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- Sustainable Business & Innovation -

Accelerating the transition towards a Circular Economy and sustainable food waste management

The case of Singapore

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PREFACE

This thesis research - as part of the master's thesis for the program Sustainable Business and Innovation - was conducted in collaboration with Utrecht University and the Embassy of the Kingdom of the Netherlands to Singapore and Brunei, which is part of the Ministries of Foreign Affairs and Economic Affairs and Climate Policy of the Netherlands.

Context of the study: The Netherlands and Singapore are aiming for a circular economy. Both countries have confined space, are highly urbanized, strong innovators, and are mostly dependent on imports for their resources. Dutch and Singaporean businesses, knowledge institutes and governments, therefore, initiated to join forces and create a basis for a circular economy in an urban context. The goal is to identify bottlenecks and solutions for the transition towards a circular economy. The role of the Embassy in this is to provide (Dutch) companies and other organizations with independent research on market developments, trends and opportunities within the field of technology and innovation, with the long-term goal to provide international collaboration and strengthen the international competitiveness of Dutch research and innovation. This thesis research is in line with this goal and to investigate the current developments of the innovation in the field of resource recovery and efficiency. Furthermore, it was partly commissioned by ReCirc Singapore, a conglomerate public private partnership of Dutch and Singaporean companies, research institutes, and the Dutch state (e.g. enterprise agency) specialized in circular economy solutions. In November of 2018 a Memorandum of Understanding was signed between the responsible ministries of Singapore and the Netherlands on extensive collaboration for resource recovery, indicating the relevance of insights into the development of resource recovery solutions to provide sound policy advice and to improve this collaboration.

ABSTRACT

Contemporary industries have a high throughput of materials without reusing or recycling resources, with detrimental consequences for ecosystems and climate. The food industry is a typical linear production system concerning tremendous amount of waste. Although the Circular Economy (CE), which aims to decouple material use from economic growth by looping materials back into the economy, is seen as a sustainable solution, little is known about what the socio-institutional transition towards a CE entails and how the transition can be measured. In this thesis, the Technological Innovation System (TIS) Framework with its seven functions of development was applied to study a CE transition in the food industry in Singapore, including mapping the structure and functions by means of desk research and 22 semi-structured interviews with expert and key stakeholders. Assessing the various technological and socio-institutional solutions brought about in Singapore, the focal TIS is in a (pre)-development phase. The lack of market formation for circular food waste products is blocking the overall development of the TIS, with low investments by the industry and low consumer demand. The function of legitimacy is weakening the function of market formation since consumers perceive circular food as unsanitary and consumers' and businesses' disposal habits are formed around a convenient waste management infrastructure. The function of guidance of the search is also blocking the development of the focal TIS, since government vision and strategies favor technological recycling solutions for heterogeneous waste over reduction initiatives. Recommendations for policy reform are based on overcoming resistance of current disposal habits, while altering perceptions of consumers about circular products is required to increase demand. Adjustment of current long-term policies is needed to induce guidance of the search towards reduction and recycling innovations.

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1. INTRODUCTION

Most economies around the globe have a high throughput of materials, which causes global resource deficiency, environmental degradation and biodiversity loss (Wieczorek & Hekkert, 2012). Consumed products are mostly discarded and landfilled, which lead to damages to surrounding environments through water pollution and soil degradation, and ultimately risking human health. Moreover, the increased demand for virgin materials strains hinterlands, with detrimental consequences for ecosystems and climate globally (Rosenzweig et al., 2011). If unaltered, this unsustainable linear pattern of consumption will lead to irreversible damages and threats to humanity (UNEP, 2011).

One example is the current food production, which is highly wasteful and inefficient. Approximately one-third of all consumable food is being discarded along the food supply chain (Gustavsson, 2011). This inefficient system leads to productivity loss, higher energy, water and resource usage, and higher costs for disposal (Tilman et al., 2001; Jurgilevich et al., 2016). Furthermore, the tremendous amount of food spillage causes environmental destruction and enormous nutrient loss; nutrients that could have economic value when utilized effectively (Jurgilevich et al., 2016).

A promising concept that might provide a sustainable solution is the Circular Economy (CE) (Mylan et al., 2016). With a systemic approach to reducing resource consumption, a CE aims to decouple material use from economic growth by looping materials back into the economy (Ghisellini et al., 2016; Mylan et al., 2016). By redefining waste as valuable resource, and designing products and production processes to be regenerative, the value of materials can be conserved. Ultimately, this could lead to reduced environmental pollution, as landfilling is made redundant and the input of virgin materials minimized (EMF, 2012).

Many countries have seen the need for a shift towards a resource effective economy (Borrello et al., 2017), and similarly, the city-state of Singapore has ambitions to become a 'zero-waste nation' (Sustainable Singapore et al., 2014). Although much has been achieved in past decades, Singapore still faces mounting problems, such as a crippling 800,000 tons of food waste per year and a confined amount of space for landfilling (NEA, 2017; MEWR, 2017a). Focusing on CE could potentially circumvent these problems, while simultaneously decreasing dependency on foreign supply (EMF, 2012). Due to these challenges, Singapore provides for a perfect case to investigate the transition to a CE.

In order to transition to a CE, Potting et al. (2017) stress the need for more empirical data on what a transition towards a CE entails and how the transition can be measured. Other scholars especially point toward missing research on what the transition means for all actors involved (Borrello et al., 2017; Moreau, 2017). A transition towards a CE is not easy to document as circular solutions require changes in technology as well as socio-institutional aspects of society, meaning changes in the way society functions with its written and unwritten rules, conventions, norms and values, consumption behaviors, and industrial standards, to name a few (Potting et al., 2017; De Jesus & Mendonça, 2018). However, research on CE so far has hardly accounted for the socio-institutional change required for a CE (Ghisellini et al., 2016; Potting et al., 2017; Moreau et al., 2017). Even more, the fact that little research has been conducted on socio-institutional change is indicated as a major obstacle for the implementation of a CE (Morea et al. 2017). Additionally, technological innovation is seen as one of the drivers for the transition towards a CE. It is, therefore, important to understand both the socio-institutional as well as the technological innovation changes required, and the interplay between them (De Jesus & Mendoça, 2018).

The aim of this research is to analyze the drivers and barriers to socio-institutional and technological innovation that advance and impede the transition towards a CE in Singapore, and how the transition can be accelerated. Analyzing a CE at large, however, is beyond the scope of this study. Since Singapore is currently dealing with a crippling amount of 140 kg of food waste per citizen per year, and space for landfilling is running out by 2035, Singapore urgently seeks ways to reduce its literally mounting food wastage (FoodBank, 2015; NEA, 2018a). Furthermore, as the food industry is identified as one the areas in which a CE can be successfully implemented (Jurgilevich et al., 2016; Borrello et al., 2017; Van Zanten et al., 2018), a focus has been placed on *the food industry* in Singapore. Thus, the following research question will be addressed: **What are the drivers and barriers that foster and hamper the transition towards a Circular Economy in the food industry within the city-state of Singapore and how can this transition be accelerated?**

To study a sustainability transition, two main theory groups with a systemic view have been developed within transition studies: the technological transition and innovation system approaches (Markard & Truffer, 2008; Markard, et al. 2012). These approaches are based on the idea that sustainability transitions are induced by novel technological breakthroughs and have, therefore, been geared towards technological innovations (Sarasini & Linder, 2017; Schlaile et al., 2017). However, although technological innovation plays a crucial role in the transition towards a CE (Mylan et al., 2016; Borrello et al., 2017), a CE transition differentiates from other sustainability transitions (e.g. renewable energy) by a stronger focus on socio-institutional change, e.g. changes in consumption models, production processes and business collaboration. In fact, innovation within CE transitions often has a focus on socio-institutional change and technological change plays a minor role or none at all (Potting et al., 2017). Transition studies, however, see technological innovation as the solution to the transition towards sustainability, while other dimensions, such as socio-institutional change, are less elaborated on (Schlaile et al., 2017). Therefore, to study the case of a CE transition, socio-institutional change requires more attention within transition studies.

Two comparable theories from both transition study approaches got most attention: The Multi-Level Perspective and Technological Innovation Systems (TIS) (Bergek et al. 2008; Markard & Truffer, 2008; Hekkert et al., 2001). In contrast to the Multi-Level Perspective, however, the analytical framework of the TIS-approach focuses on identifying obstacles (systemic problems) that impede the process of emerging technologies and its surrounding structure (Bergek et al., 2015). Therefore, the well-operationalized structural-functional approach used in TIS-studies is most appropriate for the goal of this study to identify barriers and drivers to a CE transition. However, even though the TIS-approach has institutions anchored as one of the main determinants of the innovation process (Musiolik et al., 2012), the approach needs to broaden its scope in regard to (external) socio-institutional factors (Geels, 2010), modes of production and consumption (Weber & Rohracher, 2012), and to multiple technological changes (Markard & Hekkert, 2015). This research contributes to this discussion by further identifying priority focus areas for further research with regards to applying the TIS-approach to study a CE transition.

Furthermore, increased understanding of socio-institutional barriers to the transition towards a CE can provide important insights for policy makers to accelerate the transition and can provide firms with insights on how the current market of CE technologies is developing. This could help to identify future and long-term economic opportunities and allow for the development of favorable novel technologies (Markard et al., 2009; Bergek et al., 2015).

This thesis will start with elaborating on the concepts of CE and subsequently explaining how current transition theory can be expanded to study CE transitions. Using a TIS-approach, the methods applied to study the dynamics that foster or hamper the transition will be described next. The functioning of the innovation system around CE and food waste valorization technologies was assessed. This report ends with recommendations on how to improve the innovation system around CE, and a discussion on the applicability of the TIS-approach to study the transition towards a CE.

2. THEORY

2.1 THE CIRCULAR ECONOMY PARADIGM

At present, the majority of economic processes around the world are designed in a linear fashion: Products are primarily produced from virgin materials and are discarded after use or consumption. However, this neoclassical economic production model is neglecting the finitude of resources on our planet, which has adverse effects to the environment. This linear production leads, among other things, to soil degradation, deforestation and water pollution as a result of the extraction of raw materials, or to leaching of toxic dissolved chemicals into groundwater, rivers and waterbodies due to landfilling of waste (Balmér, 1973; Murray et al., 2015; Wiedmann et al., 2015).

As an alternative economic model, a CE aims to counteract this paradigm by creating '*cyclical closed-loop systems'* of materials (Murray et al., 2015, p.372). Essentially, these loops preserve the highest value of resources and return them to the 'industrial web' to be reused for consecutive economic processes (Ghisellini et al., 2016 p.25). As a result, the use of natural resources is minimized, and in doing so, the detrimental effects on the environment reduced (EMF, 2012).

To successfully close loops, CE uses 'design to re-design' thinking and systems thinking (Murray et al., 2015, p.373). Production processes are designed to be restorative, and materials should be either part of a biological cycle, if the material can be taken up by the biosphere, or if not, by a technical cycle. Consequently, the entire supply chain - forward and reverse - should be considered to connect all series of links within the supply chain cycle (Braungart et al., 2007; EMF, 2012). Moreover, waste and resource use are minimized by reducing, consecutively reusing, and recycling of materials (Ghisellini et al., 2016). To illustrate, in the case of the biocycle, recycling can be in the form of cascading, which means utilizing materials for consecutive lower-grade applications, or, vice versa, upcycling (Borrello et al., 2017). As a last resort, recovery of energy from materials through incineration is also possible (EMF, 2012). Reducing the size of material throughput of the economy is said to be essential before closing material cycles, as the planetary threshold of materials that need to be recycled has already been exceeded (Morea et al., 2017). Additionally, a CE relies entirely on renewable energy for its processes (EMF, 2012).

The economic rationale underlying CE's principles is to preserve the economic value of materials, while simultaneously offering resilience to resource scarcity and commodity volatility, which ought to create sustainable growth and generate jobs (Yuan et al., 2006, EMF, 2012). A move from levying tax on labor to levying tax on energy and materials could be conducive to increasing employment for a CE, as remanufacturing of products is encouraged this way (Morea et al., 2017). Business model innovation is a prerequisite to harvest these benefits (Linder & Williander, 2017), and business practices with a focus on reuse, repair, remanufacture and refurbish are central. A shift to services in consumption patterns is, therefore, needed (Bocken et al, 2016; Hobson & Lynch, 2016; Mylan et al., 2016).

The following comprehensive definition is given for a CE:

> *[A Circular Economy is] 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. (Kirchherr et al., 2017, p.229)

As an alternative economic model, a CE requires a different arrangement of economic processes, e.g. more extensive recycling methods or a shift from product to services, to name a few. For these adaptations, socio-institutional changes, meaning changes in, for instance, the mindset of consumers, policy regulations, and manufacturing standards, (Potting et al., 2017), as well as the adoption of novel technological solutions (Mylan et al., 2016; Borrello et al., 2017). Due to these novel technological solutions, the transition towards a CE can partly be seen as a technological transition (Potting et al., 2017), which is part of larger societal changes in policy, industrial standards, infrastructure, user practices and in the way people think and behave, and are therefore also called socio-technical transitions (Markard et al., 2012). As the aim of a CE is to bring about more sustainable modes of consumption and production as an outcome of this socio-technical transition, the transition towards a CE can furthermore be described as a *sustainability transition* (Markard et al., 2012; Potting et al., 2017).

Currently, CE is still hardly implemented, and it is fairly unknown what the transition towards a CE entails, let alone how it can be accelerated, and a clear and manageable method to measure progress of the transition is still missing (Potting et al., 2017). There is a need for tools to measure the change processes that lead towards a CE. The well-operationalized framework of Technological Innovation Systems can provide the first tools to measure the change processes required for a CE, as institutions and institutional change are strongly anchored in this framework (Bergek et al., 2015).

2.2 Technological Innovation Systems

One of the main frameworks to study sustainability transitions is the *Technological Innovation System* (TIS) framework, which is based on the concept of *Innovation Systems* (Markard et al., 2012; Markard & Hekkert, 2015). Central in these concepts is the idea that innovations are developed by (a network of) actors and institutions in a non-linear way (Bergek et al., 2008; Schlaile et al., 2017). Also important is the idea that the societal system and technological change are intertwined: The embeddedness of technology and society is enhanced by technological development, and technological trajectories arise because successful technologies benefit from improvements such as economies of scale, a built-up knowledge base, adjustments to social norms, and users being accustomed to the technology (Kemp, 1994). This path dependent nature of technological development can also result in a lock-in, in which it becomes difficult to alter technological trajectories due to established practices and vested interests (Unruh, 2000). The interaction of technologies with its embedded systems implies that new technologies are not just competing with existing technologies but also with an established trajectory of technological improvement and larger cultural norms and values (Kemp, 1994).

A TIS may be defined as ‘network[s] of agents interacting in the economic/industrial area under a particular institutional infrastructure [...] and involved in the generation, diffusion, and utilization of technology’ (Carlsson and Stankiewicz, 1991, p. 111; Klein & Sauer, 2016). Thus, the most important components of a TIS are actors operating within networks and confined to certain institutions. Studying a TIS, however, consist of two distinct elements: A *structural* component and its *functions* (Markard & Tuffer, 2008; Hekkert et al., 2011). The structure comprises the actors of the innovation system, while the functions describe the set of activities of how these actors interact (Hekkert et al., 2011).

The structure of a TIS comprises four components: actors, institutions, interactions, and infrastructure (Wieczorek & Hekkert, 2012). *Actors* are organizations directly and indirectly generatining, dispersing, and utilizing technologies (Wieczorek et al., 2013). *Institutions* are the collection of habits, expectations and shared views structured by rules and norms. These can either be administered by authority (hard), e.g. legislation, or arise implicitly from actors’ interactions (soft), e.g. culture (Jacobsson & Johnson, 2000,

p. 630), and are area specific, as they arise from historical and spatial characteristics (Wieczorek & Hekkert, 2012). Actors *interact* in and outside of networks (Wieczorek & Hekkert, 2012), which enhances knowledge diffusion (tacit and explicit) and learning within the system (Jacobsson & Johnson, 2000). The relationships between actors are manifold, e.g. actors can collaborate or compete with each other (Edquist, 2010). Interactions occur in an *infrastructure* of knowledge, financial and physical assets, e.g. know-how, venture capital, roads respectively (Wieczorek et al., 2013). See figure 1 for a depiction of the structure.

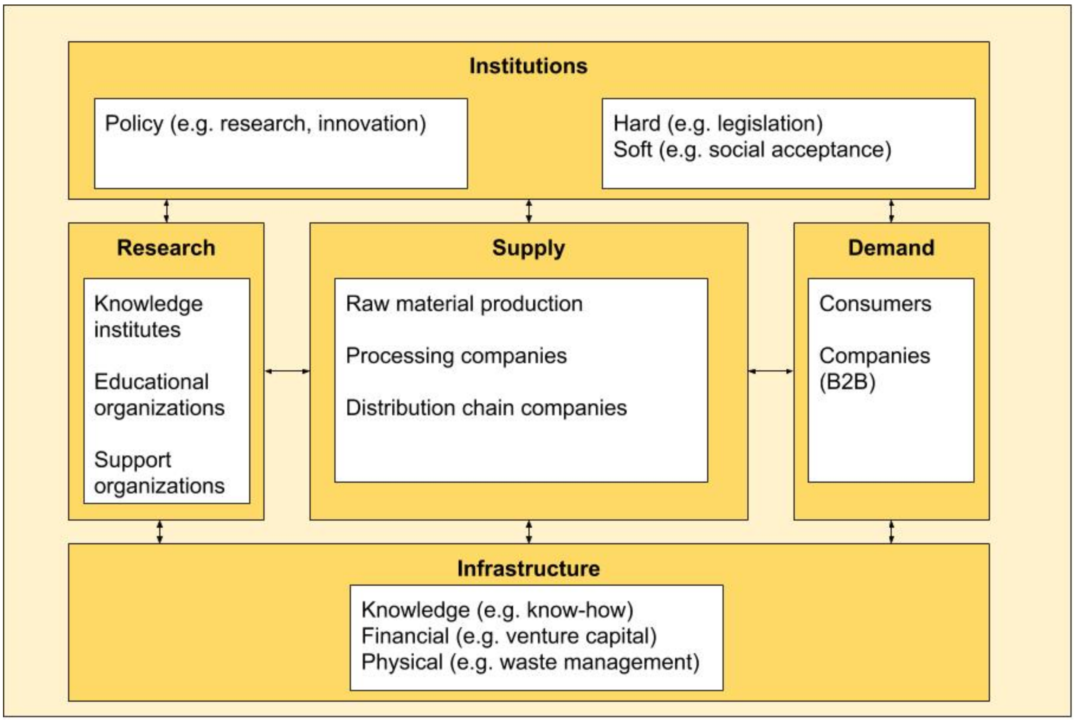

***Figure 1**. Depiction of the structure of a TIS. The arrows describe the interactions within the system (based on Kuhlmann & Arnold, 2001; Hekkert et al., 2011).*

The goal and purpose of a TIS is to develop, generate, and utilize (technological) innovations (Klein & Sauer, 2016). To gain insight into what the direction of development is, one needs to understand the system's dynamics, to potentially help guide and enhance the process. An analytical way to understand these dynamics is to map activities (Hekkert et al. 2007). *Functions* describe the set of those activities that arise from the interactions between actors and institutions (Markard & Tuffer, 2008). Mapping functions helps to understand the essential activities, to analyze patterns, and to see how these activities perform. By systematically mapping the functions, performance can be determined by how many functions are fulfilled (Hekkert et al., 2007; Bergek et al., 2008). This study will use the functions described in table 1 based on Hekkert et al. (2007).

Each function is connected with and affected by other functions: When one functions fails, others might be impeded, leading to a downward spiral. On the other hand, when functions are positively fulfilled, an upward cycle can be generated, leading to accelerated uptake (Negro, 2007; Suurs, 2009). The seven functions interact in multiple ways, but only a few starting points exist (Hekkert et al., 2007). Furthermore, the structure and functioning of a TIS depend on the extent to which the technology has diffused, and the innovation system has developed. This development follows four phases (Van Lente et al., 2003; Hekkert et al., 2011; Bento & Wilson, 2016; Markard, 2018): In the first phase, or *(pre-)development* phase, the development is characterized by different stakeholders exploring various 'search processes' and options of the innovative concept or technology. In doing so, they determine the direction in which the concept will progress, as this phase is 'marked by a growing awareness of possible new encompassing societal goals' (Negro, 2007, p.22). In the subsequent *take-off* phase the system begins to transform, and changes in the way of thinking and designing are taken place. In this phase tests are being run and regulatory support may arise. However, the existing system still overshadows the developing innovation system. In the third phase of *entrenchment* or *acceleration* the system breaks through and the different economic, regulatory and societal aspects connect to shift the dominant system in favor of the new one. In the last phase of *stabilization,* the new system has overthrown the old and has become the new standard (Van Lente et al., 2003). The development of the TIS affects its functioning as certain structures might not have been built up yet. Analyzing how the TIS has developed will determine if the TIS can move to the next developmental phase and where barriers lie to do so (Hekkert et al., 2011).

Table 1. *Functions of a technological innovation system and their descriptions (based on Hekkert et al., 2007).*

Function name (*function number*)	**Function description**
Entrepreneurial activities (F1)	Experimenting with novel technologies by new entrants and established actors, which facilitates recombination of technological applications in multiple environments (Bergek et al., 2008; Hekkert et al, 2007). Entrepreneurs take the necessary risks for recombination (Suurs, 2009), are able to apply knowledge and networks, and capture value in new business opportunities (Van Praag & Versloot, 2007).
Knowledge development (F2)	Generation of new knowledge, which is essential for technological innovation (Howells, 2002). Knowledge development comprises research programs and practical learning (Sagar & Zwaan, 2006).
Knowledge diffusion through networks (F3)	Exchange of information within a network of actors, which aligns policy targets with the newest innovations and knowledge development with current norms and values. The network acts as a framework on which other functions interact (Hekkert et al., 2007).
Guidance of the search (F4)	The necessary selection of technological varieties in a resource-limited environment, directed by needs of users and producers. The selection process is an interplay of exchanging ideas and expectations between users and producers. When expectations and initiatives coincide, the technology can gain enough traction (Negro et al., 2007).
Market formation (F5)	Formation of a market for new technologies, which are often inferior to current dominant technologies. This can either be done by creating a niche market, in which actors can increase knowledge on the new technology (functions 2, 3) and create the right anticipations (function 4), or by adjusting policy, such as tax exemptions, enabling a level playing field (Hekkert et al., 2007).
Mobilization of means (F6)	The attraction of sufficient financial and knowledge resources for activities within a TIS (Oakey, 2003). In absence of adequate capital, the innovation process will hamper and might fail. It is especially important for knowledge development (function 2) (Hekkert et al., 2007).
Creation of legitimacy/counteract resistance to change (F7)	The new technology requires help to counteract resistance of actors with vested interests in established technologies. Actors with a strong reliance in the new technology create legitimacy to counteract resistance (Hekkert et al., 2007).

Although Innovation Systems can be studied on several levels, e.g. national, regional or sectoral (Bergek et al., 2008; Hekkert et al., 2011), technological change within a CE is not only embedded in the socio-institutional infrastructure of one area or industry but spans several sectors, regions, and national borders. At the same time, a CE spans entire supply chains but does not necessarily have to comprise an entire sector. Technological change within a CE can be of a disruptive, radical, or incremental nature with horizontal and vertical novelties (Potting et al., 2017), meaning innovation affect one part of the supply chain or innovation that influences the entire supply chain (Wesseling & Van der Vooren, 2017). The TIS-framework can be used to study one specific technology (radical and incremental) and its applications but also several related technologies with the same function and a set of related knowledge fields (Bergek et al., 2008; Markard et al., 2016) The TIS is, therefore, most suitable to study the set of related (incremental) technological changes in a CE with a focus on socio-institutional change. Figure 2 describes the specific delineation of a CE in relation to other innovation system approaches, which corresponds to the delineation of a TIS.

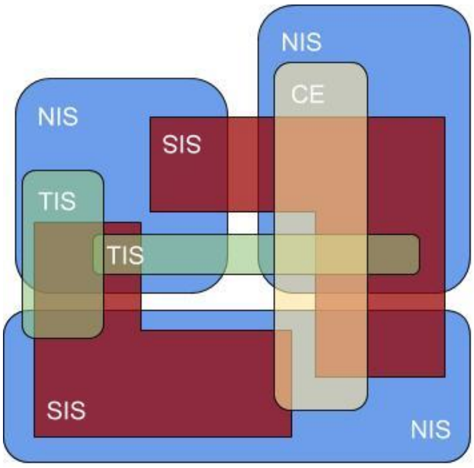

Figure 2*. Delineation of the innovation system for a specific circular economy technology field, spanning sectors and national borders. The innovation system around circular economy corresponds with the delineation of a Technological Innovation System (based on Hekkert et al., 2007; Wesseling & Van der Vooren, 2017).*

As mentioned before, socio-institutional change is one of the main factors of change in a CE transition. In order to align the TIS- framework to socio-institutional change, the concept of institutions in relation to the TIS-approach needs to be explored further. Institutions are an integral part of the TIS-approach: They act as the rules of the game while the actors are the players within the innovation system process (Hekkert et al., 2011). Within the TIS, institutions comprise cognitive, normative and regulatory elements, and include revenue models (Markard et al., 2016). However, the institutions within the innovation system are specific to the focal technology and overlook the (formation of) institutions in other sectors or of other TISs (Bergek et al., 2015; Markard et al., 2016). Therefore, the external environment in which the TIS is located needs to be considered additionally to internal institutions. This outer environment, or context, consists of a wider collection of external actors, institutions, technologies etc., and can influence the development of the focal TIS (Bergek et al., 2015; Markard, 2018). To illustrate, sector-level norms, values and regulations, such as user practices or dominant sector-wide beliefs, influence the focal TIS in terms of its legitimacy (Bergek et al., 2015). As such, institutions in the wider context form a higher order structure on which the institutions of the focal TIS are based (Markard et al., 2016). The inclusion of context can help to explain larger transitions and associated sectoral processes (Bergek et al., 2015). At the same time, the focal TIS can also influence the wider context. For instance, policy changes regarding waste management within a TIS can affect multiple sectors in which several TISs are active (Markard et al., 2016; Markard, 2018).

In relation to the wider context a TIS is situated in, the way institutions are approached within the TIS-framework can be broadened. Institutions within a TIS are considered as the main incentive structure on which actors' actions are based and are control mechanisms that diminish or remove unreliability and unpredictability (Wirth et al., 2013). According to Wirth et al. (2013), the TIS-approach assumes institutions influence actors' behavior mainly on the assurance or uncertainty of the behaviors of other actors, e.g. the way standards provide certainty for a certain technology. In this view, actor behavior is strategic and rational. However, Wirth et al. argue that behavior of actors is molded by the wider societal environment and the worldview of actors, which is irrational. They apply sociological institutional theory, which questions the rationality of actors and instead focuses on assumptions made by actors in forms of their norms, habits, unwritten rules and taken-for-granted assumptions, meaning, for example, the way actors perceive how things should be working in contrast to how they currently work. Wirth et al. distinguish several elements to this view: First, actors work according to a *normative setting* in which a particular aim is preferred (e.g. generating profits) over other aims, and which means are deemed justified to achieve this aim. Second, the *cultural-cognitive setting* describes the actions of actors in terms of how they perceive and explain their reality and how they define meaning, which is often unquestioned. Lastly, actors have certain *taken-for-granted assumptions*: actions have got habituated and have become unquestioned. Actions that go against this view can be perceived as insurmountable and unthinkable.

2.3 TECHNOLOGICAL INNOVATION SYSTEMS AND CIRCULAR ECONOMY

As previously stated, when it comes to a transition in the context of a CE, socio-institutional as well as technological change are required. In contrast to other sustainability transitions (e.g. energy), however, the focus on radically novel or disruptive technologies might not be as crucial. The aim of the transition towards a CE is the circular utilization of materials, for which changes in e.g. the supply chain, customer relations or business models are required (EMF, 2012), and radical technological innovation might be hardly needed (Potting et al., 2017). To illustrate, a CE in the food sector can rely on earlier technological advancements in the energy sector by applying anaerobic digesters for biomass with only minor adjustments for treating food waste (REF). To bring about changes required for a circular utilization of materials, socio-institutional change is the focal point of innovation, and technological innovation is present but of an incremental nature, which means that technological change is not dictating the innovation process or is even almost entirely absent (Potting et al., 2017). In order to study the socio-institutional changes in a CE transition with the TIS-approach the socio-institutional context, therefore, requires more attention.

Socio-institutional change is needed throughout the transition towards a CE as well as in a TIS. However, as stated previously, socio-institutional change is often the main driver within a CE and technological innovations are of a small concern or may be completely absent. This means socio-institutional change is the main form of innovation within a TIS centered around a CE (Potting et al., 2017). Radical and disruptive innovations are still needed but require a different alteration of societal aspects than incremental technological change (Markard & Truffer, 2008). Within the TIS-framework this incremental technological change refers to the production part of the system which involves the continuous enhancement and evolvement of production processes and established product lines with no fundamental changes in the system. The fundamental shifts will need to come from radical (technological) innovations that induce the transformation and emergence of entire new production systems. Consequently, the institutional setup of the system is similarly different in the case of these fundamental shifts (Markard & Truffer, 2008). In a CE transition, however, these fundamental changes come from socio-institutional innovation, which means that the shift of the system relies almost entirely on changes within the socio-institutional setup. Socio-institutional innovation becomes the main object of study.

Potting et al. (2017) distinguish between two forms of transitions within a CE in which socio-institutional change is dominant. The first is purely based on socio-institutional innovation with occasional minor technological changes (Potting et al., 2017). A pay-per-use model for home appliances provides an example. Adjustments to the current technology of home appliances could minimize resource use, make it better repairable, and reusable at end of life, but more than anything, the pay-per-use model requires socio-institutional changes such as changes in consumer behavior and business models (Manninen et al., 2018). In the second form, socio-institutional innovation is also dominant but requires an enabling technology that facilitates the socio-institutional change. In this case, there is not necessarily a role to play for changes in the existing technology (although incremental changes might still apply) but rather for a separate technology that enables the use of e.g. access-over-ownership models. For example, information technology provides connections between users and producers to exchange materials, products or services and to facilitate the use of pay-per-use business models (Tukker, 2015). This can be extremely beneficial to the distribution of food waste (Borrello et al., 2017). As described in the previous section, the socio-institutional setup is influenced by the context and normative, cultural-cognitive and taken-for-granted settings of a TIS. Socio-institutional change can be in the form of business model innovation, changes in consumer practices etc., which can all be influenced by the irrational assumptions made by actors. For example, business models might be designed around business practices present for decades or around perceived needs of consumers, which, in turn, can also be based on irrational assumptions. This study will apply the TIS-framework to the case of Singapore and food waste management and include socio-institutional innovation in the analysis.

3. METHODOLOGY

3.1 SYSTEM DELINEATION

Studying a circular economy in its entirety would be too extensive for one study. Therefore, the technological system boundary for the TIS under study was set to the food supply chain, and specifically the production, processing, retail, and disposal of food. The choice of spatial boundary was set on a city level, for which the city-state of Singapore was chosen (see the next chapter for more elaboration). The focal technological point of this research is on the set of technologies with the function of recycling and/or reduction of food waste, also called food waste valorization solutions in this study. Examples are on-site food waste segregation and treatment systems for recycling purposes. These digesters and composters use aerobic digestion or composting processes in tanks to speed up the decomposition process of organic material by controlling air, moisture and temperature. Specially tailored microbes and enzymes are added to further accelerate the breakdown of food into fertilizer (NEA, 2018d). The on-site digesters decompose food waste into liquid fertilizer, while composters convert food waste into soil-like fertilizer (Eco-Wiz, n.d.). Digestion technologies are considered matured but are a relatively radical innovation because of its decentralized use (Markard et al., 2009). Another (less technological) example is the use of detritivores to decompose organic matter (Borrello et al., 2017). Incorporated into this set of solutions was an analysis of other initiatives specialized in alternative food waste valorization and business model innovation, such as using food waste as animal feed. The choice for these broadly applicable applications, which apply a broad range of knowledge fields, implies a focus on a generic knowledge field. This study used a snapshot analysis and was conducted within the timeframe of March until September 2018. Hereafter, the delimited TIS on CE and food waste valorization studied here is called the focal TIS. In this study, food waste refers to 'food appropriate for human consumption being discarded, whether or not after it is kept beyond its expiry' (FAO, 2013, p.9). Food waste can be further divided into homogeneous (one food type) and heterogenous (mingled) food waste (Papargyropoulou et al., 2014).

3.2 RESEARCH SETUP

This study followed a five-step research setup following the TIS-methodology developed by Hekkert et al. (2011) applied to the case of CE. In the first step of this setup, the structure of the TIS, with its actors, institutions, interactions and infrastructure, was mapped, meaning identifying which organizations are active in the sphere of circular food industry (actors), how these organizations collaborate (interactions), what the regulatory framework looks like, and what the expectations and social acceptance of circular food are (institutions), and in which physical, financial and knowledge infrastructure these organizations reside (Wieczorek & Hekkert, 2012). In the second step, the phase of development of the TIS was determined. This allowed for the evaluation of the TIS functions in relation to its current phase, since a different phase of development of the TIS determines whether certain functions are expected to be further developed than others and which functions need to be targeted to advance the TIS to the next phase (Hekkert et al., 2011). In the third step, the TIS functions were analyzed, in which was described how the seven functions are fulfilled and how they perform. Subsequently, interactions between functions were deduced. The fourth step consisted of identifying the barriers and the possible structural origin for these barriers. In this step, the root cause of the lack of functioning was determined, since functional performance cannot be improved without modifying the structure (Wieczorek & Hekkert, 2012). Finally, in the last fifth step, the results were aligned with policy to identify obstacles for policy goals (Hekkert et al., 2011). This research setup gives an indication of the steps followed during this study. In practice, the TIS-research is conducted in an iterative process, where during each consecutive step, previous steps were used back and forth multiple times. See figure 3 for an overview of the research setup.

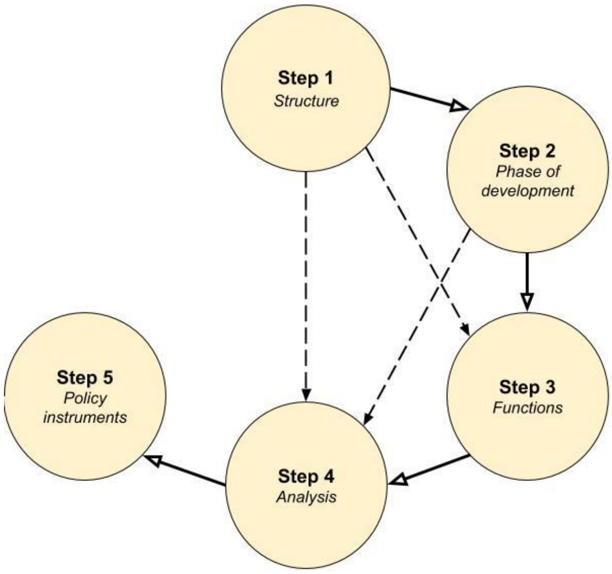

Figure 3. *Visualization of the research setup (based on Hekkert et al., 2011). The iterative process of this study is depicted by arrows, which indicate the use of each step, in consecutive steps.*

3.3 DATA SOURCES

Desk research was used in the first research step to map actors, institutions, infrastructure and interactions, by means of search engines for scientific literature - e.g. Web of Science -, industry associations, technology outlooks, company and government reports, business directories, catalogues and indexes (i.a. Economist Intelligence Unit). Additionally, grey literature, such as press articles (i.a. Eco-Business, The Straits Times, Business Times, AsiaOne) and working papers.

22 *Semi-structured interviews* were conducted with expert and key stakeholders active within the TIS to analyze how the TIS functions are fulfilled: Two knowledge institutes, fourteen businesses (six incumbent and eight startup ventures), four governmental organizations (of which three during meetings), and two non-governmental organizations were interviewed (see Appendix C for a full overview). Interviews were held either face-to-face or by means of phone and skype calls for approximately one to one-and-a-half hour from April to September 2018. Two interviews were conducted over email. Key stakeholders were mainly identified during desk research for the structural analysis. Snowball sampling was used to identify additional structures and interviewees within the TIS (Bergek et al., 2008).

A set of interview questions was derived from Hekkert et al. (2007) and Potting et al. (2017), and from CE theory (see appendix B). During the interviews, the interviewees were also asked how well each function is fulfilled by filling out a scale from 1 to 5, and follow-up questions were asked on what exactly is blocking or triggering that specific function respectively. Interviews were recorded for transcription and subsequently transcribed. If no consent for recording was given, notes were taken. All interviewees were granted anonymity. After the interview, the interviewee was given the opportunity to read the transcript and provide additional information. Additionally, six meetings and a workshop were held to ask complementary questions and to verify the findings in the interviews, which resulted in minor adjustments in to the results. An overview of all interviewees, interview types, meetings and workshop attendees are given in Appendix C.

3.4 DATA ANALYSIS

Data analysis was conducted by following the five-step methodology described above. In step 1, the structure was mapped by filling out each structural component (see appendix A). In the second step, the phase of development of the TIS was determined using several indicators derived from the work of Hekkert et al. (2011) and Bento and Wilson (2016) (see appendix D for a full overview of indicators). During the third step, the score each interviewee gave for the functions was filled out in a five-point Likert scale. This was meant as a relative analysis: The scores were used to indicate whether functions are underdeveloped compared to other functions. Next, interview transcripts were coded using NVivo coding software. Interview answers were coded by using the seven system functions. During each step, data from the first step was used to complement steps 2 and 3 (see figure 3). The findings from the first 3 steps were then combined to determine barriers and drivers in the system (step 4). Finally, recommendations for policy and further research were written (step 5).

3.5 RESEARCH VALIDITY & RELIABILITY

The validity of this study was upheld by applying multiple methods and means of data collection (i.e. triangulation) (Golafshani, 2003). The combination of desk research, qualitative expert interviews, meetings and a workshop strengthened the analysis of the TIS by compensating for weaknesses in other methods and data (Hekkert et al., 2011). This way, data was verified from different angles and bias was reduced. Moreover, a representative sample of experts with a broad range of backgrounds were interviewed, which resulted in a comprehensive data set with the inclusion of as many views as possible.

The replicability of this study is, however, minimal. This research is time-specific, technology-specific and market-specific, which means reproducing the exact same study is hardly possible. Replicating this study in a year's time will undeniably result in a distinct outcome. Moreover, comparison of various studied innovation systems is also limited (generalizability) (Hekkert et al., 2011). On the other hand, the TIS-approach has been empirically tested in various cases, which gives a reliable basis for this study.

4. CASE BACKGROUND

Currently, several pioneering cities, e.g. Amsterdam, Glasgow, Dalian, are taking the lead in developing a CE (Geng, Zhu, Oberstein, Fujita, 2009; DRO, 2012; Circle Economy, 2016), while Singapore is just about to embark on its first steps towards circularity. The city-state is well known for its focus on sustainability issues (EIU, 2012; Arcadis, 2016). Although much has been achieved in past decades, Singapore still faces mounting problems (NEA, 2017; MEWR, 2017).

Cities are a good place to study the CE-transitions due to the concentration of people, knowledge, and material flows. Due to their compact nature, and the concentration of labor and intellect, cities can potentially increase efficiency and set up effective systems to tackle overconsumption (Seto et al., 2011). Most importantly, cities are hotbeds of innovation and societal progress, making them potential drivers of sustainable solutions (Loorbach & Shiroyama, 2016). Moreover, the concentrated aggregation of materials creates circular opportunities to harness materials locally and on a large scale (Li, 2015). As relevant stakeholders are geographically close, there is a huge potential to effectively and collectively recover materials. This creates the opportunity to develop local material loops, making cities the ideal place to implement a CE (Prendeville et al., 2017).

The current food production industry and food consumption habits in Singapore are unsustainable. In 2016 alone, the small city-state produced a staggering 809,800 tons of food waste worth around S$200 million (€126m), which is a 40% increase from 10 years ago (Boh, 2017; Lim, 2017a; NEA, 2018a). Most of which is attributed to households, where on average 2.5 kg of food is thrown away per week, which comes down to ten percent of all waste thrown out (Grandhi & Singh, 2016; Lim, 2017b). Spillage of food also occurs across the supply chain within the food industry: During the import of food, at the food processing stage and at wholesale supermarkets, food is being thrown away (Grandhi & Singh, 2016). Most food waste is collected in mingled form and incinerated. Subsequently, the ash from this waste is landfilled (NEA, 2018a). If current practices remain unaltered, Singapore will need to build a new landfill every thirty to thirty-five years (FoodBank, 2015). Singapore is dependent on foreign imports for its food supply: up to ninety percent of all food is being imported from overseas (AVA, 2017). Due to land scarcity and its high level of urbanization, Singapore's agricultural sector is relatively small (Santander, 2018) Taken together with the abovementioned mounting food wastage, Singapore could face resilience issues in the future, even though the city currently ranks as world's fourth most food-secure nation (EIU, 2017). Due to these challenges, and being one the most innovative cities (Solidiance, 2013), Singapore provides for a perfect case to investigate the transition to a CE.

5. FINDINGS

5.1 PHASE OF DEVELOPMENT

Since recycling rates for food waste are relatively low at 16%, the development phase of the focal TIS was expected to be in (pre)-development prior to the start of this study. Assessing the various solutions brought about in Singapore, this assumption was met and the focal TIS is indeed still in a (pre)-development phase. There are currently various initiatives and experiments taking place and the volume of these activities is small (MNC1: MNC4; SU2; SU5; KI1; NGO1; NGO2, personal communication, 2018). Several initiatives have a working prototype, but commercialization is still hardly without governmental support. Furthermore, selection of alternatives is in favor of the technology for on-site digesters and composters. However, a dominant design is not yet in place as experimenting still occurs in this field (e.g. digester and local energy production technology developed by the National University of Singapore). Lastly, the number of actors on the focal TIS is assessed as low to medium, which was confirmed by the recurring key stakeholders mentioned during the conducted interviews.

5.2 STRUCTURAL ANALYSIS

5.2.1 Actors

Governmental organizations

In Singapore, policy is being developed very carefully. There are many different organizations responsible for the puzzle of policy making, and for each aspect of creating a stable and sustainable society a different agency is accountable. In general, governmental organizations are very hierarchical and consist of rigid structures, within as well as between organizations. For instance, the ministries set out visions, the underlying agencies develop regulations and support, and several other organizations perform research or develop technological roadmaps. In table 2, an overview has been given for all governmental organizations developing policy linked to circular economy and what their responsibilities are.

Knowledge institutes

Singapore has a strong R&D sector overall. The city-state remains one of the leading innovative cities in the world and, therefore, has high potential to develop knowledge on technical and social solutions to solving food waste issues (EDB Singapore, 2016). Currently, there are several interdisciplinary and cross-disciplinary research projects and research groups active that directly and indirectly conduct research on circular economy or food waste. Table 3 provides an overview of the most important knowledge institutes currently active in the field of circular economy. Knowledge institutes include universities, technology centers, research centers, and research institutes (Luo et al., 2012). The two major universities, the National University of Singapore and the Nanyang Technological University, mainly focus on energy recovery from and composting of heterogeneous food waste.

Educational organizations

Educational programs on the topic of circular economy are limited. So far, the National University of Singapore is the only educational institution that offers courses on food waste and circular economy. The National University of Singapore has committed itself to develop necessary knowledge for a circular economy. By increasingly focusing education on the topic, the National University of Singapore aims to deliver broadly-educated students who will reinvent the current economy towards a circular one. Through this, they provide a future knowledge base for a circular economy (KI1;KI2, personal communication, 2018).

Furthermore, the School of Chemical and Biochemical Engineering at the Nanyang technological University, focuses most on the utilization of food waste. The Food Science and Technology education program at this college especially teaches about sustainable food production systems and the reduction of food wastage at several levels within the food supply chain. The university has also set up a partnership with Wageningen University & Research from the Netherlands under this program. The partnership offers a joint Doctor of Philosophy program which focuses on conversion of agriculture raw materials into high-value products and of food waste into various high-value supplements (NTU, 2018).

Table 2. *Overview of the relevant governmental bodies within the food industry.*

Governmental level	Governmental organization	Responsibility
Ministry	Ministry of the Environment and Water Resources	❖ Manages Singapore's living environment and limited water resources. ❖ Sets out long-term environmental policies and visions.
	Ministry of National Development	❖ Plans and (re)develops land use. ❖ Responsible for developing and maintaining the primary food sector.
Prime Minister's Office	National Climate Change Secretariat	❖ Responsible for working and carrying out policies set through international agreement on climate change. ❖ Translates visions on climate change set by the government, together with the NRF, into technological roadmaps.
	National Research Foundation	❖ Responsible for determining the vision and strategy for research and innovation. ❖ Gives direction to the innovation and research agenda by providing funding to several focus areas that the government has proclaimed as urgent and important.
Agency	National Environment Agency	❖ Executive agency of the Ministry of the Environment and Water Resources. ❖ Responsible for overseeing pollution levels, providing meteorological data, and creating awareness among citizens about the environment. ❖ Responsible for monitoring and managing solid waste.
	Public Utilities Board	❖ Executive agency of the Ministry of the Environment and Water Resources specialized in managing water supply, the water reservoirs and water catchment areas and purification and treatment of all used water (sanitation and industrial).
	Agri-Food & Veterinary Authority	❖ Ensures food safety.
	Enterprise Singapore	❖ Responsible for encouraging the development of entrepreneurial activity.

***Table 3**. Overview of knowledge institutes active in the field of circular economy and food waste valorization.*

Knowledge institute	Research center	Research focus
National University of Singapore	Circular Economy Taskforce	❖ Circular economy in broader sense.
	Energy and Environmental Sustainability for Megacities (in collaboration with Shanghai Jiao Tong University)	❖ Waste management in megacities for sustainability and energy recovery. ❖ Application of food waste for energy consumption and fertilizer creation.
	Singapore-MIT Alliance for Research and Technology (in collaboration with Massachusetts Institute of Technology)	❖ Developing new solutions for future food production in resource-constrained environments.
	WIL@NUS Corp (in corporation with Wilmar International Limited)	❖ Developing technologies for the production of specific industrial enzymes and biochemicals from natural products.
Nanyang Technological University	Residues & Resource Reclamation Centre	❖ Converting food waste with other municipal waste into energy. ❖ Converting waste oil into biodiesel. ❖ Co-digestion of food waste and used water sludge. ❖ Biodegradable polymers for disposable packaging material from municipal waste.
	Environmental Chemistry and Materials Centre	❖ Developing more efficient use of fermentation and side-streams within the food production process. ❖ Improving the extraction capacity of proteins and carbohydrates from organic matter.
	NTU Food Technology Centre	❖ Enabling the collection of nutrients from biomass. ❖ Extraction of “green” chemicals from renewable resources.
	School of Chemical and Biochemical Engineering	❖ Biodegradable cling film made out of cellulose extracted from soybean residue and used cooking oil.
Ngee Ann Polytechnic	-	❖ Valorization of nutrients from wastewater or okra for consecutive use as fish feedstock. ❖ Converting spent coffee grounds into tray pallets.
Nanyang Polytechnic	-	❖ Natural fermentation of food waste.

Industrial actors

The value chain in the food industry has never been entirely linear, however, in general, a distinction can be made in several steps, with each step fulfilled by specialized organizations. These steps are commonly described as follows: Production, processing and packaging, retail and wholesale, and waste management. In a circular economy, however, this value chain could alter drastically, as a company in retail could simultaneously be a producer and vice versa. In theory, every company could close the entire cycle, and, in practice, at least to a certain extent (Borrello et al., 2017). Therefore, a description of the current value chain in Singapore is given first (see figure 4 for an overview), with notable circular initiatives, and, subsequently, an overview of all industrial actors active in the present circular food industry.

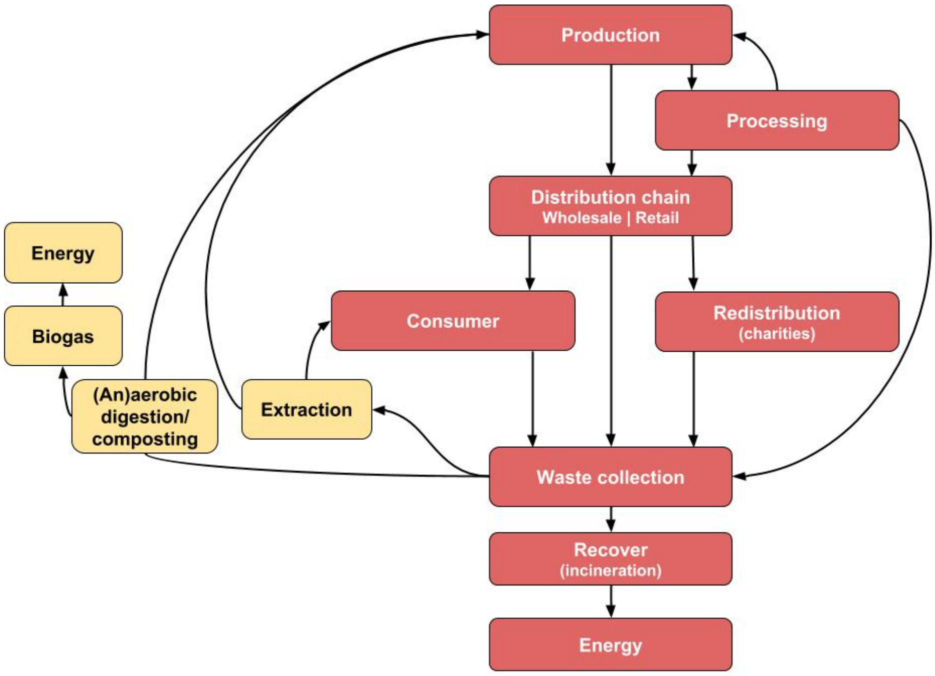

Figure 4. Depiction of what a circular value chain in the food industry could look like (based on EMF, 2017; Jurgilevich et al., 2016). The red tiles indicate the current dominant value chain in Singapore.

Most of food processed and consumed in Singapore is imported from overseas. Singapore is a small island with one of the highest population densities in the world and is, therefore, dependent on foreign supply for its food demand. Although ninety percent is imported, still about ten percent of food is being produced within the country itself (AsiaOne, 2018; AVA, 2017). Local food production is increasing; especially, urban farming has become more and more developed within the city. Several urban farming initiatives have already taken hold in, and the popularity of these farms is rising (SU1, personal communication, 2018). Some noticeable farms are ComCrop, Edible Garden City with Citizen Farm, and Heartland Farming, and there are plans for expansion (MNC4; SU1, personal communication, 2018). Some of these farms have embraced the circular economy in their business model, such as Citizen Farm who were able to integrate circular economy with social sustainability practices as well (MNC4; KI3, personal communication, 2018).

Food processing companies are those that manufacture, process, prepare or pack food, which is subsequently send to supermarkets and retailers. Among others, these comprise dairy processing plants, noodles manufacturers and bakery and flour factories. This is a key sector in terms of GDP output, and consists mainly of SMEs and only some large corporates (Oxford Economics, 2014). One company in this sector that has specifically been geared towards a circular economy is Asia Pacific Breweries Pte Ltd. This beer brewing company has several waste streams to consider, namely grains, packaging and water, and has found multiple solutions to deal with these streams in a circular way. For the leftover spent grains, the main solution is selling the grains as animal feed for local chicken farms (Eco-Business, 2016).

The food retail and wholesale sector comprise hotels and restaurants, bars, cafes, supermarkets and food caterers. This sector is one of the biggest economic sectors in Singapore responsible for food wastage (FoodBank, 2015). How much exactly is wasted by this sector is, however, unknown (SU6, personal communication, 2018). This sector consists of a mix of SMEs, large local corporation and multinational corporations. Three noticeable circular economy efforts have been taken by the retail sector in Singapore so far. Marina Bay Sands, for example, produces mushrooms with spent coffee grounds from the hotel. It serves these mushrooms in their restaurants. Amongst others, at Grand Hyatt, Pizzeria Mozza, and Open Farm Community food waste is being turned into compost using digester technology for fertilizer use, provided by companies such as Biomax Green and Eco-Wiz Group (Yap, 2016), and used for growing vegetables. Finally, Siloso Beach Resort and Oxwell & Co. are able to turn twenty percent of their food waste into compost with the use of earthworms. In turn, the companies are able to grow herbs and vegetables to provide for ten percent of sales (Yap, 2016). Efforts to reduce and reuse food wastage within this sector have also been focused on donating food through one of the four food charities. Although this saves considerable amounts of food, the charities are unable to take up leftover food from restaurants or food that has expired according to the product's expiry date. SG Food Rescue is the only charity distributing expired but unspoiled food waste.

According to the Singapore government, sixteen percent of food waste currently is being recycled (NEA, 2018a). Mainly, there are four outputs food waste is being recycled to: compost, animal feed, bio-energy and bio-fuels and non-potable water (FoodBank, 2015). The main actors involved with food recycling are Lam Tak, Eng Cheong Leong and Bee Joo Industries. There are also thirteen used cooking oil collectors active in Singapore, and one company -Alpha Biofuel- that is converting used cooking oil into biodiesel (NEA, 2018d).

One noticeable trend in Singapore is the use of on-site food waste treatment systems. Several hotels and some public schools have been using these machines to turn their food waste into fertilizer. Suppliers for these machines are Eco-Wiz Group, Flexi Systems, Westcom Solutions, Biomax Green, and Enerprof, to name a few. Others are still focused on reducing the weight of their food waste. IKEA, for example, uses a machine to take the water out of the food waste and measures every amount of food waste to reduce the amount being sent for incineration (NEA, 2018a; MNC4; MNC5; KI2, personal communication, 2018).

There is a considerable number of startups active in the field of food wastage in Singapore. Noticeable companies are the startups TreeDots, UglyGood and UglyFood. TreeDots redistributes nearly expired food and sells it to other businesses, such as cafes, restaurants and food processing companies. They provide wholesalers a service by finding buyers for smaller quantities which otherwise would spoil. About ten to fifteen percent of food is spoiled this way worldwide. UglyFood turns food waste - mostly edible food that did not meet the standards for the Singapore market - into juices, ice cream and other products. UglyGoods upcycles unavoidable homogeneous organic waste from food into products such as organic detergents, fragrances and essential oils (SU2; SU3; SU5, personal communication, 2018). Finally, treatsure is a platform on a mobile phone application where consumers can pick-up small amounts of food waste from providers all around the city (Yang, 2018), and 11th Hour is a platform application on which food retailers can offer leftover food for a discount (Ang, 2018; Lin & Boh, 2016; MNC3, personal communication, 2018). Finally, Insectta uses food waste to cultivate larvae of the black soldier fly, which are subsequently being used as feed for chicken and fish (SU2; SU4; KI3, personal communication, 2018).

All in all, there is a broad mix of MNCs, local corporations and new entrants that are working on initiatives to create a circular food industry in Singapore. Traditional SMEs are, however, predominantly missing. Table 4 provides an overview of all industrial actors.

Table 4. *Overview of all industrial actors active in the field of circular food. Solutions are categorized according to whether technology (core technology) or socio-institutional change is the dominant innovation. This is indicated by being either dominant, present or absent (blank box) indications (based on Potting et al., 2017).*

Circularity level	Organization name	Organization type	Circular economy strategy	Core technology	Enabling Technology	Socio-institutional
Reduction	The Food Bank; Fei Yue Community Services; Food from the Heart; Willing Hearts	NGO	Redistribution of food waste to the needy			Dominant
	SG Food Rescue	Nonprofit	Redistribution of food between expiry dates and spoilage to the needy			Dominant
	UglyFood	Startup venture	Processing food from food waste			Dominant
	TreeDots	Startup venture	Finding alternative buyers for nearly expired food		Present	Dominant
	11th Hour	Startup venture	After hours discount		Dominant	Present
	treatsure	Startup venture	Pick up of food waste		Dominant	Present
	Winnow	Startup venture	Smart waste measurement technology		Dominant	Present
Recycling	Asia Pacific Breweries	MNC	Creating feed from spent grains	Present		Dominant
	Insectta (part of Citizen Farm)	Startup venture	Creating feed by cultivating detritivores			Dominant
	Alpha Biodiesel	SME	Biodiesel from used cooking oil	Dominant		Present
	UglyGood	Startup venture	Processing unavoidable homogeneous organic waste from food into products	Dominant		Present
	Bee Joo Industries; Eng Cheong Leong Agri Chem	SME	Creating fertilizer from homogeneous food waste	Dominant		Present
	Biomax Green; Boon Poh Refuse Disposal; Enerprof; Datumstruct; Flexi Systems; Hirosawa Clean	SME	Providing on-site digester/composter technology	Dominant		Present

	Technic Holdings; Maeco Technologies; Westcom Solutions**;** Zero Waste Solution;				
	National University of Singapore	Knowledge institute	On-site digester technology connected to phone chargers (Boh, 2018)	Dominant	Present
	Grand Hyatt Singapore; Marina Bay Sands; Oxwell Co.; Siloso Beach Resort	MNC/SME	Using food waste to grow own produce		Dominant

Support organizations
The last category of actors active in the field of circular economy are all those not covered in the previous categories. Support organizations consist of non-governmental organizations, nonprofits, charities, and consultancies.

Many food retailers and wholesalers currently rely on charity organizations to redistribute their food surplus to the needy. Although Singapore is one of the wealthiest nations in the world when it comes to per capita income, ten percent of Singaporeans are still food insecure (FoodBank, 2015). Therefore, there are four food redistribution organizations active: The Food Bank Singapore, Fei Yue Community Services, Food from the Heart and Willing Hearts.

The Food Bank Singapore is currently the organization with the highest circularity ambitions: A part of the surplus food they collect eventually spoils as well, therefore, they are hoping to install a food digester to create biogas. In turn, this biogas can be used to run the logistics of the redistribution of the food on.

SG Food Rescue is a non-profit organization that closely resembles the other four food redistribution organizations, although they differ in the type of food that they redistribute. The other four food redistribution organizations only use food surplus, which they send to, for example, food kitchens, to be handed out to the needy. SG Food Rescue focus deliberately on food that supposedly has spoiled already. Many products in supermarkets are thrown away because the 'best before' expiry date has passed, while 'best before' dates are in many cases about food quality. This means that the food is not unsafe to eat, but it might have lost its color, flavor or texture. This is mostly the case with highly processed or canned food. SG Food Rescue creates awareness and educates people about the 'real' meaning of the 'best before' sign on food packaging.

Singapore also holds several non-governmental organizations that educate and create awareness among the public about food wastage. Zero Waste Singapore is one of these organizations. This non-profit organization provides tips and resources on how to minimize and recycle (food) waste. They also promote the 3R principle among citizens and businesses. They specifically aim for the acceleration of a circular economy in Singapore. Zero Waste Singapore uses four strategies to encourage the adoption of a circular economy: They educate with campaigns, influence governmental decisions with surveys, research and reports, collaborate with industry players, and target market problems with the promotion of technological solutions. Another organization that aims especially at reducing food waste is the Save Food Cut Waste initiative. This movement aims at educating citizens, businesses and other organizations about the impact food waste has on the environment and what the incurred social costs are. Some other lobbying and educating NGOs are WWF Singapore, Earth Society, Ground-up Initiative and Forum for the Future Singapore (Green Future Solutions, 2015).

Within Singapore, there are also organizations that aim to bridge the gap between research and industry. Most notably are Enterprise Singapore and the Agency for Science, Technology and Research (A*STAR), which both have funds available to support startups and spin-offs (SU3, personal communication, 2018).

Finally, Winnow and Gone Adventurin are two consultancies that focus on measuring the circular economy. To reduce the amount of food, one needs to know first how much food is being wasted, or in other words: what gets measured, gets managed. Winnow offers kitchens a comprehensive and easy-to-use tool to measure to amount of food that is wasted during in kitchens. In response, management can consider reducing rations if certain patterns in food wastage occur. Kitchens could throw away up to twenty percent of the food they prepare. According to Winnow, this is often equivalent to the total net profits of the restaurant. The meter empowers cooks to make better choices regarding the amount of food they use and throw away. Gone Adventurin is a social consultancy company specialized in circular economy. They help businesses with designing new and circular strategies and with their research they gather pivotal data for a circular economy. Food waste is one of their pillars and they operate in the entire Southeast Asian region (SU4; SU6; SU8; KI3, personal communication, 2018).

5.2.2 Institutions

Recycling target

Since 2009, the Ministry of the Environment and Water Resources has released its five-year Singapore Sustainable Blueprint (SSB) in which the ministry, together with Sustainable Singapore, the Ministry of National Development and the Centre of Livable Cities Singapore (a division of the latter), describe the government's vision on sustainability and its accompanied financial commitment. The plan shows Singapore's ambitions and targets for the next five years when it comes to economic, social and environmentally sustainable development. In 2014, the newest SSB was released with a clear focus on resource sustainability. One of five focus areas of the ministry have been placed on working "towards a Zero Waste Nation by 2030". The aim is to create a city that produces zero waste by reducing consumption and reusing and recycling materials for consecutive applications (Sustainable Singapore et al., 2014). Under this vision, Singapore wants to increase its national recycling rate of 60 percent to 70 percent by 2030 (MEWR, 2017b). It is, however, unclear how much each individual waste stream should contribute to this target.

In line with this vision, the National Environment Agency (executive organization under the Ministry of the Environment and Water Resources) has promoted its Reduce-Reuse-Recycle (3R) policy to try to encourage the reduction of solid waste. It has developed several guidebooks for consumers and industries to implement the 3R principle. Recently, it has developed several guides on how to reduce food wastage and disposal costs (NEA, 2018a).

These policies were underlined in a recent speech held by the chief executive officer of the National Environment Agency, Mr. Ronnie Tay, during the Clean Enviro Summit 2018. Food waste management was mentioned as one of the key focus areas within the waste management efforts taken by the agency. The CEO emphasized the efforts taken by the National Environment Agency to promote food waste reduction by consumers and to create awareness of the food waste issue and the costs involved. As an end-of-pipe solution, the CEO also mentioned the ongoing efforts to promote the uptake of on-site food waste processing facilities by hotels, shopping malls and schools. These machines can then be used to create compost for gardens in the city. The next big step in food waste management is to co-digest food waste together with used water to produce additional biogas. This new to-be-built waste management facility at Tuas is currently being developed and to be fully operational from 2030 onwards (Sustainable Singapore, 2018).

All these initiatives can be summarized in four main food waste management strategies. Strategy one entails preventing and reducing food wastage at the source. The National Environment Agency has set up several schemes and guides to promote and enable to do so. Strategy two talks about redistributing food surplus for the needy. The third strategy is recycling of food waste into usable products such as compost by on-site food waste separation and treatment. Finally, the fourth strategy is to recover energy from biomass on a large scale (NEA, 2018a). However, a step-by-step plan enforced by supplementary laws and regulations is still missing for food wastage, and an in-depth explanation on how food waste fits into the 3R narrative is also missing. A shortcoming of the 3R narrative for food waste seems to be that food waste cannot be reused but technically only reduced or recycled.

Circular economy, however, is something that has not been mentioned officially yet, although policy is still geared towards aspects of a circular economy. Practice of the "3Rs"is promoted to minimize solid waste and to increase recycling rates, and a zero-waste nation, although undefined, seems to align roughly with the ambitions of a circular economy. Only recently has the minister of the Environment and Water Resources, Mr. Masagos Zulkifli, started mentioning a circular economy in combination with the government's ambition to become a zero-waste nation (MEWR, 2018; Sim, 2018).

Financial incentives

To promote the implementation of the 3R principle, the National Environment Agency has developed the 3R Fund under its grants and incentive schemes. Organizations can apply for the 3R co-funding scheme if they plan to set up projects that can reduce waste and increase recycling. Up to S$1 million (€630k) per project can be financed this way, with a maximum of eighty percent of total costs. The projects can be in the field of redesigning production processes to reduce waste at the production, installation of waste recycling infrastructure (including waste sorting equipment), and upgrading existing waste management systems (NEA, 2018c). In practice, the 3R fund is geared towards digester and composting technologies. For instance, a food service corporate has made use of this scheme. They installed an on-site food waste treatment system to convert food waste into compost for landscape purposes in Singapore. With a tubing system, food waste at the company is transported directly to the machine. The installation of the system was funded directly from the National Environment Agency's 3R fund with a S$250k (€157.5k) subsidy. With a return on investment of about three years, the company has saved S$1,500 (€945) weekly by managing waste. This was done by saving on food waste haulage fees, operational and manpower expenses and costs of trash bags and bins. The total amount of food saved is up to 1,000 tons per year currently (MNC3, personal communication, 2018).

Furthermore, to enable a more efficient recycling system, the National Environment Agency has created the Closing the Waste Loop Initiative R&D program jointly with the National Research Foundation (Ramakrishna, 2018). This innovation program, holding S$45 million (€28.35m) in funds, aims to facilitate collaborations between knowledge and research institutes together with businesses to develop novel technologies that can provide solutions for resource recovery and minimization of waste. In other words, this program aims for research and technologies for a zero-waste nation. Four focus areas were identified for this program: (i) resource recovery from food, plastic and e-waste, (ii) alternative applications for incinerator ash to reduce the need for landfilling, (iii) safe reuse of closed-off landfills, and (iv) smart waste management systems. Currently, two calls for proposal are active on incinerator ash and plastic waste under this program, but it is expected that more will follow on food waste in the coming years (NEA, 2018b; Ramakrishna, 2018).

Next to that, the National Research Foundation provides funding for the commercialization of research through its 'Central Gap Fund' (for projects of over S$750k (€472.5k)), and for startup venture funding through its 'Early Stage Venture Fund' (S$10m (€6.3m) on a matching basis). Together with selected venture capital firms, such as Wilmar International Limited, the NRF funds tech-based startups in various sectors of which the food sector is one (NRF, 2018b; NRF, 2018c). These initiatives apply for all spin-off and startup initiatives and are not necessarily aimed at food waste valorization or circular economy, even though the food industry has been identified as a growth sector.

Finally, the Agri-Food and Veterinary Authority (an agency under the Ministry of National Development) has put emphasis on technology and R&D to increase agricultural productivity and self-sufficiency of Singapore. This R&D has been focused on breeding, disease control, aquaculture and post-harvest technologies. Moreover, technological development focuses on agro-technology and life sciences to increase productivity and yields. To support these ambitions, the AVA has set up the Agriculture Productivity Fund containing S$63 million (€39.7m), which aims to support the implementation of innovative and yield-boosting technologies for local farmers. The AVA also encourages the Singaporean population to choose local produce over imported goods. This in turn is designed to urge local producers to innovate and increase its productivity even further (AVA, 2018). As the government is aiming on converting food waste into fertilizer on a large scale through means of co-digestion, an increasing local productivity could have a positive development on the demand for fertilizer (Jurgilevich et al., 2016). Furthermore, through increasing the demand for local produced fish, vegetables and herbs, and by increasing its efficiency, the government hopes to shorten the food supply chain and, in doing so, reducing the amount of food wasted (AVA, 2018).

Infrastructure policies

To tackle the growth of food waste, the National Environment Agency acknowledges the need to separate food waste from other solid wastes to increase the recycling rate of food waste as well as of other recyclables (NEA, 2018a). As the landfill on Semakau Island is due to be full by the end of 2035, Singapore feels the urge to come up with new ways to deal with its waste. The government is looking into building an "Integrated Waste Management Facility", which should have the capabilities to separate recyclables from general waste (MEWR, 2018).

The solid waste management technology roadmap, set by the National Environment Agency, the National Research Foundation and the National Climate Change Secretariat, is the trajectory set for all residual wastes collected in Singapore, in which co-digestion of food waste and used water sludge is carried forward as most feasible technological solution for food waste for the coming decades. Anaerobic co-digestion of food waste and used water sludge is a technique that turns these two waste streams into fertilizer and generates bio-energy. The generated energy can then power Singapore households, and fertilizer can be exported when demand is inadequate within its own borders (NEA et al., 2016).

One obstacle, when it comes to food waste recycling, is the trash chutes that are installed in most flats around the city. These chutes are unequipped for separating organic from inorganic waste. Therefore, all new 'HDB' social housing flats will be installed with centralized dual chutes for recycling capabilities. On a larger scale, however, the government is looking for more short-term solutions for food waste reduction and recycling (Sustainable Singapore et al., 2014).

In order to develop the production of food in Singapore further, the Ministry of National Development, together with the Agri-Food and Veterinary Authority, focuses on urban farming and vertical farming solutions. The Ministry, therefore, aims to increase the number of urban farms in the city after the first pilots by Comcrop, Edible Garden City and Citizen Farm have proven to be successful so far. Hindered by land constraint, technological developments in vertical farming, hydroponics and aquaponics will determine the future competitiveness of Singapore's small but growing agricultural sector. The government, therefore, sees technology as the main driver and focus point to ensure future competitiveness of the sector and to intensify food production and productivity. Food waste can be converted into several valuable inputs for food production and the short supply routes in Singapore are conducive to this as well. However, local food production is still low (10%) and, therefore, the balance of supply and demand is far off (MND, 2018).

Expectations and social acceptance

Singapore is the fourth most food secure nation in the world (EIU, 2017). Consequently, the government has set strict legislation for handling food within the country. The Agri-Food and Veterinary Authority currently requires nineteen categories of food to have expiry dates. Roughly they consist of dairy, tofu, cooking oils, chocolate, fruits, vegetables, nuts and infant food. However, some products do not require expiry dates and still have dates mentioned on packaging by commercial manufacturers. These companies incentivize people to buy new products this way (NGO2, personal communication, 2018). Moreover, according to legislation 'best before', sell by' or 'use by' plus the date all have the same meaning, resulting in confusion of customers and retail wholesalers (NGO2, personal communication, 2018). However, it does mean that products passed these dates cannot be sold, which results in needlessly throwing away of food (NGO2, personal communication, 2018).

Disposal of food by companies and residents has been made convenient by the government. The disposal fee for waste for business is low and for consumers non-existent. Both groups are, therefore, not incentivized financially to reduce their food wastage (NGO1, personal communication, 2018). As a result, the industry expects the government to implement new recycling infrastructures (MNC5, personal communication, 2018). Furthermore, waste management in Singapore is also subject to strict regulations. There are regulations for those who would like to apply for a general waste collection license, for those companies aiming to redistribute food waste. Restrictions are in the form of use of equipment or vehicles, which all require high investments (MNC5; SU5, personal communication, 2018).

Finally, the social acceptance of food waste reduction and recycling is lacking. Food waste recycling by the industry and consumers in Singapore is relatively low. Within the industry, food is selected for the highest quality. This leads to needlessly disposal of edible food on the account of quality and taken-for-granted assumptions of business operations. When it comes to consumer, most Singaporeans live in high-rise residential flats equipped with chutes for garbage disposal. These chutes do not provide for recycling, and Singaporeans are mostly reluctant to segregate their waste in separate bins (MNC5; KI1; KI3; NGO1, personal communication, 2018). Consumers are also responsible for the biggest part of food wastage in the city-state (Lim, 2017a). Residents tend to over order at restaurants, hotels and events, reinforced by a prevalent buffet culture. Hotels and event organizers and other retailers have not been able or are reluctant to reduce this wastage so far. Moreover, Singaporeans prepare more food at home than they require and hardly consume leftovers the next day (Electrolux, 2015). Consumers also have misconceptions about the use of expiry dates on products and consider circular food solutions as unsanitary (NGO2; LC1, personal communication, 2018). On the other hand, Singaporeans have a strong sense of community. For example, a strong community garden trend has been encouraged and growing over the last years. Additionally, several NGOs, which distribute food surplus to the needy, run on large volunteer communities (SU1; NGO1; NGO2, personal communication, 2018; Sustainable Singapore et al., 2014).

5.2.3 Interactions

Knowledge networks

In the research field, several collaborations between knowledge institutes and industry are present on the topic of food and circular economy. Especially together with multinational corporations R&D projects with knowledge institutes have been formed in recent years (MNC1; KI1, personal communication, 2018). For instance, the National University of Singapore has set up a collaboration with Wilmar International Limited and the National Research Foundation to conduct research on clinical nutrition and synthetic biology. The research at WIL@NUS Corp, as the collaboration is called, is aimed at developing food products that contain less calories and at the same time developing novel technologies for the production of specific industrial enzymes and biochemicals from natural products. In particular, the synthetic biology aims at developing microbes and enzymes that can produce biochemicals from natural products for specific uses within the food industry and beyond. This research has the potential to effectively treat homogeneous food waste in the future, although food waste applications are not specifically mentioned within their research programs (NUS News, 2018).

The National University of Singapore's original focus has been on fundamental and applied research. This has increasingly been done in collaboration with other national and international universities, governmental bodies and industry to develop market-ready and proven technologies (NUS, 2018). For instance, within the Campus of Research Excellence and Technology Enterprise, the National University of Singapore has several research centers up and running that focus on urban systems, environment systems, energy systems, and human systems. Under its urban systems research focus, NUS is part of two research centers which focus on food waste: The Energy and Environmental Sustainability for Megacities program in collaboration with Shanghai Jiao Tong University and the Singapore-MIT Alliance for Research and Technology program in collaboration with Massachusetts Institute of Technology (MIT) (CREATE, 2018a; CREATE, 2018b).

MNCs operating in Singapore are also developing solutions of higher value together with knowledge institutes to see whether nutrients from, for instance, spent grains can be extracted. To investigate whether such solutions are possible, MNCs have set up several research collaborations with the National University of Singapore and Nanyang Technological University (Eco-Business, 2016; MNC1; MNC4, personal communication, 2018).

Next to university research, the many polytechnics in Singapore, such as Nanyang Polytechnic and Ngee Ann Polytechnic, are also involved in applied research on food waste and circular economy. Nanyang Polytechnic had been doing research on natural fermentation of food waste. Ngee Ann Polytechnic is investigating the valorization of nutrients from wastewater or okra for consecutive use as fish feedstock or converting spent coffee grounds into tray pallets. Most of this research is in close collaboration with the industry (LC1, personal communication, 2018).

The Agency for Science, Technology and Research (A*STAR) is an R&D institute that supports and facilitates research and technological innovations within Singapore. Their focus is on combining technology and science to bridge the gap between research and the industry. They collaborate with multinational companies and local businesses as well as provide for incubation of startups in the field of R&D (A*STAR, 2018). They have funded some of the startups in the field of food wastage (SU3, personal communication, 2018).

Collaboration with the government occurs regularly as well. For instance, the National Environment Agency has several research collaborations with knowledge institutes, where they provide necessary guidance and data. In return knowledge institutes tailor their research to suit the needs of the agency. Collaboration with the industry is also being encouraged (KI1; KI2, personal communication, 2018).

Political (lobby) networks

Singapore holds many non-governmental organizations that educate and create awareness among the public about food wastage. Zero Waste Singapore is one of these organizations. This non-profit organization provides tips and resources on how to minimize and recycle (food) waste. They also promote the 3R principle among citizens and businesses. They specifically aim for the acceleration of a circular economy in Singapore. Zero Waste Singapore uses four strategies to encourage the adoption of a circular economy: They educate with campaigns, influence governmental decisions with surveys, research and reports, collaborate with industry players, and target market problems with the promotion of technological solutions. Another organization that aims especially at reducing food waste is the Save Food Cut Waste initiative. This movement aims at educating citizens, businesses and other organizations about the impact food waste has on the environment and what the incurred social costs are. More lobbying and educating NGOs are WWF Singapore, Earth Society, Ground-up Initiative and Forum for the Future Singapore. Multinational companies lobby at the government for a circular economy, as some of them already have their own vision, or even in some cases, their own take-back schemes (Eco-Business, 2016). Finally, the CEO-led Business Council for Sustainable Development Singapore aims to influence policymakers in the direction of sustainable business. They advocate for monitoring of food wastage throughout the supply chain under the Food Loss & Waste Protocol (Green Future Solutions, 2015).

Industrial networks

In the field of circular economy and food wastage, there are a few notable network organizations that provide several forms of networking within the (food) industry. For instance, Green Drinks Singapore organizes networking events to link businesses, governments, NGOs and the community, and the Singapore International Chamber of Commerce organizes its Circular Economy forum annually (Green Future Solutions, 2018; SICC, 2018). Other intermediary organizations provide a platform through discussion roundtables on circular economy, such as Eco-Business. More in general, several newspapers provide information on the topic of circular economy, such as Eco-Business, the Strait Times, and the Business Times (Eco-Business, 2016; Eco-Business, 2017).

The government is also actively involved in connecting companies, research institutes and civil organizations through various platforms. The most prominent and renowned are the biannually organized events of the Singapore International Water Week, the World City Summit and the Clean Enviro Summit. These events are meant as a platform through which policymakers, industry experts and researchers can exchange their expertise on the topic of sustainability and circular economy. Although the focus of the events is on urban solutions, a great deal is geared towards the food industry. Furthermore, it shares the guidelines for its 3R scheme with the industry (Sustainable Singapore et al., 2014).

Furthermore, the government is actively interacting with other actors on the topic. For instance, in order to change cooking and eating habits of Singaporeans the government has set in place many campaigns on food waste and food preservation to create awareness about the issue (Zero Waste Singapore, 2015). So far, however, these efforts have been limited in reducing the amount of waste generated by citizens. The government also has difficulties promoting recycling habits of citizens. Most of all because most people in Singapore live in high-rise buildings equipped with garbage chutes that do not allow for separate collection of waste (Sile, 2016). The government has been unsuccessful in promoting separate collection of food waste from other waste streams. Especially because in recent years the government has promoted the use of plastic bags to collect food waste, as to prevent chutes from being contaminated with pests (MNC5; KI1, personal communication, 2018).

Next to the networks mentioned above, there are a few important business associations within the food supply chain. The Waste Management and Recycling Association and the Singapore Food Manufacturers' Association are two of those (Green Future Solutions, 2015). In recent events, a collaboration of fifty hotels in Singapore have joined hands to tackle the food waste issue together, and Enerprof is a group of construction companies that specializes in the reduction of food waste through cleantech solutions. Lastly, a public-private partnership of local and international companies is active in the field of CE and food waste (Yap, 2016).

5.2.4 Infrastructure

Knowledge infrastructure

Most knowledge development in the field of food technology and circular economy is of a tacit nature. This is because food science applies and combines different disciplines and, next to that, innovation in this field can often be replicated easily. Therefore, patents are difficult to document, or the inventor depends on secrecy. For fear of losing their competitive advantage, firms are reluctant to document and share knowledge on this topic (KI1, personal communication, 2018). Furthermore, innovation in food technology is often incremental. Given the extensive research field, more radical innovation may come from the many R&D projects on the topic in the future, but could also come from unexpected sources, as food science can be applied to many disciplines. Because of the tacit nature of knowledge development in the food industry, analysis of the knowledge infrastructure was done through qualitative interviews.

A noticeable aspect of the knowledge infrastructure in Singapore is the commercialization of research into viable products. For instance, the Nanyang Technological University focuses on bringing their scientific products to market. Three departments within university are responsible for this task: NEWRIEdu, NEWRITECH and NTUitive. Working together, they aim to identify markets for the technologies the several Nanyang Technological University research centers produce. In doing so, the university looks for ways to bridge the gap between research outcomes and the needs of the industry. It does so by encouraging and fostering entrepreneurship and by facilitating the commercialization of research (NTUitive, 2018; NTU, 2018).

Physical infrastructure

The current physical infrastructure of recycling in Singapore is an important basis on which future circular economy can be built, and, thus, can facilitate or hamper the implementation of a circular economy in the food industry; for example, the availability of a sufficient collection system for food waste (Jurgilevich et al., 2016). The current infrastructure for food waste disposal and food waste collection mainly follows waste collection of all disposables across Singapore.

Collection and distribution of food waste in Singapore is done in several ways. First of all, most household waste is collected by four public waste collectors (Veolia, SembWaste, Colex and 800 Super) which have certain designated areas in which they are allowed to operate (NEA, 2018d). Household waste is mainly collected in mingled form. As most high-rise residential flats are equipped with garbage disposal chutes, household waste can be disposed of from the highest floors. However, these mechanisms also hamper separate collection of waste, as these chutes are singular. So far, Singapore has therefore had troubles with source separation and co-mingled household collection for effective recycling (MNC5; KI2; KI3, personal communication, 2018). However, there is food waste recycling being done in Singapore. Mainly, there are four outputs food waste is being recycled to: compost, animal feed, bio-energy and bio-fuels and non-potable water (FoodBank, 2015). Collection of recyclables is also being encouraged through separate bins for food waste, cardboard, plastics and glass, however on a very small scale (6000 bins around the island for more than 5.6 million residents). The rest of the waste is sent to one of the four waste-to-energy incineration plans Singapore holds by either one of the four public waste collectors or by one of the other 346 general waste collectors. There, food waste is incinerated together with other waste materials, such as plastics, paper and metals. After incineration the leftover residue is sent from Tuas Marine Transfer Station to Semakau Landfill on Semakau island (NEA, 2018d).

The Public Utilities Board and the National Environment Agency currently manage two waste management facilities, the Water Reclamation Plant at Tuas and the Integrated Waste Management Facility respectively, where used water and solid waste is being treated separately. With the new to-be-built Tuas Nexus plant, the two agencies aim to combine the effluents of these treatments. This means sludge from domestic used water can be co-digested together with food waste to generate biogas. The food waste enhances the biogas formation from sludge in this way, and the biogas can then be used in the Combined Heat and Power plants that feed the city's electricity grid. Up to 300,000 homes can potentially be powered by using this system (Sustainable Singapore, 2018).

Overall, the waste management infrastructure in Singapore is convenient to the consumer and the industry. The disposal and haulage fees for consumers and companies are relatively low or are calculated into the price of products, and the recycling infrastructure is still relatively early stage (SU2; KI3; NOG1, personal communication, 2018; ExpatFocus, 2018).

Financial infrastructure

The following section shows the available streams of funding in the field of food waste related innovations and initiatives. Singapore has a strong banking sector and investing climate (Santander, 2018). In recent years, there has been increasing interest of investing in to businesses that follow a social or environmentally responsible cause. Investment company Temasek Holdings has created a new focus area of environment. They are willing to invest in environmentally and economically sound businesses (SU3; SU5, personal communication, 2018). See table 5 for an overview of identified organizations directly funding food valorization projects.

Table 5. *Overview of parties funding projects in or related to the field of food technology and circular economy.*

Organization name	Funding scheme	Focus area
A*STAR	Undefined	Bridging gap between science and industry
Enterprise Singapore	Startup funding	Startup ventures
National Environment Agency	3R Fund	On-site digester/composter technology
National Research Foundation	Central Gap Fund Early Stage Venture Fund	Tech startup ventures; Agriculture, Food, Human & Animal Health
Temasek Holding	Undefined	Startups with an environmental cause
Wilmar International Limited	Early Stage Venture Fund	Agriculture, Food, Human & Animal Health

5.3 FUNCTIONAL ANALYSIS

5.3.1 System function performance

In this section a short overview is given of the performance of the system function according to the interviewed key stakeholders (see table 6). Ratings for each function were derived from the average scores given to the functions by each stakeholder. Best performing functions were knowledge development and mobilization of means, and to a lesser extent entrepreneurial activity. Other functions are less developed, especially market formation and creation of legitimacy, which is in accordance with the phase of development the focal TIS currently is in (see Appendix E for a spider diagram of the functional performance assessed by the interviewees).

With the phase of development of the focal TIS still being in (pre-)development, it can, therefore, be expected that the functions of market formation and legitimacy creation are lacking behind, and the functions of knowledge development, mobilization of means and entrepreneurial activity are further developed (Hekkert et al., 2011).

***Table 6**. Performance of each function according to the interviewed stakeholders. Ratings are based on relative average scores provided by the interviewees as answer to the question how each function was fulfilled. An overview of structural. Overview of structural origin of function malfunctioning is given as well.*

System function (F#)	Average rating	Function performance	Structural component
Entrepreneurial activity (*F1*)	2-3 / moderate	❖ Several (social) enterprises are actively searching for new solutions to valorize food waste. ❖ Most initiatives are at an early stage. ❖ Scaling up of initiatives is hardly occurring.	❖ NA
Knowledge development (*F2*)	3 / moderate to strong	❖ R&D and scientific research on the topics of food technology and circular economy is deemed sufficient. ❖ Research on the social dimension of CE is lacking. ❖ Data on waste streams by different actors is missing.	❖ Lack of educational programs on food waste, food waste valorization, and circular economy. ❖ Focus of research on recovering of energy from food waste, rather than extraction from homogeneous food waste. ❖ Knowledge development is of a tacit nature, which impedes investments.
Knowledge diffusion (*F3*)	2-3 / moderate	❖ Sharing community among social enterprises. ❖ The government is providing for events and conferences. ❖ Newspapers are an important means of exchanging knowledge. ❖ Collaboration between industry and research institutes	❖ NA

		(commercialization of research) ❖ Lack of transparent data from the industry and the government.	
Guidance of the search (*F4*)	1-2 / weak	❖ The government has a vision on food waste reduction and is working on improvements. ❖ Companies mostly do not have a vision on circular economy and if they do, their vision is distinct from other companies. ❖ The industry has no clear vision and is profit driven. ❖ Selection of (technological) varieties in favor of technologies that handles heterogeneous food waste	❖ No target set for food waste recycling, only overall recycling target. ❖ Step-by-step plan enforced by laws, and regulations is missing. ❖ Circular economy is not mentioned in long-term vision. ❖ Reduce, reuse, recycle narrative poorly aligns with circular economy for the bio-cycle.
Market formation (*F5*)	1-2 / weak	❖ There is a lack of consumer and business awareness on the issue of food waste. ❖ Consumers' mentality and habits on, for instance, recycling still must change. ❖ Businesses are not actively creating awareness. ❖ Multinational corporations are investing but the industry overall is not investing sufficiently. ❖ Small market size: Expansion out of Singapore required.	❖ Missing demand for circular products and for fertilizer; low local production of food. ❖ Low number of supplementary policies on reducing food waste.
Mobilization of means (*F6*)	2-3 / moderate	❖ Researchers can apply for sufficient research funding for research on circular economy and food waste valorization. ❖ Companies and government provide for ample funding for startups, however not specifically geared towards food waste or circular economy. ❖ Government provides funding especially for on-site digesters and composters. ❖ Recycling infrastructure is lacking.	❖ Waste management infrastructure not conducive to recycling practices of citizens and businesses.
Creation of legitimacy/overcoming resistance (*F7*)	1-2 / weak	❖ Hardly any action being taken to overcome resistance. ❖ Consumers resist changing habits and fear unsanitary conditions. ❖ There is resistance from companies to change disposal habits as they only look at costs.	❖ Low disposal and haulage fees. ❖ (Too) convenient waste management infrastructure. ❖ Consumer perceptions, and consumer and industry habits.

5.3.2 Functional interactions

In the following section a more detailed description is given of the interaction between the functions of the focal TIS. Since the focal TIS is anticipated to be in its (pre-)development phase, several functions are expected to be performing better than others: Market formation and creation of legitimacy are less developed. Furthermore, guidance of the search plays a crucial role to advance the development of the system (Hekkert et al., 2011).

Guidance of the search
Currently, guidance of the search is mainly driven by the government and multinational corporations. According to the interviewees, the government has a vision on food waste management and, through this vision, applies several strategies to handle food waste. First of all, the vision of becoming a zero-waste nation by 2030 in conjunction with the Closing the Waste Loop Initiative and 3R program were mentioned as the pillars of the government's food waste management strategy for the coming years. Through these programs, the government is pushing the industry and consumers to reduce and recycle their food wastage. One interviewee said these could be considered as a vision towards a CE but according to most interviewees, CE is new and upcoming in Singapore and has only been mentioned once by the minister of the Ministry of the Environment and Water Resources, Mr. Zulkifli, recently this year (KI3; KI2, personal communication, 2018). In other words, the CE has not been completely integrated into the long-term vision of the government. Overall, the government is market-driven and would like to see the industry come up with solutions first, before implementing regulations. As described by one interviewee:

> *I don't see the government legislating to adopt circular economy [further]. The government is more market driven, whatever the market is doing, but they are pushing. They prefer to encourage new solutions through funding mechanisms, maybe public education, to try to let people do things themselves.* (KI2, personal communication, 2018)

The function of guidance of the search for CE was still seen as underdeveloped by most interviewees and assessed as weak, as they render the current recycling focus as low-grade solutions, meaning focus should be on food waste prevention and finding alternative higher value use for food waste first, as consumption of imported food is still high (KI1; KI3; SU3; SU4; SU5; SU8, personal communication, 2018).

At the same time, a group of multinational companies operating in Singapore have clear strategies on CE and align those with their sustainability visions. MNCs see CE to increase profits and, at the same time, provide an answer to the increasing pressure from consumers to take responsibility for their environmental impact (function 4) (Eco-Business, 2016; MNC1; MNC2; MNC4, personal communication). Even though these visions and strategies are not aligned with other multinationals - nor to the government -, and the extent of these strategies differ, they do develop guidance of the search in a positive way (function 4) and influence the mobilization of means positively as well (function 6): Investment companies are increasingly interested in ventures that add environmental value.

Nevertheless, the strategies set by the government have had a considerable effect on other functions of the focal TIS and on the selection for technological variants: Interviewees mentioned that selection of technologies for food waste management is in favor of on-site composter and digester technologies, as the government is supporting solutions for non-homogeneous food waste through several funding schemes (SU5; KI2, personal communication, 2018). This has effect on the functions of mobilization of means and subsequently entrepreneurial activity. This development and selection will be elaborated in the next few paragraphs below.

Mobilization of means
When it comes to funding research (function 6), funding availability for R&D overall has been increasing rapidly throughout the years, and if research aligns with one of the national challenges set by the

government (in this case their zero-waste nation vision), there is sufficient funding obtainable (KI1, personal communication, 2018). To illustrate, the problem of food waste was declared as a national challenge by the government in 2014 in its sustainable blueprint (function 4), after which government funding (S$ 900k or €567k) for R&D was allocated to solid waste treatment technology and food waste technology in particular (function 6). The government has also assigned funding especially to research on CE and food waste in general, and more funding is expected to be allocated to this field in the near future (unknown amount) (KI2, personal communication, 2018). Additionally, knowledge institutes in Singapore are encouraged to look for funding sources outside the government, and the industry is becoming more enthusiastic about research on food waste valorization, as one of the interviewees explains they receive the lion's share of their research funding from the industry (KI1, personal communication, 2018).

This, in turn, led to an increase in knowledge development on recycling technology for food waste (function 2). Since the government is looking for large scale solutions to treat heterogenous waste, research on, for instance, (co-)digestion technology was favored over technologies to reduce or upcycle homogeneous food waste: "*The government is very interested in inhomogeneous waste because it is easier for them to treat as a whole [sic]*" (SU5, personal communication, 2018).

Regarding funding for entrepreneurs, investment companies provide for enough funding for entrepreneurs, according to the interviewed startups:

> *(...) they really have invested in any businesses who kept adding value in creating a circular economy. Because Temasek funding, they have identified certain areas and environmental is actually a new area that they came up with. And for as far as we know, the other business, big businesses, they invest in other companies and startups. Like Singtel, they just came out with a new environmental fund to invest. So, I don't think funding is an issue, especially because most wealth is accumulated in Asia or Singapore, or this region, and people are getting more interested in investing in businesses with a social impact.* (SU3, personal communication, 2018)

However, investment companies would at least like to see an established customer base and, in general, all startups need to have the same credentials to successfully compete for and acquire funding, both from the government as from venture capital (SU3; SU5, personal communication, 2018). Furthermore, no funding from these companies is especially designated for startups dealing with food waste and CE:

> *And currently, there is not much funding that is specifically for circular economy, so we have to feed into any kind of funding scheme available, whether it is for startups, social enterprise or sustainable focused startups, or environmental startups. These are all the categories that we can see ourselves within, but there is no specific circular economy funding for now.* (SU5, personal communication, 2018)

Additionally, to R&D funding, the government is also providing funding for food waste reduction and recycling projects through its 3R fund. Funding through this program is allocated to on-site food waste composters and digesters by financially supporting installment costs for wholesalers and retailers (MNC2, personal communication, 2018)

Entrepreneurial activity

These recent developments have spurred entrepreneurial activity in the field of CE and food waste valorization in recent years (<2 years). All interviewees can name at least several startups initiatives. However, even considering these activities, the interviewees are moderately appreciative of the entrepreneurial activities of valorizing food waste and surplus in Singapore. Some interviewees even mention the culture and infrastructure within Singapore hardly facilitating entrepreneurship (KI1; SU2;

NOG1, personal communication, 2018). They assess the overall fulfillment of the function as moderate at best. One of the main reasons for this is related to the argument under guidance of the search, as the interviewees see most entrepreneurial activity as low value food waste valorization:

> *This is the early days of the food waste upcycling because so far in Singapore, there are a lot of movement that is, I would say, not upcycling, but it's more like recycling. I see these as totally different things. Recycling is more, for example, food waste becoming compost or fertilizer. But it's not value adding, like making a biscuit out of soybean residue. So, this is a conversion, there is no transformation. Transformation means change in nature. So, when I look at the soybean residue, fermentation would lead to nutritious beverage. That is transformation. Or the soybean residue becomes biodegradable plastic material. That is transformation. With upcycling you increase the value.* (KI1, personal communication, 2018).

In accordance with this statement, selection for a few technologies is starting to unfold regarding what the interviewees see as lower-grade solutions: In combination with the 3R funding scheme and promotion from the government (function 4 and 6), the on-site digester and composter technologies have gained a foothold after a group of ventures exploited this opportunity (function 1). According to the interviewees, several startups and companies are active in this field and are facilitating the shift to handling food waste this way (function 1). As told by an interviewee:

> *In terms of what I see them [actors in Singapore] trying to do: they are trying to find solutions that can convert huge amounts of waste. For example, eco-digesters that process inhomogeneous waste. (...). And smaller companies, I see them work on very specific kinds of waste and inhomogeneous waste as well. The specific kinds would be organic waste, and then organic waste is more like us, trying to create products out of homogeneous waste. But that is not really popular in Singapore currently. Everyone is looking at compost and inhomogeneous waste.* (SU5, personal communication, 2018)

These companies are considered to have grown in the last five years by having received considerable funding from the 3R fund from the government by the provision of installment costs for buyers (function 6). These technologies were, therefore, mentioned by the interviewees to have established for a longer period:

> *There are other new startups that are looking at composting of food waste. Eco-Wiz is one company, it's not really a start-up anymore. It's in operation for five or six years. The system is basically composting. It's a big machine that just aerobically compost the food waste that produces fertilizers. They also have another system that can actually just degrade all of the food waste into sludge.* (KI2, personal communication, 2018)

Creation of legitimacy

The increased entrepreneurial activity of recent years has had a positive effect on the legitimacy of a CE. However, there is still resistance from the industry and consumers to handle their food waste differently, i.e. recycling and reducing of food waste. Resistance to CE is mentioned mostly related to costs and awareness. Those who must invest and are incurred costs for circular solutions will oppose; partly because most SMEs in the industry have not linked food wastage reduction with cost savings yet. In general, the industry -mainly the traditional SMEs- is mostly concerned with daily operations and are at best aware of the problem of food wastage. They often do not see the connection between reducing food waste and potentially saving costs, according to the interviewed startups and multinationals directly working with industry actors:

At the start we tried to reach to them [industry companies] by sharing our impact and sharing them what we want to achieve. This was almost impossible to get any result. So, we have to talk to them in terms of costs and how they can they can recover their loss, how much they are going to pay. (SU3, personal communication, 2018)

All the supplier wants to do is make money out of it. We sell it to them, and they resell it the farmers and he makes money out of it. Do I believe that he thinks he is helping the world to become more sustainable? I don't think so. The vision is clear at a company at the center of all the activities. Down the line I am not sure. (MNC1, personal communication, 2018)

The industry is profit driven, and if circular solutions can increase profits, industry actors are more than willing to apply. However, in general, their view is that the solution should be easily implementable and not drive down profits (MNC1; SU3; SU5, personal communication, 2018). Additionally, the regulations on waste disposal for companies are currently such that companies can dispose of their food surplus and waste conveniently and without any incentive to reduce wastage, which influences their reluctance to change. An NGO states:

I think it's too easy for businesses to throw away food in terms of regulations. And I get that also because from the government perspective, Singapore is a very small economy, our regulations have to be pro-business to attract foreign companies to come and set up shop in Singapore. It has to be pro-business, and if you have too many regulations that prevent making businesses or that make it costly for businesses to set up shop in Singapore, then the businesses don't want to come here, and our economy will suffer. So, we really have to decide which is more important: Wasting food or making profits. And the government's job is to try to balance that. And I am pretty sure where the Singapore government prefers to balance to. (NGO2, personal communication, 2018)

On top of that, several interviewees mention consumers are reluctant to change habits towards more recycling, and certain circular products are perceived as unsanitary or unhealthy. An entrepreneur says:

I think, when we talk about food waste, consumers normally see them as something that is probably going to be rotten or there are like holes in them. But actually, it's not really like that, but they can't unsee whatever the media portrays to them. (SU5, personal communication, 2018)

The function of creating legitimacy is assessed as weak overall by the interviewees, and the lack of legitimacy for circular products, in turn, has influenced market formation.

Market formation

What is often mentioned by the interview stakeholders is that the market size for circular products is too small; mainly because demand for circular products is lacking. Even though consumers are aware of the problem of food wastage, evidence is missing that consumers are buying more environmentally friendly alternatives:

So, in terms of consumers, yes, I think they definitely are aware, at least the younger consumers. They know of all the issues but ultimately when they are at the point of purchase, whether it is an online supermarket or anywhere, would they actually pay more, or choose a product that is more sustainable over another product? Research has always shown that, yes, they are willing to, but apart from Unilever, I haven't seen much *evidence to say that consumers are indeed doing that.* (MNC1, personal communication, 2018)

This is underlined by most interviewees who say consumers are aware of the problem, but, at the same time, are reluctant to recycle and are unaware of how to avoid food wastage. The mentality of consumers still must change. According to the interviewed stakeholders, company investments are, therefore, low. Mainly because of the low demand for circular products. Multinational companies invest more, but in general, investments by companies are only made if profits can be increased; this applies especially to the more traditional SMEs:

> *Especially most of them are SMEs. So, when we start to reach out to them with the problem, we have to make clear to them that they can sell it [food waste] to other businesses and that it can cover their costs, which is quite logical, because we were all business and finance students. So, we think it is logically sound and economically feasible, but to them, they would rather hold on to goods to the last minutes and throw them away when there is no seller to take them off for a discount. They don't really see the food wasting, to them it is all about costs.* (SU3, personal communication, 2018)

Underlining the small market size, the interviewed startup ventures also see expanding outside of Singapore as the only way to scale up (SU2; SU3; SU5; SU6; SU7; SU8, personal communication, 2018).

Altogether, market formation is being assessed as weak by the interviewees. However, some interviewees see a rise in the number of installments of on-site composters and digesters at universities, companies and schools. According to them, this rise is mainly due to the government actively creating a niche market for this type of technology by providing for enough funding through its 3R fund, as mentioned earlier (function 6 and 1) (MNC2; LC1; KI2; KI3; NGO1, personal communication, 2018). Market formation for these technologies is strengthened by the growing entrepreneurial activity (function 1) and, through that, the legitimacy of this technology (function 7), indicating these technologies are ahead of other variants:

> *(...) it seems like most people are looking towards the technology end rather than the nature end. So, to get people to look at the natural way of doing things that makes another resistance because people maybe perceive it as being unclean. They want something that is almost sterile in a way*. (LC1, personal communication, 2018)

Knowledge development

Since both circular economy and food science are broad scientific fields, the function of knowledge development was assessed by the interviewees as moderate to strong. Knowledge development for a circular economy seems to be sufficient, according to most of the interviewees, depending on which research topics are mentioned they deem required for a CE.

Still, on several topics, knowledge development in the field of CE is mentioned to be inadequate: on data of material streams on an interfirm-level, on consumer awareness, on business incentives, and homogeneous food waste (SU3; SU4; SU5; SU7; KI1; KI2; KI3; NOG1, personal communication 2018).

Knowledge diffusion

Lastly, knowledge diffusion has an influence on knowledge development and entrepreneurial activity. According to the interviewed knowledge institutes, scientific output in the form of patents on the topic of food waste valorization and CE in general are exceptional; especially in comparison with the amount of publications brought out in Singapore. Scientists rather go directly for commercialization of their findings:

> *In terms of protection of the innovation that's difficult because the innovation by nature is very simple. It's sounds very circular economy but if you look at the innovation per se it's very simple. That will have an impact on the protection of the intellectual property because, I would say, with my technology innovation, people don't look at the details. They don't need to buy the patent, they can just do it themselves. That is a limitation of food technology innovation. As a result, we make a list in the form of intrinsic innovations of which we don't have a patent. For a patent you need to publicize. It's not really high-tech. Nanotechnology, you don't have the knowhow, you don't know how to do it. This is the difference.* (KI1, personal communication, 2018)

Therefore, knowledge development for CE mainly occurs indirectly, which tempers knowledge diffusion through scientific publications on the topic (KI1, personal communication, 2018). On the other hand, interactions between the research field and the industry is well established within Singapore, as universities acquires a part of their funding from collaborations with the industry (KI2, personal communication, 2018). Knowledge institutes in Singapore are renowned for commercialization of scientific output, rather than publications (KI1; KI3, personal communication, 2018). An example is provided by one of the interviewed startup ventures: They have acquired funding from A*STAR, a R&D institute, to commercialize their innovative valorization of food waste (SU5, personal communication, 2018). Another example is provided by one of the interviewed knowledge institutes, where they are bringing their own digester to the market (KI2, personal communication, 2018).

Additionally, current startups within the field have created a strong community in which everyone is willing to share openly. One of them acknowledges: "*The culture of social enterprise ecosystem in Singapore is such that we are very much willing to share knowledge and information*" (SU2, personal communication, 2018). Moreover, the interviewees mention the government agencies often publish news on their websites and provide for different platforms where actors can interact and share knowledge (KI2; KI3; NGO1, personal communication, 2018).

To provide an overview of the interviewee assessment, funding for research and startup ventures is hardly put forth as a problem. There seems to be enough funding available for research to develop the knowledge on circular economy and food technology further as well as for startups in general. Even more so, additional funding from the government is especially assigned to facilitate the startup climate in Singapore. Enterprise Singapore, for instance, has ample funds available to provide startups with capital (SU3, personal communication, 2018). The interviewees overall, therefore, rate the mobilization of means as stronger relative to other functions. With respect to physical resources, however, some stress the lack of a logistic infrastructure for collecting food waste separately. The interviews also show the topic of circular economy is growing within the knowledge field, and as the R&D in Singapore is generally strong, knowledge creation is hardly mentioned as a limitation by the interviewees (KI1; KI2, personal communication, 2018). Research institutes form strong ties with the industry by setting up collaborations in R&D and providing funding for the commercialization of research, which enhances knowledge diffusion. In the case of knowledge diffusion, many interviewees provided examples of how scientific knowledge is brought to market and shared on the island state. On the other hand, guidance of the search is assessed by most interviewees as weak compared to other functions; mainly because of the focus on 'low-value' recycling options. Market formation is also lacking according to the interviewees because of the lowest assessed function: creation of legitimacy. They mention the industry is reluctant to change their waste disposal practices, and the consumer is not yet willing to purchase circular products over less sustainable options.

In summary, the lack of market formation for circular food waste products is blocking the overall development of the TIS, with low investments by the industry and low consumer demand. The function of legitimacy is also forming a barrier, which is additionally weakening the function of market formation since consumers perceive circular food as unsanitary, and consumers' and businesses' disposal habits are formed around a convenient waste management infrastructure. Furthermore, the function of guidance of the search is also blocking the development of the focal TIS, since the vision and strategies set by the government favor technological recycling solutions for heterogeneous waste over reduction initiatives. The legitimacy and market formation for the digester and composting technologies is also more developed as for other initiatives, indicating the focal TIS is developing towards recycling by composting and digesting technologies.

6. Discussion

The analysis in the previous section described the lack of market formation and legitimacy for circular products as two of the main obstructions for the development of the focal TIS. One of the main structural causes identified came from consumers' perceptions of circular products, habits of consumers and businesses, and a convenient waste management infrastructure. In the theoretical background it was suggested that these perceptions and habits might not be grounded on rational behavior (Wirth et al., 2013; Mylan et al., 2016; Borrello et al., 2017)). This leads to the main goals of this study to identify drivers and barriers for socio-institutional and technological change for the transition towards a CE, and to the reflection on whether the TIS-approach applies to assess the socio-institutional changes required for a CE.

One part in which the TIS-approach can be improved to study CE transitions is by including the consumer as an integral part of the innovation process. A CE transition is unique in the sense that socio-institutional change is dominant, which in many cases involves changing habits of consumers. However, the consumer is classically not the actor under study within TIS-analyses, which traditionally focuses on individual entrepreneurs, R&D firms, university research and policy makers (Lundvall, 2016). Therefore, the perceptions, decision making, and habits of consumers were less important to identify within preceding TIS studies. Wirth et al. (2013) made a first start by incorporating informal institutions and recognizing actors' behavior might not be rested on rational decisions, as described in the theory section. However, they still looked at the perspective of *'professional'* core business actors active within the system (p.25). Business actors, however, have arguably different rationales than consumers. Within innovation studies the role of the user of innovations is widely studied and innovations are also seen as the overlap between technological opportunity and user needs (Lundvall, 2016).

Therefore, it makes sense to add the user side, or in this case the consumer, into the TIS-analysis, especially when it comes to CE transition for which changes in consumer practices are important. In order to identify the socio-institutional changes required for the development of the TIS for a CE more holistically, emphasis could, therefore, be placed on consumers as active actors within the innovation process; consumers as part of the innovation system as much as other actors within the system. This means consumers are directly and indirectly influencing the progress of the innovation systems and take part in the diffusion of solutions (Lundvall, 2016). First hints on where such additions can be placed within the TIS-approach can be found in the assumptions and perceptions of consumers. For instance, consumer acceptance and expectations of circular products can be added into the structural analysis, which has partly been demonstrated in this study, as well as consumer willingness to participate in new socio-institutional innovations. Furthermore, within the function of knowledge exchange, one could additionally investigate how users can exchange their needs easily with producers, and if producers actively engage consumers within the TIS, which is also important for the function of guidance of the search. The legitimacy and demand from a consumer perspective can also shed light on the functions of creation of legitimacy and market formation respectively.

The following provides several considerations in assessing consumer habits and perceptions. Even though the analysis shows the influence of consumers' perceptions and habits, the interviewees mainly mentioned consumer perceptions on hygiene of circular products. The statements on hygiene might have been rested on assumptions. According to Borello et al. (2017) consumers are willing to buy circular products when, for instance, composting of food waste has been used to cultivate new produce, but other factors, such as the degree of required participation or financial incentives, are more important when choosing circular products over less sustainable ones. The interviewees also mentioned a lack of demand for circular products. According to them, the consumer is not yet willing to buy circular products over less sustainable options. This could also have to do with the lack of transparent data on wastage by producers. Without the right information available about business practices, the consumer is unable to reward businesses when they offer circular alternatives (Borrello et al., 2017). However, as Wirth et al. (2013) have already indicated, actors' behaviors might not be so rational. Whichever is the main cause of reluctance for consumers to purchase circular products, the main point remains that the consumer perspective requires more emphasis in the TIS framework.

Another way to improve the TIS-framework is by incorporating business model innovation into the TIS-approach. It is being argued that for CE transitions as well as for other transitions radical technological innovation would not suffice to change current linear modes of production and consumption to more sustainable ones (Bidmon & Knab; Schlaile et al., 2017). Currently however, business model innovation is mostly seen as a form of socio-institutional change originating from technological innovation: novel technologies which induce new business models. This means business models are a part of institutions within a TIS, as suggested by Markard et al. (2016), and business models can be seen as the written or unwritten rules of how firms do business and bring value to their customers. In this sense, there can be a dominant business model within an entire sector which acts as the rules of the game in which the actors of the sector and TIS operate (Bidmon & Knab, 2016; Markard et al., 2016). Furthermore, these business models are subject to normative and cultural-cognitive contexts, meaning actors see their business practices as ''the way they simply do business'' (Wirth et al., 2013). However, business models also describe the relationship with suppliers and customers and constitutes more than just the rules of the game. Moreover, business models can be adjusted to serve different needs previously unknown to consumers (Sarasini & Linder, 2017). Bidmon and Knab (2016) go a step further and see business model innovation as a source of innovation as well as being subject to innovation.

Therefore, business model innovation is suggested in this thesis to be part of the functions of entrepreneurial activity and market formation within the TIS-framework and could be seen as entrepreneurial experimenting by different types of actors. This requires assessing the variations of business model innovation that aim at, for instance, the habituated behaviors of consumers and to entice them to use products and/or services that bring the development of the TIS further. This can also be conducted concurrently with assessing consumer habits, as described above. This could be incorporated in the functional analysis by asking actors if entrepreneurs have experimented with their business models and subsequently their motivation behind it, or by assessing whether demand and markets are created for these new types of business models. This is also in accordance with other studies suggesting improving transition theories regarding the role of business models in commercializing technological innovations (Bolton & Hannon, 2016), and seeing business models as a distinct unit of analysis within the innovation process (Bidmon & Knab, 2016; Sarasini & Linder, 2017).

Next, the findings of this study are in accordance with the considerations of Potting et al. (2017): When it comes to solutions for recycling, solutions tend to rely on (radical) technological innovation, whereas for reduction solutions socio-institutional innovation is dominant (see table 4). It seems straightforward from a political point of view to deviate from socio-institutional innovation, which is more difficult to implement than technological innovation (Borrello et al., 2017), and to focus on recycling efforts as these can rely on technological interventions.

There are furthermore several limitations on the chosen methods of this study, which need to be addressed. Firstly, the choice of snowball sampling as a sampling method for identifying key stakeholders for the interviews resulted in a skewed distribution of the interview sample: Even though a wide representation of actors were interviewed, there is an uneven distribution of organizational types in the interview sample of this study. Business actors are overrepresented (mainly MNCs and startup ventures) and an underrepresentation of actors from the knowledge field, from civil society and from governmental agencies, which might have had influence on the emphasis on the lack of market formation, and especially the lack of demand for circular products. Sampling bias was reduced as much as possible by identifying additional key stakeholders during data collection for the structural analysis (i.e. desk research), and by attending several meetings and events to confirm if most key stakeholders were interviewed. Organizing a workshop on CE and food waste in Singapore also did not result in the identification of additional key stakeholders, apart from additional government agencies (e.g. the Agri-Food and Veterinary Authority) and NGOs (e.g. Willing Hearts), and which makes it likely most key stakeholders were interviewed. This study could be improved by including more interviews with other organizational types.

The second limitation of this study relates to the ambiguous nature of the concept of CE. The CE concept is being interpreted differently by different actors (Kirchherr et al., 2017), which could have affected the assessment of the system functions. This becomes especially evident in the function of guidance of the search: The interviewees see certain circular strategies superior to other strategies or even excluded some strategies as part of a CE, even though they were all presented with the same definition prior to the interview. Including an explanation of a priority scale (i.e. reduction before recycling (Potting et al., 2017)) might have resulted in a different assessment of the function of guidance of the search. However, the different interpretations of CE were considered in the analysis by adding findings from the structural analysis.

One last point of limitation of this study is the assessment of entrepreneurial activity by the interviewees. Several interviewees also mentioned the culture and infrastructure within Singapore hardly facilitating entrepreneurship, even though Singapore ranks as one of the highest ranked cities when it comes to incubating startups (Startup Genome, 2017). Perhaps this has to do with the misconception of the definition of innovation, as the interviewees say Singaporeans are not innovative and copy from others (Roelandt et al., 1999). This might have affected the relatively low score for entrepreneurial activity and might have resulted in the discrepancy with the structural analysis, which showed a relatively diverse group of entrepreneurs.

7. CONCLUSION & RECOMMENDATIONS

In the analysis chapter (structural and functional), several structural causes were identified as the origin of the functional barriers present in the focal TIS of CE and food waste valorization solutions. This provides an answer to what the drivers and barriers are that foster and hamper the transition towards a CE in the food industry within the city-state of Singapore. An answer to how the transition can be accelerated will be given in the paragraphs below. The barriers originated from several structural causes, which are (i) consumer and industry habits, (ii) low disposal and haulage fees in combination with a convenient waste management infrastructure currently in place, (iii) the negative perceptions of and low demand for circular products, and (iv) the current (missing) overall long-term policies set by the government. These missing policies are mainly: Excluding CE in the sustainability narrative, omitting a target for food waste recycling or reduction, missing complementary laws, and misalignment of 'Reduce, Reuse, Recycle' discourse with food waste. 'Zero-waste nation' remains, therefore, an ambiguous term. These four structural causes were identified as the main origin of the functional obstacles within the TIS: the three functions of market formation, creation of legitimacy and guidance of the search; especially market formation because of a lack of demand for circular products, and for the creation of legitimacy because of Singapore's convenient waste management infrastructure with low disposal fees for consumers and the industry and accompanying habits. This leads to resistance to change and a reluctance to recycle or reduce wastage. The government maintains such a well-structured waste management infrastructure that all food wastage is handled out of sight, and, therefore, also out of mind. These two functions reinforce each other: Fueled by low perceptions of circular products and current habits of the industry and consumers, the legitimacy of recycling initiatives and, consequently, the demand for circular technologies and products are low. Overcoming resistance of current disposal habits of consumers and the industry, in combination with the convenient waste management infrastructure, is highly necessary to improve the hampering function of creating legitimacy for the focal TIS. Moreover, altering perceptions of consumers about circular products is required to increase demand and, in doing so, enhance market formation, while adjustment of current long-term policies is needed to induce guidance of the search towards reduction and recycling innovations.

Fostering drivers for the transition towards a CE in the food industry in Singapore were also identified. The functions of diffusion of knowledge and knowledge development are, in general, relatively strong. There are several research programs and initiatives in Singapore to be mentioned that focus on the area of food valorization in the form of energy recovery and nutrient extraction. Moreover, many are bridging the gap between science and practice, and the industry is actively funding research as well, which improves knowledge diffusion and commercialization. Informal collaboration within the social startup venture scene is also conducive to the diffusion of knowledge. Even though the startups are competitors, down the line they are aware they serve a common cause. Finally, mobilization of means for startup ventures and research on a circular economy is deemed sufficient and uncomplicated. Adding funding especially aimed for circular initiatives is unnecessary, as this would negate the purpose of economically viable business models within a CE (EMF, 2012).

Having said this, with the current selection of technological solutions in favor of on-site digester and composting technologies, there might be too much focus on energy recovery and composting in the long run. The focal TIS might, therefore, develop entirely around these two solutions and might stop developing further to create a CE on higher circularity levels. Especially as the throughput of resources within an economy needs to be reduced in order to make a CE sustainable (Morea et al., 2017). This leads to the recommendations resulting from these drivers and barriers.

In the last step of this study, the structural causes and blocking functions are linked to policy measures, which could effectively improve the performance of the TIS and provide a full answer to the research question on how to accelerate the transition towards a CE in Singapore. The policy goal of the Singaporean government is to become a zero-waste nation by 2030. The choice of the government for supporting on-site composter and digester technology coheres with the current physical infrastructure and habits of residents. Since the government is having difficulties persuading residents of recycling their food waste, stimulating on-site digesters and composter could possibly circumvent installing an expensive recycling infrastructure that is convenient enough for the consumer. Therefore, the government is opting for decentralized food waste management, instead of centralized mingled waste management. The following recommendations are based on this physical reality and the current path already embarked on.

In short, the (ranked) recommendations for policy reform are:

1. Install a tax rebate scheme for those who recycle and reduce more.
2. Set up a government procurement scheme for circular products.
3. Reform the policy discourse of 'Reduce, Reuse, Recycle' to better align with food waste and set a clear target for food waste recycling.
4. Give attention to startup ventures that 'transform' unavoidable food waste or that use food waste in their business model.
5. Educate the consumer that circular products are not unsanitary solutions.

The general recommendation to improve the focal TIS around CE and food waste valorization solutions is to stimulate market formation for circular products and technologies, or, in other words, create demand. Implementing a financial incentive in the form of a tax rebate for those that reduce and recycle food more will help to establish a market for the circular technologies (especially the on-site composter and digester technologies), as companies will be encouraged to change their current habits and reduce the size of their food waste. This will improve the return on investment of these technologies and will decrease resistance to recycling of food waste in general. A tax rebate will be favorable for market formation for all food waste valorization products, as the financial incentive can overcome resistance to recycling technologies. Especially businesses that recycle will have a benefit over those who are still reluctant to change. A tax rebate is also favorable as this will not disrupt costs in the short term but acts as a bonus for those who recycle and reduce more. This is also in accordance with scholars suggesting levying tax on the use of resources instead of labor to incentivize businesses to use less resources (Morea et al., 2017).

Next to that, government procurement, similar to the Dutch government (PIANOO, 2018), could be set entirely to circular products. For example, cleaning detergent for cleaning government offices could be entirely done on cleaning detergent made from food waste, as recycled alternative to normal products. Setting up such a policy would eventually increase demand for circular products and improve the market formation of the TIS. It would also set an example for consumers and businesses within the industry and change current perceptions about circular products.

Entrepreneurial activity on homogeneous food waste could be improved to reach the policy target faster and with higher value upcycling solutions. By providing a stage for other entrepreneurs, like the government has been doing for the on-site digester and composter technologies through government websites and environmental summits (NEA, 2018a), industry and consumers could experience the added value these solutions can offer and, again, alter perceptions of consumers and businesses of circular solutions.

In combination with an educational program, consumers could be informed about the cleanliness of circular products and change their perceptions of these products as well. Additionally, educating and communicating about real-life cases within the city also improves the perceptions consumers have about these products, these educational and promotion campaigns have been part of the Singapore government, such as it has done for NEWBrew, a beer brewed from recycled used water (SIWW, 2018).

Lastly, the government could add more focus to their strategy and vision on reducing food waste and increasing recycling and extraction of homogeneous food waste, improving guidance of the search in the focal TIS. The current discourse of 'Reduce, Reuse, Recycle' does not entirely align with a circular economy for the bio-cycle, as almost all circular efforts for food waste will fall under 'Recycle'. This can create confusion about the importance of other cascading, extraction and upcycling efforts, and which already has created a clear preference over one technology instead of several technologies. A monopoly for one technological solution has always been a recipe for unsustainable practices.

A short reflection on the given recommendations is also justified. Although the narrative of the Singaporean government of 'Reduce, Reuse, Recycle' does not entirely align with CE for the bio-cycle, promulgating a different discourse may also create confusion for consumers and producers. The main focus in the bio-cycle is on reducing and recycling (and alternatively recovering) of food waste but since other waste streams are simultaneously addressed through the same channel, 'Reduce, Reuse, Recycle' seems the most straightforward narrative. Moreover, educating consumers about CE products might contradict with the stringent food regulations on the island and the reputation the Singaporean government is trying to uphold. Next to that, since the Singaporean policy goal is more of an environmental nature, a possible future hampering of knowledge development should not pose a problem (Hekkert et al., 2011). However, in the long run enhancing the discourse of 'Reduce, Reuse, Recycle' could eventually also benefits research on valorizing homogeneous food waste, which could eventually enhance entrepreneurial activity in this field.

Alternatively, the current push by the government for increasing local primary production might facilitate the digester and composter technologies further, as this will increase demand for fertilizer in the future. It is questionable, however, if demand can level with supply, and it is unclear whether this is a strategy the government of Singapore is pursuing. Since this will mostly favor the digester and composter technologies more than other recycling efforts, it is expected that this policy will have a limited effect.

Finally, several recommendations for further research can be given based on the findings of this study. As already indicated in the discussion chapter, explaining the influence of consumers on TISs requires extension of the TIS-framework. Seeing consumers as active actors within the TIS-framework who can influence the innovation process can provide additional insights in the diffusion of novel technologies and socio-institutional change. Highly related to this is the subject of business model innovation and the influence it has on the development of a TIS. This study suggests business model innovation is part of both the entrepreneurial activity and market formation functions, in which multiple experiments are part of entrepreneurial activity and the creation of demand through better alignment with consumers' needs facilitates establishing new markets within the innovation system. However, more scrutiny is required to obtain detailed insights into the interplay between consumer and business models in relation to the TIS development. This is also in accordance with other scholars indicating the consumer perspective in relation to a CE needs further research (Hobson & Lynch, 2016; Prendeville et al., 2017).

Another important aspect of a CE, which has had considerably less attention in this study, is collaboration within the supply chain. Many authors stress the need for collaboration within the supply chain to close material loops effectively (EMF, 2012), and the implication of the focal TIS moving towards mainly one recycling technology might overlook the need for multiple solutions to tackle the wicked problem of food waste (found both in socio-institutional change as in technological change) (Schlaile et al., 2017). Musiolik et al. (2012) contributed greatly to this field by studying the influence of networks in the development of TISs. However, the implications of networks in the field of TIS require extension within the TIS-approach to assess how networks within a CE can contribute to include several solutions. This also implies the need for more insight into competing or collaborative solutions within the TIS, analyzed by Sandén and Hillman (2011), working towards a collaborative network of multiple (technological) solutions, and how symbiotic solutions can foster the development of a CE further.

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APPENDIX A - STRUCTURAL GROUPS

From Hekkert et al., 2011 and Wieczorek and Hekkert, 2012.

Actors:

- Governmental organizations
- Knowledge institutes
  - Research institutes
  - Universities
- Educational organizations
- Industrial actors
  - Production
  - Processing and packaging
  - Retail and wholesale
  - Waste management
  - Companies (B2B)
  - Consumers
- Support organizations
  - Banks
  - Venture capital
  - Business angels
  - Innovation and company support
  - Branch associations
  - Network organizations.

Institutions:

- Policy (research, innovation, transition)
- Hard (legislation, IPR)
- Soft (expectations and social acceptance)

Interactions:

- Knowledge networks
- Political (lobby) networks
- Industrial networks

Infrastructure:

- Knowledge infrastructure
- Physical infrastructure
- Financial infrastructure

APPENDIX B - LIST OF INTERVIEWEES

Table B1. *Overview of all interviewed organizations, interview types and dates. To protect respondents' confidentiality, interviewees are anonymized and provided with a code*

Nr.	Organizational type	Place in supply chain	Organizational group	Interview date	Interview type	Code
1	Multinational corporation	Food processor	MNCs	May 23, 2018	Phone call	MNC1
2	Multinational corporation	Retail	MNCs	May 10, 2018	Email	MNC2
3	Multinational corporation	Retail	MNCs	May 21, 2018	Face-to-face / Meeting / Workshop	MNC3
4	Multinational corporation	Retail	MNCs	September 24, 2018	Skype call	MNC4
5	Multinational corporation	Energy & recycling	MNCs	April 16, 2018	Meeting	MNC5
6	Corporation	Retail	Local corporations	May 30, 2018	Face-to-face	LC1
7	Startup company	Food producer	Startups	May 31, 2018	Face-to-face	SU1
8	Startup company	Food processor	Startups	July 4, 2018	Face-to-face	SU2
9	Startup company	Wholesale distributor	Startups	June 25, 2018	Phone call	SU3
10	Startup company	Waste processor	Startups	June 11, 2018	Face-to-face / Workshop	SU4
11	Startup company	Waste processor	Startups	July 23, 2018	Phone call	SU5
12	Startup company	Consultancy	Startups	April 17, 2018	Meeting / Email / Workshop	SU6
13	Startup company	Consultancy	Startups	April 18, 2018	Meeting	SU7
14	Startup company	Consultancy	Startups	May 28, 2018	Face-to-face	SU8
15	Research institution	Knowledge provider	Knowledge institutions	May 25, 2018	Face-to-face / Meeting / Workshop	KI1
16	Research institution	Knowledge provider	Knowledge institutions	June 4, 2018	Face-to-face / Meeting / Workshop	KI2
17	Governmental organization	Consultancy	Knowledge institutions	June 7, 2018	Face-to-face	KI3
18	Governmental organization	Agency	Government	April 19, 2018	Meeting	GO1
19	Governmental organization	Agency	Government	April 19, 2018	Meeting / Workshop	GO2
20	Governmental organization	Agency	Government	April 20, 2018	Meeting	GO3
21	Non-governmental organization	Food redistribution	Charities	May 22, 2018	Face-to-face	NGO1
22	Non-governmental organization	Food redistribution	Charities	June 20, 2018	Face-to-face	NGO2

APPENDIX C - SET OF DIAGNOSTIC QUESTIONS

After Potting et al. (2017) and Hekkert et al. (2007):

Prior to the start of the interview, interviewees are asked if they are familiar with the concepts of innovation systems and circular economy. If not, a short explanation will be given. All questions relate to the food sector and food waste in Singapore.

'[A Circular Economy is] 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.' (Kirchherr et al., 2017, p.229)

'The innovation system approach is a heuristic attempt, developed to analyze all societal subsystems, actors, and institutions contributing in one way or the other, directly or indirectly, intentionally or not, to the emergence or production of innovation.' (Hekkert et al., 2007, p414)

Questionnaire

Please describe your (circular) solution to tackle food waste and explain whether this innovation can be seen as a circular solution to your knowledge.

Experimenting by entrepreneurs (F1):

- Are entrepreneurs experimenting sufficiently with new technologies and/or revenue models on circular use and resource recovery from food production/waste within the food industry in Singapore?
    - Are new entrepreneurs entering the market (also incumbents) with new solutions?
    - Do you see entrepreneurs leaving the market?
- In what stage are these experiments? Is upscaling of solutions already taking place?
    - Are there working prototypes of solutions?
    - Are there commercial applications without subsidy?
    - Is there fast market growth or market saturation?

Knowledge development (F2):

- Is enough knowledge being developed to create circular solutions for food production and food waste?
    - Do you see enough patents, technologies and projects?
    - How is this financed?
- What is necessary to develop this knowledge further?

Knowledge exchange (F3):

- How conscious are the different actors within the food industry of (circular applications of) food waste?
    - Is there a shared belief in circular solutions?
    - Is the development of knowledge demand driven?

- How do the different actors exchange knowledge about (circular applications of) food waste?
    - Is the level of knowledge exchange on circular solutions in the food industry in Singapore high enough in the product chain?
- Do you see problems in the exchange of knowledge?

Guidance of the search (F4):
- Is there a clear vision among product chain partners on how to deal with food waste in Singapore?
- What are the expectations regarding circular solutions?
- Are visions and expectations aligned?
- What role does the government play in creating this vision?
- Is there legislation, regulations or policies that are fits this vision?

Opening markets (F5):
- Are product chain partners active in creating consumer awareness of food waste and (circular) solutions?
- Are companies investing sufficiently?
- Does the government have supplementary policies, and do they help in opening markets?
- What is needed to open up and develop the market further?
    - Who is taking the lead, public or private parties?

Mobilization of means (F6):
- Is there sufficient funding/financial resources available for realizing (circular) solutions for food waste?
    - Is this funding/these financial resources easy accessible?
- Are there specific physical means limiting the realization of solutions?

Overcoming resistance (F7):
- Is there resistance against circular application of food waste and resource-recovery solutions (among product chain partners, or in the form of regulatory barriers)?
- Is sufficient action being taken to overcome resistance against these solutions?

Table C1. *Function fulfillment was assessed after each function separately.*

Function	Very weak	Weak	Moderate	Strong	Very Strong
Entrepreneurial activity (F1)					
Knowledge development (F2)					
Knowledge diffusion (F3)					
Guidance of the search (F4)					
Market formation (F5)					
Mobilization of means (F6)					
Creation of legitimacy (F7)					

APPENDIX D - PHASE OF DEVELOPMENT INDICATORS

In order to assess the current stage of development of technologies and the TIS, a set of diagnostic questions were asked to the interviewees (see also Appendix C).

According to Hekkert et al. 2011:

Pre-development phase: *are there working prototypes?*
Development phase: *Is there commercial application of solutions?*
Take-off phase: *Is there fast market growth?*
Acceleration phase: *Is there market saturation?*

Furthermore, one can look at the indicators developed by Bento and Wilson (2016) on to what extent a TIS has matured (table 1D).

Table D1. *Overview of indicators for the development of the TIS (based on Bento and Wilson, 2016)*

	Nascent TIS	Emerging TIS	Strengthening TIS	Mature TIS
Technological application	Variety of ideas and concepts	Selection of first prototypes	Dominant design; scaling up of technologies	Standardized products and mass production
Degree of structuration:				
Actors	Very few; mostly informal	Medium number of actors	Medium to large number of actors	Large number of actors
Institutions	Very few; informal and cognitive	Dynamic number of institutions	Stabilizing number of institutions	Stable number of institutions
Networks	Knowledge and R&D networks	Network diversification	Different types of networks	Established networks

APPENDIX E - LIKERT SCALE RESULTS

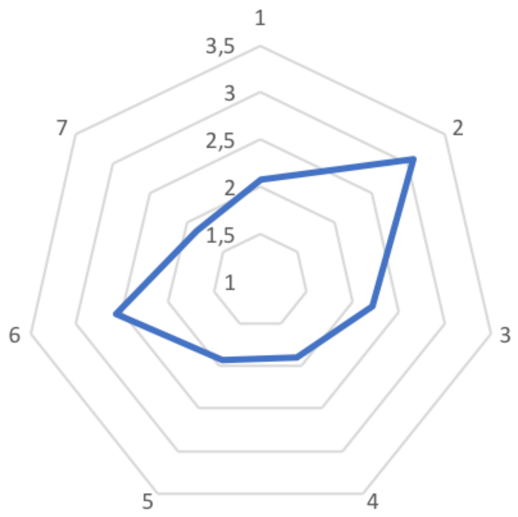

Figure E1. *Spider diagram of the functional analysis with the average scores given by the interviewed key stakeholders per function. The scale of the scores are between 1 and 5 but to increase readability the scale on the diagram is adjusted to between 1.0 and 3.5. Numbers 1 to 7 indicate the seven functions F1-7 as described in table 1.*