Unpacking Urban Agriculture:
Business Contributions to Circular Economy

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Abstract

Circular economy (CE) has received considerable interest in recent years as a strategy to resolve some of our modern urban resource challenges, and circular city models often incorporate systems of urban agriculture in their design. Much work has analyzed the benefits of urban agriculture for creating a resilient food system and as a strategy for supporting urban green space and social cohesion, however, the contributions from business models that operate within urban agriculture have not been thoroughly studied. Many urban agriculture businesses often claim high levels of resource recycling and material circularity, though whether a resource efficiency throughout the entire product lifetime (including energy and material footprint for the cultivation equipment) in comparison to current industrial strategies is truly feasible or even possible is still to be debated. This thesis builds upon work that incorporates social dimensions of CE definitions and begins to research whether the potential resource efficiency contradiction can be justified as to make urban agriculture a valid approach for circular city design. This study examined an urban mushroom farm that implements a circular business model. A qualitative summary of the business operations and resource flows were unpacked and sorted into 24 socio-economic contributions based on their interpreted relevance. The interpreted data shows that an urban agriculture business model can contribute to the building blocks of a CE through economic, ecological, social, and spatial contributions. While these contributions can contribute positively to the operationalization of CE, potential trade-offs regarding resource efficiency, use of urban space, and investment priorities need to be considered and addressed to avoid a possible watering down or greenwashing of the CE concept.

Key words *(Schlagwörter)*: circular economy, urban agriculture, business model, socio-economic contributions, recycling, start-up

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List of Abbreviations

B2B – Business to Business (sales channel)

B2C – Business to Consumer (sales channel)

CE – Circular Economy

LCA – Life Cycle Assessment

MFA – Material Flow Analysis

R&D – Research and Development

SD – Sustainable Development

UA – Urban Agriculture

USP – Unique Selling Point

1 Introduction

As we rapidly surpass several of our planetary boundaries, balancing global industrialization as well as human and environmental health, has become increasingly challenging. The over extraction and consumption of resources through a linear "take-make-use-dispose" economic model have contributed significantly to the origin and exacerbation of these challenges, which has led to a state of urgency in many parts of the world to implement strategies for establishing a resource efficient and low-carbon society. At a high level, the sustainable development goals (SDGs) provide a general blueprint for what a "peaceful and prosperous" future should look like, and to reach these goals, a number of socio-economic strategies and technological innovations will be necessary. CE as a strategy for resource efficient regions, cities, and businesses has been strongly supported in recent years by researchers, policy makers, and generally ecologically motivated individuals as it aims to transition from the more linear economic model towards a circular "take-make-use-recycle" one (Figure 1).

Urban agriculture has also stepped recently into the global development spotlight. Firstly, considering 68% of the global population will be living in urban areas by 2050 (United Nations, 2018a), food production within or near to cities will be a relevant topic for establishing adequate logistics and resilient food systems. Secondly, the potential for agricultural systems (specifically those in an urban/peri-urban context) to act as a sink for biological waste streams to recycle valuable nutrients is often proposed as a strategy within CE implementation frameworks (European Investment Bank, 2018).

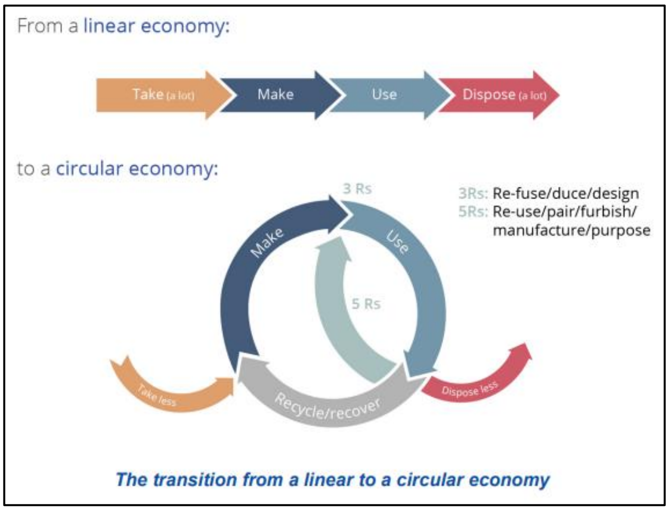

Figure 1: Transition from a linear to a circular economy (Source: European Investment Bank, 2018)

Whether CE can truly deliver on it's promise of creating a less resource intensive economy has come under criticism. The concept itself has been in development for many decades, however, most of the early work focussed on how it's implementation can create economic performance without sacrificing opportunities to achieve economic growth. The issues associated with growth-based economies has certainly faced criticism and their applicability as a future model have been called into question, but more relevant to this thesis is that until recently, the social and ecological dimensions of a CE were often overlooked.

Recent work has now begun to establish a more holistic definition of CE that includes these other dimensions, but we have now reached a stage where classic resource measurement methodologies such as material flow analysis (MFA) and life cycle assessments (LCA) are “tapped out” in their abilities to evaluate the more holistic aspects of a CE. Although these MFAs or LCAs have been state of the art for many years, they no longer succeed in fully delineating the advantages of a CE that exist beyond the system boundaries. An LCA that estimates the impact for a single product or small company can easily be performed, however, attributing the impact for specific processes near to the system boundary always becomes blurrier and more complicated. An LCA performed within a realistic timeframe for an entire industry or economic sector that fully defines the complex flows of resources is not feasible and a realistic attempt would be non-sensible. Some large companies have recognized this and have begun advertising their new product or service as “circular” in an obvious attempt to brand themselves as sustainable. This push for CE models without considering the resource use outside the system boundaries has led to an issue of “circularity for circularity’s sake.”

This exclusion of negative externalities outside of the system boundaries certainly challenges the validity of CE. However, should we be so quick to throw the baby out with the bath water and abandon the term completely? Is it valid to assume a circular product or service with a lower calculated footprint automatically carries social benefits? If not, how can the effects of CE truly be evaluated across all societal dimensions?

This thesis will look more specifically at urban agriculture and will debate whether modern urban agriculture business models contribute to a more holistic concept of CE. The main case study in this thesis will look at an urban mushroom farm in Cologne that claims to implement a circular business model by upcycling coffee grounds to use for a substrate material to cultivate the mushrooms. Urban mushroom farms, even those that cultivate using spent coffee grounds, have existed for some time, however, the idea has recently gained popularity, most likely due to the simplicity and fundamentality of the CE aspects at play, as well as the low-tech nature and low investment needed to successfully begin operation. With several major European cities now the sites of these small-scale operations, many have seen immediate success as well as attention from organizations that aim to promote urban sustainability.

This thesis is the culmination of three years real-world experimentation in the field of founding a green-start-up and comes at an interesting time, after the 2021 publication from Dorr et al., which performed a life-cycle assessment for a peri-urban mushroom farm on the outskirts of Paris. The farm analyzed in the study is an environmentally conscious operation that implements the spent coffee grounds cultivation technique. The results of the life-cycle assessment showed that the recycling of coffee grounds did in fact reduce the carbon footprint of the farm, however, the amount that was offset was small in comparison to the emissions from other activities during the cultivation process. The CO2 kilogram equivalent generated per kilogram of mushroom was similar to other industrial mushroom farms, and the study recommended that further optimization for this value could be better achieved through system optimization (e.g., cleaning to reduce contamination) rather than further implementation of CE concepts. The authors did recognize the methodological limitations of this study prevented the other elements of environmental and social sustainability to be more deeply evaluated.

This thesis builds on the body of literature that analyzes the social dimensions of CE and explores whether the potential contradiction of resource efficiency can be justified to make urban agriculture a valid approach to CE operationalization and the design of circular cities. This work.is the culmination of 3.5 years of personal “real-world” experience in founding a green start-up in the field of urban agriculture. Throughout this professional experience, two questions continually come into question: “how can we create a profitable company by generating the least number of negative externalities?” and “how much of our operations are circular for the sake of being circular?” The first question is fundamental to any environmentally themed debate, and arguably central to the current SD paradigm. For a start-up focussed on economic growth, it needs to be addressed in order not to lose track of other dimensions of sustainability. The second question is inspired from a recent title of a published review paper that critically analyzes the current state of the art in measuring and evaluating the progress and impact of implementing a circular society (Harris, Martin and Diener, 2021). For myself, it means critically analyzing my business to understand to what extent CE is a tool for meaningful, resource-saving operations, and to what extent it is a technique for simply marketing and corporate greenwashing.

To answer these questions is beyond the scope of this thesis, however, they may provide some framing to thoroughly examine how a small urban agriculture business may operate and grow in a responsible, resource efficient and profitable manner. The overarching research question that this work aims to answer is: how can an urban agriculture business model be compatible with CE frameworks beyond a purely resource-saving strategy? To attempt to answer this question, this thesis will “unpack” urban agriculture to resolve some of the values and contradictions within the current discourse of the topic to see which activities may support the implementation of a CE.

1.1 Objectives

This thesis will discuss and debate how modern urban agriculture contributes to the concept of CE. Previous studies have attempted to quantify aspects of CE through LCAs and several types of circularity indicators (Linder, Sarasini and Loon, 2017; Corona *et al.*, 2020), and these methods have been applied to other urban agriculture operations (Dorr *et al.*, 2021); however, the current methods to quantity the benefits of CE are limited and can not adequately incorporate environmental or social dimensions.

The overarching research question that this work aims to answer is: how can an urban agriculture business model be compatible with holistic CE frameworks? To attempt to answer this question, this thesis will “unpack” urban agriculture to settle some of the principles and contradictions within the current understanding of the topic to see which activities may support the implementation of a CE.

The first objective of this thesis will seek to unpack the greater socio economic and technical contributions of an urban agriculture business model, while debating some of the contradictions within field. I will attempt to conceptualize how urban agriculture may contribute to a sustainable and resilient urban food systems economically, ecologically socially and spatially.

The second objective of this thesis is to determine how these impacts may enable the operationalization of a CE. I will attempt to create causal links between the socio-economic contributions of urban agriculture operations and four CE “building blocks” outlined by the Ellen MacArthur Foundation.

This study will primarily use my personally founded, Cologne-based urban mushroom farm, Pilzling, as a case study. Pilzling was founded with the primary goal of cultivating mushrooms on spent coffee grounds and other biological waste materials, and with the aim of incorporating CE techniques into the operation wherever possible. While obviously the use of my own enterprise introduces many dimensions of bias (discussed in more detail below), this case study provides a unique inside-perspective in how a small, environmentally motivated business operates, and how it aims to pursue a circular business model.

2 Background & Conceptual Framework

This chapter is divided into four sections, in which I summarize the scientific state of the art within both the CE and urban agriculture literature, as well as provide a usable framework for how this research can be applied to the case study.

Within section 2.1 “Circular Economy”, my goal is to arrive at a definition for CE that is usable for this thesis. I will describe the concepts of a waste hierarchy, a systems perspective, and the multi-dimensionality of CE.

Section 2.2 “Operationalization of a Circular Economy” begins with three questions that aim to understand the key steps to implement CE, how CE can be measured, monitored and evaluated, and the limitations of the CE concept.

The third section, 2.3 “Urban Agriculture”, will give a general overview of the term as well as an overview of how urban agriculture can fit within frameworks for sustainable urban food systems. The final sub-section explores the case of urban mushroom farming, which will be used to compare to the main case study of this thesis.

Finally, section 2.4 provides a “takeaway” in the form of the conceptual framework to be used for this thesis.

2.1 Circular Economy

Much work has been completed in recent years in the field of CE to try and establish a common definition for the term as well as methods to measure circularity, but a clear agreed upon scientific framework has not yet been established (Haas *et al.*, 2015; Kirchherr, Reike and Hekkert, 2017; Ferreira and Fuso-Nerini, 2019; Llorente-González and Vence, 2019; Harris, Martin and Diener, 2021). My goal throughout this section is to

While CE still lacks any specific scientific framework, the concept continues to be of interest to politicians, businesses and research institutions, especially within the last decade in the EU (Mayer *et al.*, 2018; Llorente-González and Vence, 2019; Corona *et al.*, 2020). However, it is exactly this widespread deployment of the term by countless stakeholders and in different professional fields that has led to its blurred definition and understanding (Kirchherr, Reike and Hekkert, 2017). This blurriness and inability to pin down exactly its meaning is often one of the main criticisms against the concept (Corona *et al.*, 2020). As well, much of the literature aims to promote the framework, rather than to debate it critically (Valenzuela and Böhm, 2017; Llorente-González and Vence, 2019).

In its most fundamental state, the definition of a CE is a system that incorporates strategies that reduce the material and energy inputs and outputs of a system. In their 2017 review paper, Kirchherr et al. argued that the CE concept usually encompasses two main core principles: firstly, the system of practices that replace the end-of-life concept, namely through the 4R principles (reduce, reuse, and recycle, recover,); and secondly, a systems perspective that link CE to a specific societal perspective (micro, meso, macro).

As a concept, CE incorporates many different terms and ideas from other approaches, such as “cradle-to-cradle design”, “industrial ecology”, “life cycle thinking” and “Eco-design” (Merli, Preziosi and Acampora, 2018). As well, CE often intertwines with many aspects of Green Economy and Bio Economy. While they all address the use of natural resources, energy and emissions, CE and Bio Economy are generally more resource focussed while Green Economy is centered on natural processes (D’Amato *et al.*, 2017). They are limited in their ability to address all aspects of SD (Corona *et al.*, 2020), and none fundamentally question the paradigm of economic growth (Valenzuela and Böhm, 2017). Compared to the other concepts, it appears CE focusses more on processes of urbanization and industrial processes.

One of the more profound and widely cited definitions of CE is from the Ellen MacArthur Foundation:

> *“[CE is] an industrial system that is restorative or regenerative by intention and design. It replaces the ‘end-of-life’ concept with restoration, shifts towards the use of renewable energy, eliminates the use of toxic chemicals, which impair reuse, and aims for the elimination of waste through the superior design of materials, products, systems, and, within this, business models.” (Ellen Macarthur Foundation, 2013)*

This definition is used to design their circular framework, which aims to divide resources into biological nutrients and technical nutrients (Figure 2). The meaning of the term’s “restorative” or “regenerative” capabilities within the context of resource use have come into question. It is worth discussing whether these terms adequately describe the core principles of what CE aims to achieve, and if the interchangeable use of these terms may mislead some readers (Morseletto, 2020). In Morseletto’s work, he states that restoration has a more meaningful definition that relates to CE principles, but contrastingly, regeneration has a more appropriate meaning when applied to regenerative agriculture and should therefore be considered a more evocative/symbolic term with little practical application to CE.

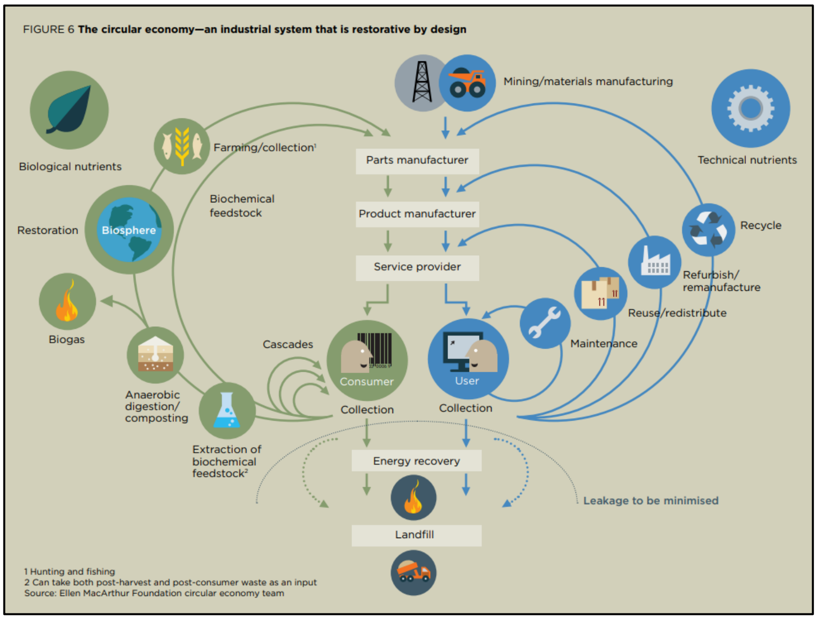

Figure 2: Circular Economy framework from the Ellen MacArthur Foundation (Source: Ellen Macarthur Foundation, 2013)

Most definitions, particularly those published prior to 2017, use a mono-dimensional conceptualization of CE that highlights prosperity through the minimization of resource use without limiting economic growth (Lieder and Rashid, 2016). This use of CE as an economic strategy still dominates the literature with 32% of papers focussing solely on the single dimension (Calzolari, Genovese and Brint, 2022), yet many researchers would argue that if CE is to be realized as an actual strategy for SD, the definition, understanding, and implementation needs to move beyond its use purely as an economic motor. Accordingly, one of the biggest ongoing discussions within the CE community is the ongoing efforts to bridge the concept from one that revolves around optimizing resource flows for economic gains, to more one that achieves more holistic trans-disciplinary goals such as SD or contribution to environmental quality (Kirchherr, Reike and Hekkert, 2017).

In their review, Kirchherr et al. found that only 13% of CE definitions referred to all dimensions of sustainability (this has increased slightly in recent years, with a more recent review by Calzolari et al. stating 15% addressed all three dimensions). Furthermore, only 3 out of the 114 analyzed definitions stated a systems perspective of CE in addition to the aim of achieving SD. The authors of the review state that the abundance of definitions makes up a sort of "circular economy babble" – one that muddles the understanding of the concept and even disrupts the momentum in its implementation. They state that despite making up most literature, subverted definitions that are incomplete or lacking comprehensiveness should be differentiated.

Implementations of CE using a subverted definition is problematic, ultimately leading to the CE concept as being yet another green buzzword (Llorente-González and Vence, 2019; Kębłowski, Lambert and Bassens, 2020).

To counter this trend, Kirchherr et al. recommend a new definition that explicitly incorporates all dimensions of SD (i.e., economic, environmental, social) into the concept:

> *“CE an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro-level (products, companies, consumers), meso-level (eco-industrial parks) and macro-level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers.”*

This definition has also been accepted and embraced by other researchers in the field of CE because it not only describes a waste hierarchy, but links CE concepts directly with the ultimate goals of SD (Giampietro, 2019; Corona *et al.*, 2020).

> *“(…) CE is seen a priori as an expression of sustainability and defining the relations would be like investigating an apple to ensure it is indeed coming from an apple tree. A more important question concerns the manner in which we can ensure that CE, in all of its diverse ways, does indeed contribute to sustainable development (…)” (Velenturf and Purnell, 2021)*

The above statement outlines the shared roots of CE and SD, thus proposing the debate should no longer be about linking the two concepts, but rather ensuring the two frameworks converge with common goals.

2.1.1 Waste Hierarchy & R-Principles

Within the CE framework, the concept of a so-called “waste hierarchy” is established. This hierarchy is a list of ordered priorities that should be considered when designing out waste (Kirchherr, Reike and Hekkert, 2017) Commonly the waste hierarchy is referred to as the 3R (reduce, reuse, recycle), however there have been additional iterations that have been developed such as the 6R or 9R principles (Corona *et al.*, 2020). Essentially, the hierarchy implies that certain processes, such as *Reducing* or

Refusing should be prioritized over more energy and material consuming processes such as *recycling.*

These principles are fundamental to the CE concept, since they can be applied to all societal levels, and over the whole lifecycle of production, consumption and return of resources (Prieto-Sandoval, Jaca and Ormazabal, 2017).

2.1.2 Systems Perspective – Levels of Scale

2.1.2.1 Macro-Level

At a macro-level, activities are considered at a global, country and city level, and the focus for a CE approach is on material flows and mass flow analyses and activities that promote a recycling oriented economy (Merli, Preziosi and Acampora, 2018; Harris, Martin and Diener, 2021). Attempts have been made to develop CE monitoring and performance evaluation frameworks at a macro scale, but first establishing a CE definition, indicator set, and baseline data set is crucial for regional implementation of CE techniques (Tanzer and Rechberger, 2019; Škrinjarí, 2020). The monitoring frameworks that do exist at a macro-level often neglect some of the more complex entities such as energy, land and water use, greenhouse gas emissions, ecological footprints, product lifespan, institutional and socioeconomic impacts of the shift toward CE, or the implications of activities related to eco-design, reuse, and collaborative consumption (Llorente-González and Vence, 2019).

Cities are considered at a macro-level, however, due to the more human-scale connections that cities have, CE within the city context begins to incorporate more aspects of ecological and social sustainability (Mayer *et al.*, 2018). A CE is especially pertinent at the city level, since many resource flows converge within the city borders in amounts worth utilizing.

2.1.2.2 Meso-Level

The meso-level describes an inter-firm or supply chain level, within geographic proximity, such as eco-industrial parks. One of the main strategies for creating circularity within this level is through techniques of industrial symbiosis, which links various industries through the exchange of materials, energy or services with the intention of achieving an economic and competitive advantage in an environmentally and socially sustainable manner (Kirchherr, Reike and Hekkert, 2017; Merli, Preziosi and Acampora, 2018; Genc *et al.*, 2019). Waste flows provide a prime instance of the interlinkages at the meso-scale. This includes examples of waste heat utilization, waste-to-energy, and waste-to-fertilizer scenarios. By coupling industrial activities in industrial parks, on-site energy production (i.e., installation of renewable energy systems) and energy required for the remediation of hazardous emissions (i.e., waste waster treatment, air filtration, waste collection) can be made more efficient through centralized processes.

2.1.2.3 Micro-Level

The micro-level of the CE concept typically looks at products, individual firms, and consumers. Within this level strategies for businesses to increase their circularity (i.e., development of circular business models, manufacturing of circular products, etc.), as well as for how to engage and educate consumers are commonly examined. An integrated and robust CE concept at a micro-level is critical for a meaningful realization of the concept because it incorporates the interaction between people and resources.

2.1.3 Multi-dimensionality of Circular Economy

The perspectives of sustainability have evolved from the threefold perspective in which the economy, society, and the environment are considered equally important to understanding the economy as the organization of society, with both dependent on the environment or to viewing the economy as a tool for managing resources to maintain or improve social well-being, environmental quality, and economic prosperity (Velenturf and Purnell, 2021) (Figure 3). Society constitutes an open system embedded in the biophysical environment to enable the sustainable coexistence of the two through two-way material flows, however, it is often at the interface and interaction of these dimensions where many of our current sustainability challenges arise. Our current rates of extraction providing primary natural resources for our organized economy to meet our personal needs as a society has upset the system enough to threaten our future existence (Komiyama and Takeuchi, 2006).

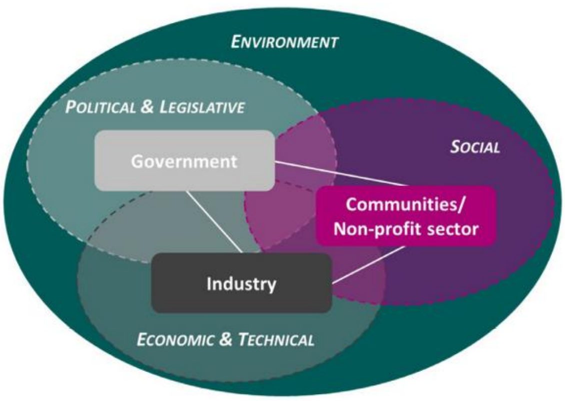

Figure 3: Model of societal embeddedness within the environmental boundaries (Source: Velenturf and Purnell, 2021)

Society is an open system embedded in the biophysical environment for their mutual sustainable co-existence. Reciprocal flows of materials both extract from and add value to natural capital, with rates of resource extraction and return to environment lower than the regenerative and absorptive capacity of the Earth." (Velenturf and Purnell, 2021) Humans are inextricably linked to nature through our very being, with and the natural resources that are consumed for our nourishment, shelter and well-being, and therefore, reshaping material flows in a CE fashion would undoubtably have an affect on our social dimension. Social aspects are important in the CE because they can provide an insight into how policies and actions impact or benefit society, and social aspects can contribute to a better understanding and monitoring efforts of the CE.

As stated in section 2.1, social and ecological aspects of CE are underrepresented when compared to the economic dimension (Marin and De Meulder, 2018). The most cited socio-economic aspects related to CE in are those related to employment; however, whether these job-related contributions are deemed as positives is still controversial. Through a systematic and thorough implementation of CE, it is estimated that 170,000 jobs could be created by 2035 in the EU (Ferreira and Fuso-Nerini, 2019). However, it is crucial to understand what kind of jobs are being created. There may be a desire among individuals to participate in a workplace that conducts value-retaining activities, but often the jobs created within the repair, reuse and recycling industries are often labour intensive, low wage and have poor health conditions (Llorente-González and Vence, 2019). Therefore, to claim that the jobs that CE create contribute to the general wellness of society, they would need to be better than the average of those in the rest of the economy.

However, to fully represent the CE concept, as defined in the introduction of this chapter, other others have argued that other social issues are also relevant, such as eradicating poverty, food security, gender equity and social wellbeing (Corona *et al.*, 2020). These issues should be included to aid in understanding any the negative externalities that may be created by moving to a CE (Padilla-Rivera, Russo-Garrido and Merveille, 2020).

2.1.3.1 Circular Economy & Urban Metabolism

The manner in which CE processes and urban resources interact with the society can be better understood through the theory of urban metabolism, which originates from Wohlman's 1965 calculations for the energy-material demands of a hypothetical U.S. city. In a way, these flows can be imagined in a biological manner by which they provide the metabolic energy needed for a city-system to "survive." While the biological metaphor of urban metabolism has faded in popularity over time, the term itself has persisted, and urban metabolism today acts as a basis for MFAs in an industrial ecology perspective, or as a conceptual model for understanding how the repeated interactions between natural resources, humans and society shapes our reality. By using an urban metabolic view of CE, it can illustrate how characteristics of social dimension interact and change resource use patterns.

While cities are often defined by their relationship between populations and space, the patterns of behaviour inside the space are often more characteristic and distinguish cities from each other. They can be characterized by such things as social or political structures, composition and function of households, roles of women, the relative importance of residential communities compared to workplaces, and so forth (Atkinson, 1995). In a way, the sum of all other characteristics is the urban metabolism of a city. The urban metabolism of a city not only characterizes the internal mechanisms of the city, but also places it within the context of our globalized network of cities.

The reason cities are at the forefront of metabolism is that act essentially as the nodes within a global system through which flows travel. Flows are the inputs, outputs and sinks of any urban/rural system. This definition would include more traditional inputs and outputs such as materials and services, or other types such as capital (financial, human), or content (information, media) (Segbers, 2011). Furthermore, cities don’t just act as a geographical network, but also change the flows themselves. For example, stock markets transform capital from one form to another in the re-investing process, and industrial processes can change raw materials into final products through added-value processing.

While the biological model of metabolism, such as an ecosystem, works well to conceptualize flows, one of its biggest shortcomings is the danger of stretching the biological analogy too far, as it fails to incorporate the complex and unpredictable nature of humans. The biological urban metabolism model may portray social structures (and the disparities within these structures) as natural law, when that certainly is not the case. One of the difficulties of the biological model is that no metabolic processes incorporate the diversity or conflict of a city arising out of the cultural, religious or linguistic differences within a population.

But though it is important to note the shortcomings of this metaphor, the term ‘urban metabolism’ has prevailed, with many authors opting for a more interdisciplinary definition, one in which human activities play an integral part in the metabolic processes. An interdisciplinary definition of urban metabolism can be based on three main concepts: changes in flows are result of how we choose to interact with them;

individual actions lead to aggregate results; and there is potential to change to sustainable patterns of consumption and production.

The first concept is based on the idea that flows and stocks are affected directly by activities by humans, which are contolled by a number of other components in a system. The activities can be simple such as purchases made, or wastes produced, but they can also be more intricate such as large decisions on where to build industrial facilities or where which companies to invest in. These activities are controlled by so-called “needs.” Needs can be biological, such as the need to drink water and eat food, or more complex and socially constructed such as the need for a car to drive to work. At the same time, the activities are controlled by facilitators and constraints. Facililitators act to make activities easier (ex. Cheaper prices, abundance of a certain good, cultural acceptance, etc.) and constraints act in opposition to make certain activities more difficult to accomplish (ex. High prices, limitations on a certain good, taboos, etc.). These needs, facilitators, and constraints are bound and controlled by much larger societal drivers. Societal drivers can be based on geographic locations, cultural beliefs, global fluctuations in markets, or a myriad of other phenomenon.

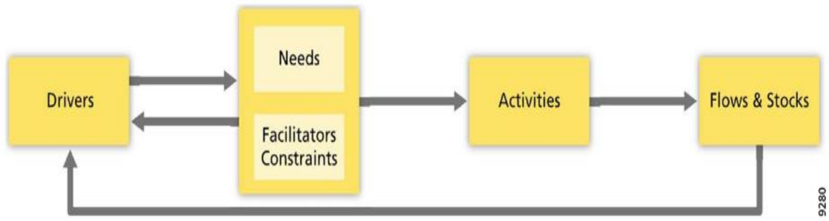

Figure 4: The inter-relations between the elements of urban metabolism (Source: Dijst et al., 2018)

However, because of the circular nature of these interactions, certain feedback style systems may emerge creating widespread societal norms and therefore demonstrating the second concept of this system. When one actitivity influences the flows or the stocks of a system, this influence is diverted back to the drivers of the system.

The third concept of this system is that change to sustainable consumption and production is possible since the mechanism by which the different components interact is not truly circular in nature. How the different components of the system interact with each other is complicated, and impossible to fully illustrate, and the degree to which the components can influence other components is constantly evolving. As well, the drivers of the system might not exclusively influence the needs, facilitators and constraints of the system, but as well as human behaviour, and the flows and stocks directly. Figure 5 tries to illustrate that idea, and the notion that certain drivers may affect some components of the system more or less than other components. As well, different types of flows such as material and energy may interact directly with each other. It also shows an additional ‘xy’ component that symbolizes external drivers such as economic or cultural shifts.

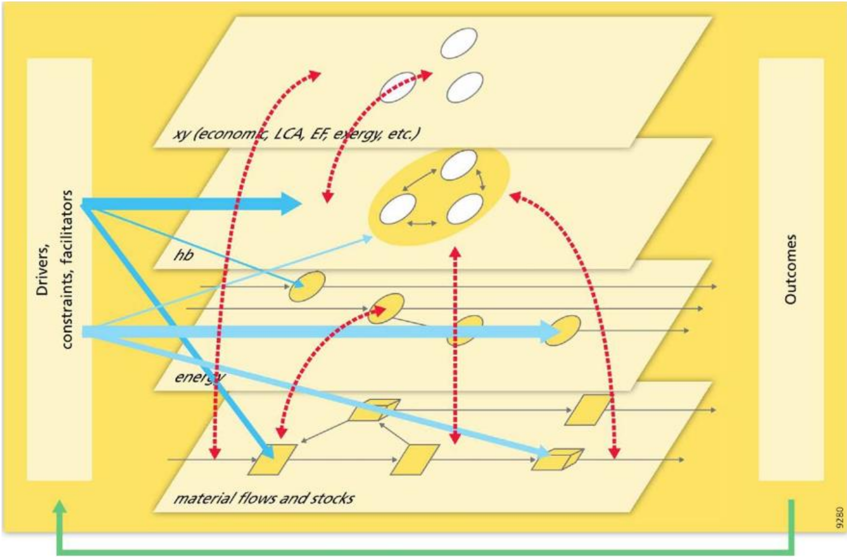

Figure 5: Interdisciplinary perspective of urban metabolism (Source: Dijst et al., 2018)

2.2 Operationalization of a Circular Economy

The uptick in academic literature on CE in recent years has come with an increase in a wide array practitioners and policy makers attempting to implement aspects of the CE to fit their present needs and plan for future scenarios (Harris, Martin and Diener, 2021). However, the implementation and transition to a CE has generated several questions of debate. Firstly, what are the key steps needed to operationalize CE, and how do these steps differ between different societal scales? This means deciding which CE strategies to prioritize and at which scale to initiate the CE transition, as well as identifying and supporting key enablers that aid in the self-propagation of the concept. Secondly, how can the transition to CE be measured, monitored, and properly evaluated? This question carries on from the initial debate on how to properly define the concept to begin with. And thirdly, to what extent is the CE concept another green buzzword in contrast to a realistic step that contributes to SD?

The steps needed to bring CE into conception and widespread use will depend greatly on the societal level and regional contexts. With such a blurred and continually debated definition, system practitioners and policy makers will have to navigate the process of implementation while academic work is simultaneously completed to define and critique the conceptual and scientific framework. Whether CE truly becomes implemented and operationalized in a meaningful manner will depend on the success of how well these two parties collaborate to bring the term forward.

Much of the work that has already been done to begin the implementation process uses CE as a tool on how to be more sustainable while also achieving economic efficiency. Compared to “sustainable development”, which is often too impossibly vague for implementation, CE represents a more operational concept. This is important for cities and companies trying to design holistic strategies for sustainability; instead of aiming for a theoretical dream scenario, they can begin with an implementable tool. While still blurry in its definition, CE as an instrument or a tool may prove to be just operational enough for these businesses and cities to begin implementation.

Nevertheless, some argue that CE should not be used as a tool, but remain as a model for resource efficient cities:

> *“CE is the “what” – the result to be achieved (the desirable outcome capable of decoupling the use of resources from natural resources), whereas, bioeconomy is the “how” (what type of biophysical processes should be enhanced to achieve the expected result)." (John et al., 2019)*

While this school of thought exists, this thesis will adhere to the more common opinion within the field that the CE and bioeconomy concepts are discrete, and rather CE should be addressed differently throughout the scales of our socioeconomic system, with the ultimate goal of the concept to minimize waste and promote social ecological sustainability among within all sectors.

2.2.1 Circular Economy “Building Blocks”

The 2013 Ellen MacArthur Foundation report was one of the first that offered an economic roadmap on how resource efficient business models can be implemented to not only achieve economic benefits for companies, but as a way of unlocking larger societal changes that allow us to make progress towards more sustainable cities and attempt to stay within our planetary boundaries.

The report begins by first examining the limits of classic linear consumption. At a global level, resource extraction has increased dramatically in recent years, from 40 billion tonnes per year in 1980 to an estimated 82 billion tonnes in 2020. The linear consumption model creates enormous amounts of waste both in the production chain and at the product end-of-life, all while consuming large sums of energy and eroding ecosystem services. While the impacts of this consumption model connected to waste generation, energy consumption and ecosystem erosion are multitudinal and incalculable, the report proposes a more tangible approach to comprehending the limitations of linear consumption. It outlines the increasing scarcity in resources, the high commodity price volatility, as well as the inefficiencies related to linear consumption. The authors claim that because of current global trends in demographics, politics, international markets, and climate, linear consumption models are not economically compatible as we transition to a greener economy.

To therefore transition away from the linear consumption model, they propose a list of four key “building blocks” that are needed:

1) New skills are required in designing and producing products that are built to last, incorporate modularisation and standardisation, easy to disassemble, produced with efficiency and with materials that are appropriate for circular systems (able to be recycled).
2) Business models need to be developed that shift “consumers” to “users” and the products consumed become services and compete on performance.
3) Innovations in reversing the cycles need to occur that make waste collection easy, cost-effective and quality-preserving, and optimize the processes related to material treatment or extraction.
4) The transition is dependent on an outside field of “enablers” that support the early change. These enablers include cross-sector collaboration, favourable investment climate, shifts in legal framework and education.

2.2.2 Implementation of Circular Economy

CE studies essentially follow two lines of action: the first aims to change the social and economic dynamics at the macro-level (top-down approach), and the second aims at supporting companies in the implementation of circular processes at the more micro-level (bottom-up approach) (Merli, Preziosi and Acampora, 2018).

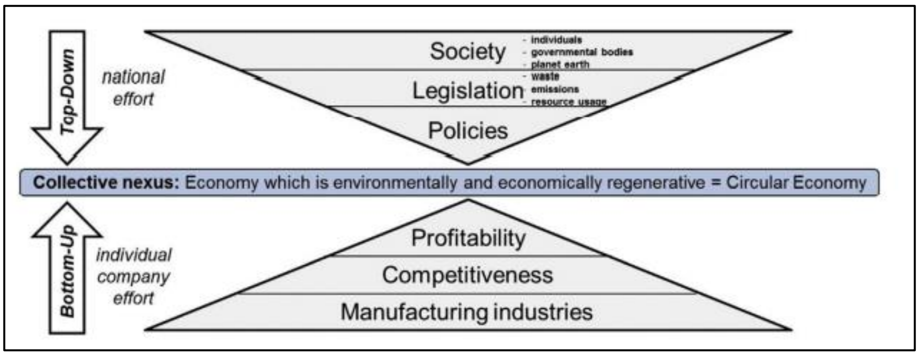

Figure 6: Approaches to circular economy implementations (Source: Merli, Preziosi and Acampora, 2018)

To implement a CE paradigm switch, implementation will have to be considered in both a top-down and bottom-up approach (Lieder and Rashid, 2016)

2.2.2.1 Top-Down Approach

In 2015 the European Commission declared a more focussed CE strategy to aid in the transition from an economy based on “take-make-consume and dispose” to one centered on recycling and reuse (Llorente-González and Vence, 2019). This strategy aims to contribute to the EU’s push for a low-carbon, sustainable and competitive economy by reducing waste and prolonging the value of resources, materials and products for as long as possible (Mayer *et al.*, 2018).

While the EU has stringent regulations on waste management, elaborate systems to collect and recover materials and is often seen as a global forerunner in the transition to more resource efficient economy, the rates of resource cycling remain low. In 2014, over 90% of materials originated from primary resources. This is despite high material recover rates (ex. 25% biomass and 70% metal), meaning these recovered materials don’t often end up cycling back into use (Mayer *et al.*, 2018). And while considering all materials including biological waste, the rates for the EU are only slightly higher than those of the global average (6%) (Haas *et al.*, 2015). The 2020 study by Škrinjarí ranked Germany as one of the top EU-performers for the implementation of CE, largely attributed to it’s waste handling capabilities and recycling capacity and number of patents related to technologies in this sector. Nevertheless, Germany ranked 6th in circular material use rate. Qualities shared among the highest performing CE countries are a high GDP p.c., well developed infrastructure, education and dedicated R&D to CE-topics (Škrinjarí, 2020).

Several major barriers to increasing socioeconomic cycling at a macro-level have been identified. Firstly, the use of fossil fuels in product processing represents a large portion of the total inputs for the mass-flow. These non-renewable resources are inherently noncircular and must be replaced by renewable energy resources. Secondly, the increase in in-use material stocks (i.e., building and construction materials) delays the inevitable fate of demolition and disposal for these materials. To therefore lower these waste flows, improved product design that aids in disassembly and recycling is necessary. Additionally, recovery rates within the ecological cycling of materials are lower than other materials (Škrinjarí, 2020). Therefore, strategies must focus less on simply substituting biomass materials, and instead more on reducing waste and ecological efficiency. This means designing systems that harbour material cycling and cascadic systems where outputs from one process acts as an input for another.

Many countries within the European Union have set a sustainability targets for the coming decades (e.g. carbon neutrality), and there are many European cities within these countries that have that have developed plans to accelerate these timelines (Paiho *et al.*, 2020). Municipal governments are drafting policies to align the developments of neighbourhoods and industrial sectors with concepts of CE (Marin and De Meulder, 2018; Ferreira and Fuso-Nerini, 2019; Gravagnuolo, Angrisano and Girard, 2019; Kębłowski, Lambert and Bassens, 2020; Paiho *et al.*, 2020).Designing cities to be circular is certainly of importance, considering that 68% of the global population will be living in urban areas by 2050 (United Nations, 2018b) and already 70% of global carbon emissions are related to urban activities (Paiho *et al.*, 2020). Integrative strategies for circular cities are therefore critical in achieving some of our larger sustainability goals.

Cities are generally the worldwide nodes on which resources flow and are mainly studied at a macro-level system, however, their design and the way these resource flows begin to interact with society at a human-scale begins to incorporate more dimensions of ecological and social metabolism (Tanzer and Rechberger, 2019) In some ways, cities act as the interface between top-down and bottom up strategies (Mayer *et al.*, 2018). The European Investment Bank (2018) states that cities can be a cradle and catalyst for the implementation of CE for the following reasons:

1) They have density and scale of citizens, businesses, and resource flows
2) They can connect stakeholders and promote a culture of collaboration
3) They can lead by example and offer/procure circular solutions and services
4) They have autonomy to regulate and incentivize
5) They can define and communicate visions and strategies
6) They can embed circular principles in city infrastructure and services

In a recent definition from the Ellen McArthur Foundation (Ellen Macarthur Foundation, 2022), circular cities are not just places where economic resource efficiency is achieved, but it should strive to improve both liveability and the resilience for its citizens:

> *"[A Circular City] embeds the principles of a CE across all its functions, establishing an urban system that is regenerative, accessible and abundant by design. These cities aim to eliminate the concept of waste, keep assets at their highest value at all times, and are enabled by digital technology. A circular city seeks to generate prosperity, increase liveability, and improve resilience for the city and its citizens, while*

aiming to decouple the creation of value from the consumption of finite resources."

To therefore begin conceptualizing a circular city, there must be some common framework as to what features a circular city should exhibit. The European Investment Bank summarizes eight core aspects that should be considered for a circular city in Figure 7. A framework such as this includes a diverse set of processes and infrastructure, and important for this thesis is that urban farms are included as a vital part of the urban bioeconomy.

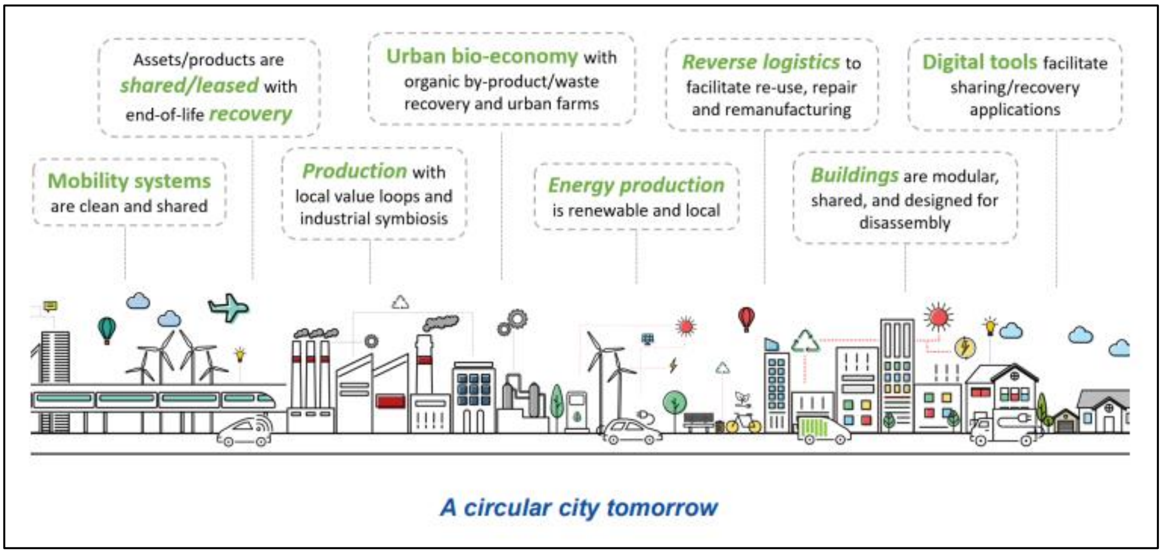

Figure 7: Core aspects of a circular city to be considered when using a top-down approach (Source: European Investment Bank, 2018)

The implementation and transition towards a CE can be interpreted as a series of niche technologies and processes that slowly integrate into the standard regime. In the example figure, urban food production is one of the proposed niches, and to successfully operationalize it to a city level, it will involve changes and adaptations in policy, social values and physical infrastructure (Figure 8).

Creating social innovations that enable community engagement, expanded public education, and more media coverage are imperative to the success of any initiative that adopts CE concepts (Winans, Kendall and Deng, 2017). Without knowledge resources, stakeholders either do not know how to respond to recycling pressures or use tactics that do not effectively reduce their waste. Successful implementation of the CE concept also requires that stakeholders have a clear understanding of the potential economic benefits, social inequities, waste reduction, reduced environmental impact, and reuse of materials.

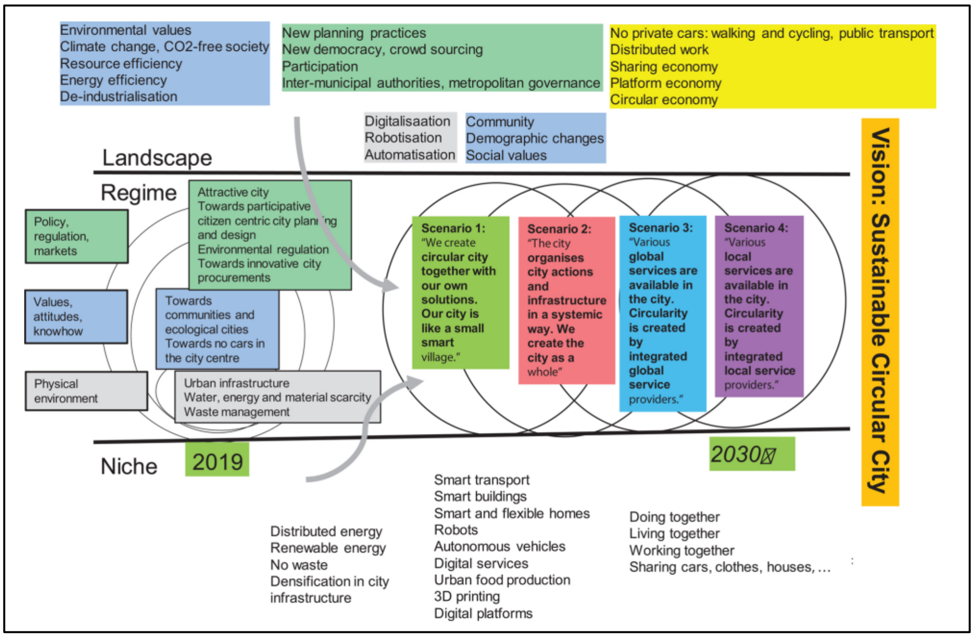

Figure 8: A process of transition toward a sustainable circular city with different operational pathways (Source: Paiho *et al.*, 2020)

2.2.2.2 Bottom-Up Approach

In recent years, there has been a huge voluntary interest from companies who see potential in the concept, mainly due to two main reasons: Firstly, the economic benefits can be achieved through efficient production methods that reduce use of expensive virgin materials and energy, and secondly, innovations in CE can be one element in broader corporate social responsibility and sustainability efforts (Horbach and Rammer, 2020). Companies that adopted CE innovations between 2012 and 2014 experienced significantly higher sales, employment growth, and financial performance than other companies in their sector in the subsequent 2014-2016 period (Horbach and Rammer, 2020).

Since companies are usually vested in specific production methods and business models, those wishing to employ CE strategies need to assess the practicality of the initiatives before investing in the change. Firms may consider using SWOT analyses as a valuable tool to determine whether CE concepts represent an economical option (Winans, Kendall and Deng, 2017).

The link between companies that utilize industry 4.0 technology (e.g. cyber-physical systems, IoT, cloud computing, etc.) and their contribution to CE has also been studied (Luthra *et al.*, 2021). Marchi and Maria (2020) found that these technologies have the possibility to "shape manufacturing processes and push forward the possibility to develop smart factories and smart products, enhancing efficiency and better control within the factory and the entire value chain." The investment in these technologies also promote a robust intra-firm network and company-customer network, which facilitates knowledge generation and sharing both at a process and product level. They found that the gathering of information along the value chain allowed firms to make sound decisions on how to implement CE strategies. These industry 4.0 technologies also enhance product traceability which is critical for ensuring responsible handling of the materials pre- and post-consumption.

“Encouraging and implementing harmonized simple product alternatives to better facilitate recycling Progress can focus on select aspects (e.g., material substitution) in the short term, with others (e.g., changing the overall design and form) being long-term goals” (Jacobs *et al.*, 2022)

“Materials recycling facilities (MRFs) have faced multiple operational challenges, including:

- Identifying which materials are recyclable;
- Separating materials from one another;
- Ensuring purity and avoiding contamination that could degrade the value of recovered materials;
- Establishing or transporting to markets that could purchase recovered materials

Such challenges tend to increase as products become more intricate or durable in design and production; contain multiple materials, particularly if some are hazardous; or consist of components that are intimately joined together.” (Jacobs *et al.*, 2022)

2.2.3 The Circular Business Model Canvas

One of the most fundamental instruments for the bottom-up implementation of a CE is through the implementation of a circular business model, and in the last several years, several business model frameworks have been designed and published to help companies plan their operations and integrate green practices to increase their sustainability (Antikainen, Valkokari and Mcclelland, 2016; Lewandowski, 2016; Circulab, 2019; Pieroni *et al.*, 2020). Instead of concentrating solely on creating economic value, the sustainable business model innovation concentrates on creating value for a broader range of stakeholders and takes into consideration the benefits from societal and environmental perspectives (Antikainen, Valkokari and Mcclelland, 2016). Many of these frameworks follow a similar canvas design, with a range of blocks that breakdown the activities and goals of a company into easy-to-digest packets for early-stage company planning. The planning blocks of each canvas overlap somewhat when discussing key elements related to customers, product or value proposition, activities, and resources. Some explicitly incorporate sustainability aspects into the canvas design and others even begin organizing these sustainability concepts into a CE style design (Lauten-Weiss and Ramesohl, 2021).

Circular Business Model	**Description**
“On-Demand”	Producing a product or providing a service only when consumer demand has been quantified and confirmed
“Dematerialization”	Replacing physical infrastructure and assets with digital/virtual services
“Product Life Cycle Extension/Reuse”	New products are designed to be durable for a long lifetime. Design improvements might be needed to also facilitate easier repair, particularly by third parties
“Recovery of Secondary Raw Materials/By-Products”	Value optimization by creating products from secondary raw materials/by-products and recycling, whether open or closed loop
“Product as a Service (“PaaS”)	Company delivers product performance or defined results rather than the product or service itself.
“Sharing Economy and Collaborative Consumption”	Lending or collaborative consumption amongst users, either individuals or organizations, but where some form of transactional arrangement is provided.

Table 1: Types of circular economy business models (Source: Rossi *et al.*, 2019)

In a recently published paper out of the Wuppertal Institute by Lauten-Weiss and Ramesohl, a framework for a circular business model that examines in a more abstract view how a company creates, delivers and captures value is proposed (Figure 9). The authors acknowledge that while traditional business model frameworks can be helpful, this new framework reorganizes traditional “linear” business model frameworks to fundamentally integrate three key CE principles by the Ellen MacArthur Foundation: (1) Design out waste and pollution, (2) keep products and materials in use, and (3) regenerate natural systems. To achieve this, the framework abandons a typical canvas

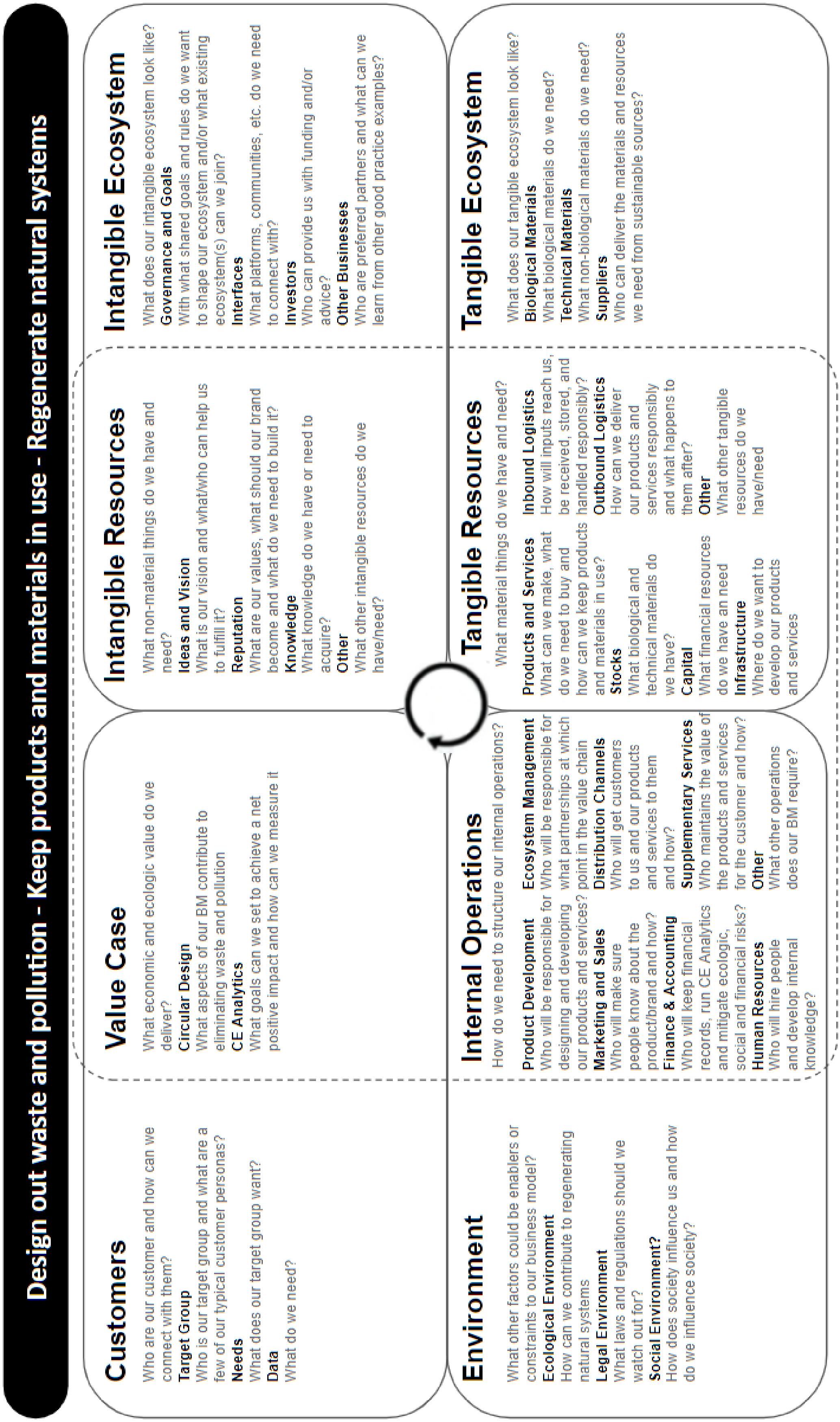

Figure 9: Circular Business Model Canvas (Source: Lauten-Weiss and Ramesohl, 2021)

layout and instead implements a circular design to its spatial format. The framework features an inner circle containing ideas, resources, and values controlled internally within the organization, and an outer circle containing external conditions that are outside direct control of the organization. The application of the framework is devised to follow a specific order, where each spatial block of the framework is to be filled out in sequence and the content of each block building upon and relating to the content of the adjacent blocks.

While the spatial fields within the framework cover many dimensions of corporate operation detailed in previous frameworks, the illustrative design and planning pattern is fashioned to fundamentally integrate circular practices, and to better explain the value proposition of a CE business model to outside actors. One interesting aspect of the framework useful for this study is the division between intangibility and tangibility both within the internal operational circle, as well as the external ecosystem circle.

2.2.4 Measuring, Monitoring and Evaluation of Circular Economy

A big topic within the CE field is the ongoing debate about how to adequately measure, monitor and evaluate the implementation of the framework. Much academic literature on the topic of circular cities has focussed on practical tools to model and measure resource flows borrowing from the studies of mass flow analyses at a macro-level (Virtanen *et al.*, 2019). By studying CE only in this matter, it confines the strategy to one that is focussed primarily on waste management and recycling.

Within the framework for circular cities by Ferreira and Fuso-Nerini, they outlined 13 city sectors that should be considered or analyzed for synergies and can be targeted for different policies and strategies. However, due to the complex nature of how these sectors interact can make measuring the impact of CE difficult.

Two tools that have seen early success in the ability to quantify circular processes have been LCAs as well as Material Circularity Indicator (MCI) studies (Corona *et al.*, 2020), however, at a project scale, these tools do not fully evaluate the environmental or social performance of circular practices (Saade *et al.*, 2022).

2.2.5 Challenges by Implementation

The evaluation of CE limited in several ways. The current indicators to evaluate circularity are based on large scale mass flow calculations using data based on imports, domestic extractions, waste processing and emissions (Corona *et al.*, 2020; Škrinjarí, 2020; Harris, Martin and Diener, 2021). Measuring circularity at micro and meso-levels are limited by both a system boundary context, but as well, a temporal boundary (Paiho *et al.*, 2020). The first limits the analysis by creating arbitrary geographic limits on what is actually considered in the circularity indicator. This can sometimes neglect critical resource consuming processes in the supply chain. The other is decides an arbitrary time frame for the production, which might ignore embedded emissions that are on very long time scales (e.g. construction materials for buildings and factories). The yielding results of these regional studies usually infer one or both of the following: i) resource efficiency within system boundaries is achieved, but not necessarily decreasing impact when expanding system boundaries or considering the entire lifecycle of the products/processes within the system (ie. the impact has been exported), and ii) regardless of what the circularity performance index indicates, the CE implementation creates some other form of social and ecological benefits (Škrinjarí, 2020).

Empirical studies that aim to compare larger regions on their CE capacity often lack the data-resolution or a measurable variable that is consistent throughout the data set. The challenge in measuring regional CE benefits through a system of empirical indicators derived from resource flows in a material flow or mass flow analysis is exactly the challenge in measuring the CE within smaller systems (i.e. product- or firm-level) that only use resource flow indicators (ie. life cycle analysis). There is no doubt that the accuracy of these statistics is constrained by the quality and coverage of reporting. Requirements and standards in reporting among EU countries vary significantly, leading to errors, discrepancies and results that are unable to be cross validated. As well, to properly evaluate and monitor the performance of CE, the scope needs to be broadened beyond rudimentary mass-flow data based on primary and secondary material use. This is critical because these larger mass-flow statistics amalgamate materials and resources, which may mask specific materials that either have a low share of the mass or have specific impacts that are of higher interest for circularity regulations. For example, plastics exert a specific environmental impact, but are often counted fossil energy carriers or critical metals.

The design of a CE concept for cities also suffers faces the same fundamental challenge as higher levels: the need for a specific definition and framework (Ferreira and Fuso-Nerini, 2019; Paiho *et al.*, 2020). Additionally, creating a CE at a city-scale is faced with numerous other challenges at an implementation scale. These challenges can be related to business operations, policy shortcomings, lack of technical problems, and gaps in knowledge (Paiho *et al.*, 2020). It's important to analyze these challenges, because in some ways they are embedded from higher levels of the societal system, but they also encompass and lock in the stakeholders and consumers that operate within the micro-levels of the system. They manifest as limitations within the business model, restrictions from policy and regulations, technical constraints, and knowledge challenges. These challenges are explained below and are summarized in Figure 10.

Businesses often come into critical consideration for their role for implementing CE, but it is important to consider the demand for secondary materials in the marketplace is low, especially when compared to the price of virgin materials that don't consider the social and ecological price of harvesting or manufacturing. As well, businesses face problems securing adequate investments for appropriate machinery or infrastructure, and some businesses may have vested interests in maintaining their current activities. Support for businesses needs to incentivize new business models, and prices for virgin materials needs to reflect costs associated with all aspects of production.

Policies and regulations remain a significant limiting factor for meaningful implementation strategies. Existing regulatory frameworks can be inflexible and stifle innovation, while political support for new projects can be difficult due to changes in governing bodies. When decisions for new policies are made, they are often fragmented and sector specific, which limits the ability to create integrated strategies. Cities need to design policies that connect and create synergies between all sectors and support stakeholders throughout the value chain.

Technical problems remain in the general production methods of companies, which lock in linearity to products, as well as the downstream recycling and waste handling of linear products. Therefore, the entire infrastructure of supply chains needs to be evaluated and designed for efficient implementation of CE.

Knowledge gaps and general lack of awareness that exist in city management, industry actors and the public may result in a barrier to CE implementation. Consumers may be hesitant to consume secondary products, use recycled materials, or switch their consumption to renting and repairing rather than buying new. Business models based off a traditional linear value chain often prevail over those that tend to incorporate circular measures, and this may be due to some business actors lacking a clear idea of how to implement CE strategies or why they are necessary. Often CE is viewed in a very strict sense of waste management, so education should focus on a more integrated approach. Information sharing is consistently cited as a barrier to the success of CE initiatives and an in-depth assessment of ongoing CE initiatives identifies barriers to a sustainable CE due to insufficient or excessive material flows, lack of transportation and infrastructure, and absence of regulations that permit resource exchange (Winans, Kendall and Deng, 2017).

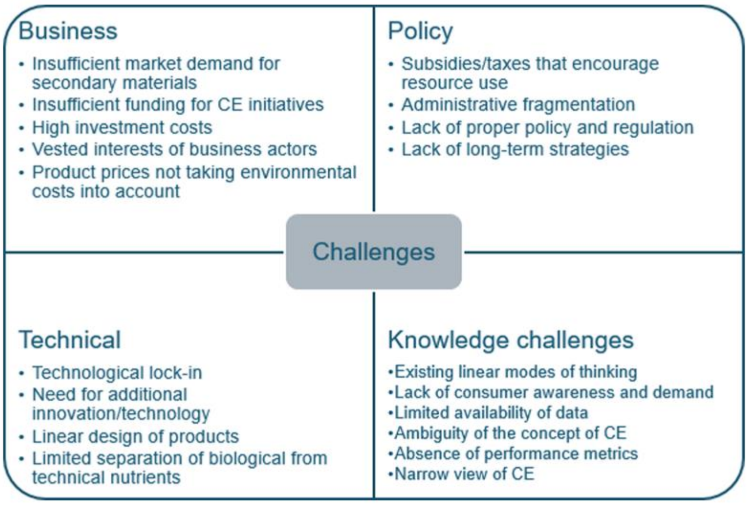

Figure 10: Summary of the challenges presented for implementing circular economy (Source: Paiho *et al.*, 2020)

Social awareness plays a critical role in a successful transition from a linear economy to a CE. The social awareness movement is underway, and educational programs, public campaigns, and seminars have grown significantly in recent years (Lieder and Rashid, 2016). This movement has so far been well supported by public institutions and is gaining gradual support from industry. Efforts to raise awareness require a change in people's mindset to focus on the performance of products and their usability, rather than thinking in terms of new or used products.

2.2.5.1 Circularity for Circularity's Sake

Urban metabolism research and the use of MFAs or LCAs have laid the foundation for understanding and optimizing how and resources enter and leave a system, as well as given insight to system complexity (John *et al.*, 2019). However, the usefulness of these studies ends directly where this new debate begins.

Closing resource loops with the intention of designing a CE may create in-system efficiency but looking beyond the system boundaries may show that the metabolic impacts have just been shifted to a new location or form (Harris, Martin and Diener, 2021; Kopnina and Padfield, 2021; Velenturf and Purnell, 2021). Nevertheless, many studies have concluded that while the impact still exists (and may or may not have increased), it may be negated by some of the positive socio-economic side-effects that a CE might bring about (Corona *et al.*, 2020; Saade *et al.*, 2022). For example,

The increase in the amount of circularity indicator systems and literature aiming to quantify circular performance at both a micro- (product or firm) and macro- (city or regional) level has given stakeholders and researchers a clearer understanding of how CE may be defined and implemented, however, some authors argue that the bounty of measurement tools and indicator systems that now exist may drive "circularity of circularity's sake" - decisions and actions based on the sole purpose of increasing the desired circularity metric, without considering the total environmental performance of the activity (Harris, Martin and Diener, 2021; Kopnina and Padfield, 2021). They describe that the belief or goal of a perfect circular system can be taken too far, and that the costs associated in pursuit of circularity can outweigh the net benefits. The authors claim that without proper framework and monitoring, the pursuit for circular products and services risks a future "*circular [green]washing*" – a marketing tool for companies based on false or inaccurate information.

Additionally, the total impact and implications among all system levels must be considered when evaluating circular performance. For example, a circular system at a micro-level may generate environmental performance and efficiencies in delivering a specific product or service, however, the system must ensure that the impacts do not simply move to a higher system level (i.e. rebound effect) to more toxic or damaging alternative along the life-cycle (i.e. burden shifting) and/or beyond the capabilities of the indicator system (i.e. "cherry picking", limited scoping) (Fratini, Georg and Jørgensen, 2019; Tanzer and Rechberger, 2019; Harris, Martin and Diener, 2021).

The 2021 review paper by Harris et al. assesses the recent literature within the field of CE to give an overview of the implications of circular products and services. The study did not aim to just review CE performance indicator and monitoring systems, but to assess the interlinkages between different societal levels. The analysis was divided into macro- (national or city), meso- (industrial estate/symbiosis), and micro- (product or service) level societal systems with four goals of understanding how environmental impacts of CE is quantified at each level, how these indicators link to environmental impact, whether the assessment methods used for different levels can be interrelated, the implications for monitoring the transition to a CE.

The findings on the linkages between circularity indicators and environmental impacts revealed that some correlation measurements at the product level have been accomplished (i.e., LCA results coupled with circularity indicators), but at higher meso- and macro-level scales, there is little to no research on the correlation between the two. This essentially means that no studies have been conducted that attempt to link circular indicators designed at scoring CE performance/transition within sectors, cities, or nations and the total environmental impact of a specific product.

For whatever reason a firm makes the decision to use a circular business model, it's important that the CE concept doesn't lose its relevancy by firms using the term without a meaningful approach (i.e., using the CE in a greenwashing fashion). To prevent this loss of relevancy, professionals in the CE industry need to develop and implement robust evaluation, scoring and monitoring indexes for companies and products. While there is some progress in this development, specific indicators for the micro-level are still at an early stage compared to the macro-level of analysis (Merli, Preziosi and Acampora, 2018). Currently, LCAs are the main tool for evaluating the environmental impact of a specific product or service (Merli, Preziosi and Acampora, 2018). Certainly, the impact of circular product can be compared to a non-circular product using LCA, but the tool fails to directly measure any aspects of circularity, and therefore some elements of social sustainability may not be accounted for. Work by Linder et al. has developed a metric for evaluating the cycles and circularity index of different product parts (Linder, Sarasini and Loon, 2017). This metric accounts for the handling/reuse/disposal of the different components at different stages in the product lifecycle.

2.3 Urban Agriculture

Urban agriculture can be briefly defined as “the growing of plants and trees and rearing of livestock within or on the fringe of cities (intra-urban and peri-urban agriculture, respectively), including related input provision, processing and marketing activities and services” (De Zeeuw, Van Veenhuizen and Dubbeling, 2011). In very few parts of the world is urban agriculture an unfamiliar phenomenon, and while, the methods and techniques differ significantly, the primary goal is the cultivation of plants or animals. Contributions by urban agriculture to total food production may be small in comparison to rural production, however, it can represent a significant source of household food security for low-income families in many parts of the world (FAO, 2020). Now, as many cities and policy makers look for strategies in creating sustainable urban food systems, urban agriculture is being examined as a possible tool for enhancing food security, resiliency, and food sovereignty (Chatterjee, Debnath and Pal, 2020).

Urban agriculture can be practiced in a wide variety of settings, including fields, vacant public land, gardens, rooftops, cellars, and barns. It may also include the implementation of modern technologies that utilize soilless farming techniques, such as hydroponics and aquaponics. These techniques allow for the abilities to regulate light intensity, temperature, and humidity, which may allow for year-round production and generally achieve higher yields per square meter compared to traditional agricultural practices (Okemwa, 2015; Pattillo, 2017). They also and have the benefit of requiring less water and fertilizer inputs due to their closed-system constructions. Nevertheless, these systems are often limited by their higher energy and initial-setup costs.

Food production in the 21st century must meet higher than ever standards and regulations, and therefore, companies wishing to pursue a business model that engages in urban agriculture activities should closely monitor and adhere to regional regulations and policies that govern this matter. Urban agriculture certainly bears some health concerns. Firstly, food grown in polluted settings bears the risk of contamination by urban pollution in air and water. As well, agricultural systems can create health hazards by introducing pests or diseases, and the application of pesticides or fertilizers can negatively affect air and water quality. Nevertheless, the policies and regulations that govern these processes are indeed in many urban regions vague, outdated or completely absent. Instead, due to processes of urbanization, food production has often been considered for many decades as a rural policy topic, and in some ways, has led to an idea that urban food production is somehow an outdated remnant of the past. Wiskerke (2020) argues that this has resulted in shortcomings in food studies, planning and policies in recognizing cities as the greatest spaces for demand, that urban food insecurity is much more an issue of availability, accessibility and affordability instead of a production failure, but also that there has been a delay in research that examines the role of urban food production as a SD strategy or the role of cities as food system innovators.

This is changing in some cities, as urban food councils and authorities have committed themselves to addressing the topics related to the promotion of healthy and resilient urban food systems.

2.3.1 Urban Food Systems of the Future

Feeding the world's 9-10 billion people in 2050 will become an immense challenge, and as the proportion of urban residents continues to rise, much of the attention from institutions and policy makers is focussed on how to feed cities. Based on the growth in agricultural production in recent years, we are on pace to being able to grow enough food by this time, however, growing enough food sustainably is another challenge (FAO, 2018). The Ellen Macarthur Foundation reports that by 2050, 80% of all food produced will be consumed in urban areas, which may create an important opportunity for cities to influence how food is grown and reduce the costs that are generated by current methods.

Currently, For every dollar spent by the consumer on food, two dollars in health, environmental and economic costs are borne by society during the production of food (Ellen Macarthur Foundation, 2019). These costs include the enormous green house gas emissions generated by industrial food production and processing, as well as health impact from polluted land, water, and air. The number of human deaths attributed to this pollution is expected to rise, with numbers eclipsing the current rate of obesity by the year 2050.

To feed our global cities sustainably, innovations must focus on low impact/resource efficient farming methods, as well as strengthening the distribution network between rural-urban areas. These optimizations to the food system need to focus not only on economic and cost efficiencies, but include the diverse dimensions of SD that cover health, social, environment, and good governance (Figure 11) (Vieira *et al.*, 2018).

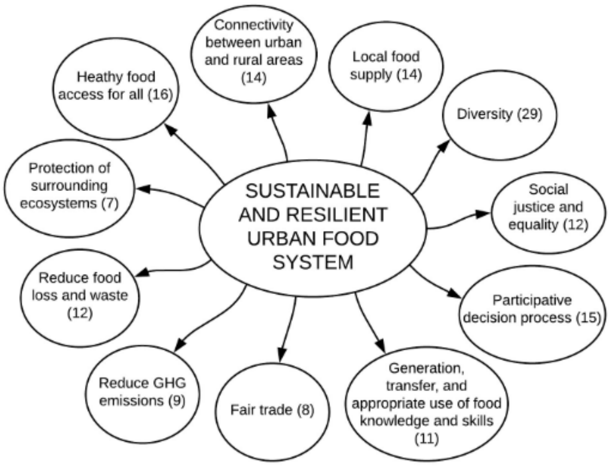

Figure 11: The topics related to creating a sustainable and urban food system (the numbers relating to the number of resources that mentioned each topic) (Source: Vieira *et al.*, 2018).

Creating a sustainable food system is really a supply chain challenge where optimizations need to be considered at every level: sustainable and production, low energy and resource efficient manufacturing, low emission distribution with reverse logistics, and collaborative retailer networks (Taghikhah, Voinov and Shukla, 2019). Throughout these supply chain steps, one of the biggest goals is to reduce the amount of waste generated. Food waste has enormous costs across all dimensions of sustainability (Sehnem *et al.*, 2020):

- Economic: spending on materials, wasted transportation, costs to manage waste,
- Environmental: land and water use, CO_2/Greenhouse Gas (GhG) emissions, landfill waste
- Social: stigma of wasting food, hunger

Possibly the most impactful pathway to a more sustainable food system is to change dietary habits toward a lower proportion of animal products, which could significantly reduce the material intensity of the entire system itself (Haas et al.; Biesbroek et al.; Stehfest et al.; Kiss et al.). I will not look in depth at methods or the effects of this dietary shift, however, I will acknowledge that a shift towards a plant-based diet does include a reduced resource footprint. Throughout the supply chain, innovations need to focus on extending product lifespan, connecting suppliers and purchasers to facilitate efficient trade, enhancing shared economy and adopting 3R techniques at all levels. An added dimension to the 3R implementation would be the adopting of an urban bioeconomy where all organic waste and by-products are recovered and used as feedstock for nutrient or chemical recovery, with residuals returned to the soil in an appropriate manner, while also generating value (European Investment Bank, 2018; Ellen Macarthur Foundation, 2022). Nutrients could be captured within the organic fraction of municipal solid waste and wastewater streams and processed to be returned to the soil in forms such as organic fertiliser – used for both urban and rural agriculture. Such a system could also provide a more resilient, diversified and cost-effective energy system in the city through the generation of electricity from wastewater, biofuels and biorefineries. These will offer additional revenue streams to the city, capitalising on the utilisation of material and nutrients that are already in use (Sehnem *et al.*, 2020).

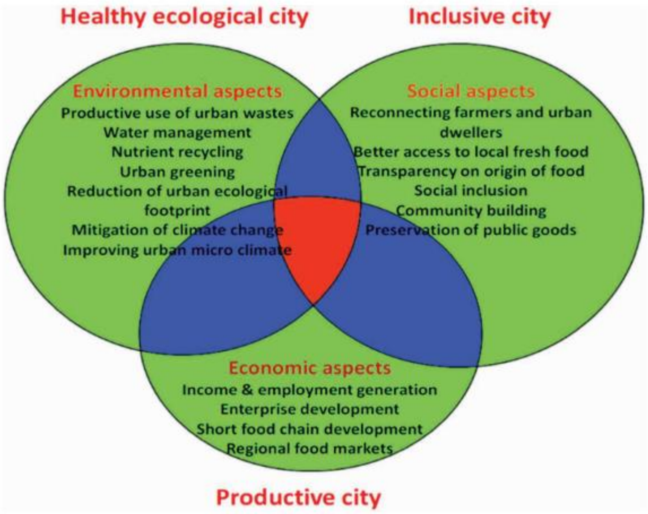

Figure 12: The benefits of urban agriculture for sustainable urban development (Source: Wiskerke, 2020)

Urban agriculture has the potential to contribute benefits across all societal dimensions for the development of sustainable urban food system (Figure 12). Urban food production reinforces interactions and resource flows that influence economic, ecological, spatial, and social themes, and broadly speaking, it has the potential to shift how we grow, trade, transport and eat food. A list of 24 of these themes are displayed in Figure 13.

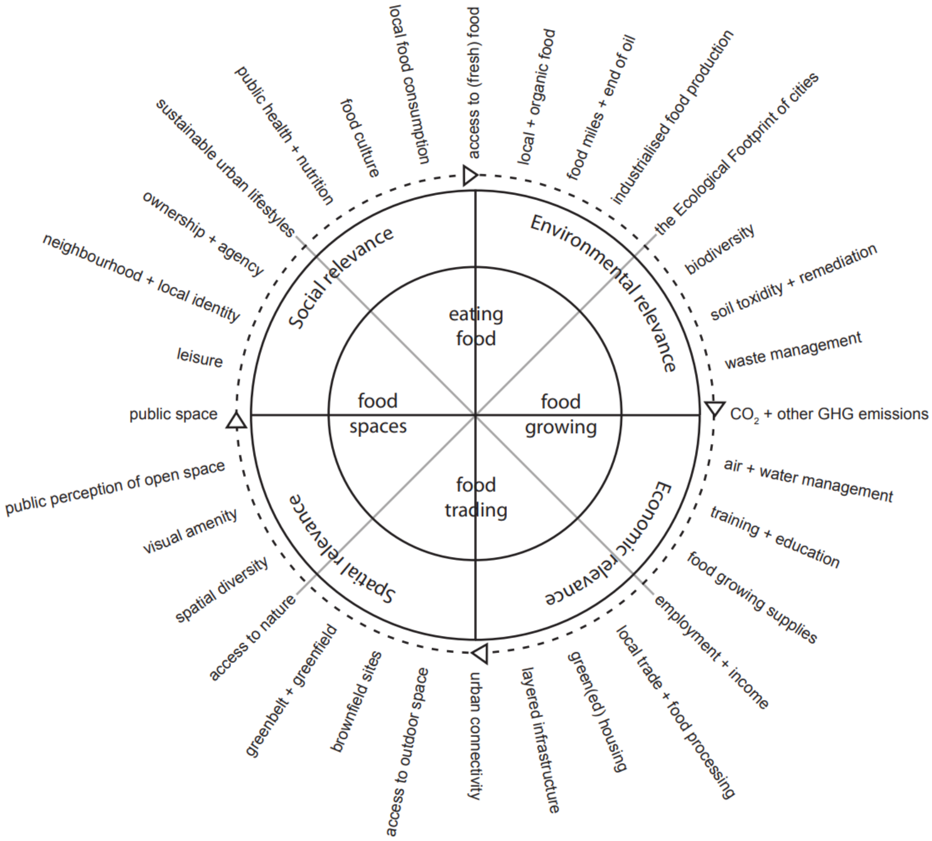

Figure 13 Socio-economic contributions matrix of urban agriculture (Source: *Viljoen and Wiskerke, 2012)*

An urban agriculture production system is strongly present as a strategy for facilitating and supporting a more circular urban food system, by creating a network that encourages the creation of ‘local value loops’ (Ellen Macarthur Foundation, 2019) This means more local production, and increased and more diverse exchanges of value in local economies. Through urban farming, the city will be able to supply some of its own food, reusing food waste and sewage in closed and local loops to produce vegetables, fruit, and fish. To offset the high costs for land in the city, agriculture is undergoing a digital transformation as it seeks to use technological solutions to increase yields while reducing food losses and adverse environmental impacts. Digitalization, as well as new technologies (e.g., aquaponic, urban farming, and precision farming) and circular behaviors, can transform this sector, increasing irrigation efficiency by 20–30% and reducing pesticide use by 10–20% and fertilizer consumption by 70–90% (Ferreira and Fuso-Nerini, 2019). Not only can they create resource efficiency, but indoor urban vertical farming implemented within European cities can be profitable with a payback period usually between 2-6 years depending on the size and types of technologies installed (Avgoustaki and Xydis, 2020). These types of closed system farming can reduce waste by applying circular processes, however a circular agriculture system does not result in zero emissions, and simply increasing the chain of circular processes does not automatically create more efficiency (Fan *et al.*, 2018). The indoor cultivation methods as well as the implementation of circular processes must also consider the higher demand for electricity. The local grid electricity has a major influence on the total climate change impact of indoor farming, with grid systems such as France having a much lower impact due to the high proportion of nuclear energy (Dorr *et al.*, 2021).

The capacity and benefits of cities to act as agricultural production hub needs to be properly evaluated, but by properly evaluating, it must be clear that even if cities could technologically produce enough food within the urban limits to meet the demand, it would also be completely impractical. The Ellen Macarthur Foundation (2019) estimates the theoretical maximum that urban agriculture could supply is around 30% of the total urban demand. Local sourcing of food can play a major role in building urban resilience, supporting regional plant species cultivation, renewing a sense of connection between consumers and producers, as well as improving the overall quality of food. But of course, local only makes sense when appropriate. The appropriateness is conditional upon the city and individual consumers, as well as many aspects, including geography and seasonal availability, food access and supply chain dynamics, and health and cultural demands (Vieira *et al.*, 2018). The appropriateness also depends on the definition of local, and while urban agriculture surely fits this definition, building a circular food system will depend far more on the ability to reconnect cities and the peri-urban areas around them.

2.3.2 Urban Mushroom Farming

The role of mushroom farming both as a form of urban agriculture and as a strategy for CE has been growing in interest in recent years. The global demand for mushrooms has been increasing with the per capita consumption increasing from 1 to 4.7 kg/year between 1997 and 2013 (Grimm and Wösten, 2018). As a food item, they provide a balanced composition of minerals, vitamins and are rich in fibre and protein (Reis *et al.*, 2012). The natural ability of fungi to break down biomaterials may allow it to be used for waste management strategies, or for the generation of nutrient rich soils.

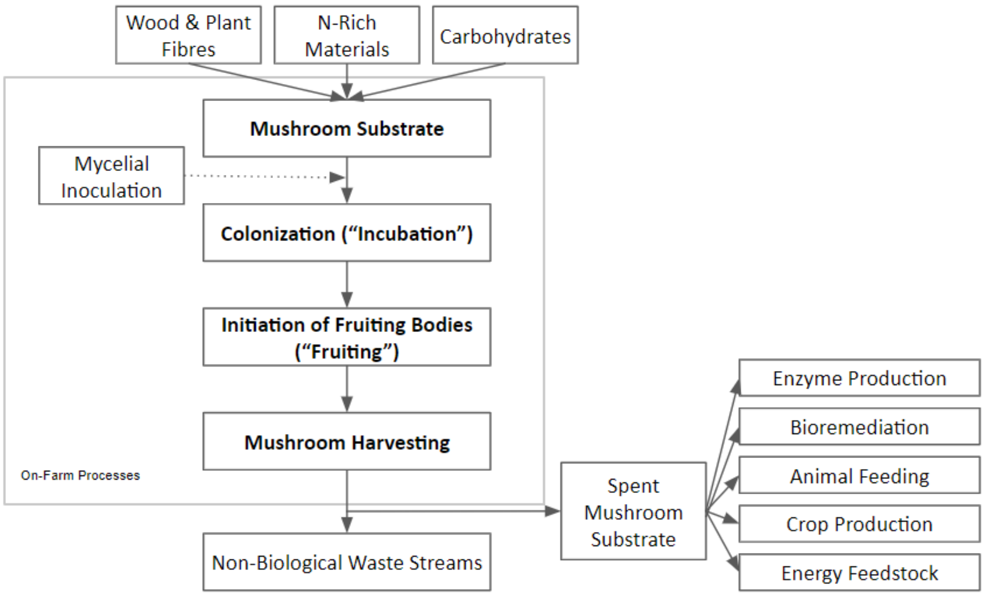

Figure 14: Mushroom production cycle (Adapted from *SoPhan and Sabaratnam,* 2012)

Wood-loving species of Mushrooms from the genera *Pleurotus, Lentinula,* and *Hericium* have seen a lot of success in commercial cultivation. The cultivation technique of these mushrooms involves the preparation of a substrate which is commonly bagged or jarred before being pasteurized or sterilized and inoculated with the mycelial fungal tissue. Due to the controlled preparation and handling procedure of the mushrooms, it is possible to cultivate these mushrooms in high volumes using limited amounts of space and has been conducted recently in urban farm settings (Chang, 2007).

Creating a biologically efficient substrate for mushroom cultivation is important to maintain the economic yields required for farm operation. Normal substrate mixtures for these species of mushrooms are made from lignocellulosic biomass (containing cellulose, hemicellulose and lignin), which are some of the most abundant forms of bio-waste including animal waste, agricultural waste, forestry residues, grasses, and woody materials (Block, Tsao and Han, 1958; Adebayo and Martínez-Carrera, 2015). While these materials are usually sourced from an agricultural setting, there is a new interest in exploring the potential of urban bio-wastes as an efficient substrate material, such as coffee grounds (Alsanad *et al.*, 2021), spent brewer's grain (Reis *et al.*, 2012; Sözbir, Bektas and Zulkadir, 2015), bakery waste, tea leaves (Yang *et al.*, 2016), cardboard and paper (Girmay *et al.*, 2016; Grimm *et al.*, 2020). By integrating urban biomaterials into the substrate, it can divert these materials from entering into waste streams that may be directly burning or sent to landfills. For farms located within or close to cities, it can also reduce the need for agricultural by-products to be transported from surrounding areas.

A life cycle analysis for an urban mushroom farm that uses spent coffee grounds as substrate materials was conducted by Dorr et al. (2021). The system boundaries and the delineation of the different life cycle stages are shown in figure 15.

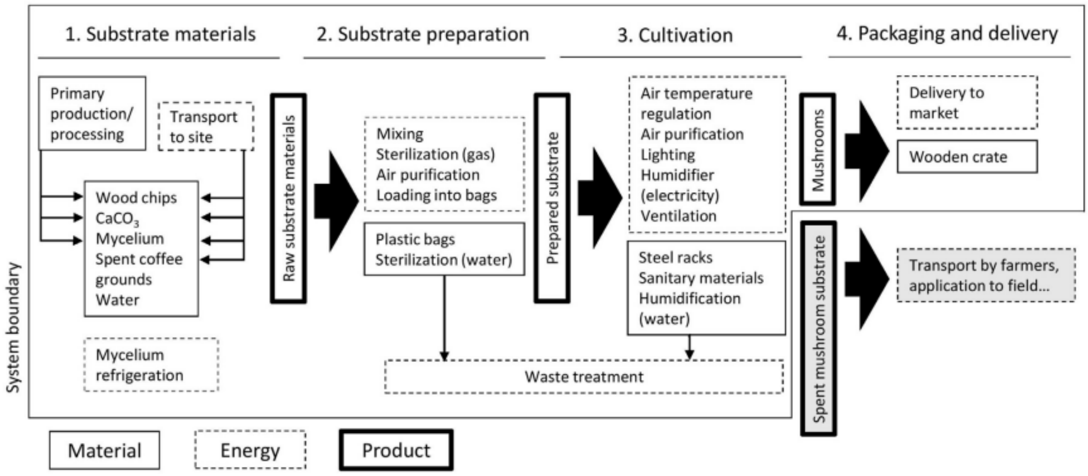

Figure 15: Overview of on-farm processes and life cycle stages considered for LCA analysis (Source: Dorr *et al.*, 2021)

Some of the biggest impacts from the farm were through the sterilization process, which represented a total of 43% of the total climate change impact. This was due to the gas consumption of the device. Another major impact included the electrical consumption for air temperature utilization, humidification, and ventilation; however, due to 78% of the French electrical grid being composed of nuclear energy, the climate change impact was comparatively low. as well as the wooden packaging materials.

Of the total process, the re-use of coffee grounds represented a total of 0.19 kg CO2 eq/kg mushroom (6%) sequestration of carbon from spent mushroom substrate, and overall, the results showed that the climate change impact for the circular farm technique was similar or lower compared to other types of cultivation techniques, such as those for button mushroom or standard oyster mushroom cultivation. However, while the use of spent coffee grounds did lower the total impact, maintaining a consistently high yield and avoiding contamination had a more significant impact. Therefore, efficiency improvements to the entire system are likely more important than simply integrating further circular principles

Within the life cycle analysis from Dorr et al, the SMS was counted as a carbon sink, however, a detailed analysis was not included in the system boundaries. While the transfer of the material to a secondary site would naturally include an emissions footprint, the SMS is no longer regarded as waste by many within the fungal industry but rather as a renewable resource (Mohd Hanafi *et al.*, 2018; Pérez-Chávez, Mayer and Albertó, 2019; Zied *et al.*, 2020). The SMS can be used a soil conditioner, with experiments indicating that the addition of spent mushroom substrate can significantly increase the soil mineral nitrogen content (Lou *et al.*, 2017; Owaid, Abed and Al-Saeedi, 2017). SMS can also be used in a number of environmentally friendly technologies such as plant growing substrate (Zhang, Duan and Li, 2012), animal feed (Grimm, Kuenz and Rahmann, 2020), and the derived enzymes are also potentially useful for bioremediation of pollutants (Chiu *et al.*, 1998; Purnomo *et al.*, 2010; Rinker, 2017) and other industrial biotechnology purposes (Phan and Sabaratnam, 2012). The remaining SMS can also be used for biogas generation, as the raw material is broken down by fungal metabolism as a pre-treatment before anaerobic digestion, and the residue of fermentation from the biogas process can also be reused for mushroom cultivation (Pérez-Chávez, Mayer and Albertó, 2019). These productive processes could be integrated into a sustainable cycle in which the residues from one activity become the substrate for another activity (Rinker, 2017; Pérez-Chávez, Mayer and Albertó, 2019).

Finally there is a lot of research in mycelium based material as an alternative to hydrocarbon based products such as polystyrene and other packaging materials (Robertson *et al.*, 2020). Companies are researching the best way to form and process these materials, however, these materials could be formed from the spent mushroom substrate (Grimm and Wösten, 2018; Schritt, Vidi and Pleissner, 2021).

2.4 Conceptual Framework

My analysis and interpretations of the case study data will be made in reference to the conceptual framework outlined in this section.

Throughout my thesis I will adopt a multi-dimensional concept of CE, and will therefore, use the definition by Kirchherr et al. (2017). By using this more comprehensive definition, it naturally embraces some (but not all) aspects of SD.

Implementation of urban agriculture has been considered by researchers, policy makers and business owners as a strategy for sustainable and circular cities, however, since the implementation of the CE activities outlined in the case study were achieved through the decisions of a small business that implements a circular business model (specifically one that generates value on the recovery of secondary raw materials), the case will be considered a bottom-up approach to CE operationalization. The individual business activities can thus be analyzed, since these essentially represent the constant ongoing decision making and steering of the CE implementation.

The business model will be depicted using the framework by Lauten-Weiss and Ramesohl (2021), particularly because it distinguishes between tangible and intangible resources, and through it’s design, it clearly portrays an internal and external environment. The flow of resources through the business model will be understood through an underlying model of urban metabolism explained in section 2.1.3.1. This model by Dijst et al. (2018) introduces an interdisciplinary perspective to resource flows, and explains a framework to link social dimensions in the form of societal drivers to the flows and stocks of tangible resources. It is beyond the scope of this thesis to describe the individual societal drivers within this case study, but a simple understanding that flows are shaped through the needs of people and society, can be used to reason that the customer needs directly influence both the tangible and non-tangible resource flows of the business.

In order to breakdown and sort the activities and interactions of the case study, I will apply the urban agriculture contributions matrix by Viljoen and Wiskerke (2012). This matrix plainly separates the different contributions of urban agriculture and was chosen specifically due to the multi-dimensional perspective of the framework. After sorting and classifying the activities of the business to contributions, these activities will then be analyzed in how they may facilitate the operationalization of CE by examining how they may be causally linked to the four building blocks from the Ellen MacArthur foundation described in section 2.2 (build new skills, shift customers from consumers to users, innovate waste management, and support from outside “enablers”).

Concept	**Key Literature**	**Elements**
Circular Economy Definition	(Kirchherr, Reike and Hekkert, 2017)	- Economic, social, ecological dimensions - References sustainable development
Circular Business Model Canvas	(Lauten-Weiss and Ramesohl, 2021)	- Distinguishes between tangible & intangible resources - Depicts internal and external environments
Underlying principles of Urban Resource Flow	(Dijst *et al.*, 2018)	- Interdisciplinary approach to urban metabolism - Links social dimensions to tangible resources
Contributions of Urban Agriculture	(Viljoen and Wiskerke, 2012)	- Inter-dimensional perspective (economic, social, ecological, spatial)
Building Blocks for Circular Economy Operationalization	(Ellen Macarthur Foundation, 2013)	- List of 4 “building blocks” for CE implementation

Table 2: Summary of the conceptual framework for the study

The methodology for data collection and analysis are discussed in more detail in the following chapter.

3 Methodology

The study aims to conceptually unpack a series of activities, goals, and contradictions within an urban agriculture business model to conceptually model how an urban agriculture business model may contribute to and enable CE. The research will employ inductive methodologies based on the case study of Pilzling to create new theories on how these contributions are linked through business activities.

The unpacking of Pilzling's operations (Objective 1) will begin with a broad synopsis and summary of the business operations that took place during the study period including input and contextualization from three professional interviews.

To then interpret how these contributions may enable the operationalization of a CE, I will employ a modified Sorensen network to show the interlinkages and interactions between the Pilzling activities, their socio-economic contributions, and their effect on several CE building blocks.

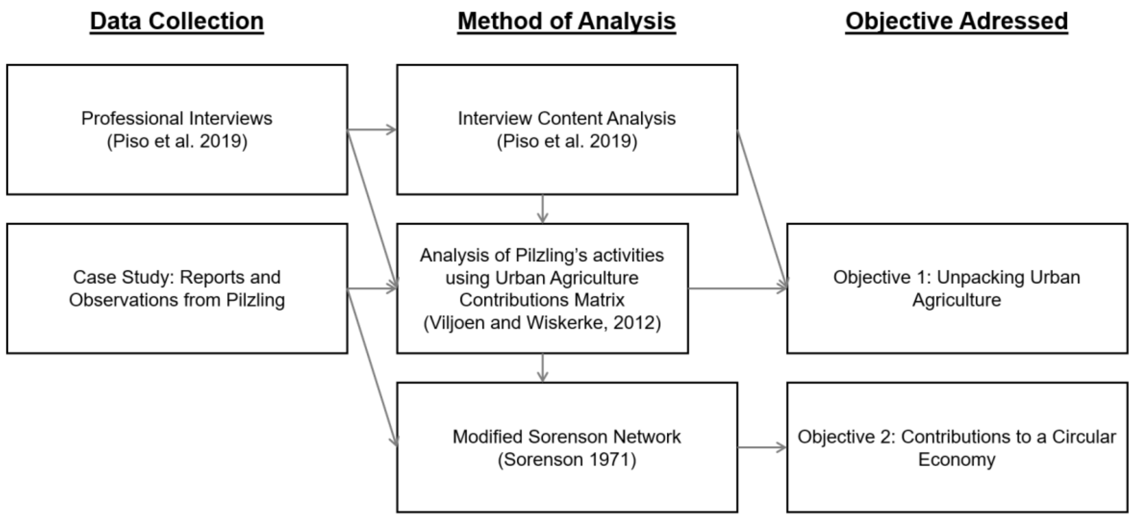

Figure 16: Overview of the data collection and analysis methods used for this thesis.

3.1 Data Collection

3.1.1 Professional Interviews

This thesis will be aided by three professional interviews. The goal of the interviews is to create a high-level discourse about urban agriculture, resource efficiency as well as social and environmental sustainability.

The structure of the interview and my analysis will be based on Piso et. al (2019) “Types of urban agricultural stakeholders and their understandings of governance”; however, I will not ask the participants to rank certain metrics, and therefore, the statistical analysis will not apply.

The interviews will be conducted in a semi-structured manner, with open ended questions related to the above topics. Interviewees will receive a list of topics to be discussed and the interviews will begin with a short introduction. In the first section of the interviews, I will ask opening interview questions about why participants became involved, and their values related to urban sustainability and resource efficiency. In the middle and closing interview questions, I will ask about the impact of, and their evaluation of urban agriculture resource efficiency.

The results of the interviews will be used to establish a common understanding of urban agriculture and the main case study. and the case I will use the interviews to provide additional background information, as well as to build more on the theoretical framework of sustainable urban agriculture and CE.

The following interviews are to be conducted:

Cristian Wedgwood, Nexus Farms Co-Founder
Cristian Wedgwood was selected because he is a young entrepreneur in the field of urban farming. He is the co-founder of Nexus Farms and has worked for several other tech and urban farm start-ups. The goal of the conversation is to explore different dimensions and opportunities of the urban farm start-up space.

Florian Sanders, Food Council of Cologne (Ernährungsrat Köln und Umgebung) Managing Director
Florian Sanders was chosen because of his work for the Food Council of Cologne and his great interest in topics of urban sustainability and agriculture. The goal is to get an insight into the goals and impact of the Food Council’s activities and projects as well as to discuss the planned Food-Hub project that is planned in cooperation with WandelWerk.

Verena Hermelingmeier: KLuG e.V. and WandelWerk Project Management Team

Verena Hermelingmeier was chosen because of her research background in urban transformation and her position on the KLuG e.V. and WandelWerk project management team. As Wandelwerk is currently implementing several activities in the field of urban agriculture, I would like to gain insights into how these types of small-scale production facilities contribute to urban transformation and development.

3.1.2 Case Study Observations & Reports

A single case study, Pilzling, will act as a general representation of urban agriculture and be the primary source of data for this thesis. The data will be presented mostly as a firsthand qualitative account with supporting documents where possible.

In Chapter 4, I will provide the background and general overview to the case study, including a description of the location, company goals and vision of Pilzling, as well as a general overview of the business model using the business canvas framework from Lauten-Weiss and Ramesohl.

I will then give a detailed synopsis of the Pilzling operations in Chapter 5 of the activities and events that took place during the study period. The data will be organized temporally in three sections: project setup, internal operations, and end of Pilzling 1.0/next steps.

3.2 Data Analysis

3.2.1 Urban Agriculture Contributions Matrix

To understand how the business model of Pilzling and its resulting resource flows interact with the external ecosystem, the activities will be analyzed using the urban agriculture contributions matrix by Viljoen and Wiskerke (2012).

This matrix is designed to give a basic overview of how urban agriculture may affect specific topics across different societal dimensions. I will attempt to score the Pilzling operations on their relative relevancy towards each socio-economic contribution, based on activities and events that occurred during the study period.

3.2.2 Modified Sorensen Network

A modified Sorensen network will be used to model the causal interlinkages between the business activities and their socio-economic contributions to their effects on the four CE building blocks.

The Sorensen network was developed in 1971 to establish “causal chains” and to show how these chains may trigger a series of change (Sorensen, 1971; Clark *et al.*, 1978). The Sorensen network has been utilized commonly in the environmental impact assessment community for identifying potential risks and suggesting possible mitigation measures (Mason and Moore, 1998; Noble and Harriman, 2008). While it has a strong capacity for displaying intermediary links in complex environments, “the network is primarily a tool for identifying impacts, not evaluating them” (Hyman and Stiftel, 1988).

To limit the scope of the analysis, I will limit the input activities to the core internal activities of Pilzling and only consider the contributions that are most (“highly”) relevant to the case.

3.3 Scope and Limitations

The scope of this study focusses on the contributions of an urban agriculture business to the local food system of Cologne. Since Cologne is embedded in a much larger global food system, it is undoubtably affected by events (natural, political, economic) that take place at a more global scale; however, most of the data collection and discussion will analyze the processes and material-flows at a micro-level.

This study will be conducted almost entirely through qualitative methods including interviews and observations. This thesis will perform neither an in-depth economic analysis to understand urban agriculture at a macro scale, nor a comprehensive household survey to examine patterns of access or utilization. Therefore, the quality of data is limited to the knowledge of those approached and the quality of data collection methods. Furthermore, deductions about the social aspects within the food system are influenced from my own observations and understanding.

Finally, it should be acknowledged that the primary case study of this thesis, Pilzling, is an entrepreneurial venture of mine, and therefore I am financially and emotionally invested in the overall project. Interpretations of Pilzling and the activities presented may therefore be subjected to different forms of bias.

The scope and limitations of this study should be considered when interpreting any conclusions, which should be used as an early step for more comprehensive studies on the topic.

4 Case Study: Pilzling

The case study presented and analyzed in this thesis is Pilzling - an experimental urban mushroom farm in Cologne with the primary goal of cultivating mushrooms using recovered waste streams from the city as substrate. During the research period, a 15-month project was undertaken by me and a team of two additional founders in the WandelWerk transformation center in the Ehrenfeld district of Cologne. The project was backed by the KLuG e.V., the Cologne Food Council (*Ernährungsrat, Köln und Umgebung*) NRW Founder scholarship (*Gründerstipendium*), local restaurants and businesses, and local community members.

At the time of writing this thesis, Pilzling GbR is still operational. The 15-month WandelWerk Project is now referred to as Pilzling 1.0, with ongoing plans to build a larger, more permanent iteration of the farm, currently designated Pilzling 2.0.

In the sections below, I will present the Pilzling business model and describe events and interactions that took place over the course of the project. In the later chapters of this thesis, I will analyze how this case study relates to concepts and other exemplars of urban agriculture and CE.

4.1 Project Background & Conception

4.1.1 Background

Pilzling was founded in mid-September 2020, however, groundwork for the project had already been indirectly established during the previous two years from my ongoing work of founding and operating my first business venture in the field of urban agriculture, Nexus Farms. Nexus Farms was founded with the goal of exploring business models based on the application of aquaponic technologies and with the longer-term goal of designing a large-scale aquaponic production facility in Cologne's city limits.

At the core of the Nexus Farms business strategy was the aim to achieve resource efficiency, and therefore economic advantage, through the deliberate use of various waste resource flows. For example, the main waste flow fundamental to the aquaponic model is the fish excrement, which is used as a nutrient source for the plants. Additional waste-flows included industrial waste-heat, food-factory scraps, and underutilized spaces. Many of the proposed Nexus Farm projects also entailed a conscious degree of community building and education through the plan of hosting workshops and courses, as well as by designing the facilities to act as so-called “living-labs.”

The goals of Nexus Farms changed during the onset of the Corona Pandemic, and consequently, none of the loftier company goals were ever realized. Nevertheless, I gained skills and expertise on how to establish a small business in the urban agriculture industry, had established a small network of industry actors, and had developed a deeper understanding of waste recovery business models.

4.1.2 RRR Entrepreneurship Training (04-11.09.2020)

The original conception and planning of the business model occurred during a one-week online summer school course, “Resource Recovery and Reuse (RRR) Entrepreneurship” from CEWAS offered jointly from the ITT TH Köln and Ain Shams University. During the one week of training, a team of four students and I researched and put together a hypothetical business model for an urban mushroom farm that recovered waste coffee grounds. The model was inspired by similar farms in existing in other European cities such as *Beyond Coffee* (Copenhagen), *GroCycle* (UK), *Le Champignon de Bruxelles* (Brussels), and *PermaFungi* (Brussels).

Throughout the duration of course, I presented some of the research findings to a close friend and now current business partner, Christian Vetter. Upon hearing the ideas, mutual interest was confirmed, and we decided to try and replicate the model in a real-world experiment. To fund the experimental business venture, we agreed on an equal 2,500 capital investment.

4.1.3 First Site Visit of WandelWerk (08.09.2020)

The first site visit to WandelWerk and the future Pilzling 1.0 location occurred on 08.09.2020. The site was immediately considered desirable due to the location, access, and building utilities. During this visit, WandelWerk was still at an early stage in construction and the overall concept was still in infancy, however, the opportunity to be part of a so-called “transformation center” was considered a major advantage. Due to the low starting budget, the original development plan was to find a place just big enough to perform the necessary activities to achieve a minimum viable product, and 15-25 m^2 was believed to be sufficient, therefore, the original goal was to use a small, ~20 m^2 room in the rear corner of the building. The original timeline for the project was only for nine months until the end of May 2021 due to the pending building re-development. The project management team indicated that there was a small possibility of extending the lease; however, this extension was uncertain, and tenants should anticipate only short-term use of the space.

4.1.4 Project Planning & Original Lease Agreement (08-16.09.2020)

In the days following the first site visit, Christian and I expressed immediate interest in the location and began discussing the opportunity with the WandelWerk project management team. An abbreviated business and finance plan was promptly created to begin modelling various basement-use scenarios and production possibilities (Annex 1). The business model was primarily derived from the research and work completed during the RRR Entrepreneurship course. Additional research for farm design and cultivation techniques were conducted as well during this time. Although lacking any in-depth market analysis, the team decided on a strategy during the nine-month lease agreement to complete construction as fast as possible and maximize production early to establish a consistent harvest schedule.

On the 16th of September, Pilzling met the project management team to propose several basement floorplans. The proposed agreement also informally called for contributions that would provide mutual benefits to the Wandelwerk, for example, through labor or profit sharing, and/or public tours. We suggested that the farm could facilitate tours to demonstrate CE concepts, provide artists with substrate for making zero-waste mycelium-based materials (e.g., lamps), and close resource loops within the building by using coffee grounds waste and providing compost for the greenhouse.

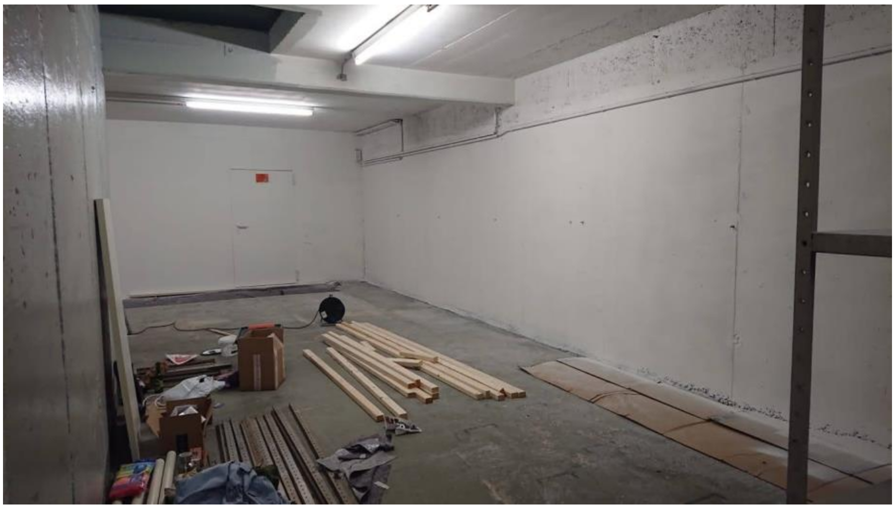

Figure 17: Basement of Wandelwerk used for the construction of the farm

The project management team granted us permission to use a total of 60 m^2 of basement space (Figure 17). Due to the higher start-up costs of the larger basement space, Pilzling proposed a rental agreement that included a staggered monthly rent, which would allow time to finish construction and establish a regular production schedule. The total price of 390 Euros/month (6.50 Euro/m^2) would therefore apply March onwards (Note: In a later formal agreement, the price was established at 45Euros/month for the entire tenancy; however, this was later reduced to zero and Pilzling GbR paid no rent for the 15-month WandelWerk lease term).

4.2 Corporate Goals

Implementing a circular business model was planned from the initial founding. From the Pilzling GbR Articles of Association (Annex 1) signed 12.10.2020:

> *The object of the company's business is the sustainable agricultural cultivation and sale of gourmet varieties of mushrooms. Business operations must work towards resource efficiency in line with agreed upon standards.*

The agreed upon standards for resource efficiency were never clearly defined, but some early examples of resource efficiency can be exemplified by the original construction and setup of the facility and discussed in more detail in section 5.2.1.

The concept of CE was fundamental to many of the Pilzling activities. The term was used in many communications from the beginning onwards. For example, the hashtag “#circulareconomy” was used in the first Instagram post on 03.10.2020. The term has remained a key part of the corporate guiding principle, with the most current iteration of the Pilzling Manifesto (Annex 1), drafted and agreed to by all current members, stating:

> *“We are making agriculture more circular, integrating urban farming into the cityscape, and reconnecting people with food production.”*

Also, within the Manifesto as part of the company declarations:

> *“Whenever possible, we integrate methods of circular economy within our business model.”*

As demonstrated in the above statements, Pilzling does not refer to itself as a “CE business,” or state that it *is* “circular,” but instead opting for language that elucidates a constant improvement in “circularity.”

4.3 Location: WandelWerk, Cologne

For the planned business model, we required a centrally located space with basic plumbing and high-voltage electricity that would permit simple construction modifications to facilitate the farm functions and necessary equipment (ventilators, humidifiers, shelves, sink). We considered the central location to be critical for improved access to cafes, which would allow for convenient collection of the waste coffee grounds as well as the ability to perform the collection by bicycle. Other desirable requirements included darkness and stable temperatures.

At the time of the project conception, a new urban transformation center organized by the Cologne non-profit organization, KLuG e.V. was being completed. The center, WandelWerk, was an experimental model for sustainable urban development that transformed a former car-dealership into a shared space for public and private activities. From a recent 2022 excerpt from the KLuG e.V. website:

> *“WandelWerk - a project of KLuG - Köln leben und gestalten e.V. - served as a model project for a center of social-ecological change from September 2020 to November 2021. Within the framework of a 15-month interim use, committed individuals, collectives, startups and associations created an experimental space for sustainable urban development on 4,802m² of a former car dealership in the "Liebigquartier" (Cologne - Neuehrenfeld). Civil-society engagement, public welfare-oriented management, creative development, and social encounters came together at this place and were translated into future-oriented concepts. Together with you, we want to continue to realize visions for the people- and climate-friendly city of tomorrow today. The WandelWerk was just the beginning!”* (Source: WandelWerk Website, Translated from German)

A consistent topic throughout the 15-month WandelWerk project was the idea of providing space to smaller organizations that normally don’t have access to space. From the WandelWerk mission statement:

> *WandelWerk is a center for social-ecological transformation in Cologne. We are convinced that a place is needed for all those who are committed to the climate-friendly and fair city of tomorrow. Here, committed Cologne residents can network, rent space at low cost and work hand in hand on the vision for a good life for all.*

When asked in the April 2021 interview for this thesis what the goals were for WandelWerk and what was specifically meant by “social ecological transformation”, project management team member, Verena Hermelingmeier, spoke of creating a small ecosystem where resource flows can be visible, which can be used as a model for higher city-level contexts:

> *"[We're trying to] give space to the [smaller organizations], but really having a local focus and trying to build up an ecosystem where new and novel approaches can flourish, where you have these small [resource] cycles, that really work and where you can show that [they work], [..] and more on this level of urban production in a city-wide context."* (Verena Hermelingmeier Interview, 18:09)

To bring about this social-ecological transformation, WandelWerk was designed to create:

a) a free space in which people can shape their future collectively. We bring people with all their different ideas and skills together and jointly implement ideas for a better world.
b) a place where future-oriented entrepreneurship is tried out and exemplified -- with an understanding of value creation that goes beyond the purely financial and thinks of business first and foremost in terms of the common good.
c) the center of a model neighborhood in which the socio-ecological transformation is being tested and professionally guided. Here, what should be the standard for a future-oriented Cologne 2030 is being created today.

The car dealership used by WandelWerk was only leased for interim use, as the building was scheduled to be demolished once construction plans for new housing were approved.

To accommodate the activities proposed by the WandelWerk, the center was divided into three different areas:

1) The urban lab ("*Stadtlabor*"), which was an ongoing process to develop a model neighborhood, or a place where ideas for a sustainable future are actively implemented.
2) The Economic Hub ("*Wirtschaftshub*), which was a social-innovative ecosystem in which ideas and projects for an alternative supply chain and value creation system are supported, implemented and experienced.
3) The Community Center, which was an open, enabling, and creative space where individuals are empowered and encouraged to work together to shape their futures.

4.4 Pilzling Business Model

The Pilzling 1.0 farm business model was based on two primary use- (“value-”) cases: recovery and processing of secondary raw materials, and urban food production. The farmed product was sold through both local business to consumer (B2C) and business to business (B2B) channels to customers looking for sustainable low impact food, as well as interesting, high-quality ingredients. Figure 18 portrays the business model using the circular business model canvas from Lauten-Weiss and Ramesohl.

The business canvas delineates both the tangible and intangible resources that interact with the Pilzling operations. The intangible resources include the circular business model, the corporate values (Pilzling Manifesto), data and brand. Included as well within this section are the values and concepts related to the re-use of an industrial building and a business plan that implements innovative farm methods. The tangible resources included the urban mushroom farm and equipment, the Pilzling team, bicycle logistics, fresh mushrooms, coffee grounds, tours, and tech products.

The Pilzling ecosystem is defined by intangible ideas that are outlined by other institutions (SDG’s, EU Circular Economy Action Plan), or values that are maintained by other supporters or network actors (Zero Waste Cologne, Ernährungsrat Cologne, RegionalWert AG, Himmel un Ääd, Ehrenfeld Community), as well as tangible network actors that supply key infrastructure and support (Wandelwerk) or act as a source or endpoint for some of the biological input material (local cafes, urban gardens).

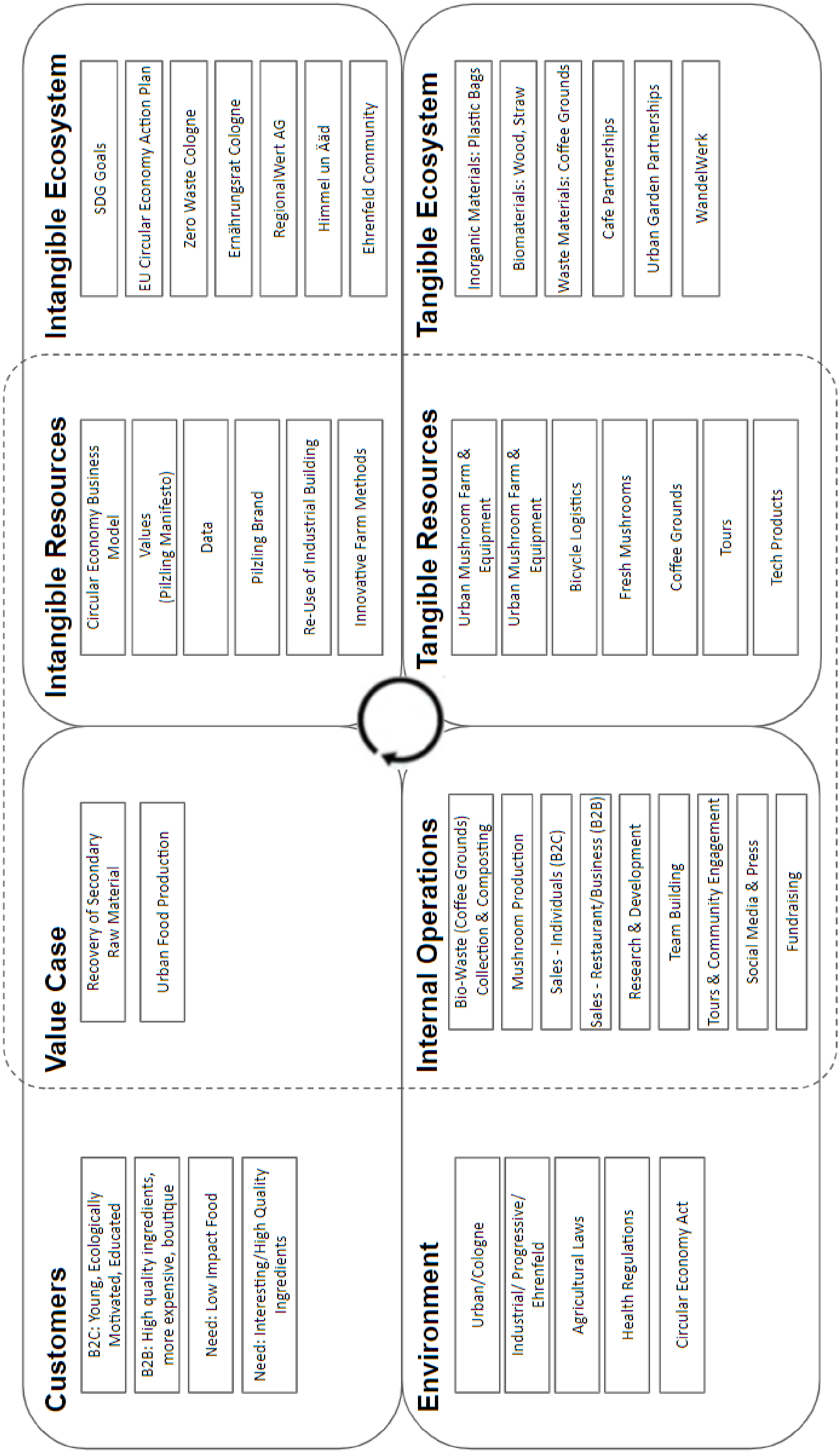

Figure 18: Pilzling Business model depicted using the circular business model canvas from Lauten-Weiss & Ramesohl (2021)

The internal operations performed on a regular basis can be categorized into nine main activities and are summarized below:

1) Waste Management (coffee grounds collection and composting):
    a. Regular waste material pickups by bicycle
    b. Communication & joint marketing with Cafés
    c. Storage and processing of waste materials
    d. Composting of spent substrate
2) Mushroom Production
    a. Supply chain management
    b. Mixing and Bagging of substrate
    c. Inoculation and incubation of mushrooms
    d. Harvesting and packaging of mushrooms
    e. Farm cleaning and equipment maintenance
3) Sales – Individuals (B2C)
    a. Receiving orders and payments
    b. Organizing on-farm pickups
4) Sales – Restaurant/Business (B2B)
    a. Receiving orders, payments
    b. Delivery by bicycle
5) Research & Development
    a. Substrate experimentation to increase yields
    b. Digital control (industry 4.0 technology) experimentation
    c. New product development (new strains, grow boxes, mycelium materials)
6) Team Building
    a. Attracting new talent and onboarding of team members
    b. Training and ongoing skill development
7) Tours & Community Engagement
    a. Technical tours for visitors
    b. Attending community events (technical talks, workshops, social events)
8) Social Media and Press
    a. Photo and video creation
    b. Blog posts and updates
    c. Marketing of products
    d. Interviews and media production
9) Fundraising
    a. Financial planning and strategy development
    b. Funding applications
    c. Investor relations

These operations are analyzed in more detail in section 5.2.2 with reference to specific events.

5 Data

The data collected for this thesis is described in the following two sections.

5.1 Professional Interviews

Three interviews were completed for this thesis. The goal of the discussions was to present a comprehensive analysis of urban agriculture that includes a debate on resource efficiency and a discussion on social and environmental sustainability.

Each of the interviewees received a list of potential topics for the interviews that pertained to their expertise, as well as to the main themes of this thesis: urban agriculture and resource efficiency. The list of topics and transcripts for each interview are attached in Annex 2.

The interviews will be used for establishing common terminology and framing some of the discussion.

5.2 Pilzling Activities

5.2.1 Project Setup (09.2020 – 12.2020)

The original investment to construct and setup the farm as well as to begin production was decided for 5,000 Euro, with an additional 3.000 Euro planned to buy secondary equipment once the farm was in production. To stay within this budget, the farm was intended to be "low-tech" in the sense that the infrastructure was to be built from easy-to-source, hardware-store materials, and the electrical equipment was designed using basic components and open-source software.

The main construction and setup of the farm was completed over the course of three months. The construction and setup activities were planned and carried out in a manner that would allow initial production to begin 3-4 weeks before the end of construction, thereupon allowing the first mushroom batches to incubate and be ready for immediate fruiting.

Major tasks that needed to be completed:

- Sourcing of Equipment
- Cleaning and painting of facility
- Lighting installation

- Construction and insulation of outer farm walls and door
- Assembly of incubation shelves
- Water & sink installation
- Setup of basic farm infrastructure (e.g., tables, shelves, appliances, etc.)
- Heating installation
- Construction of fruiting chamber walls and door
- Ventilation and humidification system installation
- Construction of fruiting chamber shelves
- Installation of digital and automation controls

To keep construction costs to a minimum, we agreed to source equipment and materials from second-hand sources when possible. This was also done intentionally to lower the material footprint of the farm, and to further strengthen the circular concepts of the farm (Figure 19). Some important pieces of the farm infrastructure were therefore either self-built or second hand, which later led to problems in the operation of the farm and are discussed in more detail below.

Figure 19: Construction materials were second where possible

5.2.2 Internal Operations (10.2020 - 11.2021)

Waste Management: Coffee Grounds Collection & Composting

Collection of coffee grounds began during the initial construction. Cafes were selected based on proximity to the farm and focussed on locations that were based in the Ehrenfeld and Nippes neighbourhoods. Unexpectantly, every café where management was approached was eager to participate.

The collection program changed throughout the project. The first method was to give participating cafes given reusable 5 or 10L containers to collect and store the coffee grounds on site. The containers were picked up and swapped for a new container three times per week by bicycle (Figure 20). This arrangement proved to be complex and communication between Pilzling team members and Cafe staff was difficult. It was also discovered that on site storage introduced potential contamination. Later collection programs implemented a once per week pickup, with no storage of coffee grounds between pickups.

Throughout the operation, cafes were active in their participation, and were willing to adapt their processes to fit our requests and new pickup programs. Many cafes stated on multiple occasions that they were happy that they could contribute to a CE effort.

Figure 20: Bicycle logistics used to transport coffee waste throughout the project

After the cultivation process, spent mushroom substrate was composted and stored outdoors on the WandelWerk site. Local garden groups collected the spent substrate on a regular basis.

Mushroom Production

Production began during the initial construction, and throughout the project, a total of five types of mushrooms were cultivated, with three (oyster, king oyster, shiitake) becoming main crops. The basic production stages were like the on-farm processes summarized in figure 14. Throughout the 15-month operation, production methods and work-flow techniques improved, however, the basic process remained consistent. The coffee grounds were mixed with straw or woodchips to by hand or with a concrete mixer to create a mushroom substrate, which was then packed into plastic cultivation bags. The substrate was pasteurized with an electric steamer, before being inoculated with a mushroom spawn (carrier of the mycelium) and sealed. After inoculation, the bags stayed in a dark warm incubation space for several weeks for the mycelium to colonize, before being placed on wooden shelves in a brighter, humid, and highly ventilated room for the final fruiting. The process was self-learned by the founding team through YouTube videos and books on the topic.

Throughout the pilot project, mushroom spawn was produced by a local supplier and picked up on a bi-weekly basis. These pickups were often accompanied with conversations regarding the production to trade knowledge and ideas (Figure 21).

Figure 21: Purchasing of spawn from local supplier

Based on the production plan calculations at the start of the project, the farm was built and operated for a planned output of 100 kg/week. However, this value was never achieved due to ongoing challenges within the cultivation process. One of the main challenges was handling contamination. This contamination was assumed to be caused from inadequate pasteurization techniques, and from the wooden shelving which was difficult to keep sterile. Due to the heightened contamination, the production ranged from 10-35 kg per week. A thorough R&D effort was initiated in April 2021 to begin trying to find a recipe to increase yields, which was successful in raising the biological efficiency in all cultivated species. Throughout the operation, fluctuating and diminished harvests created missed business opportunities and frustration among team members.

Figure 22: Contaminated specimen most likely showing signs of bacterial blotch.

Research & Development

Research and Development was focussed on improving production yields as well as new product development.

One of the significant challenges encountered during the operation was the management of biomaterial in a safe and hygienic manner. Improper handling, pasteurization, or mixing had a high tendency to become contaminated by mold or bacterial infection. The operation was originally planned to use a chemical pasteurization technique, however, after major losses during the first two batches, the team built two sterilization barrels using an old steel drums and steam generators. Research was also performed on optimizing workflows and cultivation-block handling procedures throughout the cultivation process. A major research topic was the substrate mix ratios between different waste products, wood, straw, and grain. Throughout the 15-month operation, the substrate yielded varying amount of mushrooms, with a biological efficiency sometimes as low as 25% including losses. However, towards the end of the Pilzling 1.0 operation, contamination created less impact and the biological yields had reached over 90% for some batches.

Research that focussed on the digital controlling of the farm conditions (humidity, temperature, CO_2) was another main topic that ultimately influenced the yield amount. A custom setup of sensors and microcontrollers was installed and constantly optimized throughout the project (Figure 23). The sensor types and positioning were discovered to have a huge impact on the results, and throughout the operation, device timing and parameters for the conditions were fine-tuned. To be used for marketing and showcase purposes, a remote farm system was also built, which utilized the same digital controlling as the main farm.

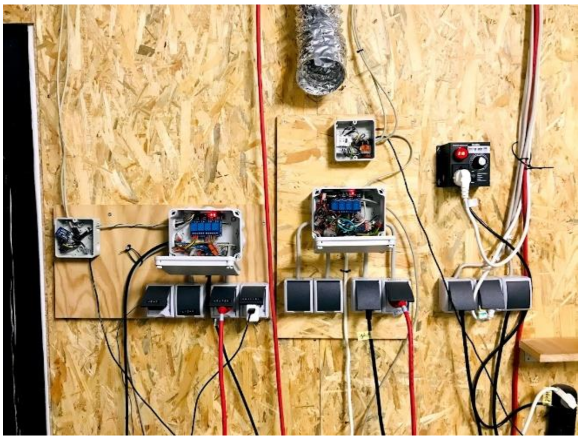

Figure 23: Custom hardware setup for the digitalization and automated controlling of the farm

New product development was an ongoing task to increase revenue streams. The team decided in Spring 2021 to begin experimenting with a “home grow box” design, which would allow customers to cultivate mushrooms at home. A market ready product was designed, but due to the end of Pilzling 1.0 operations, no product has been delivered, and only pre-orders have taken place.

Team Building

The success of the Pilzling 1.0 operation and continued interest in advancing the company to a secondary stage is significantly substantiated through the growth and expansion of the core team.

In January 2021, four months after the project began, Fabian Bokel joined the founding team taking on a role that managed the technical and digital infrastructure of the farm. In November 2021, Vanessa Michaelis joined the founding team, taking on a role that managed the visual design of the company including the design aspects of new products. At the end of Pilzling 1.0, all founders held equal shares in the company, however, this has since changed and is discussed in section 5.2.3.

Team building also took place in the form of collaboration with other freelancers and small business. For example, the team partnered with a carpenter who was interested in working with the spent substrate to design mycelium materials. Initial experimentation has yielded promising results, and the Pilzling team is still in conversation about fining deeper ways to collaborate to pursue a new business field.

Tours & Community Engagement

Pilzling maintained an open-door policy except during active production as a partial agreement for the rental of the WandelWerk space. Guests to the farm were given an informal technical overview of the farm and the Pilzling activities usually ranging from 5-15 minutes. These guests were both customers, as well as visitors to the WandelWerk facility. The informal tours allowed for visitors to ask questions as well as express support or concerns for the project and its activities.

Pilzling also participated in many community events such as technical talks, workshops, and social events in the WandelWerk building and throughout the city. These events were sometimes held within the framework of urban production, or sustainable innovations, and therefore, Pilzling was invited as a representative for small producers; however, some events (e.g., Anthropos Play) were more cultural or artistic in nature, and Pilzling was therefore invited as a thematic guest.

Figure 24: Farm tour offered to visitors and customers

Sales

All mushrooms were sold to local customers, which consisted of both individuals and businesses.

Individual customers were able to order mushrooms through our website, and which were later picked up in-person upon harvesting. Pilzling also participated in a local *Marktschwarmer,* where customers could order mushrooms and other products through the platform and pick up their ordered product once-per week in a specified collection area. Both sales strategies facilitated the opportunity for customers to ask questions, and those who picked up mushrooms from the farm were often given a tour showing how the farm operated.

Restaurant customers comprised boutique restaurants that focussed on using quality ingredients and included some prominent establishments through the city. The mushrooms were often prepared in unique ways or used with other gourmet ingredients.

Social Media & Press

Much of the public relations and marketing took place through online social media channels. The company was active on Instagram and Facebook, as well as maintained a website and blog. Posts were designed to be informative and usually to present a major company update (e.g., start of sales, events taking place, new team members, etc.).

Throughout the operation, Pilzling was also featured in several press releases and media programs. This included three articles in the local Cologne newspaper (*Kölner Stadtanzeiger)*, a state-wide radio broadcast about mushrooms (WDR), an article in the German Food Review. Media support was also received from the Creative NRW Organization after the Start Art Week pitch competition and Urbanana Prize.

Fundraising

As a growth-oriented start-up, Pilzling was also active in fundraising throughout the study period. Considerable time was spent writing applications, designing business plans, and maintaining investor relations. The themes addressed by Pilzling (urban food production, recovery of secondary raw materials) were considered innovative and desirable for funding programs and private investment.

Several funding mechanisms were approached:

- Public Funding Programs:
  - Special Program “Environmental Economy” (“*Sonderprogramm Umweltwirtschaft*”)
  - Founders Scholarship NRW (“*Gründerstipendium NRW*“)
  - EXIST Scholarship
- Crowdfunding through Startnext
- Prizes and Grants:
  - Hans Imhoff Startup Prize
  - Cologne Business Framework
  - NRW URBANANA
- Private Equity and Angel Investors

The Pilzling 1.0 operation was able to self-sustain its activities with income generated through the sale of products, therefore funding was only received from the Founders Scholarship and through the Startnext Crowdfunding campaign, while other mechanisms were/are intended to advance plans for a larger scale operation (discussed in section 5.2.3).

5.2.3 End of Pilzling 1.0/Next Steps (11.2021 – Present)

The Pilzling 1.0 farm remained in operation until November 2021, when the WandelWerk was permanently closed to allow the planned demolition and property development.

Using remaining funds acquired through the NRW founders’ scholarship and Startnext crowdfunding campaign, the team pursued plans to expand the business and build a Pilzling 2.0 operation. A location was found within the Cologne inner city, and a 6-month lease was signed in April to allow for planning and fundraising for a

10-year lease in the facility (up until the end of the project study, the company is currently still active in these activities). The Pilzling 2.0 farm is based on a similar business model established during the Pilzling 1.0 operation, however, with a 750 m^2 floor plan, production is expected to increase 1800-2000%. Investment in professional equipment such as mixing devices and an autoclave are proposed, and systems that facilitate better biological control of the farm are being considered. To aid in the profitability of the farm, a large R&D effort will be focussed on mushroom-based food products. The company plans to hire an additional 3-5 employees during the first year to achieve the goals set out in the business plan.

The team is currently fundraising to acquire the financial resources needed for the renovation, construction and first year of operations. During the planning of Pilzling 2.0, Vanessa and Fabian both stepped down from company management roles due to a refocusing of interests, however both members still play an active role in the company development.

The full business plans are outlined in the 2022 Pilzling Business plan (Annex 3).

6 Unpacking Urban Agriculture

This chapter will analyze the activities of the Pilzling business model and address the first objective of the thesis.

6.1 Socio-Economic & Environmental Contributions

Within this section, the Pilzling activities outlined in Chapter 5 are sorted and scored on their relevance within the different dimensions of the urban agriculture contributions matrix.

Dimension	Contribution	Not relevant	Relevant	Highly relevant
Environmental	Local & Organic Food			■
	Food Miles			■
	Industrialized Food Production			■
	The Ecological Footprint of Cities		■	
	Biodiversity	■		
	Soil Toxicity & Remediation		■	
	Waste Management			■
	CO2 & GHG emissions		■	
Economic	Air & Water Management		■	
	Training & Education			■
	Food Growing Supplies		■	
	Employment & Income		■	
	Local Trade & Food Processing			■
	Green(ed) housing	■		
	Layered Infrastructure		■	
	Urban Connectivity			■
Spatial	Access to Outdoor Space	■		
	Brownfield Sites			■
	Greenbelt & Greenfield	■		
	Access to Nature		■	
	Spatial Diversity		■	
	Visual Amenity	■		
	Public Perception of Open Space		■	
	Public Space	■		
Social	Leisure	■		
	Neighbourhood & Local Identity			■
	Ownership & Agency	■		
	Sustainable Urban Lifestyles			■
	Public health & Nutrition		■	
	Food Culture			■
	Local Food Consumption			■
	Access to (fresh) food		■	

Table 3: Relevance of socio-economic themes to the Pilzling business model

6.1.1 Environmental

Local & Organic Food – Highly Relevant

The Pilzling farm was based directly within the city limits of Cologne. The production amount was up to 40 kg/week, and since this amount was not suitable for wholesale distribution, all products remained within the urban food network of Cologne. Throughout the 15-month operation, all products sold were through direct marketing to individual people and restaurants. The customers were able to inquire directly to the farm management regarding questions and concerns they may have.

The production was not certified organic; however, the processes use bio- and bio-quality inputs when possible. The planned Pilzling 2.0 facility will produce between 500-600 kg/week, but despite the higher volume, distribution is still planned at a local level. The team is interested in establishing a bio-certified production, however, more bio-certified waste-providers will need to be found.

Food Miles – Highly Relevant

The food miles attributed to the final harvested products at Pilzling are low due to the urban location. All products were delivered locally, with the most distant regular customer (not including individuals) situated 6 km from the farm and all outgoing deliveries were made entirely with cargo-bike transportation.

Transportation of substrate and other production materials is higher than an industrial farm since the materials must first travel to a manufacturing and/or distribution center. The largest input by volume is wood chips and sawdust, and as the operation scales, the company plans and collaborate with a local sawmill for wood chips and saw dust, which would decrease the food miles within the supply chain. However, some the transportation of substrate materials is offset by the amount collected from spent coffee grounds from the urban area, which were also collected using a cargo-bike.

In the case from Dorr et al (2021), the farm was located a distance of 35 km from a city where spent coffee grounds were collected, and 45 km from where the product was delivered, and since these distances had to be travelled multiple times per week, they represented a significant amount (16%) of the total CC impact. Because of the more central location of Pilzling and use of cargo-bike logistics, it is assumed that the CC impact contributed by delivery and spent coffee grounds collection would be significantly lower.

Industrialized Food Production – Highly Relevant

The production of mushrooms at Pilzling followed a non-industrial process, however, the activities were designed in a way that can eventually be scaled for a highly productive commercial activity.

During Pilzling 1.0, mixing of substrate was often performed by hand or with the aid of simple tools. Machinery and equipment throughout the farm were self-built (e.g. pasteurization barrels, automation equipment, etc.). The non-industrialized production methods were often admired by customers, with several commenting throughout the operation that due to our methods, they felt that they could trust the product more.

The non-industrialized production did create higher amounts of contamination throughout the production. Insufficient pasteurization and unoptimized farm layout/design (i.e., small production space, fruiting room layout, immobile shelves) are assumed to be the largest contributors to these losses. Contamination rates per batch sometimes reached as high as 50%, where industrial farms usually experience a rate of less than 1% (based on site visit of *Pilzgarten)*.

Following a more industrial production is in fact desirable in terms of resource efficiency since it can substantially reduce the total impact of the farm. It was cited in the literature case study by Dorr *et al.* (2021) that by implementing stricter hygiene and handling procedures, the contamination rate of 25% could be significantly reduced and higher yields could be experience, which could therefore reduce the total climate change impact by 43-46%. Going forward, the Pilzling 2.0 operation is planned to sterilize the substrate using an autoclave.

The Ecological Footprint of Cities – Relevant

Urban agriculture is often seen as a strategy to reduce the ecological footprint of cities; however, for an intensive operation such as Pilzling that uses considerable amounts of energy and electricity, these benefits are not clear and an LCA specifically for the Pilzling farm would need to be conducted in order to confirm that.

Biodiversity – Not Relevant

No significant contributions to biodiversity.

Soil Toxicity & Remediation – Relevant

Spent substrate produced by Pilzling was picked up by local garden associations which used the material for compost material and soil conditioning. As production increases, the company intends on continuing to build partnerships with local businesses and agricultural producers to ensure spent substrate ends in a natural system.

As discussed within chapter 2.3, spent mushroom substrate can be used to remediate soil impacted by industrial contamination and increase soil fertility.

Waste Management – Highly Relevant

One of the core business activities and the foundational idea to the company formation was the collection and use of urban bio-waste materials for mushroom cultivation. Over the course of the 15-month test farm, 1777 kg of coffee grounds were collected from café partners within the nearby area. The use of secondary materials in the production offset some of the need for raw-virgin materials (sawdust, woodchips, straw).

The collection of material and preparation of substrate in an efficient and hygienic manner remained a difficult task for the company. Firstly, creating a robust collection system in partnership with the cafés was a complex activity since every café had different workflow systems and variability in their on-site storage space for a collection-container. Often, small pieces of plastic and other café-waste were found mixed into the coffee grounds, since the employees had not learned the new waste-separation workflow. The pickup schedule also had to be carefully planned, since the cafes had different opening hours and expectations for timely pickup. On-farm storage and preparation of the material was often cumbersome due to the weights and shapes of the storage containers.

Managing the waste leaving the farm was also an ongoing activity. The plastic cultivation bags had to be first separated from the substrate and properly disposed, and the spent substrate was then stored on-site before being picked up by garden groups.

As production scales, the amount of biomaterials needed will need to increase. The Pilzling 2.0 farm is planned to use a similar cultivation method, however, logistics will have to be better planned since this amount was not economically feasible when considering the labour hours required in the pickup and processing steps. Despite the challenges posed by the collection and recycling system, Pilzling sees a large opportunity to expand their operations in the direction of waste management. The company first plans to extend the range of biomaterials used in the substrate to other biomaterials such as spent brewer’s grain, bakery waste, and cardboard. Collaborating with fewer but larger partners will lead to a more efficient pick-up system, and Pilzling plans to monetize the waste collection at a later stage. As well, the use of waste-materials in their operations has proven to be an interesting concept for marketing and public outreach.

CO2 & GHG emissions – Relevant

The intensive nature of Pilzling’s operation involves the constant use of electric ventilators and monitoring systems and fridges, as well as intermittent and/or seasonal use of equipment such pasteurization units, autoclaves, mixing devices, heaters, and other small devices.

The carbon capture from the waste collection and use of coffee grounds represents a small offset in the total emissions, but it is not enough to make the farm CO2 negative. Based on the similarities between Pilzling and the literature case study by Dorr *et al.* (2021), it can be assumed that the CO2 equivalent emissions per kg of mushroom would be a similar value, which, according to the authors, is also comparable or slightly less under an optimized scenario to other industrial mushroom farms.

6.1.2 Economic

Air & Water Management – Relevant

Water was used for the substrate preparation, humidification, and on-farm cleaning. For every one tonne of substrate, about 500L of water was used. Humidification requirements was estimated to be between 4-6 L/m2 per day. These values are not significant and would be comparable to other urban production centers or restaurants.

Pilzling also filters their emitted air to ensure low spore emissions. This increases operational costs slightly to replace the filter on a regular basis and will involve a higher investment cost for a robust ventilation and filtering unit in the next facility.

Training & Education – Highly Relevant

Training and Education was a major part of the Pilzling operations, mainly through farm visits and tours. Part of the original rental agreement was to allow public tours of the facility, which occurred regularly during the 15-month operation.

The tours allowed members of the community to see first-hand how their food was produced and opened discussion about the methods and reasoning for our production methods. This discussion had two major effects. Firstly, it allowed visitors to question their own knowledge and lack there of about food production and trade. Many visitors expressed that they were unaware how mushrooms were grown, and often stated that this lack of knowledge extended to other fresh food production industries as well. Secondly, the discussions allowed the Pilzling management to better understand concerns and demands about the products and activities of the farm. Two of the more consistent concerns was the use of electricity and single use plastics.

No educational or workshop courses were given during the Pilzling 1.0 pilot, however, they are planned for the next operation. These courses would offer attendees the hands-on opportunity to dive deeper into the biological aspects of mushroom farming.

Training also took place in other forms such as the internal training of new team members, as well as the learning that took place through R&D.

Food Growing Supplies – Relevant

Pilzling did not produce any food growing supplies during the Pilzling 1.0 operation, however, a home-grow-kit was developed during the time and is planned for sale beginning in a Pilzling 2.0 operation. The home-grow-kit would allow customers to produce small amounts of mushrooms in their homes.

Planned as well for the Pilzling 2.0 operation is the production of inoculated substrate blocks for other farmers.

Employment & Income – Relevant

Pilzling 1.0 was founded and constructed by two people, but as production began, two additional founders were onboarded. The operations of the farm including cultivation, sales and marketing, maintenance and administration were enough for all founders to be required for 30-40 hours/week. Due to the low production, the amount generated in sales was not enough to pay salary to the founders. In November 2021, the Pilzling team began receiving the 1000 Euro NRW Founder's Scholarship, which allowed a fourth team member to be onboarded.

The company has set ambitious visions for creating a fair and safe workplace in the future. Job applications and interest from individuals has demonstrated an early demand for employment. Through conversations, many of these individuals have expressed the desire to work for an impact-driven company.

To pay a meaningful salary to founders and employees, the Pilzling 2.0 operation plans a much higher production volume. It is also planned, that an additional three permanent employees (farm manager, sales leader, production leader) as well as up to four part-time production staff will be required.

Local Trade & Food Processing - Relevant

Much of the produced product was sold to local restaurants, distribution services, and food product manufacturers. These services and added value processing allow other businesses to collaborate with Pilzling and often benefited both parties.

For example, Pilzling purchased most of its spawn requirements from a local producer, and because of the regular orders and on-site pickups, a discount was given, and delivery costs were excluded. This partnership is planned to develop further with conversations beginning around forming a joint venture agreement.

Green(ed) housing – Not Relevant

No significant contributions to green(ed) housing technologies.

Layered Infrastructure – Relevant

Implementation of industry 4.0 technologies such as the installation of sensors and microcontrollers as well as the design and use of a digital data management system and smart-phone app occurred during the Pilzling 1.0 operation. The team has applied for a scholarship that would fund the further development of the hardware and software with the goal of creating an AI system for on-farm decision-making.

The use of these industry 4.0 technologies has improved resource efficiency within the firm. Until now, digital inter-firm connectedness is still not present, however, the company aims to develop digital strategies that allow for integrated harvest to sales methods

Urban Connectivity – Highly Relevant

The sales network established by Pilzling is based entirely in Cologne, and product was sold through direct marketing. Due to the urban location, new customers were acquired primarily through word-of-mouth, social media campaigns, or on-farm visits.

B2C sales are usually arranged through orders on the website, or through 3rd party platforms such as *Marktschwarmer*. B2B sales to restaurants and other food businesses are arranged normally by phone usually several days before delivery and based on available product for the week. Sales to a weekly vegetable box subscription company (Himmel un Ääd) allowed for distribution to private customers in Cologne.

The direct sales business model allowed for strong relationships with some customers to develop and offered the opportunity for customers to speak with Pilzling staff to give feedback when necessary.

Being located in Wandelwerk attracted many urban actors to the farm that were not directly related to the urban agricultural or mushroom industry. This mix of visitors allowed for a variety of ideas to be exchanged and improved the network of Pilzling.

6.1.3 Spatial

Access to Outdoor Space – Not Relevant

No significant contributions to access to outdoor spaces.

Brownfield Sites – Highly Relevant

The controlled environmental nature of mushroom cultivation allows it to be performed in a variety of spaces, especially for brownfield sites and those that may not be suitable for other businesses. The WandelWerk location could be considered a brownfield site since it was an empty auto-dealership and mechanic shop and had no secondary use.

The Pilzling 1.0 operations were very in line with the values proposed by the KLuG e.V. and the goals for Wandelwerk. As stated by the Wandelwerk team, “civil-society engagement, public welfare-oriented management, creative development, and social encounters came together at this place and were translated into future-oriented concepts.” By converting the brownfield site into a center that hosts future friendly technologies and ideas, the Wandelwerk embodied the idea of urban revitalization. This idea brought a lot of urban residents to the site that were passionate about creating a sustainable form of urban living.

Greenbelt & Greenfield – Not Relevant

No significant contributions to greenbelts & greenfields.

Access to Nature – Not-Relevant

No significant contributions to access to nature.

Spatial Diversity – Relevant

Wandelwerk represented a diverse space for the city of cologne, however, whether Pilzling was part of this spatial diversity could be debated. The operations of Pilzling took place on commercially designated space, therefore, in terms of *public* spatial diversity, Pilzling contributes very little. However, through conversations with stakeholders, some were happy to know that an urban farm project was taking place in Cologne, with some referring to the project as “unique” or “state of the art.”

Visual Amenity – Not Relevant

No significant contributions to visual amenity.

Public Perception of Open Space – Relevant

One of the key goals of WandelWerk was to demonstrate how access to space can create new forms of social-economic activities. During the 15-month project, the WandelWerk hosted numerous activities and acted as a central location for urban stakeholders including the public to discuss the value and use of urban space.

Visitors to the Pilzling 1.0 farm could witness the experimental processes undertaken. Through these tours and public interactions, Pilzling often discussed the importance of trying new things and challenging the industrial status quo. Many visitors reacted positively to the ideas and goals of a circular based agricultural production system, and by being located in WandelWerk, Pilzling was able to be a key case study for the project in the benefits of providing space to these types of new concepts.

Public Space – Not Relevant

No direct contributions to public space.

6.1.4 Social

Leisure – Not Relevant

No significant direct contributions to leisure.

Neighbourhood & Local Identity – Highly Relevant

Pilzling 1.0 was situated in the Ehrenfeld neighbourhood of Cologne. This location was partially chosen due to its reputation as a hub for progressive people, ideas, and activities. It was assumed during the planning phase of the project, that by leveraging the Ehrenfeld location and by emphasising efforts to act ecologically, a strong community support and interest in the business could be established, which could facilitate early success.

The waste collection activities formed partnerships with some of Cologne’s most popular cafés, which assisted in some of the early marketing activities of Pilzling. Often, during the waste-collection tours, members of the public would inquire about the activities and ask what was happening to the collected materials. Some customers and visitors of Pilzling were people that heard of the farm through their local café.

Building a local Cologne identity continues to be an important part of the Pilzling marketing strategy. On all communication channels, Pilzling introduces itself as “Cologne’s Circular Mushroom Farm” (“*Kölns kreislaufbasierte Pilzfarm”*). As Pilzling expands, part of the branding strategy will continue to leverage local stakeholders, such as cafes and restaurants, but larger businesses will also be targeted.

Ownership & Agency – Not Relevant

No significant contributions to ownership and agency

Sustainable Urban Lifestyles – Highly Relevant

The central location of Pilzling allowed for many customers to visit the farm for in-person pickups. During farm-pickups, customers often stated that they ordered specifically because they wanted to support a sustainable activity. Many customers came to pick up the mushrooms on their way to or from another event or activity taking place in Ehrenfeld.

The decision to remain in the city for the Pilzling 2.0 operation was made to continue building the brand and reputation. While a more rural based operation could allow for lower rent prices and a larger production, networking with urban stakeholders and participating in the daily life of the city would become more difficult.

Public health & Nutrition – Relevant

Fresh Mushrooms can be considered a healthy food product and are sometimes referred to as a superfood. The planned activities for Pilzling 2.0 involve the manufacturing of several food products. These products range from dried mushrooms, to mushroom based-meat replacement products. The processing procedures plan to use organic ingredients and do not involve high amounts of added sugar, fats, or preservatives.

Food Culture – Highly Relevant

The urban location of Pilzling allowed the company to participate in several cultural aspects of the food system.

Pilzling focusses strongly on creating gourmet, high-quality products. Gourmet mushrooms are esteemed food products in western Europe and Germany and can receive high market prices (up to 30 euros/kg). These high prices are often considered exclusive and can therefore add a level of status to meals. Some of the restaurants that Pilzling supplied were high-end Michelin certified, which are influential within the culinary scene and often set new food trends.

A significant cultural debate surrounding mushrooms as a possible meat replacement exists. By replacing meat-based dishes with a mushrooms, the goal is to reduce GhG emissions and total environmental impact. Pilzling is active in this conversation and is developing a line of mushroom-based meat replacement food products.

Local Food Consumption – Highly Relevant

Products cultivated during the Pilzling 1.0 farm were sold entirely to local consumers. This was partially due to the low production and inability to sell to a larger area; however, it is planned to continue expanding the restaurant portion of the business in the future, which would contribute to local consumption.

By collaborating with local businesses and produce distributors, the products produced by Pilzling were often packaged with other local producers. This was the case with the vegetable box delivery company, which collects products within a local radius of up to 400km from Cologne.

Access to (fresh) food – Relevant

The central location of the farm facilitated efficient distribution and logistics. This avoided very little product not getting sold, since any leftover product could be sold at a discount to people in the nearby area. The prices per kilogram were higher than the market prices of similar products offered at supermarkets and were comparable to products that are organic-certified. These higher prices and gourmet branding may be considered a barrier to access for some consumers.

6.2 Discussion

Of the 24 contributions, a total of twelve were scored as highly relevant for the Pilzling business model. These contributions represented all societal dimensions; however, social, and environmental dimensions were the most applicable. For some of the contributions, especially those related to the ecological dimension (e.g., food miles, local organic food), tangible resource flows were the most important and relevant for examination. In contrast, some of the contributions, particularly those that took place in the social dimension (e.g., neighbourhood & local identity, sustainable urban lifestyle, etc.) were based much more on the flow of intangible resources such as information, values, and ideas.

As to whether this evaluation method or the contribution framework chosen for this study adequately characterises and interprets the relevance of Pilzling activities across all dimensions is open to debate. For example, many of the spatial aspects of the framework factor in outdoor urban agriculture, which is why only one spatial aspect (Brownfield sites) was selected as relevant for further analysis. To include indoor dimensions, a framework could include an assessment of building type and use, and whether it is a purpose-built or reused building. Another quality that may be overlooked in this framework is the modern technological aspects of urban agriculture, especially the implementation of industrial 4.0 digital monitoring and control technologies.

This matrix also excludes any aspects that may be considered “negative” contributions. To address this structural bias in the matrix, I attempted to balance my interpretations by addressing some of the negative externalities of the Pilzling operations. For example, while the Pilzling business model fundamentally strives to be low impact, the ecological footprint of cities was scored only as relevant due to the biological inefficiencies of the farm and to justify the inevitable impact of the electricity use.

7 Contributions to Circular Economy

To address the second objective of this thesis, this chapter will interpret the business model contributions towards a CE. The Sorensen network (Figure 25) displays the intertwined relations between Pilzling operations, and the most relevant socio-economic contributions that were outlined in section 6.1. These contributions are then causally linked to the four CE building blocks through thirteen impacts. I will discuss these interlinkages in more detail below.

7.1.1 New Skills for Circular Products & Services

Already, many businesses operating within the vertical farming scene have successfully demonstrated that an urban agriculture business model can function, however, very few of these businesses refer to themselves as implementing circular practices. As urban agriculture continues to be touted as a possible strategy for sustainable food systems and circular cities, it then sets up a contradiction: why is urban agriculture a circular strategy if few businesses are operating with a circular business model? Furthermore, the challenges related to implementation outlined in section 2.2.5, and more particularly those that lead to the so-called “circularity for circularity’s sake” may also erroneously associate any of the perceived contributions to CE to those occurring from the “circular” business model of the farm. Furthermore, a more critical examination of the products and services in the form of a LCA or MFA would be needed as to determine whether they truly fit a CE paradigm on a tangible level, and in addition to being tedious for every urban farm and urban farm product or service, it would continue to overlook contributions to the social dimension. Therefore, it is more valid to look at whether there is a contribution to *new skills* for circular products or services, which were assigned to three effects and impacts: increased industry research and development, innovations to traditional business model, and creation of new jobs.

Research and development for new products was especially relevant for mushroom cultivation techniques and technologies (1-C) as well as procedures for waste handling (1-D) with the primary goals of increase the farm output while lowering use of virgin materials. Due to the smaller scale and urban nature of Pilzling’s operations, cultivation techniques had to be designed to meet the requirements for a smaller space and without the use of industrial equipment. Throughout the study period, key innovations improved the waste handling and substrate mixing techniques, pasteurization processes, and the digital environmental controls on the farm. The R&D process and resulting innovations generated skills related to urban farm design, biological system control, and digital equipment implementation.

□	Tangible Resource Flows
○	Intangible Resource Flows
ϕ	Both Tangible & Intangible Resource Flows
•	Contribution Towards Circular Economy

Pilzling Internal Operations	A. Local & Organic Food	B. Food Miles	C. Industrialized Food Production	D. Waste Management	E. Training & Education	F. Local Trade & Processing	G. Urban Connectivity	H. Brownfield Sites	I. Neighbourhood & Local Identity	J. Sustainable Urban Lifestyles	K. Food Culture	L. Local Food Consumption
Socio-Economic Contributions	Enviro.	Enviro.	Enviro.	Enviro.	Econ.	Econ.	Econ.	Sp.	Social	Social	Social	Social
Urban Mushroom Production	□	□	□		ϕ	□		ϕ	○		○	□
Bio-Waste Collection & Composting		□		□	ϕ		○					
Sales: B2C	□	□			ϕ					○		□
Sales: B2B	□	□			ϕ	○	○		○		○	□
Research & Development			○	○	ϕ							
Team Building					ϕ							
Tours & Community Engagement					ϕ		○	ϕ	○	○	○	
Social Media & Press					○		○		○		○	○
Fundraising			□	□								

A	B	C	D	E	F	G	H	I	J	K	L	**Effects & Impacts**	**Circular Economy Building Blocks**
		•	•									1. Increased Industry Research & Development	**1. New Skills for Circular Products & Services**
	•		•									2. Innovations to Traditional Business Models	
				•								3. Creation of New Jobs	
				•					•		•	4. Increased Value and Appreciation for Food	**2. Shifting "Consumers" to "Users"**
	•		•		•	•						5. New Waste Collection Methods	**3. Innovations in Waste Management**
			•									6. Optimized material handling processes	
•	•		•	•	•	•	•	•	•	•		7. Increased Cross Sector Collaboration	**4. Support from System Enablers**
	•	•	•									9. Increased Investment Opportunities	
		•	•									10. Shifts in Legal Framework	
•	•	•	•	•	•	•	•	•	•	•	•	11. Increased education about CE	

Figure 25: A modified Sorensen network depicting the interrelations between the Pilzling resource flows, their socio-economic contributions, and causal relationships to CE building blocks

Innovating a traditional business model (i.e., agriculture) also generated skills related to circular business management, urban network building, and technical implementations. The Pilzling business model was based primarily on a secondary raw materials/by-product recovery model that collected spent coffee grounds and recycled them to produce mushroom substrate (2-B). While the reuse of agricultural by-products is commonplace within the mushroom industry, the reuse of urban waste streams is an evolving sector. Some companies have developed urban bio-material substrates that are able to compete with traditional substrates on a biological efficiency basis, however, it may come at a higher operational cost due to smaller scales of economy. This means smaller producers may be able to establish a niche producing a sustainable substrate alternative, however, to achieve this, farms will need to learn how to leverage the benefits of waste recycling in a profitable manner to attract investment and achieve a cost advantage. The urban location of the business also allowed the business model to leverage local branding to fetch a higher sales price from both B2B and B2C sales, as well as implement bicycle logistics for both incoming and outgoing materials (2-D).

Throughout the study period, Pilzling created work for four people on a nearly full-time basis. No wages were paid during the 15-month operation and all compensation was provided through the NRW Founder Scholarship, but when asked whether an unpaid position is still considered a “job” Verena Hermelingmeier stated:

> *“A job can mean ‘making money’, or also having meaningful work to do. […] you guys are learning a lot at the moment, and maybe at some point everything you’re learning now, and all the skills you develop will help you make money off what you're doing. And growing and then maybe really creating more jobs.”*

Based on this reasoning, it can be considered that Pilzling created four jobs (3-E). Before the employment began, all team members had little to no experience in urban agriculture, mushroom cultivation, or circular business operation, but through the team building, and research development enough skills were developed in these fields to secure interest in expanding the business. The future steps stated in section 5.2.3 outline the intent to establish the Pilzling 2.0 farm, which is planned to hire three to five additional team members in the first two years. This creation of jobs combined with the business expansion can than be an economic testament that skills related to circular products or services support the operationalization of CE.

7.1.2 Shifting “Consumers” to “Users”

The shift from consumers to users aims to eliminate the “end of life” concept. It reinforces the idea that a product should not be considered consumed and worthless, but used and ready for reuse. One of the more common types of such a model is the “Product as a Service” (“Paas”) type, where companies may provide the product through a lease or rental agreement. This business model has been generally backed by CE supporters, since it generally puts the company in a position to take responsibility for the product throughout the entire lifespan of the product including the installations, maintenance, upgrades, take-backs, and end of use treatments. Companies therefore focussed on product performance, quality, and extending product lifespan (i.e., eliminating planned obsolescence) generally outperform their competition and consequently reduce waste throughout their value chains.

Within the food industry, delivery services and restaurants have begun using “Food as a Service” business models by providing on-demand services to customers to replace both restaurant and at-home cooking. However, despite the “service” term, these models fail to take on any responsibility for the food product (or packaging) throughout the product-lifetime. By ignoring the later stages of the product lifespan, food companies benefit as consumption increases, and therefore, it brings to question whether the PaaS business model can be applied to the food industry as a CE strategy. For that reason, I would propose that the food industry needs to redefine performance and what it means to shift towards a more user-based system. If one of the ecological goals of a performance business model is to reduce waste on the consumer end, then I would argue that circular businesses models in the food sector can achieve this by lowering waste. From the perspective of shifting consumers to users, this means, focussing on consumer strategies that increase the value and appreciation for these products.

Contributions from Pilzling that increased the value and appreciation for food products were linked through both tangible and intangible resource flows. The company implemented a sales strategy that leveraged high quality products for a higher price point, which was achieved through organic production methods (non-certified) and often used their urban location and “same-day harvest & delivery” as a USP for product freshness (4-A). These qualities allowed the company to market their product in the same class as other gourmet and high-grade products. As well, Pilzling was able to communicate and present these qualities through educational and science-based discussions to visitors during on-site tours (4-E).

The activities of Pilzling also contributed to the increased appreciation for food through intangible resource flows, such as the company values, the business model, and Pilzling brand. Stated within the Pilzling values: “*We respect people and nature. We don't prioritise profit over ecological or social sustainability. Whenever possible, we integrate methods of CE within our business model.”* Values such as these were often disseminated through communication channels such as community events, social media and other press releases, as well as on-farm conversations.

While some consumers value fresh local produce based more on the physical quality of the product, the effects of the intangible resources influence rather a perceived product value. This perceived value can influence what people think is important to consume within a diet and can lead to a so-called “growing of the plate” – increasing the ingredient options (those with particular value) for a specific diet or dish.

> *“[…] people associate what you eat with status, and if what we are doing can replace the idea of “meat consumption” as a signifier of status, with “urban vegetable product” as a symbol of status, I view that as a success.” (Interview with Cristian Wedgwood)*

This increase of options may result in some people opting for low-impact ingredients without foregoing satisfaction, and if these ingredients replace a high-impact item, some resource efficiency can be achieved.

7.1.3 Innovations in Waste Management

Waste management innovations that contributed to reversing the urban biological material cycles occurred through creating new collection methods, as well as optimizing the material handling processes.

The collection system was organized by Pilzling and was operated using bicycle logistics to maintain low operating costs (5-B). The collection system was modified and adapted throughout the operation to meet the needs of Pilzling and the cafes, as well as to ensure the quality of the waste was preserved between the time of generation to time of recycling (5-D). Due to the bicycle logistics, collection routes were planned in the local surroundings of the farm (5-F), and throughout the operation, new cafes joined the collection program often having heard throughout the urban network or through social media about the Pilzling services. Since most cafes were eager to participate in the program, the collection system was able to leverage a certain connectivity between the cafes to ensure that the waste being collected was to a certain quality standard. Cafes therefore were more careful about separating their waste in an organized and clean manner to ensure they could remain within the program (5-G).

Due to the biological susceptibility of the collected material and likelihood of contamination, the handling procedures within the Pilzling cultivation processes were constantly being improved (6-D). As one of the main R&D topics throughout the Pilzling 1.0 operation, ensuring the resources did not get wasted by contamination was an important factor in the overall operating costs and resource efficiency of the farm.

7.1.4 Support from System Enablers

The CE system enablers provide external support for the operationalization of a CE, and this external support provides a framework for the success of an early CE network. Therefore, the socio-economic contributions from Pilzling with respect to these system enablers, occurs entirely within the external the urban and CE ecosystem.

The business activities interacted and attracted interest from both commercial and non-commercial organizations, and throughout the Pilzling 1.0 operations, numerous partnerships across different sectors were developed. Perhaps the most notable forms of cross sectoral collaboration were the waste management partnerships between Pilzling (urban agriculture) and the local cafes and restaurants (gastronomy), however, other forms of collaboration occurred with food delivery companies (logistics), maker spaces (technology), online and media content creators (entertainment), carpenters (design), as well as local photographers and videographers (art). As part of the Wandelwerk community, Pilzling benefited and was supported by the network, but also contributed to the space by attracting people to the center and assisting or attending activities and events within the building or extended community.

CE business models, as well as innovative companies in the agricultural technology sector are both attracting new investments in recent years. Urban agriculture is certainly an emerging field, with recent companies such as *infarm* demonstrating that there is a large interest in funding innovations within this sector. Based on funding acquired through the NRW Founder Scholarship, the Pilzling business model certainly meets a level of “innovation.” As the Pilzling business enters it’s first round of investor-led funding to build the next farm, it could prove to be an interesting investment for a portfolio in the sector. By being active in the Cologne urban agriculture and waste-management start-up ecosystem, a confirmed investment could bring further attention from investors to the region or to the sectors.

One of the biggest hurdles for emerging technologies, concepts or industry in any sector is the navigation of local and national legal frameworks, since operating within a "regulatory grey zone" can be a risky proposition. For example, German laws that govern both the commercial primary production of food in cities, as well as how bio-waste materials can be recycled into materials for food production are not well defined. There is no law that says food production can't take place on a commercial property, however, this food production can not fall under the framework of agriculture since agricultural food production requires agriculturally designated land. Likewise, the rules governing "waste" are very strict within the German legal frameworks, however, if the coffee grounds are considered to still have value and are labeled as a "by-product," they can be further processed under normal food hygiene rules. In other words, both of Pilzling's primary value cases engage in legal grey areas. Innovating within these areas can often go unnoticed until an industry is already well established or pressure from citizens or other businesses actors force a regulatory authority to act. Activities within these grey areas may be risky, however early industry players can sometimes create shifts in the legal framework that create favourable conditions for future development.

Education regarding CE is one of the more nuanced enablers, and I would propose that this education or learning can be interpreted in three ways. Firstly, learning can take place through the simple transmission of an idea, to teach someone about a concept. This type of "transactional learning" takes place for example when someone hears that CE can reduce resource use, and they support the idea simply because they understand it to be good from an economic/ecologic/social perspective. Secondly, a learning of best practices takes place when individuals, businesses, or organizations hear or see something and begin to replicate some of the processes. For example, a business can learn from another business, repeat the process in their own facility, and shape their business using practice techniques. This type of "industry learning" can help leverage innovation both through competition or through collaboration and shared resources. Thirdly, a type of learning can also take place that transcends sectors and occurs as a type of societal learning. This type of "network learning" may originate from a common goal, but the methods and activities to reach the goal differ throughout the society. In her interview, Verena Hermelingmeier referred to this group learning as a "learning entity," that can set out to be transformative together and co-produce their context together.

The twelve socio-economic contributions selected for analysis were interpreted to have all led to an increased education about CE. For example, the local sales of fresh product to customers allowed a simple learning of the Pilzling CE business model and the importance of buying local produce (11-A, 11-B, 11-F, 11-L). This was reinforced with tours of the facility when individual customers came to the farm to pick up their mushrooms. Through the operations, Pilzling networked with other small producers and industry partners (11-G), who could visit the farm and learn best practices for managing a small business or about the cultivation techniques (i.e., how to handle waste materials, how to mix substrate, how to control the farm, etc.) (11-C, 11-D, 11-E). The Pilzling activities also created the third type of system learning:

> "*I think that small companies are sometimes underestimated in what they can do, by not only acting in a local context, but also having a 'lighthouse' or 'role model' effect. […] Especially Pilzling as an example, everyone wants to see it, and it inspires people to do things differently, to think of new way innovative ideas how to produce, for example, food in the city. If it turns out that mushrooms don't actually make sense for urban production or for feeding a population, then still I think you guys have shown that it's possible to develop new ways of urban food production."* (Verena Hermelingmeier, interview)

Most of this learning occurred by through the flow of intangible resources that contributed to making a Wandelwerk, a previously brownfield site, a greater place (11-H) or that flowed into the local neighbourhood and contributed to a shifting of food culture, and inspiring of people to purse a more sustainable urban lifestyle (11-I, 11-J, 11-K).

7.2 Circularity for circularity's sake

Most of the study examines the Pilzling business model and resulting contributions in a supportive and laudatory manner. This is of course a critique for much sustainability science, and since urban agriculture normally fits the current script for sustainable city design, it is hard to find frameworks that include the downsides of its implementation.

Although not one of the main objectives of this thesis, I think it is important to analyze some of the counter points of urban agriculture to avoid a conclusion that simply promotes its implementation for the enabling of CE. Since no framework was found in the literature that analyzes how new activities can inhibit CE (some exist for examining institutionalized inhibitors), I would therefore present three inhibiting factors in the form of trade-offs.

Trade-Off for Ecological Resource Efficiency

In addition to high real estate prices, urban agriculture also faces the challenge of increased natural resource use, and whether the proposed ecological efficiencies for controlled environment agriculture are feasible or even possible have yet to be decided. Our global food demands and regional food security should not be governed strictly by the total amount of resources required to produce our crops, however, if urban agriculture is to be realized as a legitimate strategy for urban food systems, and circular city design, it needs to be planned carefully. This means using renewable energy, designing out waste, and using sustainable (re-used or recycled) inputs whenever possible.

It also means applying circular concepts only where they make sense. In the example of the shelves made of recycled wood, the uncontrolled contamination was a major contributor to wasted tangible resources, as well as the intangible resources. Therefore in this case, the business would have operated much more efficiently if the shelves were made from a new, more resilient material.

Trade off for Urban Space

Most urban food projects are currently small scale, however, if companies begin to scale operations, or if some of the larger urban farm concepts are ever realized, spatial trade-offs need to be considered. Growing food within the city can contribute positively from a spatial perspective, however, profit seeking urban farm projects should not take priority over other urban spatial requirements (i.e., housing).

Trade off for Sustainable Investments

Overcoming the initial high costs to urban agriculture for both the R&D as well as the equipment will require significant financial investments. While a lucrative urban agriculture can certainly help build a sustainable investment portfolio that may invest in other diversified sustainability technologies, it can also be argued that every euro spent in the R&D for urban agriculture technology is a euro not spent on implementing an already proven technology that acts to limit climate change or other environmental challenges.

8 Conclusion

This thesis opened with a question of whether urban agriculture business models could be considered compatible with holistic CE frameworks. This thesis built upon a current CE definition that underlines the importance of a CE model that not only creates economic value, but also ecological and social value.

The first objective of this thesis aimed to unpack the current discourse and understanding of urban agriculture through the analysis of the Pilzling case study. A detailed overview of the business model was presented, and the activities that occurred throughout the 15-month pilot project at Wandelwerk were summarized. The activities were then abstracted and scored on their relevance within different socio-economic contributions. A total of twelve contributions were scored as highly relevant within the Pilzling business model with representation across all societal dimensions, but most falling within the social and environmental dimensions. Whether this method of scoring, or the contributions framework selected for this study adequately characterizes and construes the relevancy of the Pilzling activities equally across the dimensions can be debated. This is because some aspects such as the spatial relevance for indoor urban agriculture and the technological innovations may be underrepresented in this matrix.

The second objective of this thesis intended to link how these contributions may enable the operationalization of a CE by creating causal links to four CE “building blocks.” Firstly, new skills for circular products and services were interpreted to have been created during the Pilzling operations by the increased R&D, the circular business model innovations, and creation of new jobs. Secondly, the Pilzling business model contributed to increasing the value and appreciation of food, mainly through intangible resource flows and interactions that facilitated social learning. Thirdly, the activities related to urban bio-waste collection contributed to innovations in waste management, especially in the creation of bicycle based logistic strategies. Finally, the Pilzling business model impacted the CE system enablers by increasing cross-sector collaboration, attracting and creating investment potential, operating in undefined legal domains, and by strengthening CE education within all socio-economic dimensions.

While urban agriculture may be a positive contributor to the operationalization of CE, three trade-offs were identified. Resource inefficiencies as well competition for urban space and sustainable technology investment funds should be recognized as possible inhibitors to a more holistic CE concept. While these trade-offs don’t entirely compromise the notion of urban agriculture as a viable strategy for circular cities, they should be acknowledged and considered on a case-by-case basis to ensure that urban agricultural businesses are implemented in a sensible and strategic manner.

Future Work

Quantified data regarding resource flows were outside the scope of this thesis, and the conclusions stated above begin to only provide a foundation of how to interpret the theoretical contributions of an urban production business towards CE. Therefore, I would suggest further steps need to be taken to measure the impact the flow of these resources may have. Firstly, more LCA and MFA data about urban agriculture like that generated from the study by Dorr et al. (2021) needs to be completed to quantify the material resource flows in different regions, different cultivation techniques, and for different products. Secondly, to begin quantifying the impact of the intangible resource flows, methodologies that analyze social learning and consumer choices should be employed.

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