potential implications of reclaimed wastewater reuse for irrigation on the agricultural environment: The knowns and unknowns of the fate of antibiotics and antibiotic resistant bacteria and resistance genes – A review. *Water Research*. https://doi.org/10.1016/j.watres.2017.07.004

Coppens, J., Meers, E., Boon, N., Buysse, J., & Vlaeminck, S. E. (2016). Follow the N and P road: High-resolution nutrient flow analysis of the Flanders region as a precursor for sustainable resource management. *Resources, Conservation and Recycling*, *115*, 9–21.

Cordell, D., Drangert, J.-O., & White, S. (2009). The story of phosphorus: Global food security and food for thought. *Global Environmental Change*, *19*, 292–305. https://doi.org/10.1016/j.gloenvcha.2008.10.009

Cornel, P., & Schaum, C. (2009). Phosphorus recovery from wastewater: needs, technologies and costs. *Water Science & Technology*, *59*(6), 1069–1076. https://doi.org/10.2166/wst.2009.045

Cox, C., Pradhan, M., & Vanderbeck, I. (2019). Bittersweet nature of nitrogen calls for better management practices | UN Environment. Retrieved May 5, 2019, from https://www.unenvironment.org/news-and-stories/story/bittersweet-nature-nitrogen-calls-better-management-practices?fbclid=IwAR06pOs8-HEH9YlpbZfLEPcCLlWNo5rYjnXGlRVg0cCaTh2VaeaB-BxEcP4

Cullen, J. M. (2017). Circular Economy: Theoretical Benchmark or Perpetual Motion Machine? *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.12599

D'Odorico, P., Davis, K. F., Rosa, L., Carr, J. A., Chiarelli, D., Dell'Angelo, J., … Rulli, M. C. (2018). The Global Food-Energy-Water Nexus. *Reviews of Geophysics*, *56*(3), 456–531. https://doi.org/10.1029/2017RG000591

De Schoenmakere, M., Hoogeveen, Y., Gillabel, J., & Manshoven, S. (2018). *The circular economy and the bioeconomy. Partners in sustainability*. Retrieved from https://www.eea.europa.eu/publications/circular-economy-and-bioeconomy

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In D. A. Buchanan & A. Bryman (Eds.), *The SAGE handbook of organizational research methods* (p. 738). Sage.

Deviatkin, I., Lyu, L., Chen, S., Havukainen, J., Wang, F., Horttanainen, M., & Mänttäri, M. (2019). Technical implications and global warming potential of recovering nitrogen released during continuous thermal drying of sewage sludge. *Waste Management*. https://doi.org/10.1016/j.wasman.2019.04.031

Di Maio, F., Rem, P. C., Baldé, K., & Polder, M. (2017). Measuring resource efficiency and circular economy: A market value approach. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2017.02.009

Dodds, W. K., Burgin, A. J., Marcarelli, A. M., & Strauss, E. A. (2017). Nitrogen Transformations. In G. A. Lamberti & F. R. Hauer (Eds.), *Methods in Stream Ecology. Volume 2: Ecosystem Function* (3rd ed., pp. 173–196). Academic Press. https://doi.org/10.1016/B978-0-12-813047-6.00010-3

Dolman, M., Jukema, G., & Ramaekers, P. (2019). *De Nederlandse landbouwexport 2018 in breder perspectief*. *Wageningen Economic Research*. Wageningen.

Dri, M., Antonopoulos, I. S., Canfora, P., & Gaudillat, P. (2018). *Best Environmental Management Practice for the Food and Beverage Manufacturing Sector, JRC Science for Policy Report, EUR 29382 EN*. Luxembourg. https://doi.org/doi:10.2760/2115

Dutch Ministry of Infrastructure and the Environment. (2016). *General Assessment Methodology (GAM). Method to determine the required decontamination effort for discharges based on the properties of substances.* Retrieved from https://www.helpdeskwater.nl/onderwerpen/applicaties-modellen/applicaties-per/vergunningverlening/vergunningverlening/abm-algemene/general-assessment/

EC. (2010). *The nitrogen directive of the EU*. Retrieved from http://ec.europa.eu/environment/pubs/pdf/factsheets/nitrates/de.pdf

EC. (2019). Sustainable Food. Retrieved from https://ec.europa.eu/environment//eussd/food.htm

El-Haggar, S. M. (2007). *Sustainable Industrial Design and Waste Management. Cradle-to-cradle for Sustainable Development.* Cambridge et al.: Academic Press. https://doi.org/10.1016/B978-012373623-9/50004-6

Elkington, J. (2004). *The Triple Bottom Line, Does it All Add Up? Assessing the Sustainability of Business and CSR.* (J. Henriques, Adrian; Richardsen, Ed.). Earthscan. Retrieved from http://www.johnelkington.com/archive/TBL-elkington-chapter.pdf

Ellen MacArthur Foundation; Granta Design. (2015). Circularity Indicators. An Approach to Measuring Circularity.
Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Methodology. Retrieved from https://doi.org/10.108/S1479-357120150000007007

Ellen MacArthur Foundation; McKinsey Center for Business and Environment; Sun. (2015). *Growth Within: A Circular Economy Visionfor a Competitive Europe*. Retrieved from https://www.ellenmacarthurfoundation.org/publications/growth-within-a-circular-economy-vision-for-a-competitive-europe

Ellen Macarthur Foundation. (2015). *Circularity Indicators. An Approach to Measuring Circularity. Methodology.* Retrieved from http://www.ellenmacarthurfoundation.org/circularity-indicators/.

Ellen MacArthur Foundation. (2015). *Delivering the Circular Economy. A Toolkit for Polcymakers.* Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_PolicymakerToolkit.pdf

Ellen MacArthur Foundation. (2017a). Case Studies. Kalundborg Symbiosis. Effective industrial symbiosis. Retrieved April 12, 2019, from https://www.ellenmacarthurfoundation.org/case-studies/effective-industrial-symbiosis

Ellen MacArthur Foundation. (2017b). Circular Economy System Diagram. Retrieved April 12, 2019, from https://www.ellenmacarthurfoundation.org/circular-economy/infographic

Ellen MacArthur Foundation. (2017c). What is a Circular Economy? Retrieved February 27, 2019, from https://www.ellenmacarthurfoundation.org/circular-economy/concept

EllenMacArthur Foundation. (2019). Our food system is no longer fit for the 21st century. Here are three ways to fix it. Retrieved June 10, 2019, from https://www.weforum.org/agenda/2019/01/how-to-build-a-circular-economy-for-food/

ESA. (2015). MELiSSA. Closed Loop Compartments. Retrieved July 8, 2019, from https://www.esa.int/Our_Activities/Space_Engineering_Technology/Melissa/Closed_Loop_Compartments

EU Commission. (2019). Introduction to the EU Water Framework Directive - Environment - European Commission. Retrieved May 23, 2019, from http://ec.europa.eu/environment/water/water-framework/info/intro_en.htm

European Commission. (2006). *Integrated Pollution Prevention and Control. Reference Document on Best AvailableTechniques in the Food, Drink and Milk Industries*. Retrieved from https://eippcb.jrc.ec.europa.eu/reference/BREF/fdm_bref_0806.pdf

European Commission. (2011). Roadmap to a Resource Efficient Europe. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52011DC0571&from=EN

European Commission. (2018). *A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment Updated Bioeconomy Strategy*. Brussels. https://doi.org/10.2777/478385

eurostat. (2017). Glossary:Carbon dioxide equivalent. Retrieved July 14, 2019, from https://ec.europa.eu/eurostat/statistics-explained/index.php/Glossary:Carbon_dioxide_equivalent

FAO. (2011). *The State of the World's land an Water Resources. Managing systems at risk.* Retrieved from http://www.fao.org/3/i1688e/i1688e.pdf

FAO. (2018). *European Price Report. Groundfish.* Retrieved from http://www.fao.org/3/i8465en/I8465EN.pdf

FAO. (2019). Aquacultur Feed and Fertilizer Resources Information System. Striped Catfish - Growth. Retrieved July 12, 2019, from http://www.fao.org/fishery/affris/species-profiles/striped-catfish/growth/en/

Fertilizers Europe asbl. (2011). *Carbon footprint reference values. Energy efficiency and greenhouse gas emissions in European mineral fertilizer production and use*. Retrieved from www.danfertilizers.com

Figge, F., & Thorpe, A. S. (2019). The symbiotic rebound effect in the circular economy. *Ecological Economics*, *163*, 61–69. https://doi.org/10.1016/J.ECOLECON.2019.04.028

Garza-Reyes, J. A. (2015). Lean and green e a systematic review of the state of the art literature. *Journal of Cleaner Production*, *102*, 18–29. https://doi.org/10.1016/j.jclepro.2015.04.064

Geertjes, K., Baas, K., Verschuren, S., Kaashoek, R., & Graveland, C. (2016). *Fosfor in afvalwater en slib*. *22 Maart*. Den Haag. Retrieved from https://www.cbs.nl/-/media/_pdf/2016/12/fosfor-in-afvalwater.pdf

Geissdoerfer, M., Bocken, N. M. P., & Hultink, E. J. (2016). Design thinking to enhance the sustainable business modelling process e A workshop based on a value mapping process. https://doi.org/10.1016/j.jclepro.2016.07.020

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Geissdoerfer, M., Morioka, S. N., de Carvalho, M. M., & Evans, S. (2018). Business models and supply chains for the circular economy. *Journal of Cleaner Production*, *190*, 712–721. https://doi.org/10.1016/j.jclepro.2018.04.159

Geissdoerfer, M., Savaget, P., Bocken, N. M. P., & Hultink, E. J. (2017). The Circular Economy – A new sustainability paradigm? *Journal of Cleaner Production*, *143*, 757–768. https://doi.org/10.1016/J.JCLEPRO.2016.12.048

Geng, Y., Fu, J., Sarkis, J., & Xue, B. (2012). Towards a national circular economy indicator system in China: An evaluation and critical analysis. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2011.07.005

Genovese, A., Acquaye, A. A., Figueroa, A., & Koh, S. C. L. (2017). Sustainable supply chain management and the transition towards a circular economy: Evidence and some applications. *Omega (United Kingdom)*. https://doi.org/10.1016/j.omega.2015.05.015

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, *114*, 11–32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gill, P., Stewart, K., Treasure, E., & Chadwick, B. (2008). Methods of data collection in qualitative research: interviews and focus groups. *British Dental Journal*, *204*(6), 291–295. https://doi.org/10.1038/bdj.2008.192

Glasbergen, P. (2011). Understanding partnerships for sustainable development analytically: The ladder of partnership activity as a methodological tool. *Environmental Policy and Governance*, *21*(1), 1–13. https://doi.org/10.1002/eet.545

Gontard, N., Sonesson, U., Birkved, M., Majone, M., Bolzonella, D., Celli, A., … Sebok, A. (2018). A research challenge vision regarding management of agricultural waste in a circular bio-based economy. *Critical Reviews in Environmental Science and Technology*. https://doi.org/10.1080/10643389.2018.1471957

Graedel, T. E., Allwood, J., Birat, J. P., Buchert, M., Hagelüken, C., Reck, B. K., … Sonnemann, G. (2011). What do we know about metal recycling rates? *Journal of Industrial Ecology*. https://doi.org/10.1111/j.1530-9290.2011.00342.x

Grant, S. R., Gorur, S., Young, J. C., Landine, R., Cocci, A. C., & Churn, C. C. (2002). An Anaerobic Exercise. A comparison of anaerobic treatment technologies for industrial wastewater. *Environmental Protection*. Retrieved from https://eponline.com/Articles/2002/11/01/An-Anaerobic-Exercise.aspx?admgarea=ht.water.wastewater

GRI. (n.d.). GSSB Work Program and Standards review. Retrieved April 29, 2019, from https://www.globalreporting.org/standards/work-program-and-standards-review/

Griffiths, P., & Cayzer, S. (2016). Design of Indicators for Measuring Product Performance in the Circular Economy (pp. 307–321). https://doi.org/10.1007/978-3-319-32098-4_27

Guinée, J. B., Heijungs, R., Huppes, G., Kleijn, R., de Koning, A., van Oers, L., … Gorrée, M. (2001). Life Cycle Assessment: An Operational Guide to the ISO Standards. *The Netherlands: Ministry of Housing, Spatial Planning and the Environment*, (May), 692. https://doi.org/10.1007/BF02978784

Haupt, M., Vadenbo, C., & Hellweg, S. (2017). Do We Have the Right Performance Indicators for the Circular Economy?: Insight into the Swiss Waste Management System. *Journal of Industrial Ecology*. https://doi.org/10.1111/jiec.12506

Heineken. (2018). Transitioning towards a circular economy. Retrieved April 9, 2019, from https://www.theheinekencompany.com/sustainability/case-studies/mexico-circular-economy

Hopcroft, F. J. (Ed.). (2014). *Wastewater Treatment Concepts and Practices*. New York: Momentum Press. Retrieved from https://ebookcentral-proquest-com.tudelft.idm.oclc.org/lib/delft/reader.action?docID=1816350

Huysman, S., De Schaepmeester, J., Ragaert, K., Dewulf, J., & De Meester, S. (2017). Performance indicators for a circular economy: A case study on post-industrial plastic waste. *Resources, Conservation and Recycling*. https://doi.org/10.1016/j.resconrec.2017.01.013

Iacovidou, E., Millward-Hopkins, J., Busch, J., Purnell, P., Velis, C. A., Hahladakis, J. N., … Brown, A. (2017). A pathway to circular economy: Developing a conceptual framework for complex value assessment of resources recovered from waste. *Journal of Cleaner Production*, *168*, 1279–1288. https://doi.org/10.1016/J.JCLEPRO.2017.09.002

International Trappist Association. (n.d.). Internationale Vereniging Trappist. FAQs. What are the criteria for the ATP label? Retrieved July 8, 2019, from https://www.trappist.be/en/faqs/

ITA. (n.d.). Internationale Vereniging Trappist - About ITA. Retrieved June 15, 2019, from https://www.trappist.be/en/about-ita/

Johansson, S., Ruscalleda, M., Saerens, B., & Colprim, J. (2019). Potassium recovery from centrate: taking advantage of
Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

autotrophic nitrogen removal for multi-nutrient recovery. *Journal of Chemical Technology & Biotechnology*, *94*(3), 819–828. https://doi.org/10.1002/jctb.5828

Jouhara, H., Khordehgah, N., Almahmoud, S., Delpech, B., Chauhan, A., & Tassou, S. A. (2018). Waste heat recovery technologies and applications. *Thermal Science and Engineering Progress*, *6*, 268–289. https://doi.org/10.1016/J.TSEP.2018.04.017

Joyce, A., & Paquin, R. L. (2016a). The triple layered business model canvas: A tool to design more sustainable business models. *Journal of Cleaner Production*, *135*, 1474–1486. https://doi.org/10.1016/j.jclepro.2016.06.067

Joyce, A., & Paquin, R. L. (2016b). The triple layered business model canvas: A tool to design more sustainable business models Keywords: Business model innovation Sustainable business models Business models for sustainability Triple layered business model canvas Triple bottom line. *Journal of Cleaner Production*, *135*, 1474–1486. https://doi.org/10.1016/j.jclepro.2016.06.067

Kalundborg Symbiosis. (n.d.). Kalundborg Symbiosis. Retrieved May 3, 2019, from http://www.symbiosis.dk/en/

Kefalas, A. G. (1998). Think globally, act locally. *Thunderbird International Business Review*, *40*(6), 547–562. https://doi.org/10.1002/(SICI)1520-6874(199811/12)40:6<547::AID-TIE3>3.0.CO;2-F

Kirchherr, J., Reike, D., & Hekkert, M. (2017a). Conceptualizing the circular economy: An analysis of 114 definitions, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Kirchherr, J., Reike, D., & Hekkert, M. (2017b). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling*, *127*(September), 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Klijnhout, A. F., & Van Eerde, P. (1986). *Some characteristics of brewery effluent*. *J. Insi. Brew* (Vol. 92). Retrieved from https://onlinelibrary.wiley.com/doi/pdf/10.1002/j.2050-0416.1986.tb04435.x

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular Economy: The Concept and its Limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, *175*, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

LaTrappe Trappist. (n.d.). Our story. A true story about a genuine brand. - La Trappe Trappist. Retrieved April 12, 2019, from https://www.latrappetrappist.com/en/our-story/

Lawlor, D. W., Lemaire, G., & Gastal, F. (2001). Nitrogen, Plant Growth and Crop Yield. In P. J. Lea & J. Morot-Gaudry (Eds.), *Plant Nitrogen* (pp. 343–367). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-04064-5_13

Lester, A. (2014). *Project Management, Planning and Control : Managing Engineering, Constructi...: EBSCOhost* (6th ed.). Oxford: Butterworth-Heinemann. Retrieved from http://web.b.ebscohost.com.ezproxy.leidenuniv.nl:2048/ehost/detail/detail?vid=0&sid=2b6fcb29-9db0-410e-8a1d-c584d5f5c6f2%40pdc-v-sessmgr01&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3D%3D#AN=486496&db=nlebk

Lewandowski, M. (2016). Designing the Business Models for Circular Economy—Towards the Conceptual Framework. *Sustainability*, *8*(1), 1–28. https://doi.org/10.3390/su8010043

Li, R. H., & Su, C. H. (2012). Evaluation of the circular economy development level of Chinese chemical enterprises. *Procedia Environmental Sciences*. https://doi.org/10.1016/j.proenv.2012.01.151

Lieder, M., & Rashid, A. (2016). Towards circular economy implementation: A comprehensive review in context of manufacturing industry. *Journal of Cleaner Production*, *115*, 36–51. https://doi.org/10.1016/j.jclepro.2015.12.042

Linder, M., Sarasini, S., & van Loon, P. (2017). A Metric for Quantifying Product-Level Circularity. *Journal of Industrial Ecology*, *21*(3), 545–558. https://doi.org/10.1111/jiec.12552

Linderholm, K., Tillman, A.-M., & Mattsson, J. E. (2012). Life cycle assessment of phosphorus alternatives for Swedish agriculture. *Resources, Conservation and Recycling*, *66*, 27–39. https://doi.org/10.1016/J.RESCONREC.2012.04.006

Lipińska, D. (2018). The Water-wastewater-sludge Sector and the Circular Economy. *Comparative Economic Research*, *21*(4), 121–137. https://doi.org/10.2478/cer-2018-0030

Lüdeke-Freund, F., Gold, S., & Bocken, N. (2019). A Review and Typology of Circular Economy Business Model Patterns. *Journal of Industrial Ecology*, *23*(1), 36–61. https://doi.org/10.1111/jiec.12763

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Malhotra, H., Vandana, Sharma, S., & Pandey, R. (2018). Phosphorus Nutrition: Plant Growth in Response to Deficiency and Excess. In F. M. Hasanuzzaman M., Oku H., Nahar K., & Hawrylak-Nowak B. (Eds.), *Plant Nutrients and Abiotic Stress Tolerance* (pp. 171–190). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-9044-8_7

Marchand, K. (2014). How to Select the Proper KPI (Part 1). Retrieved June 17, 2019, from https://www.dundas.com/support/blog/how-to-select-the-proper-kpi-part-1

Massara, T. M., Komesli, O. T., Sozudogru, O., Komesli, S., & Katsou, E. (2017). A Mini Review of the Techno-environmental Sustainability of Biological Processes for the Treatment of High Organic Content Industrial Wastewater Streams. *Waste and Biomass Valorization*, *8*(5), 1665–1678. https://doi.org/10.1007/s12649-017-0022-y

Maxime, D., Le Marcotte, M., & Arcand, Y. (2005). Development of eco-efficiency indicators for the Canadian food and beverage industry. https://doi.org/10.1016/j.jclepro.2005.07.015

Mayer, A., Haas, W., Wiedenhofer, D., Krausmann, F., Nuss, P., & Blengini, G. A. (2019). Measuring Progress towards a Circular Economy: A Monitoring Framework for Economy-wide Material Loop Closing in the EU28. *Journal of Industrial Ecology*, *00*(0), 1–15. https://doi.org/10.1111/jiec.12809

Merli, R., Preziosi, M., & Acampora, A. (2018). How do scholars approach the circular economy? A systematic literature review. *Journal of Cleaner Production*, *178*, 703–722. https://doi.org/10.1016/j.jclepro.2017.12.112

Merlo, O., Eisingerich, A. B., & Auh, S. (2014). Why Customer Participation Matters. *MITSloan Management Review. Research Feature.* Retrieved from https://sloanreview.mit.edu/article/why-customer-participation-matters/

Metcalf & Eddy Inc., Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). *Wastewater Engineering: Treatment and Reuse. 4th ed.* (4th ed.). McGraw-Hill, New York: Jones, Elizabeth A. https://doi.org/10.1016/0956-053X(92)90028-H

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food manufacturing waste: A review. *Journal of Cleaner Production*, *65*, 28–41. https://doi.org/10.1016/j.jclepro.2013.10.051

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., … Dewulf, J. (2019). Circular economy indicators: What do they measure? *Resources, Conservation and Recycling*, *146*(November 2018), 452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

Moriguchi, Y. (2007). Material flow indicators to measure progress toward a sound material-cycle society. *Journal of Material Cycles and Waste Management*, *9*(2), 112–120. https://doi.org/10.1007/s10163-007-0182-0

Moro, A., & Lonza, L. (2018). Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. *Transportation Research Part D: Transport and Environment*, *64*, 5–14. https://doi.org/10.1016/J.TRD.2017.07.012

Mosier, A., Syers, J. K., & Freney, J. R. (2013). Nitrogen Fertilizer: An Essential Component in Increased Food, Feed, and Fiber Production. In A. Mosier, J. K. Syers, & J. R. Freney (Eds.), *Agriculture and the Nitrogen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment*. Washington D.C.: Island Press. Retrieved from https://books.google.nl/books?hl=de&lr=&id=dO0PbWN4vjUC&oi=fnd&pg=PR11&dq=nitrogen+cycle+agriculture&ots=bdy3StnNbA&sig=A0trA9cmd4bIsDFKWPgsROc83MM&redir_esc=y#v=onepage&q=nitrogen cycle agriculture&f=false

Muster-Slawitsch, B., Weiss, W., Schnitzer, H., & Brunner, C. (2011). The green brewery concept - Energy efficiency and the use of renewable energy sources in breweries. *Applied Thermal Engineering*. https://doi.org/10.1016/j.applthermaleng.2011.03.033

Naik, S. N., Goud, V. V., Rout, P. K., & Dalai, A. K. (2010). Production of first and second generation biofuels: A comprehensive review. *Renewable and Sustainable Energy Reviews*, *14*(2), 578–597. https://doi.org/10.1016/j.rser.2009.10.003

NextGen. (2019). La Trappe (NL). Retrieved January 27, 2019, from https://nextgenwater.eu/demonstration-cases/la-trappe/

Niero, M., & Kalbar, P. P. (2019). Coupling material circularity indicators and life cycle based indicators: A proposal to advance the assessment of circular economy strategies at the product level. *Resources, Conservation and Recycling*, *140*, 305–312. https://doi.org/10.1016/j.resconrec.2018.10.002

OECD. (2014). *OECD Studies on Water. Water Governance in the Netherlands. Fit for the Future?* OECD Publishing. https://doi.org/10.1787/9789264102637-en

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Olajire, A. A. (2012). The brewing industry and environmental challenges. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2012.03.003

Organizing4Innovation. (2018). Business plan, case, model, or canvas? - ORGANIZING4INNOVATION. Retrieved May 6, 2019, from https://www.organizing4innovation.com/business-plan-business-case-business-model-or-business-model-canvas/

Osterwalder, A., Pigneur, Y., Smith, A., Bernarda, G., & Papadakos, P. (2014). *Value Proposition Design*. Hoboken, New Jersey: Wiley.

Pandey, N. (2018). Role of Plant Nutrients in Plant Growth and Physiology. In F. M. Hasanuzzaman M., Oku H., Nahar K., & Hawrylak-Nowak B. (Eds.), *Plant Nutrients and Abiotic Stress Tolerance* (pp. 51–93). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-10-9044-8_2

Parmenter, D. (2015). *Key Performance Indicators. Developing, Implementing, and Using Winning KPI's* (3rd ed.). Hoboken, New Jersey: John Wiley & Sons, Inc.

Pauliuk, S. (2018). Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations. *Resources, Conservation and Recycling*, *129*, 81–92. https://doi.org/10.1016/j.resconrec.2017.10.019

PBL Netherlands Environmental Assessment Agency. (2017). *FOOD FOR THE CIRCULAR ECONOMY PBL Policy Brief*. Retrieved from https://www.pbl.nl/sites/default/files/cms/publicaties/PBL-2017-Food-for-the-circular-economy-2878.pdf

PBL Netherlands Environmental Assessment Agency. (2018). Circular economy: what we want to know and can measure Framework and baseline assessment for monitoring the progress of the circular economy in the Netherlands Policy Report, 92.

Pollution Control Service. (2019). New German Sewage Sludge Regulation sets the Standard for Phosphorus Recovery. Retrieved from https://www.pcs-consult.de/en/news/New-German-Sewage-Sludge-Regulation-sets-the-Standard-for-Phosphorus-Recovery

Polman, P., & Bhattacharya, C. (2016). Engaging Employees to Create a Sustainable Business. *Stanford Social Innovation Review*. Retrieved from https://ssir.org/articles/entry/engaging_employees_to_create_a_sustainable_business

Pope Francis. (2015). *Laudato Si'. On Care for our Common Home. Encyclical Letter*. Rome: Catholic Truth Society.

Quagrainie, K. K., Flores, R. M. V., Kim, H. J., & McClain, V. (2018). Economic analysis of aquaponics and hydroponics production in the U.S. Midwest. *Journal of Applied Aquaculture*. https://doi.org/10.1080/10454438.2017.1414009

Ranta, V., Aarikka-Stenroos, L., & Mäkinen, S. J. (2018). Creating value in the circular economy: A structured multiple-case analysis of business models. *Journal of Cleaner Production*, *201*, 988–1000. https://doi.org/10.1016/j.jclepro.2018.08.072

Rao, A. G., Reddy, T. S. K., Prakash, S. S., Vanajakshi, J., Joseph, J., & Sarma, P. N. (2007). pH regulation of alkaline wastewater with carbon dioxide: A case study of treatment of brewery wastewater in UASB reactor coupled with absorber. *Bioresource Technology*, *98*(11), 2131–2136. https://doi.org/10.1016/J.BIORTECH.2006.08.011

Reuter, M. A., & Van Schaik, A. (2016). Recycling Indices Visualizing the Performance of the Circular Economy. *World of Metallurgy - ERZMETALL*, *69*(4), 5–20.

Richardson, J. (2008). The business model: an integrative framework for strategy execution. *Strategic Change*, *17*(5–6), 133–144. https://doi.org/10.1002/jsc.821

Ritala, P., Huotari, P., Bocken, N., Albareda, L., & Puumalainen, K. (2018). Sustainable business model adoption among S&P 500 firms: A longitudinal content analysis study. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2017.09.159

Roorda, P. D., Ca, O., Jones, K. P., Ca, K., Friesen, P., Ca, O., … Ahmad M.A. (2007). CO2 emissions of PV in perspective of a renewable energy economy. In N. H. Reich, E. A. Alsema, W. G. J. H. M. van Sark, & E. Nieuwlaar (Eds.), *22nd European Photovoltaic Solar Energy Conference, 3-7 September 2007, Milan, Italy*. Milan. https://doi.org/10.1590/s1809-98232013000400007

Saadabadi, S. A., Thallam Thattai, A., Fan, L., Lindeboom, R. E. F., Spanjers, H., & Aravind, P. V. (2019). Solid Oxide Fuel Cells fuelled with biogas: Potential and constraints. *Renewable Energy*, *134*, 194–214. https://doi.org/10.1016/j.renene.2018.11.028

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., & Kendall, A. (2019). A taxonomy of circular economy indicators. *Journal of Cleaner Production*, *207*, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Scheepens, A. E., Vogtländer, J. G., & Brezet, J. C. (2016). Two life cycle assessment (LCA) based methods to analyse and design complex (regional) circular economy systems. Case: Making water tourism more sustainable. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2015.05.075

Schenkel, M., Caniëls, M. C. J., Krikke, H., & van der Laan, E. (2015). Understanding value creation in closed loop supply chains – Past findings and future directions. *Journal of Manufacturing Systems*, *37*, 729–745. https://doi.org/10.1016/J.JMSY.2015.04.009

Selatile, M. K., Ray, S. S., Ojijo, V., & Sadiku, R. (2018). Recent developments in polymeric electrospun nanofibrous membranes for seawater desalination. *RSC Advances*, *8*(66), 37915–37938. https://doi.org/10.1039/C8RA07489E

SEMiLLA Circular Systems. (2019). About IPStar/SEMiLLA Circular Systems. Retrieved February 20, 2019, from http://www.semilla.io/about/00c0e73d/0/about-semilla-circular-systems

Seneviratne, M. (2016). *Treatment Technologies. ZDHC. The Roadmap To Zero Programme.* Retrieved from https://www.roadmaptozero.com/fileadmin/pdf/Files_2018/Wastewater_Treatment_Technologies_for_the_Textile_Industry-FINAL.pdf

Sengupta, S., Nawaz, T., & Beaudry, J. (2015). Nitrogen and Phosphorus Recovery from Wastewater. *Current Pollution Reports*. https://doi.org/10.1007/s40726-015-0013-1

Short, S. W., Bocken, N. M. P., Barlow, C. Y., & Chertow, M. R. (2014). From refining sugar to growing tomatoes: Industrial ecology and business model evolution. *Journal of Industrial Ecology*, *18*(5), 603–618. https://doi.org/10.1111/jiec.12171

Siebert, A., O'Keeffe, S., Bezama, A., Zeug, W., & Thrän, D. (2018). How not to compare apples and oranges: Generate context-specific performance reference points for a social life cycle assessment model. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.06.298

Simate, G. S., Cluett, J., Iyuke, S. E., Musapatika, E. T., Ndlovu, S., Walubita, F., & Alvarez, A. E. (2011). The treatment of brewery wastewater for reuse: State of the art. https://doi.org/10.1016/j.desal.2011.02.035

Sousa-Zomer, T. T., Magalhães, L., Zancul, E., Campos, L. M. S., & Cauchick-Miguel, P. A. (2018). Cleaner production as an antecedent for circular economy paradigm shift at the micro-level: Evidence from a home appliance manufacturer. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2018.03.006

Stehouwer, R. (2010). What is sewage sludge and what can be done with it? Retrieved July 7, 2019, from https://extension.psu.edu/what-is-sewage-sludge-and-what-can-be-done-with-it

Stein, I. (n.d.). Abwasser Analysezentrum. Parameterübersicht. Retrieved July 7, 2019, from https://www.abwasser-analysezentrum.de/parameteruebersicht-abwasser

Stindt, D., & Sahamie, R. (2014). Review of research on closed loop supply chain management in the process industry. *Flexible Services and Manufacturing Journal*, *26*(1–2), 268–293. https://doi.org/10.1007/s10696-012-9137-4

Sun, D., Gao, Y., Hou, D., Zuo, K., Chen, X., Liang, P., … Huang, X. (2018). Energy-neutral sustainable nutrient recovery incorporated with the wastewater purification process in an enlarged microbial nutrient recovery cell. *Journal of Power Sources*, *384*, 160–164. https://doi.org/10.1016/j.jpowsour.2018.02.049

Suters, R., Lindeboom, R., van de Kerckhove, T., Luther, A., Clauwaert, P., Rabaey, K., … Flameling, T. (2016). *MELiSSA TECHNOLOGY in the Koningshoeven brewery. Feasibility Study. [Confidential]*.

Sutton, M. A., & Billen, G. (2011). Technical Summary. In M. A. Sutton, C. M. Howard, J. W. Erisman, G. Billen, A. Bleeker, P. Grennfelt, … B. Grizzetti (Eds.), *The European Nitrogen Assessment: Sources, Effects and Policy Perspectives*. Cambridge: Cambridge University Press. Retrieved from https://books.google.de/books?hl=de&lr=&id=oX3oFqAM9GkC&oi=fnd&pg=PR1&ots=xkEk4E4p24&sig=SZc7jb_uuuj3e4a2YMD2HEvEPTw&redir_esc=y#v=onepage&q&f=false

Teece, D. J. (2010). Business Models, Business Strategy and Innovation. *Long Range Planning*, *43*(2–3), 172–194. https://doi.org/10.1016/J.LRP.2009.07.003

ten Wolde, A., & Kunert, A. (2019). The Circularity Check. Retrieved from https://ecopreneur.eu/wp-content/uploads/2019/01/Circularity-Check-Workshop-15-1-19.pdf

Tewari, P. K., & Bewtra, J. K. (1982). Alpha and Beta Factors for Domestic Wastewater. *Water Pollution Control Federation*. Wiley. https://doi.org/10.2307/25041683

Disclaimer: This is the public version of a MSc-thesis student project. Although the research was carefully performed, the dynamic nature of the project it describes requires that the involved companies are consulted prior to using this information to avoid miscommunication and ensure the most up-date description of the actual situation.

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a Methodology for Developing Evidence-Informed Management Knowledge by Means of Systematic Review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Tseng, M.-L., Fung Chiu, S., Tan, R. R., & Bella Siriban-Manalang, A. (2013). Sustainable consumption and production for Asia: sustainability through green design and practice. *Journal of Cleaner Production*, *40*, 1–5. https://doi.org/10.1016/j.jclepro.2012.07.015

U.S. Chamber of Commerce Foundation. (2017). Measuring Circular Economy, Circular Economy Toolbox. Retrieved July 26, 2019, from https://www.uschamberfoundation.org/circular-economy-toolbox/about-circularity/measuring-circular-economy

Udo de Haes, H. A. (2002). Industrial ecology and life cycle assessment. In R. U. Ayres & L. W. Ayres (Eds.), *A Handbook of Industrial Ecology*. Edward Elgar Publishing. Retrieved from https://www.elgaronline.com/view/1840645067.00021.xml

UN. (1987). *Our Common Future. Report of the World Commission on the Environment and Development*. Retrieved from http://netzwerk-n.org/wp-content/uploads/2017/04/0_Brundtland_Report-1987-Our_Common_Future.pdf

UNEP; SETAC. (2011). *Towards a Life Cycle Sustainability Assessment. Making informed choices on products*. Retrieved from https://www.lifecycleinitiative.org/wp-content/uploads/2012/12/2011 - Towards LCSA.pdf

UNEP. (2005). *Options for decoupling economic growth from water use and water pollution. A report of the Water Working Group of the International Resource Panel.* Retrieved from https://www.researchgate.net/publication/301807298_UNEP_2015Options_for_decoupling_economic_growth_from_water_use_and_water_pollution_Report_of_the_International_Resource_Panel_Working_Group_on_Sustainable_Water_Management

UNEP DTIE. (n.d.). Resource Efficient and Cleaner Production. Retrieved May 3, 2019, from http://www.unep.fr/scp/cp/

UNEP, Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., … Siriban Manalang, A. (2011). *Decoupling natural resource use and environmental impacts from economic growth*.

United Nations ESCAP. (2009). *Eco-effciency Indicators: Measuring Resource-use EEciency and the Impact of Economic Activities on the Environment United Nations Environment and Development Policy Section Environment and Development Division*. Retrieved from https://sustainabledevelopment.un.org/content/documents/785eco.pdf

Van Lier, J. B., Mahmoud, N., & Zeeman, G. (2008). Anaerobic Wastewater Treatment. In *Biological Wastewater Treatment. Principles, Modelling and Design* (pp. 401–442). London: IWA. Retrieved from https://ocw.tudelft.nl/wp-content/uploads/Chapter_16_-_Anaerobic_Wastewater_Treatment.pdf

Veltman Vis Service B.V. (2013). Meerval. Retrieved July 12, 2019, from https://veltmanvis.nl/meerval/

Venkata Mohan, S., Nikhil, G., Chiranjeevi, P., Nagendranatha Reddy, C., Rohit, M., Naresh Kumar, A., & Sarkar, O. (2016). Waste biorefinery models towards sustainable circular bioeconomy: Critical review and future perspectives. https://doi.org/10.1016/j.biortech.2016.03.130

Verberne, J. (2016). Building Circularity Indicators. Retrieved from https://prezi.com/dtlihektyiwf/building-circularity-indicators/

Vercalsteren, A., Christis, M., & Van Hoof, V. (2017). SUMMA+ Indicators for a circular economy, 43.

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate Change and Food Systems. *Annual Review of Environment and Resources*, *37*(1), 195–222. https://doi.org/10.1146/annurev-environ-020411-130608

Waarts, Y., Sluis, A. Van Der, & Timmermans, T. (2011). *Reducing Food Waste. Obstacles experienced in legislation and regulations*.

Waterschap De Dommel. (2004). Beleid af-en aanhaken grote lozers. Wetstechnische informatie. Retrieved July 7, 2019, from https://www.dommel.nl/cvdr/CVDR272369_1/Beleid+af-+en+aanhaken+grote+lozers.html

Wen, Z., & Meng, X. (2015). Quantitative assessment of industrial symbiosis for the promotion of circular economy: A case study of the printed circuit boards industry in China's Suzhou New District. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2014.03.041

WeSustain, MVO Nederland, & ecopreneur. (2019). Circularity Check. Retrieved from https://system.wesustain-esm.com/circularity-check/main.html/Login;jsessionid=45E3E8CAEACF231F7BADC99AFEAB17A6?series=10032&org=12151&page=S

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UB_DATAMANAGEMENT_CRKOMPASS&portal=3541CSsustainalize

Widheden, J., & Ringström, E. (2007). Life Cycle Assessment. In I. Johansson & P. Somasundaran (Eds.), *Handbook for Cleaning/Decontamination of Surfaces* (Volume 2, pp. 685–720). Amsterdam et al.: Elsevier. https://doi.org/10.1016/b978-044451664-0/50021-8

Wing, ZON, & DHZ. (2016). *Wel Goed Water Geven! Werkprogramma Zoetwatervoorziening Hoge Zandgronden 2016-2021.*

Withers, P. J. A., van Dijk, K. C., Neset, T. S. S., Nesme, T., Oenema, O., Rubæk, G. H., … Pellerin, S. (2015). Stewardship to tackle global phosphorus inefficiency: The case of Europe. *Ambio*, *44*(2), 193–206. https://doi.org/10.1007/s13280-014-0614-8

Yara. (2018). *Fertilizer Industry Handbook 2018*. Retrieved from https://www.yara.com/siteassets/investors/057-reports-and-presentations/other/2018/fertilizer-industry-handbook-2018-with-notes.pdf/

Zeeman, G., Kujawa, K., De Mes, T., Hernandez, L., De Graaff, M., Abu-Ghunmi, L., … Lettinga, G. (n.d.). Anaerobic treatment as a core technology for energy, nutrients and water recovery from source-separated domestic waste(water). https://doi.org/10.2166/wst.2008.101

Zink, T., & Geyer, R. (2017). Circular Economy Rebound. *Journal of Industrial Ecology*, *21*(3), 593–602. https://doi.org/10.1111/jiec.12545

Zörb, C., Senbayram, M., & Peiter, E. (2014). Potassium in agriculture - Status and perspectives. *Journal of Plant Physiology*, *171*, 656–669. Retrieved from https://pdf.sciencedirectassets.com/273190/1-s2.0-S0176161714X00052/1-s2.0-S0176161713003611/main.pdf?X-Amz-Security-Token=AgoJb3JpZ2luX2VjECsaCXVzLWVhc3QtMSJHMEUCIC4V7dV%2F2jWOq7DPjvGuZRsBO7b1WXQv2ME48f7QEVMpAiEA3lNrBVgI1kfpr5Cl9moGz3wk9cuPBKseqYzx2oifAx

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Appendix

Appendix I Indicator Development

Appendix I.1. Indicator Calculations

Appendix I.1.a. Products: Calculation if multiple products

At a company level, for each of the waste products created, or waste streams treated the question on the level and quantity of the product needs to be filled out, and an average will be calculated. Thus, the final result will be company waste re-use value.

Equation 1 Company waste re-use value:

$$CV = \frac{\sum_{i=0}^{6} a_i i}{\sum_{i=0}^{6} a_i}$$

The formula gives a sum of the values *i* from 0 to 6 in accordance to the product type chosen multiplicated by the weight of the product with a_0 being the amount of the waste in kg not re-used at all to a_6 being the amount of waste in kg being used for the creation of medicines. The result gives the average rating of all products combined.

Appendix I.1.b. Packaging: Indicator Calculation – MCI

The MCI is calculated as follows (Ellen MacArthur Foundation; Granta Design, 2015):

$$MCI^*{}_P = 1 - LFI \cdot F(X).$$

The MCI is comprised of the Linear Flow Index (LFI) and the F(X).

The LCI measures the degree of circularity and is calculated as follows:

$$LFI = \frac{V + W}{2M + \frac{W_F - W_C}{2}}$$

The linear flow index sums up the virgin feedstock V and the unrecoverable waste W and divides it through twice the products mass M and half the unrecoverable waste flow from producing recycled feedstock for a product minus the unrecoverable waste from recycling parts of a product.

The utility factor F(x) measures the utility x of a product, meaning the life-span of the product divided by the average life-time of the product according to the industry sector times the use intensity of the product divided by the average. One of the two can be used to calculate the LFI while the other is assumed to be 1. The use intensity can be assumed average for building materials and packaging, and thus calculated by substituting with 1. In this case, the calculation for the

$$utility\ x = \frac{L}{L_{av}}$$

The function F(x) was chosen in a way to ensure the same impact of changes in utility as in changes of circularity. For this reason:

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$$F(x) = \frac{0.9}{x}$$

In a case of a single product, an existing tool to calculate the MCI, designed by the Ellen MacArthur foundation can be used. The resulting value can be entered in this scorecard. (Be aware that this can only be done for one single product).

If several product streams are involved, which will most likely be the case with various packaging or building materials, the MCI of a department can be used. It allows to combine different products, such as different packaging types, or different building materials, as needed for this question. The department-based MCI_D uses a normalizing factor based on the different weight of the materials. This allows to retrieve an average value for all the material types in the building or packaging as can be seen in the formula below:

$$MCI_{D(\alpha)} = \frac{1}{N_{D(\alpha)}} \sum_{\beta} \left(N_{R(\alpha,\beta)} \cdot MCI_{P(\alpha,\beta)} \right),$$

With the normalization factor per department being

$$N_{D(\alpha)} = \sum_{\beta} N_{R(\alpha,\beta)},$$

And NR is the normalizing factor for the products ranging from α to β.

(Ellen MacArthur Foundation; Granta Design, 2015, 21-26;48)

While water and energy emissions are not directly included in this indicator, they can be incorporated with the supplementary indicators provided by the Ellen MacArthur Foundation. (Ellen MacArthur Foundation, 2015)

Appendix I.2. Validation Session Changes

Several changes of the CE indicator scorecard were performed after the validation and consultation sessions with experts and peers. The following section gives a summary of the main changes and considerations.

The questions for the first building block *products* were reduced from nine to seven questions to avoid redundancy and to reduce complexity of the scorecard. In addition, more research on percentages for resource and nutrient recovery was done.

The *customer* building block saw only small changes in question 8. Testing how aware a company was of the knowledge of their customers was added as response 1 after the first validation session, where this was suggested as a measurable replacement for the more imprecise and vaguer 'active customer involvement' level.

Questions were reduced for *supply* and *production* after the expert consultation, as some questions were considered redundant or too time consuming.

For the section *key resources* towards a CE, the waste stream as a resource plays an important role. However, many of the indicators already deal with the input material, and its usage, and to avoid

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repetition, after further discussion with experts, no additional indicator was created for the waste stream as a resource. While the physical building materials and equipment should be taken into consideration when truly creating a CE, it is not seen as part of the core concern of a CE for the food and beverage industry and will therefore be considered outside of the frame. This was also done in response to feedback from experts in order to make the initial core scorecard more user-friendly and less complex to use while focussing on the main challenges. (Interview Sustainalize 2019) While the question relating to building material was left out in can be considered for future development of the scorecard, for instance, by using MCI for calculating the impact of the building and equipment materials in a CE. It needs to be taken into account, that this will heavily impact the time needed to fill out the scorecard.

For the building block *transportation,* the distances for transport were aligned with the scorecard for technical material loops designed by WeSustain after a consultation with Sustainalize.

While the building block system change originally contained a question regarding land use change, this was removed after the consultation sessions as it was found too complex for companies to respond to and was seen as a hurdle in filling out the scorecard. It remains, however, an important element that should be considered when assessing circularity in more detail.

The most important criteria that was highlighted by all respondents was the time needed to fill out the scorecard as well as the general level of difficulty for filling out the scorecard. Overall, the validation sessions led to several changes in the structure of the scorecard as well as the questions themselves and resulted in a more compact version of the scorecard with 24 instead of 32 questions. In addition, it was suggested to let companies instead of external agents fill out the scorecard. To further facilitate filling out the scorecard, a new design was made in Microsoft Excel offering automatic and immediate results after filling in the questions.

Appendix I.3. Explanation Indicator Development

Appendix I.3.a. Supplementary Information Building Block A

The following table shows the concentrations that are expected from BAT WWT treatment, and are needed to minimize the impact on the environment. (European Commission, 2006) These values were taken as a basis for the indicator questions A.3. to A.7. The questions focused in particular on the amount of phosphorus, nitrogen, and potassium extracted from the waste stream and recovered for the newly created product.

Table A-1 BAU concentrations expected after WWT, based on EC's BAT for the FDM sector. (European Commission, 2006, vii)

Parameter	Concentration (mg/l)
BOD_5	<25
COD	<125
TSS	<50
pH	6 – 9
Oil and grease	<10
Total nitrogen	<10
Total phosphorus	0.4 – 5
Better levels of BOD_5 and COD can be obtained. It is not always possible or cost effective to achieve the total nitrogen and phosphorus levels shown, in view of local conditions.	

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Appendix I.3.b. Supplementary Information Building Block C: Production – Energy

Question asks the company for the percentage of renewable energy forms they use for production processes. Here, renewable energy, is defined as energy coming from non-fossil fuels. Biofuels are counted as renewable form of energy, however, only if second or third generation biofuels are used, as these are considered to not compete with land use for food production and typically stem from agricultural or forest waste products. Third generation biomass is typically associated with algae. (Naik, Goud, Rout, & Dalai, 2010)

Appendix I.3.c. Supplementary Information Building Block C: Production - Water

To measure the circularity of the water stream for the product created or the company, the rate of recycling of the stream as well as the quality are of importance. This can be similarly shown as materials in a technical loop. Thus, important are the amount of recycled water that is used as input as well as the amount of water reused/recycled after the usage in the production processes for the product. The quality of the water plays an important role as well, to take into account pollution of the water stream either when discharging or re-using it. Thus, for this reason three questions were created. For water reuse or recycling, the two terms will be used interchangeably as a certain amount of treatment is seen necessary to make the water flow circular, and thus, will be referred to as 'recycled'. No circular system can be a 100% circular as there will always be minor efficiency losses, for this reason a 4% range was allowed for the highest value; for the values between 0 and 100, and average progression of 20% was chosen.

Appendix I.3.d. Supplementary Information Building Block D

Inclusion of CE principles can be closely related to this approach which covers three dimensions: The formal dimension, such as job description, the psychological dimension, such as rewards, recognition and commitment, as well as the social dimension, including culture and values. The development of the level of involvement scheme for employees builds on the considerations on how to involve employees in a sustainable business. (Polman & Bhattacharya, 2016) A first step is seen in ensuring that employees are aware of the long-term vision of the company (response 1). In a second step, employees should also learn how economic performance is connected to circularity that encompasses environmental and social benefits (response 2). In a third step the company should support knowledge and expertise building on CE, for instance, through workshops and traineeship options (response 3). Engaging employees and aligning personal and corporate goals is seen as a fourth step. This can also apply to CE challenges. Employees are asked to identify which area of CE they can connect with the strongest. This could for instance, be water reduction and circularity, due to a lack of clean water in their region (response 4). The employees should then be given the chance to work on this issue or present solutions that will be implemented, for instance in the form of co-creation. This allows to truly lead to a change in work methods, perspectives and motivations that could be seen as a 'system change' within the company. Creating a healthy competition during is seen as another element to further the development of sustainability, and in the case of this research, CE. Competition, can be argued, is not needed in every case. However, it might be beneficial to improve the work motivation of some employees and was therefore included together with co-creation (response 5). As a final point, the article recommends sharing achievements inside and outside the company. In the case of CE, this could be done in the form of sharing results from the CE indicators and communicate the achievements of the company to the public, to partners and other stakeholders, and to the employees. Showing the higher purpose of the goal, for instance, system change in the case of a CE, could further help motivate employees (response 6). The 6 grades of this question build on the elements identified in the article. The actions were rated based on the level of involvement of employees. Informing employees to an extend where they gain knowledge but remain passive received a lower rating while actively engaging and involving employees and allowing them to take part in creation processes received a higher rating. The actions rated higher are assumed to be taken together with the lower rated options. For instance, co-creation, assumes employees' access to training and expertise building as without this as a basis, no apt decisions can be made when deciding on new or improved products or processes.

Appendix I.3.e. Supplementary Information Building Block G

Taking into consideration potential external costs is of central value in establishing a CE. In a truly CE, externalities will be re-used to a minimum as a closed system will not lead to damage outside of the system. However, a business based on CE needs to ultimately be profitable. This can be either by taking into considerations externalities or by managing resources in a way to not only have lower impacts but also higher profits. Thus, in an ideal scenario a well-constructed business model will lead to resource decoupling. Resource decoupling refers to a reduction in raw materials needed per € of outcome produced. (UNEP, 2005) For this reason, high value re-use should be the preferred option for re-purposing waste. In addition, by circulating and re-using materials, fewer new raw materials are needed and therefore a lower impact on the environment can be achieved (assuming processing of the waste has a lower environmental impact than harvesting new raw materials). As every business is different a percentage rating cannot be applied. This led to the choice of the question on profitability of the CE project. An extension of this section with additional financial indicators is suggested for the future further development of the scorecard.

Appendix I.4. Additional Suggestion for Calculation of GHG Emissions

There are several ways how to calculate the GHG emissions of a product. In the case of this scorecard question, only the difference in emission between the BAU scenario is needed.

When regarding the change in emissions between products or after production changes, it is not always necessary to know the emissions of the entire value chain. In this case it is enough to have an understanding of the estimated overall emissions, and a detailed understanding of the emissions of the elements to be substituted. For instance, creating 1kg of phosphorus fertilizer would require the comparison of the production of fertilizer (the extraction from the waste stream could be excluded, as it is needed for treatment of the water stream to avoid environmental damage) with the mining, transporting and processing to create 1kg of phosphorus from raw materials (Linderholm et al., 2012). Thus, the net $CO_{2eq.}$emissions reduction can be calculated as:

Net reduction = Avoided emissions – emissions of recovery process (in CO_{2eq}).

$CO_{2eq.}$ emissions include other the impact of other greenhouse gasses, expressed in the impact of CO_2 emissions. The most relevant for the food and beverage sector, aside from CO_2 emissions are methane CH_4 and nitrous oxide N_2O. For instance, 1 ton of N_2O has the same global warming potential as 296 tons of CO_2 when released into the atmosphere.

Table A-2 Major greenhouse gases in the food and beverage industry. (eurostat, 2017)

Gas	Global warming potential (with CO_2 as reference value)
CO_2	1
CH_4	25
N_2O	298

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To calculate this indicator, data from literature as well as from the company is needed.

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Appendix II CEBM and Scorecard Alternative Usages

Appendix II.1. Considerations for Calculations of the Scorecard – Discharge Prices

To get drinking water from the Brabant Water company, the price for companies requiring more than 300 m^3 per year is set at 0.46€ per m^3. In addition, a fee has to be paid for providing the water and the water network. The fee is paid annually and depends on the amount of m^3 needed per hour. The rate is € 83.74 per m^3. (The rates are based on the latest prices, adapted in 2018.) (Brabant Water, 2018). Considering that the La Trappe brewery draws 9000 m^3 per year, this would amount to approximately 4140 + with an estimated flow of 6m^3 per h this would add around 500€ in service fees per year. The water costs per year for La Trappe are therefore around 4650€ annually. These numbers are relatively insignificant, and do not by themselves constitute a profitable business case for circularity. However, climate change and rising temperatures increase the risk of draught in the region and put water supply at risk. This is an important driver for the development of circular solutions for the region. (NextGen, 2019)

The discharge costs for the waste water, on the other hand, amount to approximately 250 000€ per year. Extraction of valuable secondary raw materials and reduced treatment needs as a result therefore offer a more potential for a circular economy business model. (Questionnaire Istvan Koller)

Appendix II.2. Calculations of Energy Use and Emissions in the Scorecard

Emissions and energy usage were compared to business as usual (BAU) scenarios to give an indication on the performance of the company. BAU data was obtained from literature.

CO_2 emission calculations were based on life-cycle assessment data on types of biofuels and regular fuels for the production of biogas in the anaerobic digester of the MELiSSA technology as well as data received by the company. An overview can be seen in *figure A-1*.

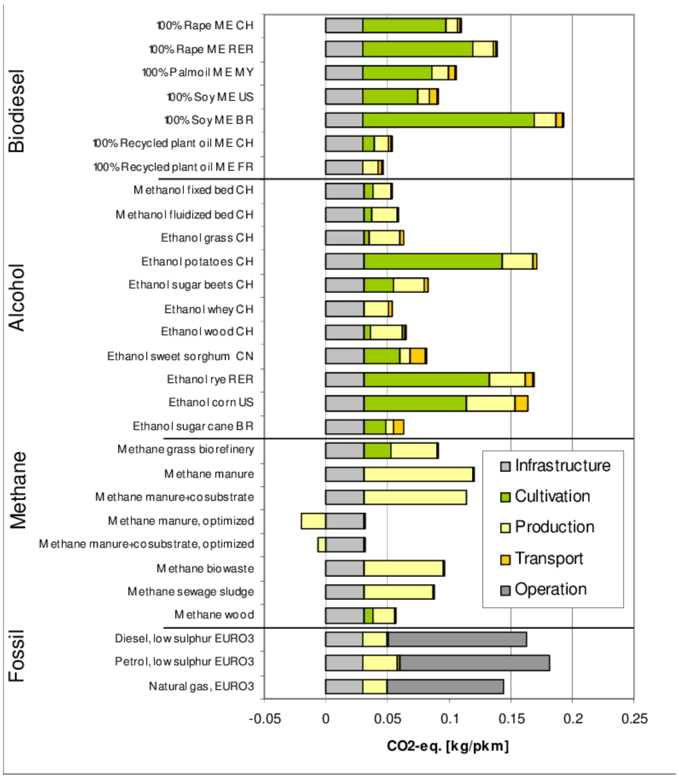

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Figure A-1 CO_2-eq. emissions of different fuels based on an LCA. (Zah et al., 2007)

CO_2eq. emissions of fertilizer production and usage were based on values obtained for European fertilizer production and usage (Fertilizers Europe asbl, 2011) as well as data received by the company. Production and use of urea was taken as a BAU, as 50% of nitrogen fertilization of crops takes place in this manner, and the shares are increasing. Urea contains 46% nitrogen. Urea production accounts for 0.91 kg $CO_{2eq.}$ emissions per kg of product produced and requires 23.45 MJ per kg produced. However, urea has high N_2O losses after field application, which results in 5.12 kg CO_2eq. emissions is use is considered as well. Other forms of nitrogen-based fertilizers typically only have half of the emissions during the use phase. For phosphate P_2O_5 fertilization, diammonium phosphate (DAP) or monoammonium phosphate (MAP) (containing 46% P respectively) was used as BAU as they were applied in almost half of the cases. They require 6.76 MJ per kg produced and emit 0.73 kg CO_2eq per kg of product (2.03 kg CO_2eq. if use is incorporated). The BAU for potassium is muriate of potash (MOP) which is used in 60% of all cases globally and has an average emission rate of 0.25 kg CO_2eq. per kg product and requires 3 MJ per kg to produce. (Fertilizers Europe asbl, 2011; Yara, 2018)

For a BAU electricity usage the average Dutch electricity mix with 0.55 kg CO_2eq. emissions per 1 kWh of electricity supplied was selected. (Moro & Lonza, 2018) Depending on the production and type of solar panel, electricity provided from PV panels (taking into account their production), produce 0.05-0.3 kg CO_2eq. emissions per 1 kWh of electricity provided. (Roorda et al., 2007) An average of 0.175 kg CO_2eq. was chosen as a basis for calculations.

The CO_2 emission reduction for SEMiLLA was assumed in the following way. The biogas created in the process is seen to be used as a substitution of a fossil fuel source. The treatment and production of biogas requires 9.7 kWh of electricity for 26 m3 of methane per day. This translates into 70 kWh of electricity generated per day if a conversion efficiency of 25% is assumed. This production step can therefore be seen as an energy positive production step. (However, to avoid large conversion losses, direct usage of the biogas, for instance, for transportation is suggested, rather than for electricity generation.) Including transportation, methane produced from sludge or food waste has approximately 0.09 kg CO_{2eq} emissions per kg of product as compared to 0.16-0.18 kg of CO_{2eq} emissions for regular diesel or petrol (see *figure A-1*). This would allow for up to 56% less emissions than in a BAU scenario (if applied to transportation and not electricity production). The energy usage of the nitrification unit is 70 kWh per day, or 40 kWh per kg of N. In addition, there are expected N_2O emissions during the nitrification process that are highly potent in terms of GWP. Since this is not stated otherwise, these emissions are assumed to be in line with BAU emissions during typical nitrification processes. No reductions as compared to BAU are assumed for this case. Since these are two separate compartments and products the average of these two were taken (4 + 0) yielding a 2 on overall CO_2 emission reduction. It needs to be pointed out that this calculation offers only a rough assumption used to test the framework. More detailed emission data is needed to double-check this assumption in practice. For Biopolus, it was assumed that the BAU would refer to water drawn from the ground and compost from low-energy food waste and thus the energy required to clean the water stream and heat the sludge to re-use it for energy production would be higher in comparison, and consequently increase rather than reduce emissions. For the BioMakery, the average value from the combined technologies was taken. This is a simplified representation that was chosen due to lack of data and to get a rough estimate of the results.

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Appendix II.3. Calculation Scorecard SEMiLLA

To understand the full CEBM for the MELiSSA technology, in a first step, the compartments will be viewed separately. Then they will be combined in one CEBM and assessed with the developed scorecard. Two main compartments are ready to be developed for practical application and for potential sale. These are compartment C-I performing anaerobic digestion as well as C-III performing nitrification and denitrification with the use of microfiltration and reverse osmosis.

C-I Anaerobic Digestion

The anaerobic digester is estimated to process 18m^3 of waste flow per day. If the input is assumed to be brewery wastewater and cheese makery waste water, [ex.]. Focusing on the food waste of the restaurant as well as the black water waste from the different toilet streams is from a financial point of view more feasible. The assumed waste stream for the following business model for C-I is therefore the municipal stream stemming from the restaurant and the monks' quarters.

Table A-1 CEBM for compartment I of the SEMiLLA technology. [ex.]

C-III Nitrification/Denitrification

Adding nanofiltration and reverse osmosis would allow the creation of water at drinking level quality, as it filters out pathogens and bacteria. However, the better the filtration, the more pressure and energy is needed to perform it, making it highly costly and only profitable for highly concentrated fluids. For beer waste streams, microfiltration would offer a way to filter out suspended particles as well as bacteria without the increased need for further filtration, as the waste stream is relatively unproblematic and treatment with UV light for disinfection is followed.

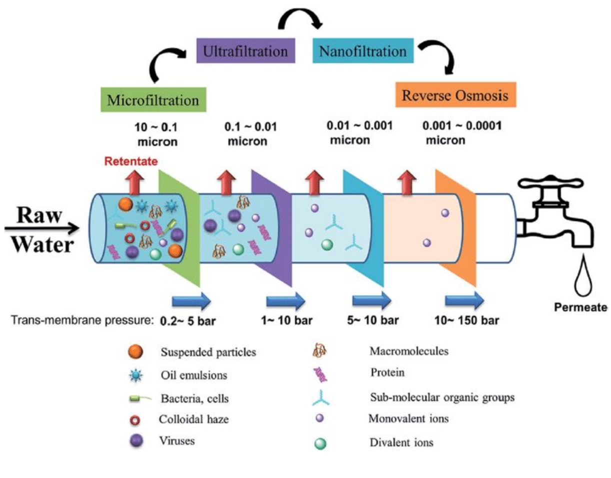

Figure A-2 Levels of filtration. (Selatile, Ray, Ojijo, & Sadiku, 2018)

Table A-2 CEBM for compartment III of the SEMiLLA technology. [ex.]

The costs and the products of these two compartments were then combined into one CEBM canvas, which can be found in chapter 5.4.1.

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Appendix III Case Study La Trappe

Appendix III-a Site Visit Protocol

SITE VISIT & Guided Tour: La Trappe, Tilburg

Company site visit report

Disclaimer: Some of the information given is confidential and is not to be shared with people outside of this research project.

Date: May 2019

Present:

- The company site visit was led by Brother Isaac and from the Water Board of De Dommel and joined by representatives from SEMiLLA.
- Brother Isaac is the main responsible for the beer production from the side of the abbey and holds the recipes for the various beers brewed at La Trappe. He is also in charge of the sustainability projects at the brewery, the knowledge exchange between Trappist abbeys, and the overall installation of the 'BioMakery' and the side-products created from it.
- Istvan Koller, The Water Board De Dommel, manages the BioMakery.
- Representatives of SEMiLLA, who is responsible for the instalment of two compartments within the BioMakery where municipal waste from the restaurant and the abbey will be treated, the water cleaned and nutrients from it extracted.
- Researchers of the University of Antwerp

The tour gave insight over the treatment processes, and the quality tests conducted on-site as well as the production of various products from waste and research undertaken for creating further value. The tour also involved a semi-structured interview with Istvan Koller based on a pre-formulated questionnaire (which is added to the appendix) to create additional data.

Tour and interview with Istvan Koller and Brother Isaac

Trappist beer production

To brew Trappist beer and to carry the brand, certain rules need to be followed. The beer brewing process needs to be embedded in a living community of monks. There are 22 monks living at the monastery (ranging from 40-70 years) and some monks from the partner monasteries in Uganda and Indonesia. New employees at La Trappe are integrated into this life-style by sharing the living quarters of the monks for 24 hours before they start their new job. During this time, they live and eat in silence and are without WIFI. This helps them to identify with the original idea of the La Trappe beer which is to reflect the way it is brewed by 'tasting silence' when drunk.

The abbey owns the beer brand and all recipes as well as all the brewery buildings. The monks decide on new flavours or types of beers. They cooperate with the Royal Swinkels Family Brewery (or known as Bavaria), who are owning the brewing equipment and manage the brewing process. While the monks decide on the taste, the Swinkels Family chooses the ingredients.

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The revenue from the brewery goes in parts to Swinkels Family and to the abbey. Parts of the abbey revenue are used for charity programmes, for instance, the partner monasteries.

Reasons for sustainable production

Father Isaac and Istvan Koller also explained the reasoning of the belief in sustainability, which is founded in the belief on the earth as god's house and is based on an encyclical letter by Pope Francis.

Steps towards a Circular Economy

La Trappe gradually wants to achieve a circular economy. The BioMakery will follow a step by step approach to reach this goal.

1. Step: Cleaning the water and introducing it to a canal that leads to a reservoir for agricultural use. Farmers do not need to draw from ground water anymore and will as a result reduce water demand. Before discharge, the water flows through the plant nursery of the abbey therefore replacing previous ground water drawing for the growing of these plants.
2. Step: Use cleaned water for bottle cleaning. This will reduce water requirements per litre of beer produced from 7l to 3.5l (as 3.5l are required simply for bottle cleaning). Only possible if water has sufficient quality. For this reason, it is at the moment still drawn from ground water.
3. Step: 100% circularity of the water stream to even use the water directly for the beer consumption. Research projects at La Trappe: SEMiLLA, Biopolus' and ESA's MELiSSA project to reuse municipal waste water; ESA's and InVitro's Belissima project to reduce micro-pollutants and projects, for instance, with the University of Ghent on re-using waste materials and nutrients. The MELiSSA project runs within the NextGen Horizon2020 project and involves 30 different partners and 9,96 mio. € funding from the EU Horizon 2020 research and innovation programme. The project was kicked off in July 2018 and runs until July 2022. The Belissima project received 650.000€ in funding from BELSPO (Belgian Science Policy).

Functioning of the BioMakery

In a guided tour through the premises the functioning of the BioMakery was explained. This can be found in the case study (chapter 4). Explanations were given on detailed treatment system, ways of testing, and current and future plans for the BioMakery. This was documented with a set of photos of the information boards provided.

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Appendix III-b Questionnaire with Istvan Koller

Questionnaire filled out by Istvan Koller on May 15th, 2019 as a follow-up to the interview during the site visit.

1. What was the main motivation for creating this CE project?
   a. *The consumption of fresh water worldwide is growing faster than the growth of the population. Circular solutions are needed.*
   b. *The abbey members pray 7 times a day to praise creation, and after that they continue to pollute the earth. They don't want that anymore*
   c. *Waterboard De Dommel wants to set up testing grounds* (playgrounds, living labs) for the future water management focused on maximum circularity and innovation*

definition: a permanent, viable, concrete concept so that there is sufficient time (years and years) to innovate.

2. How did the project develop?

That is a very broad question. From innovation it can best be described via innovation funnel, see figure. But it is also a process of trusting, cooperating and accelerating. With the necessary problems because the construction world is still insufficiently sustainable, and the authorities do not know how to handle permits properly.

3. What does circular economy mean to you?
   The circular economy is, inter alia, economical use of our resources in a way that there is no or as little as possible waste. This by processing residual flows in such a way that it is suitable to be applied with value elsewhere. It is not only closing the loop, but more, see figure:

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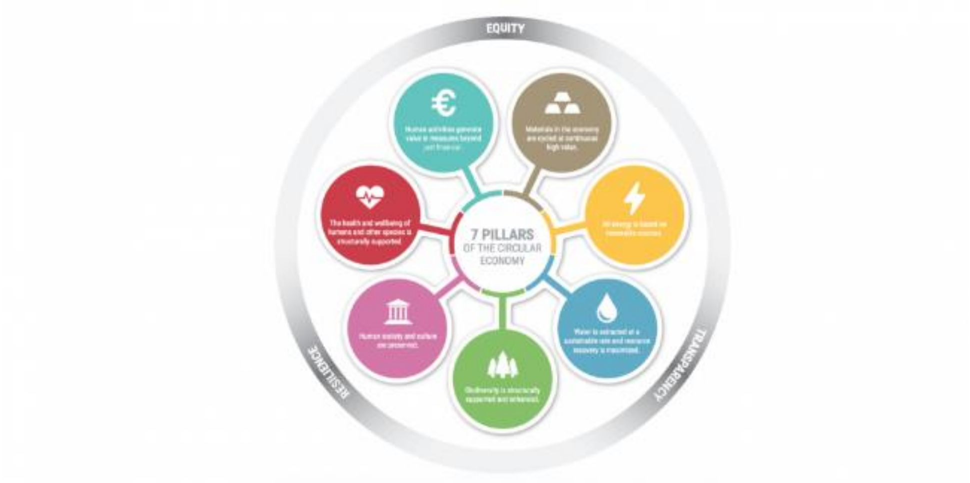

4. How much beer does La Trappe produce per day or hour? And how much is the waste flow (and its composition) per day or hour?
   The yearly production is 90.000 hectolitre beer, with a maximum of 125.000 hl beer.
   Daily production varies enormously depending on which type of bear and whether one or two or … batches can be made in one day.
   The daily wastewater flow is around 320 m3 (420 max.) daily. [ex.]

5. What is the main beer produced? Where do all the components come from? And how is it distributed/sold?
   - *Main (and only) beer are de trappists beers https://www.La Trappetrappist.com/nl/*
   - *From everywhere, but sustainable.*
   - *The beer is distributed by Bavaria en is sold in supermarkets en in café's/restaurants.*
6. How much water is needed/ drawn every day? And what are the costs for doing so?
   90.000 m3/year. [ex.]

7. How is the waste stream currently used and treated? (before the installation of the greenhouse) And what is the standard for the quality of the water after that? What is the composition of the waste stream after the WWT?
   Not treated, only buffered before discharge.
   The composition See 4 and that is the composition for discharging it on the big Municipal Water Treatment utility in Tilburg.
   The composition after WWT [ex.]

8. What are the costs associated with this?
   [ex.]

   What are the expected costs for the new construction of the greenhouse? How many full-time employees will be added after it is installed? (expected salary/occupation if possible)
   [ex.]

9. What are the costs of connecting the restaurant and the monk's quarters to this? And what are the expected flows from there (in liters, concentration if possible – with water?)
   [ex.]

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10. What are the main partners for this project and how often is there contact between them? What information is exchanged (e.g. detailed production data from farmers about quality?)
    Main partners are The Abbey, Waterboard De Dommel, Biopolus, Hoppenbrouwers, MJ Oomen. Intensive contact.

11. What is the expected energy demand of the greenhouse (for the various process steps)?
    To do that I have to go in detail into the engineering. At the end the greenhouse will be energy neutral due to exchange heat (aquathermie) and solarpanels.

12. How will this energy be created?
    See 11.

13. What will be the expected size of the greenhouse and the capacity for plants? / fish?
    n.a.

14. What is the current price of the plants they sell?
    n.a.

15. What impact do they see this project will have on the region/ country/ other projects? What will visitors be able to see/learn?
    The impact is already world-wide as the EU stated that this can be an example for the world. In the NextGen project (EU, also China, Japan and Korea) this will be practices.
    The urgency on one hand. And good news on the other hand, that there are solutions if you belief in it.

16. What is the maximum and minimum amount of waste water than can get treated by the MNR? What will be the expected average? **What is the efficiency of the system? And how does this change with varying water flows?**
    See answers above
17. How long does it take to treat it?
    __________7h____
    ____
18. For the waste from restaurants and private quarters, what is the expected amount? How will solid waste be treated/processed?
    At this moment the waste from restaurants etc. will not be treated at the BioMakery.
19. What are the nutrients planned to be extracted?
    N en P
20. What will be the expected composition of the water stream after the cleaning processes?
    See above
21. Are there currently already waste or side-products being repurposed and sold?
    Yes, the wei from the cheesefactory
22. How much waste energy can be used for heating of the greenhouses? What is the ratio of reused waste heat to the energy consumed in the brewing process as well as in the greenhouse complex?
    The heat in the wastewater from the brewery will be used for heating the greenhouse and also the Proeflokaal
23. What is the expected life-span of the greenhouse complex/ the MNR?

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Normally we say 2 times 15 years. Good to know is that we used madaster (a material passport). So al building components have a kind of economical value when de construction is dismanteled.

24. What are the expected maintenance costs?
    We put this in the business case together with operational cost,

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Appendix IV Scorecards

Appendix IV-a Scorecard Outline

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CE Indicator Scorecard

for Products Created from Biological Waste Streams

GENERAL IMFORMATION

Name company	
Contact person	
E-Mail	

QUESTION NR.	QUESTION	RESPONSES	INDICATOR NAME	SCORE	Justificat
Value Proposition		PLEASE FILL IN THIS COLUMN			
1	What is the total waste stream from the company's production processes in kg per year? (excluding water)				
	PRODUCT NAME				
	PLEASE FILL IN YOUR PRODUCTS HERE	**SELECT**	Product Weight in % (of all products from the waste stream)		
Product 1		0 Treatment but not reused (e.g. landfilled)	100%	0	
Product 2 (if applicable, else leave blank)				0	
Product 3 (if applicable)				0	
Product 4 (if applicable)				0	
Product 5 (if applicable)				0	
	Total product weight in kg per year		unknown		
2	Average Score Products		**PRODUCTS**	**0**	
		SELECT			
3	What amount of P do you recover from your waste stream?	0 We do not remove or recover P.		0	
4	What amount of N do you recover from your waste stream?	0 We do not remove or recover N.		0	
5	What amount of K do you recover from your waste stream?	0 We do not remove or recover K.		0	
			NUTRIENTS	**0**	
6	How much energy is saved through the production of the new product from waste as compared to production in a non-circular manner?	0 negative or 0%	**ENERGY**	**0**	
7	How much water is saved through the production of the new product from waste as compared to production in a non-circular manner?	0 negative or 0%	**WATER**	**0**	
B					
8	The Level of Customer Awareness and Inclusion: How are customers involved in the circularity of the product?	0 There is no direct interaction with customers.		0	
Value Creation					
9	Supply: For what percentage of the supplied inputs do you know the exact origins e.g. the farmer producing the raw material?	0 negative or 0%		0	
10	Supply: What percentage of your suppliers work with a certification scheme for CE are rated as circular (using a metric based on energy, nutrients and water usage or a different certification)?	0 negative or 0%		0	
			SUPPLY	**0**	
11	Production – Energy requirements: What % of the energy input for the product creation comes from a waste stream or from renewable energy sources?	0 0%		0	
12	Production – Energy requirement: What percentage of the energy used in the company is being re-used, e.g. as waste heat?	0 no waste energy is being recovered		0	
			PRODUCTION: ENERGY	**0**	
13	Production – Water: What % of the water used in the waste product recovery process is being re-used afterwards?	0 0%		0	
14	Production – Water: What is the water quality after the production (& cleaning) process?	0 Polluted water		0	
			PRODUCTION: WATER	**0**	
D					
15	How do you involve your employees in your vision of creating a CE?	0 They are not involved.	**EMPLOYEES**	**0**	

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Value Delivery: Partners & Transport				
16	Partners: At what stage is the collaboration between you and your partners on creating a CE?	0 We do not have any partners.	**PARTNERS**	**0**
17	Transportation: What mode of transportation is used to transport the raw materials to the company?	0 Mostly airplanes		0
18	Transportation: What distance is involved in the transportation process until the raw materials reach (and leave) the production facility of the company?	0 Global supply chain and production steps around the world		0
			TRANSPORTATION	**0**
19	Packaging: What is the material circularity indicator score for potential packaging of the material?	0 0.00-0.1	**PACKAGING**	**0**
	Info: To calculate this score, please use the MCI tool provided by the Ellen MacArthur foundation			
Value Capture				
20	Is there a net profit from creating a CE based on the waste streams used?	0 It will cost us money (excluding including the negative externalities we are substituting).	**PROFIT**	**0**
Value Anchoring				
21	Systems Perspective: Our company is actively involved in creating a CE within	Write "1" if applicable		
	a. Our suppliers			
	b. Our partners			
	c. Our production			
	d. Our production facilities and equipment			
	e. Our logistics			
	f. Our consumers		sum	0
22	Systems Perforation: Our company was active in	Write "1" if applicable		
	a. Promoting CE to consumers through education (e.g. tours through the company, educational center, labelling of product…)			
	b. Promoting CE to partners (e.g. seminars, meetings on CE strategies,…)			
	c. Promoting CE to supply chains (e.g. trainings, implementation of labelling schemes, support and education, financial support)			
	d. Promoting CE within the company's workforce (e.g. through training days, information sessions)			
	e. Promoting CE through research on-site from own R&D team and/or university research groups			
	f. Incorporating CE into our vision and business model		sum	0
			SYSTEM CONSIDERATION	**0**
23	Long-term impact: How much waste was avoided in % as compared to the BAU production of the company?	Please answer Question 1		
	SELECT (see value above blue field)	0 negative or 0%		0
24	I.2. What is the net reduction of CO_{2eq} emissions of the product created from the waste stream in comparison to the business as usual (BAU)?	0 negative or 0%		0
			POLLUTION REDUCTION	**0**

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Appendix IV-b Scorecard SEMiLLA

The scorecard results can be found in the Excel file ''SEMiLLAIPStar_researcher'' that was added to this thesis.

Appendix IV-c Scorecard Biopolus

The scorecard results can be found in the Excel file ''Biopolus_researcher'' that was added to this thesis.

Appendix IV-d Scorecard BioMakery of La Trappe

The scorecard results can be found in the Excel file ''La TrappeBioMakery_researcher'' that was added to this thesis.

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