High-value food waste valorisation in the Amsterdam Metropolitan Area:

A combined environmental-, socio-technical- and network analysis of anaerobic fermentation technologies for fatty acids production, from a nexus governance perspective

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Image frontpage: https://www.arcadis.com/en/australia/arcadis-blog/richard-collins/working-together-to-reduce-food-waste-in-australia/

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A combined environmental-, socio-technical- and network analysis of anaerobic fermentation technologies for fatty acids production, from a nexus governance perspective

by:

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Executive summary

The unprecedented major scale and rapid rate of urban growth put an increasing pressure on natural resources for providing energy, materials, and food- and nutrition security. Likewise, an alarming major increase can be witnessed in the generation of food waste (FW) in urban areas. While megacities contribute to 6.7% of the global population, 12.6% of global waste disposal can be attributed to them[1]. 30 to 50% of produced food is never consumed, and FW constitutes 25 to 30% of municipal solid waste in high-income countries which is expected to grow 35% until 2025[2]. One of these high-income, highly urbanized areas is the Amsterdam Metropolitan Area (AMA), where the related impacts of FW treatment create important environmental and socio-economic challenges that demand optimisation in terms of reduced environmental impacts and enhanced resource recovery.

The AMA poses an interesting case study with high ambitions for a circular economy in relation to organic and biobased resources, yet a comprehensive regional strategy for circular and sustainable FW waste treatment remains uncomposed, while effective FW prevention does not emerge. Especially with regard to techniques that obtain more high-value, circular products as aimed for by the Dutch government. Only few studies investigate these high-value techniques, and more importantly lack to demonstrate the role of governance in the socio-technical transition that is required, and the impact it has on the main actors in the current system, as it requires a change from a systems perspective.

Therefore, this research applies a two-dimensional nexus governance approach specific to the context of three high-value valorisation techniques in the AMA that use fermentation technologies for fatty acids production (i.e. Chaincraft for feed additives, Amsterdam Green Campus for food additives, and the FABULOUS-project for bioplastics). It investigates how these technologies could contribute to more circular and sustainable FW valorisation. This is respectively analysed by means of a socio-technical analysis and social network analysis, including a baseline study of available FW flows and an environmental assessment (EA) of the investigated technologies.

First of all, it demonstrates the relevance of the high-value valorisation technologies, since unavoidable household FW is almost equal to avoidable household FW flows, hence indicating the considerable importance of redirecting treatment technologies for these remaining bulk flows. Also, the more homogenous FW flows from companies were found highly relevant due to their composition (mainly fruit and vegetables), and suitability as an inexpensive feedstock. With regard to sustainability, the EA demonstrated that despite its higher energy and water demand, the niche technologies could be promising if the higher economic output, the (circular, sustainable and nutritional) added value and substitution effect of conventional plastics and food/feed additives, and the potential to use renewable resources as inputs are taken into account. But mainly, the socio-technical- and social network analysis provided valuable insights in how this transition to circularity could be accomplished, by appointing its main barriers and opportunities. All in all, it requires (1) increased regional collaboration of waste processors, niche technologies and governments; (2) flexible legislation and economic incentives from the national government for biobased alternatives to lift the ‘institutional and political’ lock-in; (3) an overall more holistic- and system perspective including all environmental impacts to come to the most circular and sustainable regional (food) waste management strategy; (4) and increased knowledge exchange and

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[1] Kennedy et al. (2015).

[2] Adhikari et al. (2006), Adhikari et al. (2009), Melikoglu et al. (2013), Kaza et al. (2018).

experimentation with regard to the quality, processes and added value of platform applications of the fatty acids to lift the ‘techno-economic’ lock-in by creating a market.

Overall, this research demonstrates that the nexus approach can increase circularity via high-value FW processing in the AMA, by designating the most important aspects to consider for achieving a just circular and sustainable FW treatment system. However, it also shows not just the importance of intersectoral nexus governance for this transition, but also transboundary governance. The former refers to close collaboration of governments and waste processors, and the biochemical- and waste processing sector, to increase integration from a F-E-W nexus perspective for optimal resource utilisation. Whereas the latter indicates the importance of better mutual governmental collaboration on a regional scale. Also, prevention of food waste should always be the overall aim to reduce related environmental impacts on the long-term, for which the investigated technologies offer a medium-term solution by dealing with present bulk FW flows and providing high circular- and economic outputs with the potential to reduce environmental impacts.

Keywords: *Nexus governance, food waste, high-value valorisation, multi-level perspective, social network analysis, Circular Economy*

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Above all, I want to dedicate this research to my beloved father, who I know would have been equally excited about the research focus, as he was the one who inspired me to pursue a career in sustainability.

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List of Abbreviations

AGC	Amsterdam Green Campus
AMA	Amsterdam Metropolitan Area
BSF	Black Soldier Fly
EA	Environmental Assessment
FW	Food Waste
MFA	Material Flow Analysis
MLP	Multi-Level Perspective
SNA	Social Network Analysis
VFA	Volatile Fatty Acids

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1. Introduction

1.1 Field of context

The current major scale and rapid rate of urban growth puts an increasing pressure on natural resources for providing energy, materials, and food- and nutrition security. Accordingly, this incremental demand for natural resources results in numerous economic, social and environmental challenges, of which the generation and treatment of waste holds an important issue. While megacities contribute globally to 6.7% of the population, 12.6% of global waste disposal can be attributed to them (Kennedy et al., 2015). This trend also accounts for food waste (FW) generation. Most food production takes place outside cities boundaries, which is why until recently the food system and urban developments were typically treated as separate systems (Pothukuchi & Kaufman, 1999). However, an overwhelming portion of the food produced worldwide is consumed within cities, indicating the interconnection of (peri-)urban areas in the global food system (Geldermans et al., 2018). More specifically, 30 to 50% of produced food is never consumed and encompasses a bulk flow that accords with billions of dollars wasted annually by developed countries in the world (Soethoudt & Vollebregt, 2019; Melikoglu et al., 2013; Kaza et al., 2018). At present, FW constitutes 25 to 30% of municipal solid waste (MSW) in high-income countries and is expected to grow 35% until 2025 (Adhikari et al., 2006; Adhikari et al., 2009). So, while current consumption patterns put an increasing pressure on natural resources for production of food, the related impacts of FW *treatment* create equally important environmental and socio-economic challenges that demand optimisation in terms of reduced environmental impacts and enhanced resource recovery (Zeller et al., 2019).

1.2 Problem statement: Dutch urban food waste sustainability challenges

One of these high-income, highly urbanized countries is the Netherlands, a country that has relatively high separation and recycling rates of MSW compared to other EU countries[3] (Dijkgraaf & Gradus, 2014). And even though the majority of municipalities in the Netherlands separately collects vfg waste, challenges still exist around processing flows of urban FW in a more sustainable manner (Tonini et al., 2020). Despite that prevention is highly situated on the Ladder of Moerman and much research has focused on prevention measures, the research of Soethoudt and Vollebergt (2019) shows no significant reduction of FW since 2013 in the Netherlands. Hence still leaving significant bulk flows of FW that should be processed in a circular, and sustainable manner.

The Dutch national government expressed its ambitions for the circular economy in the food sector in the transition agenda 'biomass and food', where it states the future goal: "*Optimal valorisation of biomass and residual flows into circular, bio-based products*" (Rijksoverheid, 2018, p. 4). Also, current academic research of, for example, Slorach et al. (2019), Babbitt (2017), Dahiya et al. (2018), Tonini et al. (2010) and Teigiserova et al. (2019) demarcates the need for a holistic sustainability perspective to provide a comprehensive picture of the potential of FW valorisation techniques. This holistic approach should include relevant life cycle environmental impacts beyond related GHG emissions, such as energy and water intensities for optimal (re)use of these resources

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[3] i.e. 32% recycling, 27% composting and 41% incineration.

(i.e. closing the loop) from a Circular Economy perspective. To avoid burden shifting of environmental impacts and to transition to truly sustainable and circular processing of FW.
The problem statement that results from these insights is therefore stated the following: Significant bulk flows of FW still remain despite prevention and reduction efforts, and currently FW in the Netherlands is not yet processed in the most circular and sustainable manner, i.e. creating high-value outputs and recovering available resources without burden shifting potential environmental impacts.

1.3 Knowledge gap: a nexus governance perspective

Current research on FW valorisation techniques mainly tends to focus on environmental impacts, by applying a life cycle analysis approach on status quo techniques (anaerobic digestion, composting, incineration) (Slorach et al., 2019; Tonini et al., 2020). Few studies analyse valorisation techniques that obtain more high-value, circular products as aimed for by the Dutch government. Also, they lack to demonstrate the role of governance in the socio-technical transition that is required, and the impact it has on the main actors in the current system, as it requires a change from a systems perspective (Zhou et al., 2018; Teigiserova et al., 2019). Even more, as Stein and Jaspersen (2019) claim that it is of great importance to understand the management (i.e. governance) of inter-organisational networks and relations that are part of a cross-sectoral issue, such as high-value FW processing (i.e. water, energ, food sectors). The authors claim that the novel concept of *nexus governance* can play an important role for managing these cross-sectoral issues, however few studies investigated the true potential of it.

Hence, the knowledge gap that this research aims to fill, is twofold. First of all, appropriate implementation of high-value techniques calls for a more holistic approach that prevents burden shifting between environmental impacts (i.e. emissions, water supply and energy demand), and takes into account the role of all involved actors from different sectors (i.e. waste-, food-, water- and energy sector), which demands a nexus governance approach. Secondly, the above-mentioned research shows that current literature and research tends to focus on rather prescriptive ambitions and general applications on the global level of high-value valorisation techniques, while investigating context specific case studies is required for a better understanding of the socio-spatial implications of these techniques, by including relevant stakeholders and analysing potential synergies.

1.4 Research focus: three techniques in the Amsterdam Metropolitan Area

This research aims to go beyond current research by applying a nexus governance approach specific to the context of three high-value valorisation techniques in the Amsterdam Metropolitan Area (AMA). The AMA poses an interesting case for analysing this socio-technical transition towards high-value FW valorisation, as it is a region that has ambitions for the Circular Economy high on the agenda[4]. Also, current techniques already include recycling of resources from FW, however it demands a further development towards more high-value techniques, while simultaneously minimising related environmental impacts (Van Velzen et al., 2013; Rijksoverheid, 2018; Welink, n.d.). The nexus

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[4] See the ambitions of the City of Amsterdam in the 'Amsterdam Circular 2020-2025 Strategy' and the 'Innovation and implementation program Amsterdam Circular 2020-2021'. And the ambitions of the AMA on: https://www.metropoolregioamsterdam.nl/ontwikkelplan-circulaire-economie-mra/ & https://www.metropoolregioamsterdam.nl/wp-content/uploads/2019/10/Concept-MRA-Agenda-2.0.pdf

governance approach specifically creates a deeper understanding by investigating the main drivers for achieving this transition.
The three techniques investigated are that of: (1) Chaincraft, (2) Amsterdam Green Campus, and (3) the FABULOUS-project, that respectively aim to process FW into animal feed additives, food additives and bioplastics. These end-products are obtained via short and medium chain fatty acids, which are a product of fermentation techniques. These techniques were chosen as the high-value valorisation techniques to be investigated, because they provide great relevance with regard to momentum in current academic literature that focuses on 'biorefinery' techniques for a circular economy, and because of the strong nexus focus of the technologies where the water, energy and food sector are involved. The latter demanding appropriate cross-sectoral nexus governance.

All in all, this research provides an understanding of the particular environmental impacts and socio-technical drivers in the transition towards high-value processing of FW via fermentation biotechnologies, from a nexus governance perspective. Doing so by investigating the environmental impact of the fermentation techniques, the opportunities and barriers for the transition towards large scale application, and by investigating the influence on the current actor configuration to understand how certain changes might remove these barriers. This is respectively analysed by means of a socio-technical analysis and social network analysis (Dubbeling et al., 2016; Coudard, 2019; Stein & Jaspersen, 2019; Wittmayer & Loorbach, 2016; Geels, 2019; Buth et al., 2019). The present research thereby helps to unravel potential pathways of the transitions towards more high-value valorisation of FW in the AMA and what is requisite to achieve this transition in a sustainable manner.

These insights serve as a general understanding of these high-value techniques and it provides policy recommendations for the City of Amsterdam, the AMA, and other regions for circular and sustainable FW valorisation at a large scale. Lastly, these insights contribute to academic research by concluding on the role of nexus governance in the cross-sectoral challenges that the Circular Economy transition faces. In doing so, this research aims to answer the following research questions:

Main research question:

How can nexus governance increase circularity via high-value food waste processing in the Amsterdam Metropolitan Area?

Sub research questions:

1. *What is the current state of food waste processing in the AMA and how is the food waste system organized?*

2. *Which processes are involved in high-value fermentation biotechnologies, and what is its potential and environmental impact related to the status quo?*

3. *What are the opportunities and barriers to large scale application of these techniques in the AMA?*

4. *How will the introduction of fermentation technologies influence the organization of the current system and how could these changes help to remove the main barriers for large scale application?*

2. Theoretical Framework

For answering the research questions above, this research focuses on four main aspects: an updated (1) baseline assessment of food waste flows in the AMA respectively to their treatment method, an (2) environmental assessment that investigates the potential of the fermentation niche technologies, and a (3) socio-technical- and (4) social network analysis that resp. uncover opportunities and barriers for large scale application, and the changes in the network that can help to overcome these barriers. This chapter describes the main theories that together provide the theoretical framework behind this research approach.

2.1 Industrial Ecology and Systems Theory

This research focuses on tackling the socio-technical challenge of dealing with bulk food waste flows in urban areas and recovering the highest potential value via low environmental impact waste valorisation measures. It requires an integrated approach that incorporates system thinking to link the environmental, technical and social sustainability challenges, which the field of Industrial Ecology (IE) aims to do by applying a holistic *system perspective*.

This systems perspective central in the field of IE stems from (complex) systems theory for sustainability, entailing the notion that "*the whole is more than the sum of its parts*" (Bertalanffy, 1968, p. 55; Meadows, 2008) and that "*the performance of a system cannot be optimised by optimising its subsystems in isolation from one another*" (Oliemans et al., 2019, p. 4). Meaning that sustainability issues are considered so-called 'wicked problems' known for their complex nature, originating from the fact that they contain multiple political, economic, social and technical factors that influence the systems *non-linear* behaviour over time and over different spatial scales (Lifset et al., 2017; Dwyer, 2011; Wiek et al., 2012; Block et al., 2019). Systems thinking is the analysis tool of systems theory to investigate these wicked problems and stresses the notion to analyse systems in its entirety, instead of merely looking at its subsystems as separate components. The aim is to find overall patterns, cycles and structures in the system to understand its behaviour and feedback loops, and ultimately find the right leverage points. Which are the "*places in the system where a small change could lead to a large shift in behaviour*" (Meadows, 2008, p. 145).

It is the problem of food waste, and specifically processing of food waste, that consists of such a wicked problem, since it contains for example, food collection policies, behaviour of consumers with regard to wasting food, economic incentives for producing energy from waste, and technical (niche) innovations, that altogether influence the development over time, different spatial scales and governance levels. Therefore, this system's perspective is applied for investigating the valorisation techniques in their entire system. Meaning, in relation to the water and energy sector via an analysis of water and energy intensities of the techniques, relative to the overall environmental impact of the technologies including their by-products and substitution effects (see section 6.4). But also by connecting this environmental perspective with a governance perspective to find the 'right leverage points' for transitioning towards more high-value valorisation techniques.

2.2 Food, energy and water systems: a nexus theory approach

Systems theory and -thinking from the field of IE strongly links to the holistic *nexus theory* that aims an integration of energy-, water- and food sectors. Sustainability challenges in cities namely often occur at the intersect of these sectors and burden shifting between sectors and impact categories should be prevented (Boas et al., 2016; Wang et al., 2018; Kibler et al., 2018). This food-water-energy (FEW) nexus is a well-known concept within the nexus approach that facilitates policy decision making by "*optimiz*[ing] *these synergies and manage trade-offs*" (Kaddoura & El Khatib, 2017, p. 114). Regarding food waste, the FEW nexus provides a framework for understanding the influence of human behaviours and decisions on food waste management (e.g. composting versus fermentation technologies), as different processes demand different inputs of water and energy (Kibler et al., 2018). Kibler et al. (2018) highlight that few studies focus on these actual (context specific) water and energy impacts of post-disposal food waste. Below, figure 1 provides an overview of the FEW nexus in the context of food waste processing in the AMA.

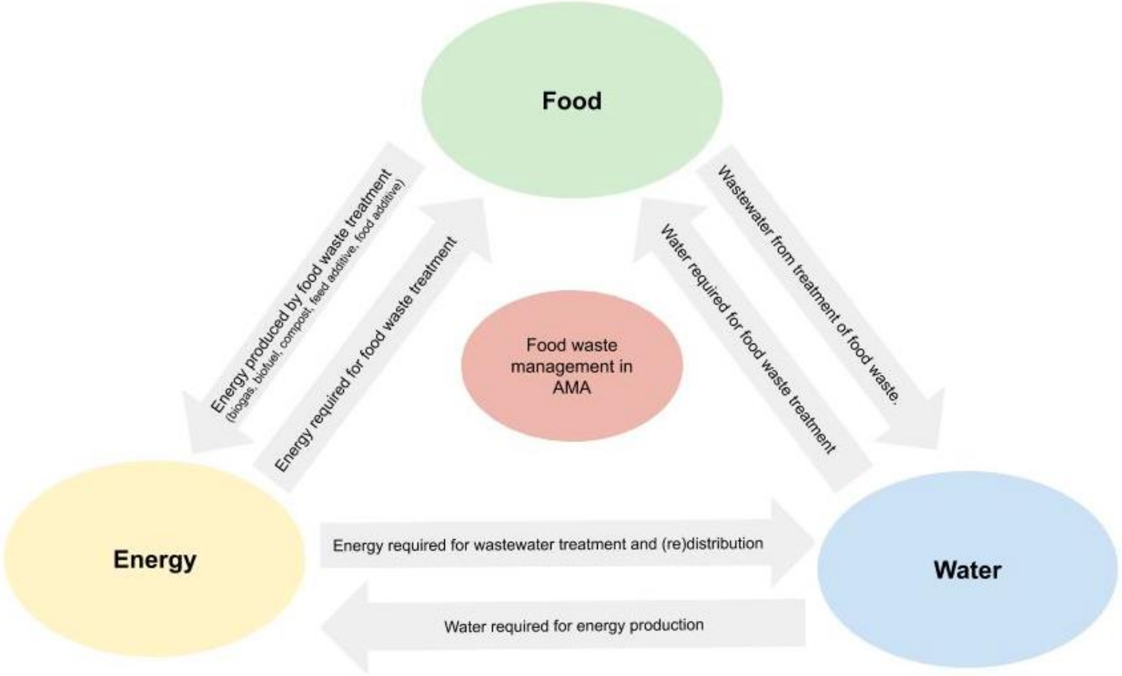

Figure 1. Role of the FEW nexus in the food waste processing system in the AMA.

2.2.1 Definition of food waste

Before delving into the application of this nexus approach to the governance of food waste processing in the AMA, it is of great importance to clearly define the concept of 'food waste', as current academic literature does not succeed in offering a common definition applied across multiple studies (Teigiserova et al., 2019).

Following the definitions highlighted in Teigiserova et al. (2019) based on European definitions used in the EU FUSIONS project and FLW protocol, a distinction can be made between food loss and food waste, edible and inedible food waste, and avoidable and unavoidable food waste. Concerning the first, food loss is considered "*the decrease in quantity and quality of food*", whereas food waste is a subset of food loss and entails "*food that has been left to spoil or expire as result of negligence by the actor (predominantly, but not exclusively, the final consumer)*" (FAO, 2014, p. 3 & 4). Food waste can thus be distinguished from food loss as focusing solely on the decrease in quantity. This research focuses on food waste as *the quantity of food wasted by actors,* and not on the potential quality loss of food.

Furthermore, in this research food waste is regarded to contain both avoidable and unavoidable food waste (Kilbert et al., 2018; Geldermans et al., 2018). Particularly, since this allowed for the selection of the three valorisation techniques that are able to process both more homogenous flows from the agricultural-, food processing-, and manufacturing sector and more mixed food waste flows from households. In this research it is argued that avoidable and unavoidable food waste resp. accord with the definitions of edible and inedible food waste adopted in Teigiserova et al. (2019), following the European FUSIONS and FLW-Protocol definitions (excluding feed and biomass not intended for human use). Examples of inedible food parts are bones and peels, but also oils and coffee grounds (note that, for example, peels of potatoes and carrots can be regarded edible).

2.2.2 Nexus governance

The nexus approach conceptualizes food waste as a cross-cutting issue, which requires appropriate governance in all relevant sectors, including the water and energy sector (Laso et al., 2018). Therefore, the present research includes the novel theory of *nexus governance* to analyse opportunities, barriers, and policy recommendations for large scale application. Previous research in transition management accentuates the necessity to do so by claiming governance to be a ‘critical factor’ in realizing a socio-technical transition (Bos & Brown, 2012; Davis et al., 2016). It is the novel theory of nexus governance as a transition governance approach that grasps an understanding of the underlying systems of the agencies that drive the system (Loorback et al., 2017). More specifically, for understanding *system behaviour* and induce *social learning* in the aim of a sustainable transition, nexus governance is a rather novel concept that provides an approach to understand the complex problem of this research that is cross-sectoral, covers multiple geographical boundaries and governance levels. Nexus governance stems from the same assumption that the energy, water and food sectors are interlinked and require an integration of governance systems. Stein and Jaspersen (2019) define nexus governance as:

> “*The* ***relational structures and processes*** *that connect actors across sectors, governance levels, geographical boundaries and/or public, private and civic spheres, and that provide* ***steering mechanisms*** *for the integration of management and governance systems across different policy domains”* (p. 379).

It is these relational structures and steering mechanism that are be analysed in this research by means of a socio-technical analysis and social network analysis (SNA), and provide an answer to the main research question to which extent nexus governance can contribute to enhance the transition towards high-value valorisation techniques in the AMA. A further demarcation of the concepts related to nexus governance, and how they are used to examine the system under study, can be found in the conceptual framework.

2.3 Transition Management Theory: socio-technical transitions

Following these theories that provide the overarching approach for the present research, a more well-directed theory is that of Transition Management (TM) Theory, which allows the specific analysis of the transition towards large scale application of fermentation techniques in the overall socio-technical food system of the AMA. It comprehends to do so by offering a theoretical approach and by analysing potential transition pathways (Geels & Schot, 2007; Loorbach et al., 2017).

2.3.1 Transition pathways

For the purpose of understanding the trajectories of socio-technical transitions, Geels et al. (2019) defined a theory of four common pathways that help in enhancing desired sustainable development of concerned technologies. As they claim that different types of alignments between the social groups, activities and institutions result in different transition pathways. The first pathway is the *substitution pathway* and describes niche-innovations breaking through due to landscape pressures that enable them to enter the regime (i.e. creating windows of opportunity), whereby radical innovations substitute the current technology. These new entrants can be both citizens, communities, activists or parties from different sectors. Secondly, the *transformation pathway* delineates the improvement of existing technologies, by which niche technologies form a symbiotic relation with existing technologies for improvement. This pathway is known for its Incremental nature, where the transition performs in stages. Thirdly, the *reconfiguration pathway* entails the incorporation of symbiotic niche innovations for 'local problems' in the regime, whereafter the architecture of the regime slowly changes by adopting several other niche innovations. Contrary to the former two pathways, this one constitutes a sequence of multiple innovations. Lastly, the *de- and realignment pathway* includes a large and sudden change (suchlike with the substitution pathway), but no specific niche innovation is available for substitution, multiple niche innovations will compete with each other.

Additionally, Geels et al. (2019) state that different pathways can sequence each other when landscape pressures occur. It is claimed that these shifts in pathways not merely depend on external, but also internal influences, as actors play an important role via e.g. policy goals and instruments, and costs and desirabilities. Specifically, they suggest that nonlinear (i.e. iterative) processes can occur in between the shift from one pathway to another. For example: *"A transition may change from a substitution pathway to a reconfiguration pathway if incumbent actors are able to change the institutions so that they offer support for continued existence of regime technologies besides niche-innovations."* (p. 901).

In short, TM theory provides a means to analyse the nexus system of food waste processing in its entirety (i.e. food, water and energy sector) over multiple geographical boundaries and governing systems. By describing its involved phenomena and actors, and its (multiple) pathway(s), an understanding of the main opportunities and barriers can be formed to achieve more circular valorisation of food waste in the AMA. Additionally, it is crucial to also deliberate a theory that enables the analysis of the social network of the current food waste processing system, since the involved actors and their relations play an important role in either creating or removing the barriers (Schot & Geels, 2008; Farla et al., 2012). Hence, for answering the last sub question of this research, the subsequent paragraph describes the social network theory.

2.4 Social network theory

Thus, it is aimed to gain a better understanding of how the introduction of the niche fermentation technology might influence the composition of the current food processing network and its relations in the AMA, to comprehend the ability of fermentation technologies to transform the current system towards high-value, circular and sustainable food waste valorisation. This ability can be appointed by analysing how actor roles might shift and policy recommendations can be adjusted correspondingly.

Social network theory provides an approach to investigate these social networks. The theory defines social networks as social structures, which consists of actors that are presented as nodes, and the relationships between these actors, presented as lines (edges). The actors can present, for example, individuals, companies, governmental bodies or cooperations, and the relationships can also be of any type (e.g. transfer of knowledge, exchange of material or financial resources) (Tichy et al., 1979). Studying involved actors and their relationships can unravel underlying patterns of relations that shape governance processes and environmental outcomes, and/or vice versa (Lubell et al., 2014; Bodin & Crona, 2009; Robins et al., 2011; Jaspersen, 2019).

More importantly, Stein and Jaspersen (2019) put the significance of social network analysis "*at the heart of nexus analysis and thinking*" (p. 378). Nexus systems namely involve multiple actors and networks from multiple sectors (food, water, energy), which asks for an approach that deals with "*shared problem construction*" and "*collective solutions*", as no single actor can govern the system in its entirety (p. 377) (see also figure 2). Stein & Jaspersen (2019) combine insights from sociology and social network research to be able to investigate the potential of nexus governance. They propose a framework consisting of three strands (a structural dimension, a relational dimension, and a narrative dimension) to examine this role of nexus governance. This framework is further elaborated in the conceptual framework in the subsequent chapter.

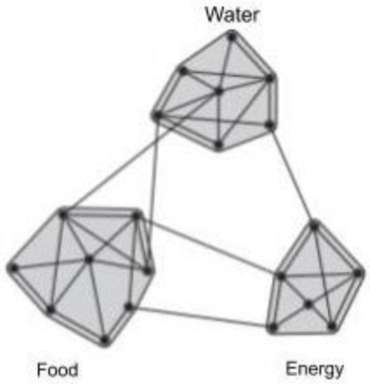

Figure 2. Interlinked networks of the food-energy-water nexus in 'wicked problems' (Source: Stein & Jaspersen, 2019).

3. Conceptual Framework

The previous chapter provides an overview of the theories that form the building blocks of this research: i.e. systems theory, nexus governance theory, transition management theory, and social network theory. This chapter further explains the concepts that these theories consist of and that thereby present the main, interconnected, variables to be studied in this research[5].

As described in the theoretical framework, the main goal of this research is twofold: (1) analysing opportunities and barriers of fermentation technologies by means of a socio-technical analysis, and (2) analysing its influence on the current system to understand how these changes might resolve the barriers.

3.1 Investigating the role of nexus governance

As discussed in section 2.4, Stein and Jaspersen (2019) propose a framework for investigating nexus governance in local contexts. Their framework consists of three strands: (1) a structural dimension, (2) a relational dimension, and a (3) narrative dimension. The first strand investigates the main structural configuration of the networks in the nexus, herewith identifying the main actors and their position in the network. This approach is strongly linked with the Social Network Analysis (SNA) tool that is often applied in social network theory (see section 3.2 for an explanation of SNA). Secondly, the relational dimension describes the relationships between these actors more in-depth, by investigating the type of relations, their content and quality. Herewith it provides insights in the (governance) coordination within the network, and from which sector certain issues are addressed. Lastly, the third strand proceeds on step further by analysing the underlying narratives that can be determinative for the implementation and adaptation of policy. Narratives namely "*embody ideas concerning what forms of action and interactions are possible, feasible, desirable, and efficacious*" (Tilly, 2002, p. 8-9). It is especially this latter strand of the framework that assists in investigating the potential of nexus governance in the system of food waste processing in the AMA, since a certain narrative that is accepted in the network(s) (e.g. current processing of food waste via incineration and composting is circular 'enough') might limit the diffusion of niche developments such as fermentation technologies. See figure 3 for a visualisation of the framework.

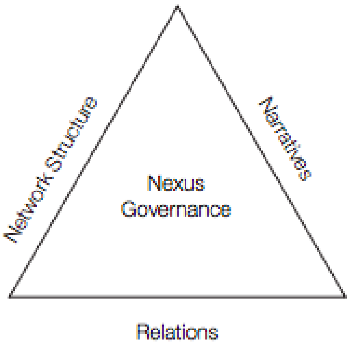

Figure 3. The relational conceptual framework of Stein and Jaspersen nexus governance (2019).

However, in this research it is argued that it is not solely narratives, beside the structural and relational dimension, that determine the role of nexus governance. There are also landscape pressures such as

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[5] See Adom et al. (2018) for the role of a conceptual framework in qualitative research.

geopolitics and demographics, and regime aspects (e.g. knowledge base, existing technologies) that determine these narratives and consequently determine to what extent nexus governance can play a role in enhancing the transition. Therefore, this research proposes an adjusted framework of Stein and Jaspersen (2019) that also includes the so-called 'multi-level system'.

In this framework the first and second dimension of network structure and relations are combined into one dimension. Firstly, since both describe characteristics within the food waste processing nexus system itself such as the type of actors and their interactions. Secondly, because both the structure and the relations can be analysed by applying a combined quantitative and qualitative SNA as will be elaborated in section 3.2 and 4.3.4. The first dimension thus delineates the position in, and influence of the three fermentation biotechnologies on, the current actor configuration of actors from different sectors that might demand a certain role of nexus governance.

Moreover, the adjusted framework proposes a second dimension in which the multi-level system is combined with the narratives dimension, as these narratives are formed in a constant interplay with the former. It adds an extra layer from a socio-technical approach that describes underlying external landscape, and internal niche and regime pressures that influence the narratives and thereby also the potential role of nexus governance. See figure 4 for a visualisation of the proposed framework.

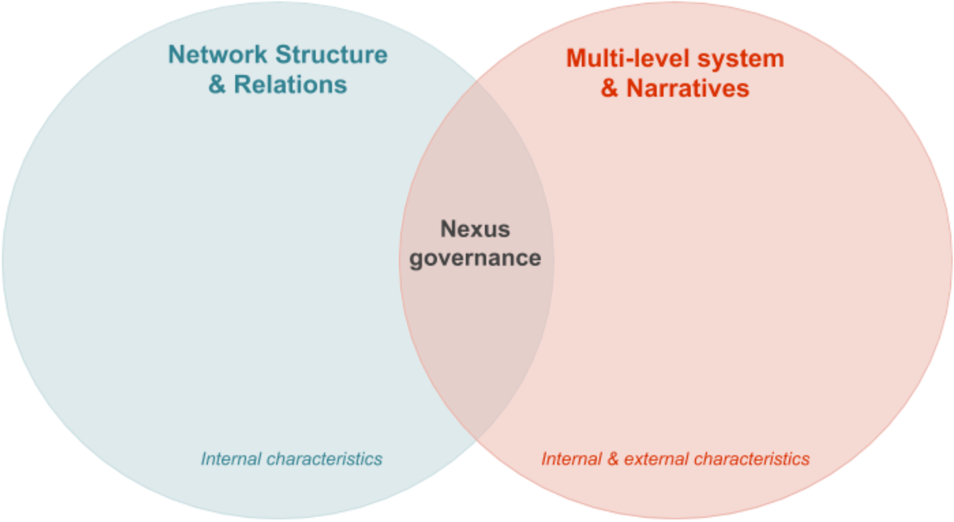

Figure 4. The adjusted relational conceptual framework of Stein and Jaspersen (2019) proposed for this research.

In this research the 'multi-level system' dimension is applied by performing a socio-technical analysis following the *Multi-Level Perspective* concept. Secondly, the structural and relational dimension of the framework is applied by performing a *Social Network Analysis* to understand the actors and relations of both the current and future actor system. From these two dimensions, and their insights and data collection combined, a conclusion can be drawn on the main narratives that are present in the food waste valorisation system of the AMA, and more particularly how they influence the transition towards high-value valorisation of food waste. Following this framework, (policy) recommendations can be formed from which it can be concluded how nexus governance can play a role in accelerating the transition towards sustainable high-value food waste valorisation from a Circular Economy perspective.

3.2 Socio-technical transitions

3.2.1 Multi-Level Perspective

Before describing the transition pathway of food waste valorisation in the AMA by means of high-value fermentation technologies, it is crucial to have a clear picture of the involved actors, and the socio-economic and technological factors that might influence this pathway. As stated above, the so-called Multi-Level Perspective (MLP) framework is used in this research to perform this socio-technical analysis. This analysis shows the potential transition pathways the three high-value fermentation biotechnologies are to encounter. Hence it facilitates in answering the first three sub research questions of this research:

1. *What is the current state of food waste processing in the AMA and how is the food waste system organized?*
2. *Which processes are involved in high-value fermentation biotechnologies, and what is its potential and environmental impact related to the status quo?*
3. *What are the opportunities and barriers to large scale application of these techniques in the AMA?*

The multi-level perspective (MLP) framework is often used framework in transition management research, that aims to visualize the multi-level concept underlying transition research, by describing path dependencies, external and internal crises, institutional change, and emergence of radical innovations, bringing the system to a new equilibrium by a certain pattern of change. And it is this specific pattern that is endeavoured to be understood for enhancing the transition (Loorbach et al., 2017). The MLP is defined by multiple actors, activities, and rules and institutions, and it contains both a global and local component. The former describing the overall pathway of the transition, the latter describing local specific activities and mechanisms (Geels, 2019). Within the MLP a distinction is made between the niche, regime and landscape level, which are explained below.

Regime level

The regime level that constitutes *shared rules and institutions*, consists of several subsystems that shape these rules and institutions. It includes a technological, political, cultural, societal, scientific and market regime that combinedly determine the shared rules and institutions (Geels & Kemp, 2007). Consequently, the regime level entails different types of lock-in mechanisms that emerge from these different disciplines and influences the (niche) innovation to be incremental and path-dependent (Geels, 2019). More specifically, a lock-in mechanism refers to the process in which a certain tangible or intangible circumstance (i.e. regulations, values, costs) reinforce the current state of affairs, creating this path dependency for new innovations to diffuse.

Geels (2019) appoints three different lock-in mechanisms that are present in these socio-technical systems:

1. Techno-economic lock-in mechanisms:
   Referring to the (1) sunk costs, and (2) the low cost and high performance of existing technologies, relative to new innovations (in the niche level).

2. Social and cognitive lock-in mechanisms:
   Referring to (1) shared mindsets, (2) social capital which entails the networks, relationships and knowledge accumulation of actors in the system, and (3) lifestyles and user practices.
3. Institutional and political lock-in mechanisms:
   Referring to (1) existing regulations that hinder new innovations, and (2) the related power of existing actors in the regime to use their policy regime to prevent change in these regulations.

Also, these rules and institutions determining the existing lock-in mechanisms, can be *regulative*, *normative* or *cognitive*. Whereby the regulative rules refer to explicit rules, regulations, and policies via either rewarding or punishing mechanisms. Normative rules refer to norms and values and expectations, and cognitive rules refer to paradigms and beliefs, and is mainly based on cultural grounds (Geels, 2004).

Lastly, beside the shared rules and institutions, and the actors present in the regime level, these socio-technical regimes also consist of *tangible artefacts* (i.e. material artefacts), also influencing the lock-in mechanism as mentioned above. One could think of the sunk costs in available materialistic infrastructures such as factories or electricity cables (Smith et al., 2010).

Landscape level

Moreover, the landscape level of the socio-technical system can be more specifically defined as: “*the exogenous environment that usually changes slowly,* [which] *influences dynamics at the niche and regime level, but cannot be influenced (easily) by those dynamics”* (Kamp, 2008, p. 277). As shortly stated before, this exogenous environment can entail different types of landscape pressures. In relation to this, Van Driel and Schot (2015) define three different landscape pressures: (1) landscape pressures that change slowly or not at all (e.g. climate), (2) pressures that change on the long-term (e.g. geopolitics, demographics), and (3) rapid external shocks (e.g. wars, economic crises). The landscape level can therefore be defined as the most stable level of the socio-technical system.

Niche level

The radical, protected innovations in the niche level can take different forms. Geels (2019) defines 4 types of innovations that can be present in the niche level: (1) radical technical innovation, (2) grassroot and social innovation, (3) business model innovation, and (4) infra-structural innovation. Whereby 1,3 and 4 can be demarcated as market-based innovations that focus on the market economy, profit and commercial activities. Whereas 2 as grassroot innovation focuses on the social economy, ideologies, and is based on voluntary activities and funding (e.g. decentralized energy production, urban farming).

MLP claims that transitions take place due to interactions between these levels, including three underlying statements: (1) niche-innovations slowly achieve momentum, (2) both niches and landscape pressures can put pressure on the regime, and (3) when the regime is destabilized, it offers ‘windows of opportunity’ for niches (Geels, 2019; Geels et al., 2017). Also, four phases can be distinguished within the framework in which the transition can be located. Respectively being (1) experimentation, (2) stabilization, (3) diffusion into mainstream markets or disruption by not achieving so, and (4) institutionalisation into the regime.

The figure below presents a concise overview of the MLP framework as described above, including the different regime disciplines, its lock-in mechanism creating path dependency and incremental change, and windows of opportunities for niche innovations via landscape pressures or internal momentum.

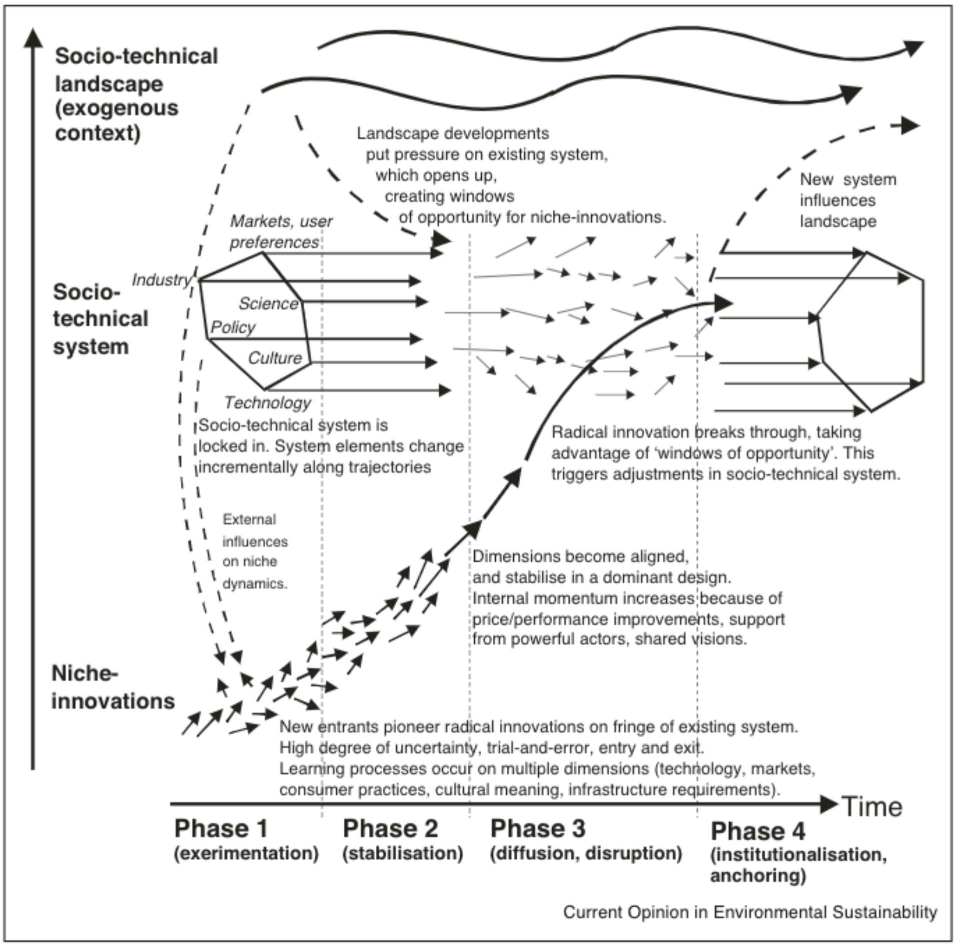

Figure 5. The multi-level perspective framework of socio-technical transitions (source: Geels, 2019).

3.2.2 Opportunities and barriers

By using the Multi-Level Perspective to describe the regime, landscape and niche levels of the current waste processing system in the AMA, this provides a description of the *structure* of the system (Hekkert et al., 2011). However, as argued by Hekkert et al. (2011), different innovation systems may contain similar components such as actors, institutions, networks and technologies. Therefore, it is the *functioning* of the system that is important for understanding the performance of the system, and the related opportunities and barriers that might enhance or block the breakthrough of the innovation (Hekkert et al., 2011).

Hence, the seven system functions of Hekkert et al. (2011) will be used in addition to the MLP framework. The seven system functions enable to conclude on the opportunities and barriers of the socio-technical transition of the fermentation biotechnology, by describing the current fulfilment of these seven functions. Hekkert et al. (2011) namely state that analysing how innovation systems function, "*allows to address the performance of the system"* and thereby "*present[s] insight in what they are doing and whether this is sufficient to develop successful innovations*" (p. 4). The seven system functions are considered key processes required for successful innovation systems, and are the following:

1. Entrepreneurial experimentation and production;
2. Knowledge development;
3. Knowledge exchange;
4. Guidance of the search;
5. Market formation;
6. Resource mobilisation;
7. Counteract resistance to change.

Additionally, it should be noted that the importance of the seven system functions differ per innovation system, dependent upon the phase of development that it is in. These development phases are defined by Hekkert et al. (2011) as: (1) the pre-development phase, when a first (lab-scale) prototype is produced, the (2) development phase, when the technology is applied commercially for the first time, the (3) take-off phase, meaning diffusion of the technology on a larger scale including market growth, and the (4) acceleration and (5) stabilization phase that describe the processes until market saturation (see figure 6). These development phases match the earlier mentioned four phases in the context of the multi-level perspective framework of Geels (2019) and Geels et al. (2017). Where stabilization in the framework of Geels (2019) is meant much more as earlier stabilization of the technology itself (internal momentum) before it diffuses into mainstream markets.

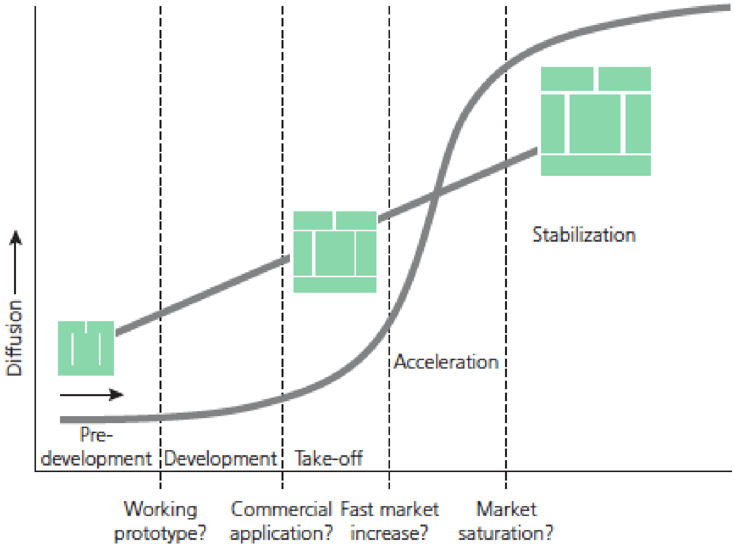

Figure 6. Development phases of a Technological Innovation System that influence the importance of the seven system functions (source: Hekkert et al., 2011).

Per system function, Hekkert et al. (2011) provide indicators and relevant questions to ask, to examine the current status of the functions, which were used in this research to examine the opportunities and barriers of the three fermentation biotechnologies in the AMA. They were used as the foundation for semi-structured interviews with experts in the current food waste processing system in the AMA. Important since Hekkert et al. (2011) denote the significance of assessing the functioning of the system with input from "*experts and key stakeholders that are active in the innovation system*" (p. 4). The table presented in Hekkert et al. (2011) that includes these indicators and questions, can be found in the appendix.

Finally, the current status of the seven system functions can be visualized in a spider-diagram such as the one below, as recommended by Hekkert et al. (2011). Where the functions with the lowest score, can be concluded upon as the ones that form the barriers for the socio-technical transition. Additionally, Hekkert et al. (2011) provide 3 research steps to identify these functional barriers:

1. *"Determine which system functions are forming a barrier.*
2. *Determine for each system function which structural component forms a barrier [...] (e.g. actors, institutions, networks, technology, knowledge, external factors).*
3. *Describe the relation between cause and barriers" (p. 13).*

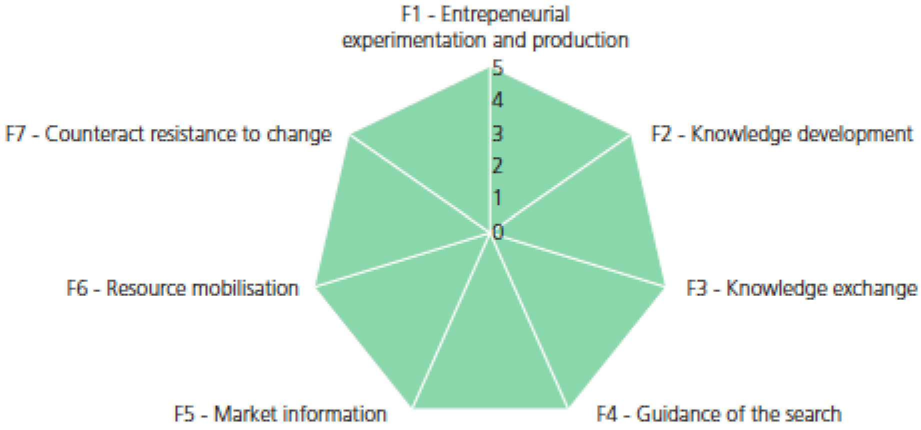

Figure 7. An example overview of the system functions fulfillment (source: Hekkert et al., 2011).

3.2

Social network analysis

In this research a social network analysis (SNA) facilitates the analysis of the influence of the fermentation biotechnologies on the actor configuration of the current food waste processing system. Herewith it allows for answering the fourth sub research question of this research:

4. *How will the introduction of fermentation technologies influence the organization of the current system and how could these changes help to remove the main barriers for large scale application?*

First of all, following the definition of Breiger (2004), SNA can be defined as:

> *"The disciplined inquiry into the patterning of relations among social actors, as well as the patterning of relationships among actors at different levels of analysis"* (p. 195).

More specifically, SNA can be used to examine the projected transition process of an innovation to conclude upon ways to overcome the main barriers. For doing so, the SNA tool enables the analysis of both the relationships (i.e. edges) between actors (i.e. nodes), as the structures and patterns of these relationships. The latter is performed by investigating network properties such as network density, network structure, the degree of connections of an actor, and the strength of relationships (Buth et al., 2019).

The framework of Buth et al. (2019) provides a tool for analysis that strongly relates to the adjusted framework of Stein and Jaspersen (2019). Therefore, both a quantitative and qualitative SNA was performed. The methods used for data collection for these types of analysis, and the investigated network properties for the quantitative SNA (i.e. network shape, network density, betweenness centrality, and strength of the relation) are explained in the methods chapter hereafter.

3.4 Narratives

Adding to the second dimension of the proposed nexus governance framework, this research also investigates the main narratives that determine the implementation and adaptation of policies that can enhance the transition towards high-value food waste valorisation. Hence it supplements to answering the third research question:

3. *What are the opportunities and barriers to large scale application of these techniques in the AMA?*

The analysis of the narratives is taken apart from the 'multi-level system' dimension in the socio-technical transitions analysis, because both the concepts and data collection from the socio-technical analysis and the social network analysis combinedly allow to recapitulate the main narratives present in the existing actor system of food waste processing and valorisation in the AMA. As discussed in section 3.1 in the description of the framework of Stein and Jaspersen (2019), narratives "*embody ideas concerning what forms of action and interactions are possible, feasible, desirable, and efficacious*" (Tilly, 2002, p. 8-9). Hence narratives have an influence on what, and how, policies are shaped and implemented, and analysing these narratives can help understand the opportunities and barriers of governance across sector boundaries (i.e. nexus governance) (Stein & Jaspersen, 2019). Insights on the narratives thus contribute to the outcomes of the opportunities and barriers analysis of section 3.2 by comprehending the main narratives that determine the way actors think a certain desired future state of the system should or could be accomplished.

3.5 Conceptual model

Summarizing, this research performs both a socio-technical- and social network analysis (the former including a baseline MFA of FW flows, and a comparative environmental assessment of the technologies), supplemented by an analysis of the main narratives. Respectively to gain insights in the transition pathway(s) of the fermentation biotechnologies and the opportunities and barriers to enhance this transition towards high-value food waste valorisation, and to gain an understanding of the influence on the current actor configuration and how this could overcome the barriers. Figure 8 presents the conceptual model that shows the interrelations of the research focus, the concepts and the outcomes, as described in this paragraph.

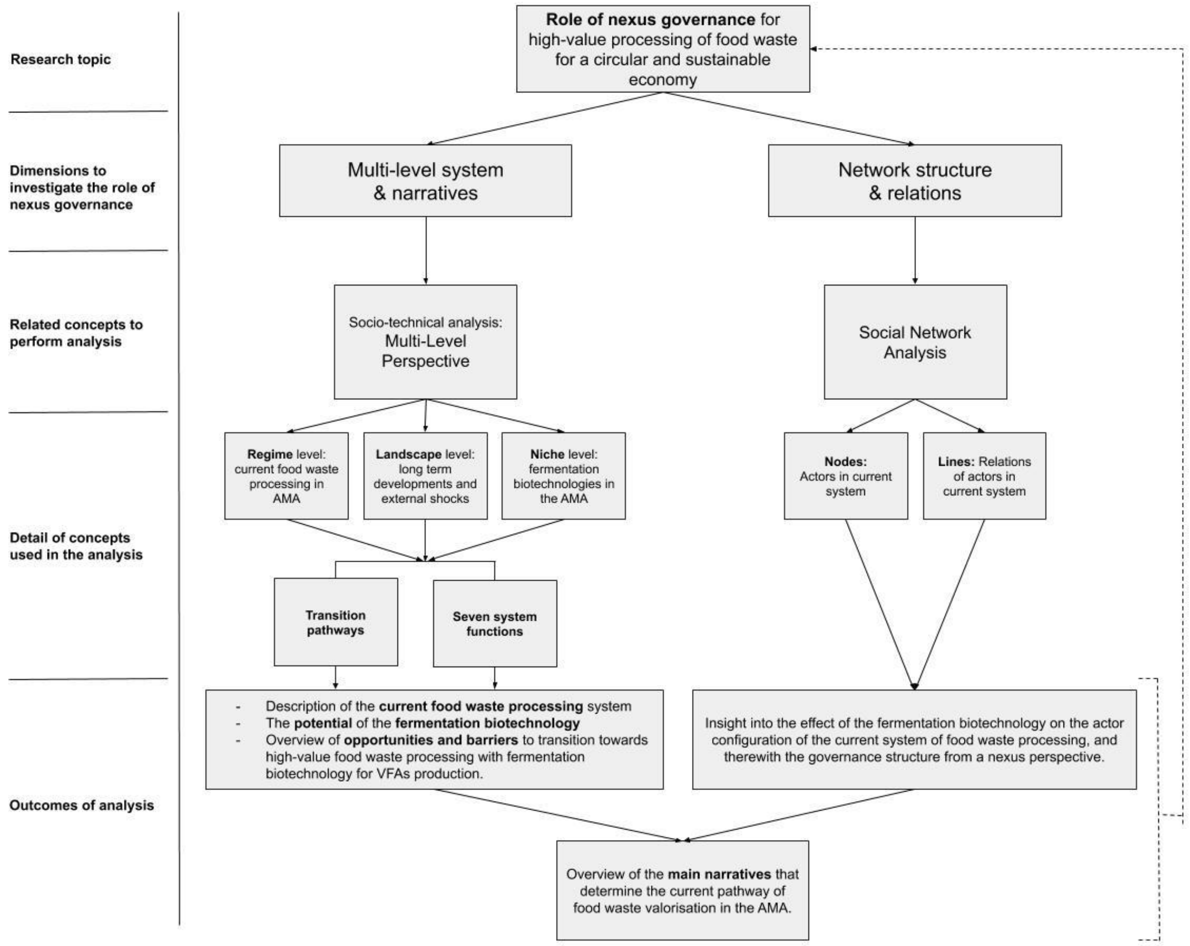

Figure 8. The conceptual model applied in this research.

4. Methods

To perform the research steps and examine the concepts as delineated in the conceptual framework, several methods have been used in this research, containing both primary and secondary data. The methods are explained in this chapter and presented in chronological order accordingly to the (iterative) research process. First, the case of the fermentation biotechnologies for fatty acids production in the AMA was selected based on its relevance in academic literature, policy documents and momentum of current technologies. Subsequently, specific methods for data collection and data analysis have been used that are further elaborated below (see figure 9 for a concise overview of the research steps). By combining both qualitative analysis for the socio-technical analysis and the SNA, and quantitative analysis for the SNA, MFA and environmental assessment, this research applies a mixed method research approach. Combinedly, the conceptual framework, research questions, and the methods presented in this chapter form the process stages and structure of the research, which are also summarized in the Research Flow Diagram at the end of this chapter.

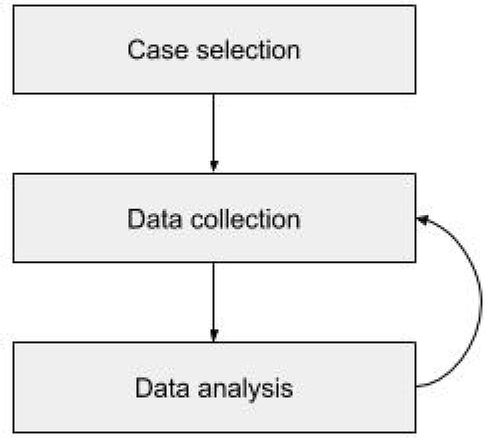

Figure 9. The (iterative) research steps performed in this research.

4.1 Case selection: high-value fermentation techniques

Combining the momentum in academic literature, and in current policy and innovation in the AMA, a selection of the most relevant high-value valorisation techniques was made, to be investigated in this research (see appendix for background context). To start with, both academic literature and momentum in the AMA demonstrate the interest in biochemical techniques (e.g. biorefineries) to process food waste, either from homogenous flows or mixed postconsumer household food waste, into new biochemical compounds (fatty acids) (see for example Tonini et al., 2019; Teigiserova et al., 2019; and previously mentioned circular strategy and innovation and implementation programmes of the City of Amsterdam and the AMA organisation). Both the techniques of the Amsterdam Green Campus, Chaincraft, and FABULOUS concern such biochemical processes in the specific practice of the AMA. The fermentation biotechnologies investigated in this research thus offer the potential to process a wide range of food waste types, and provide products that go beyond current products from food waste in the AMA (i.e. incineration, digestion, composting).

The relevancy of the case investigated is also highlighted by the short-term changes in the City of Amsterdam where organic waste is expected to be collected separately in the near future, meaning that high-value valorisation of food waste will become more attractive. Herewith referring to the statement of Tonini et al. (2019) that currently low-value techniques are more favourable in the AMA due to the low quality of collected food waste (mixed with residual waste).

Moreover, these fermentation techniques for fatty acids contain a strong nexus focus where the water-, energy- and food sector are involved (see figure 1 in TF). Also, from a circular economy perspective, valorisation of food waste can be deemed most efficient if different types of resources are most optimally recovered following the order of the Waste Hierarchy of Lansink (Parto et al., 2007). These two statements combined demonstrate the need to investigate its truly circular and sustainable potential in relation to the status quo. Thereby referring to a nexus system that demands a nexus governance perspective (Stein & Jaspersen, 2019).

It should not go unmentioned that the Black Soldier Fly (BSF) technique is also mentioned in academic literature as another potential high-value valorisation technique, but while the technique is currently applied in the Netherlands by the company Protix, the technique is not mentioned in policy documents of, or experimented with in, the AMA. Also, the BSF technique focuses on a whole different niche product for added value compared to the fatty acids production of AGC and Chaincraft, namely proteins via insects for animal feed, thereby falling outside the scope of this research.

4.2 Data collection

4.2.1 Desk research for socio-technical analysis

The first method that has been applied for data collection purposes concerns desk research in both academic literature and grey literature for the socio-technical analysis. Grey literature entailed online data sources such as policy documents and websites. This desk research was conducted to collect data on the current food waste processing system of the AMA, including information on the involved actors, rules and institutions, tangible artefacts, and (historical) landscape pressures in the current food waste processing system. Furthermore, desk research was also conducted for a first exploration of the processes in fermentation biotechnologies, and its position as a niche technology in the current system.

With regard to the boundary of the actor system, the scope was defined by including actors that are directly involved in the processing of food waste in the AMA. This reaches from the point where the food waste is generated and collected, to the point where a 'semi-end product' results from the valorisation process and is sold to, or used by, a specific actor[6]. Therefore, merely actors directly involved in the application of the products from both the current and potential future food waste processing in the AMA (e.g. compost, energy, biochemicals) are included to show the nexus-based relations of actors.

4.2.2 Semi-structured interviews for socio-technical analysis

These insights from the desk research have been further consolidated by performing semi-structured interviews. The semi-structured interviews on the one hand helped in validating the data collected via the desk research, and on the other hand supplemented for answering the third sub research question

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[6] 'Semi-end product' refers to the fatty acids produced by the investigated niche technologies. The fatty acids from FABULOUS would for example be sold to a company that processes the fatty acids into a plastic with specific characteristics, that in its turn can be used by a company that makes plastic products out of it.

of this research. Consequently being able to conclude on the opportunities and barriers for diffusion and large-scale application of fermentation biotechnologies (for chapter 7).

Semi-structured interviews do not follow a strict predefined set of interview questions, but rather a predefined set of interview topics. It was chosen to employ this interview structure, because this question structure enables for an open discussion with the interviewee and the possibility for the interviewer to steer the interview towards other topics that might deem relevant in the course of the interview (Bryman, 2016; Schmidt, 2004). Semi-structured interviews therefore require a prior analysis of the research subject to determine the predefined topics to be addressed during the interview. The previous desk research and the concepts of Hekkert et al. (2011) facilitated this prior knowledge.

For privacy reasons, the interviewees were first always asked if they permitted the recording, and it was explained to them that the recording would merely be used for the purpose of this research and deleted afterwards. Full transcripts of the interviews can be found in the appendix.

12 experts from the selected actor organisations in the current system were approached to participate in semi-structured interviews. 8 experts were first approached based on the outcomes of the desk research. I.e. based on the actors that are established in the current regime, landscape en niche level (see the MLP framework in the conceptual framework). Subsequently, a ‘snowball sampling approach’ was applied to approach other relevant experts. For example, when participants referred to other experts in the field that were suggested to have important knowledge on the topic. It was chosen to interview at least one person from each actor group (i.e. government, waste processors, niche technologies, knowledge institutes). Eventually 6 interviews were conducted, since the purpose of the interviews was to find the opportunities and barriers based on expert judgement from within the system - as suggested by Hekkert et al. (2011), for which a sample of 6 experts was considered significant to supplement findings from the desk research. Also, because at this point a level of information saturation was experienced. See the appendix for a full overview of the contacted and interviewed actors.

Interviewees were asked about the opportunities and barriers of the large-scale implementation of high-value valorisation techniques in general and fermentation biotechnologies, based on the seven system functions fulfilment of Hekkert et al. (2011) as presented in the conceptual framework. The specific list of predefined research topics and related open questions can be found in the appendix.

4.2.3 Desk research for material flow analysis

For the sake of providing a baseline study of the actual food waste flows present in the AMA, an MFA was performed as part of the analysis of the current regime in the first chapter. A MFA is an analytical tool to analyse “*the metabolism of materials and substances*” in a predefined system, based on the principles of mass balance equations (de De Haes and Huijengs, 2009, p. 219). The goal of the MFA was to quantify the food waste flows generated by households and companies per food type and sector of origin, and linking them to their respective currently applied treatment method. Desk research for the households and companies MFA included data collection on the volumes and types of food waste in the AMA from academic sources (i.e. Geldermans et al., 2018; Cinderela, 2020; Coudard, 2019) and field research (Voedingscentrum, 2020). The geographical scope of the MFA was determined by the boundaries of the AMA, including all 32 municipalities (see figure 10). Whereas the temporal scope was set to ‘most recent data available’, appearing to be 2019 for the households MFA and 2018 for the companies MFA.

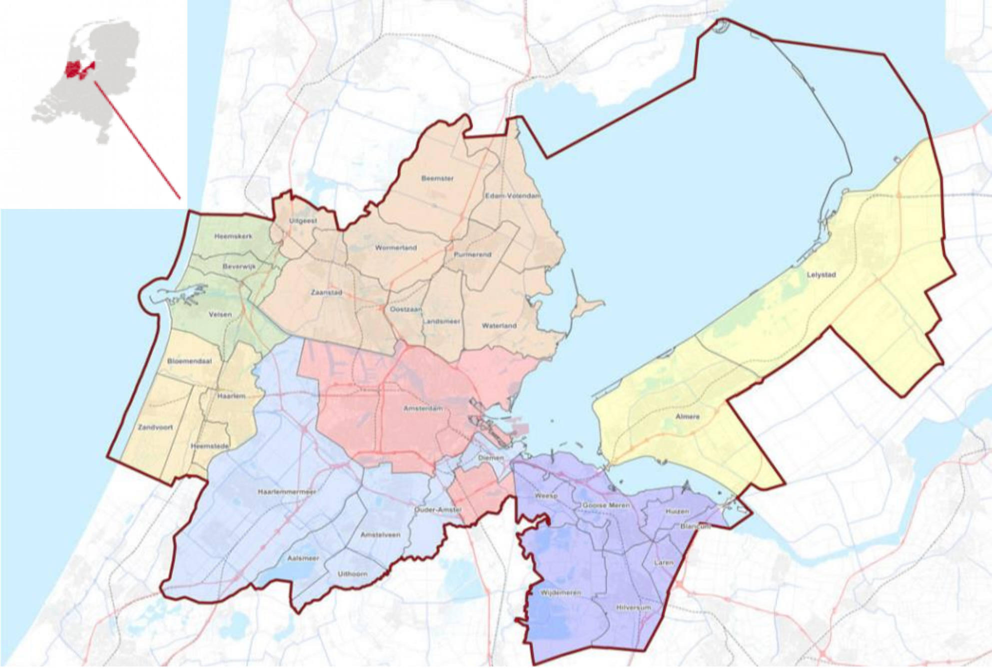

Figure 10. The 32 municipalities of the AMA (source: www.metropoolregioamsterdam.nl).

Household MFA

For households the data of the field research of the Voedingscentrum (2020) was used to define food waste flows per type of food per Dutch inhabitant. Subsequently, the bottom-up method of Coudard (2019) applied to the city of Amsterdam was employed to calculate the avoidable (both solid and liquid) and unavoidable food waste per food type, per municipality of the AMA (based on the number of inhabitants per municipality, obtained from the CBS Stateline database). See the appendix for the inventory data per inhabitant from the Voedingscentrum.

Thereafter, it was calculated what quantities of household food waste would end up in resp. vfg- and residual waste by means of characterisation factors provided by the top-down methodology of REPAiR in Geldermans et al. (2018). These numbers present the percentage of avoidable and unavoidable food waste present in both vfg and residual waste based on the urbanisation rate of municipalities (see table 1). The urbanisation rates and the quantities of total vfg and residual waste of all municipalities in the AMA (n = 32) were consulted from the CBS Stateline database resp. for the year 2019 and 2018[7].

The total food waste quantities per municipality in vfg- and residual waste calculated by the latter method were subsequently normalized to the totals of the bottom-up method of Coudard (2019) and the Voedingscentrum (2020). This normalisation was performed based on a calculated ratio of avoidable and unavoidable food waste respective to the total avoidable and unavoidable food waste in the AMA ending up in resp. vfg- and residual waste.

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[7] See Statline data on: https://www.cbs.nl/nl-nl/maatwerk/2019/31/kerncijfers-wijken-en-buurten-2019 and https://opendata.cbs.nl/statline/#/CBS/nl/dataset/83452NED/table?fromstatweb

Table 1. Inventory data household food waste per treatment method (vfg/residual) (source: Geldermans et al., 2018).

Urbanisation rate	**addresses / km²**	**% ua fw in res**	**% a fw in res**	**% ua fw in vfg**	**% a fw in vfg**
1	≥ 2 500	14.83	13.00	13.07	5.90
2	1 500–2 500	8.55	15.70	6.55	4.25
3	1 000–1500	9.40	10.70	5.70	2.60
4	500–1 000	9.90	11.83	13.60	6.40
5	< 500	4.90	11.30	17.55	7.65

Companies MFA

Data for the companies MFA was collected from the recently developed webtool database from the EU-funded H2020 CINDERELA project. This database contains data of the year 2018 on organic waste from companies in a selected area in the EU, based on NACE codes and European Waste Catalogue (EWC) Codes. NACE codes indicate the 'economic activity group' of all registered companies based on the 'Statistical Classification of Economic Activities in the European Community' (the full list of codes can be consulted here). Additionally, the EWC codes label all waste produced in the EU on three levels of detail: chapters, sub-chapters and entries (for a full overview see here). For the case of the Netherlands in the webtool, this includes data labelled by EWC codes based on data from the Landelijk Meldpunt Afvalstoffen (LMA) (the national contact point for waste registration). The webtool allowed to make an inventory data overview of all food waste originating from companies in the AMA. The following steps were performed to obtain the inventory data from the webtool:

1. *Scope selection:*
   The pre-uploaded dataset of 'organic waste 2018' was selected, and the 32 municipalities of the AMA (still 33 in the tool, as it contains data of 2018 and 'Haarlemmerliede en Spaarnwoude', was still a separate municipality from 'Haarlemmermeer').
2. *Material analysis:*
   A one-dimensional dataset was downloaded on 'material-level' including all organic waste produced in the AMA in 2018, on 'entry-level' of the EWC codes. This had the main purpose to gain an understanding of all waste flows including in the 'organic waste' dataset (e.g. plant tissue waste, animal tissue waste, materials unsuitable for consumption or processing). Regarding these categories it should be mentioned that they also contain fractions of organic waste, though based on the current classification scheme of the EWC, a clear division between organic and food waste could not be made.
3. *Economic Activity analysis:*
   Nonetheless, it was aimed to make a 'food waste selection', by matching the waste categories and quantities with the economic activity groups (two-dimensional download of data on material- and economic activity level). The economic activity groups not relevant for food waste treatment by the selected niche technologies were deselected from the dataset (e.g. wholesale of clothing and footwear, manufacture of paper and paperboard, manufacture of oils and fats(!)).

4. *Aggregation to economic activity group:*
   Subsequently, the flows of food waste based on the EWC codes were aggregated to sector level based on economic activity groups (i.e. agriculture, manufacturing, waste management (including waste registered at the point of collectors), wholesale and retail, accommodation and food services). Resulting in an overview with the origin of food waste in a certain sector, and destination in a type of food waste (e.g. vegetables, meat, fish, beverages). This aggregation was executed in Excel, as the tool did not allow to conveniently deselect non-relevant sectors.
5. *Add food waste quantities in residual waste:*
   As a large portion of food waste from companies ends up in residual waste, this quantity was still to be added to the total overview. It was aimed to calculate this quantity following a similar methodology, however residual waste quantities per sector were not present in the webtool, and not openly accessible for the researcher of this study. Therefore, food waste totals in residual waste in the AMA were normalised from a previous REPAiR study based on a similar methodology of the year 2016 (i.e. ratio of food waste in residual waste compared to food waste separately collected).
6. *Connect to treatment methods:*
   Lastly, the food waste flows were linked to their respective treatment methods in the webtool by downloading a two-dimensional dataset on material- and treatment method level, thereafter deselecting the previously defined 'not-relevant' sectors in Excel.

4.2.4 Desk research for environmental analysis

The MFAs of food waste flows were combined with an environmental assessment of the water and energy requirements of the fermentation biotechnologies under study. These assessments have the main goal to estimate whether the investigated technologies are not merely promising from an economic perspective (i.e. high-value output), but also from an environmental perspective (i.e. equal, or lower environmental impact compared to the status quo). This analysis was performed by quantifying the amount of water and energy inputs required relative to the produced economic outputs when high-value valorisation would be applied on a large scale in the AMA (scenario 2), compared to the status quo (scenario 1). Also in relation to the potential additional by-products produced and substitution of corresponding market products, which provides an overview of the potential of the biotechnologies as a high-value technology for the circular economy in the AMA.

Data collection for the environmental analysis included data collection on water- and energy intensities of different food waste processing technologies. This entails the direct water- and energy consumption of the technologies during the treatment processes in the AMA region. Meaning that it thus not includes more indirect water- and energy impact related to embedded impacts (e.g. water and energy for food production) or, for example, land use changes. This data was mainly obtained from the research of Coudard (2019) but specified by findings from academic literature where required. Table 2 provides an overview of these water and energy inputs, and the economic output of the three niche technologies investigated in this research.

Table 2. Energy and water inputs, and economic output of the three niche fermentation technologies.

Technology	**Energy requirement (MJ/t of FW)**	**Water requirement (m^3/t of FW)**	**Economic output (€/t of FW input)**
Chaincraft: butyric acid (C4) for animal feed additive	10,387	43	1219*
AGC: VFAs (C12-18) for food additives	23,143	2	440*
FABULOUS: lactic and propionic acid (C3) for bioplastics	10,387	43	1219*

* Based on market prices in Bastidas-Oyanedel & Schmidt (2018) and output efficiencies of the three technologies in Coudard (2019).

Based on interviews and the desk research, it was assumed that Chaincraft produces butyric acid (C4) for later conversion into a feed additive, whereas the FABULOUS-project produces propionic acid (C3) for later application in bioplastics. It should be noted however that Chaincraft currently only produces fatty acids for animal feed, but aspries to produce a wider range of platform chemicals in the (near) future to also produce for e.g. bioplastics, paints, and plasticizers (van Stralen, personal communication, 2020), thereby probably also increasing the economic output as indicated above. Furthermore, the economic output per tonne of food waste for the AGC technology was determined based on the physical output assumption of 176 kg / t food waste input in Coudard (2019), based on the value-added chemical furfural. It was assumed that furfural has a similar added value as the fatty acid for food additives produced by AGC, as it was stated in the interview that it has an nutritional added value (relative to the merely stabilizing added value of the 'pectin' chemical). Moreover, from the survey it became apparent that the fatty acids produced by AGC are in a higher range of acids (i.e. C12-18), however no current literature found could clarify current market prices for these higher range fatty acids. Therefore, an upper range price of 2500 € / tonne output product was assumed (somewhat higher than the C3 and C4 fatty acids). Though it should be noted that also the assumption on the output per tonne food waste is based on lab-scale application of these technologies, thereby indicating an expected higher output efficiency and market price in the (near) future.

Also, the economic output prices are based on market prices of fatty acids, so it can be assumed that market prices for eventual output products will be even higher (e.g. the bioplastics, and feed- and food additives). Also, taking into consideration that cost reductions for these novel technologies are expected in the (near) future (Baumann & Westermann, 2016).

Lastly, it was stated in several interviews that wastewater treatment is often present on-site of waste treatment plants (i.e. the case for FABULOUS-project, perhaps also Chaincraft). Therefore, it might be assumed that when this water is reused in the processes, this replaces part of the freshwater inputs needed for the technologies as indicated above.

The quantities presented in table 2 are used in section 6.4 to calculate the environmental impacts and benefits of implementing the niche technologies on a large scale in the AMA (i.e. scenario 2), relative to the status quo (i.e. scenario 1). Therefore, table 3 shows the same water- and energy intensities, and economic output for technologies current applied in the AMA for processing food waste.

Table 3. Energy and water inputs, and economic output of the status quo food waste processing technologies in the AMA (source: Coudard, 2019 - if not otherwise stated).

Technology	**Energy requirement (MJ/t of FW)**	**Water requirement (m^3/t of FW)**	**Economic output (€/t of FW input)**
Mixed residual incineration with energy recovery	131	3	253
Anaerobic digestion with combined composting (vfg household waste)	250	1	224
Composting	101	-	20
Biological cleaning and processing for animal feed*	720*	0.3*	40**

* Based on the research of Vandermeersch et al. (2014).

** Based on output prices from Duynie Feed (2020)[8]

4.2.5 Surveys for social network analysis

Furthermore, quantitative surveys have been conducted with actors from each actor group in the current actor system (as appeared from the prior socio-technical analysis), to collect quantitative data for the social network analysis. This data was used to map the current actor configuration, by representing actor groups as nodes and their relations as edges. For collecting this data and designing the survey questions, the present research followed the framework and methods applied by Buth et al. (2019), as substantiated in the conceptual framework.

Again, finding respondents for the surveys was based on desk research and following the snowball sampling technique. All actors in the current food waste processing system of the AMA, that became apparent from the interviews, were contacted with the question to participate in the survey (see the appendix for a full overview of the respondents contacted and interviewed). Eventually, 4 actors from each actor group filled in the survey and were interviewed. It should be noted though that actors from more actor groups (total of *n* = 14) were asked to participate in the survey exercise, however due to time constraints or lack of response, eventually these 4 actors were consulted for the survey. Nevertheless these 4 actors still represented the main actors of the system under study (niche technologies, current waste processors, knowledge institutes, governments), and additional insights about more periphery actors (e.g. animal feed sector, agricultural sector) was obtained from the interviews and qualitative part of the surveys.

Following the framework of Buth et al. (2019), the participants were asked to fill in two surveys where they were asked about the frequency of interaction with other actors in the system. One survey asked these questions for the current system, whereas the second survey asked these questions for the future system, including the large-scale application of fermentation biotechnologies for high-value valorisation of food waste. The future system was based on a future vision and provided with the first survey to the participants (see data analysis section for explanation on future vision). Respondents were asked to fill in the first survey and read a future vision before the (virtual) meeting. Then, during the meeting, they were asked if they had questions or feedback regarding the future vision and were asked to fill in the second survey. Finally, respondents were questioned for the reasons behind

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[8] https://www.duynie.nl/download/11071/duynie-feed/prijslijst/201005_Prijskrant_Duynie_RUNDVEE_extern__2020-39.pdf

potential changes in relations of actors between the current and future system. This way, the quantitative survey was complemented by a qualitative interviewing method to assure that the respondents understood the future vision correctly, and to enrich the obtained insights from the surveys beyond merely statistical outcomes. It thereby provided a normative substantiation of the changes in the actor configuration, to understand the complex interrelations in the current and future system of the AMA, and to conclude upon the main narratives in the system under study.

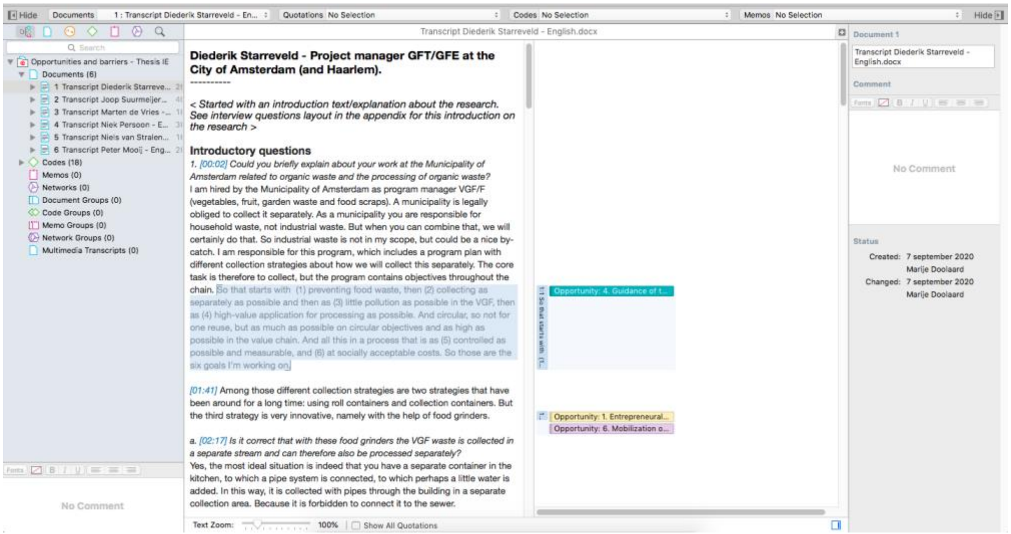
4.3 Data analysis

4.3.1 Material flow analysis

The outcomes of both the household and companies MFA were visualised in a Sankey diagram, in order to conclude upon the main sources of food waste, the ratio of unavoidable versus unavoidable food waste for households, and their subsequent treatment methods. The main goal for identifying these flows was to analyse how these flows could be valorised in a high-value and sustainable manner with the investigated niche technologies in the assumed scenarios.

4.3.4 Socio-technical analysis

The outcomes of the semi-structured interviews for the socio-technical analysis based on the seven system functions by Hekkert et al. (2011) were analysed by means of transcribing and labelling in the software Atlas.ti. The goal of this analysis was to come to the main opportunities and barriers of the niche technology in the current food waste processing system of the AMA, by means of expert judgement. All six interviews were uploaded into Atlas.ti and quotes in the interviews were labelled according to it representing either an 'opportunity' or 'barrier' in one of the seven system functions (e.g. knowledge development, resource mobilisation, etc.). This type of analysis allowed an easy aggregation of the main opportunities and barriers per function and to conclude upon them, without overlooking important statements. Below, two screenshots are provided of the analysis performed in Atlas.ti. Respectively showing labelling of a quote, and selecting the outcomes per function. Eventually, the qualitatively described opportunities and barriers were summarized in a spider diagram, as suggested by the theory of Hekkert et al. (2011).



Diederik Starreveld - Project manager GFT/GFE at the City of Amsterdam (and Haarlem).

< Started with an introduction text/explanation about the research. See interview questions layout in the appendix for this introduction on the research >

Introductory questions

1. [00:02] *Could you briefly explain about your work at the Municipality of Amsterdam related to organic waste and the processing of organic waste?*

I am hired by the Municipality of Amsterdam as program manager VGF/F (vegetables, fruit, garden waste and food scraps). A municipality is legally obliged to collect it separately. As a municipality you are responsible for household waste, not industrial waste. But when you can combine that, we will certainly do that. So industrial waste is not in my scope, but could be a nice by-catch. I am responsible for this program, which includes a program plan with different collection strategies about how we will collect this separately. The core task is therefore to collect, but the program contains objectives throughout the chain. So that starts with (1) preventing food waste, then (2) collecting as separately as possible and then as (3) little pollution as possible in the VGF, then as (4) high-value application for processing as possible. And circular, so not for one reuse, but as much as possible on circular objectives and as high as possible in the value chain. And all this in a process that is as (5) controlled as possible and measurable, and (6) at socially acceptable costs. So those are the six goals I'm working on.

[01:41] Among those different collection strategies are two strategies that have been around for a long time: using roll containers and collection containers. But the third strategy is very innovative, namely with the help of food grinders.

a. [02:17] *Is it correct that with these food grinders the VGF waste is collected in a separate stream and can therefore also be processed separately?*

Yes, the most ideal situation is indeed that you have a separate container in the kitchen, to which a pipe system is connected, to which perhaps a little water is added. In this way, it is collected with pipes through the building in a separate collection area. Because it is forbidden to connect it to the sewer.

Document 1: Transcript Diederik Starreveld - English.docx

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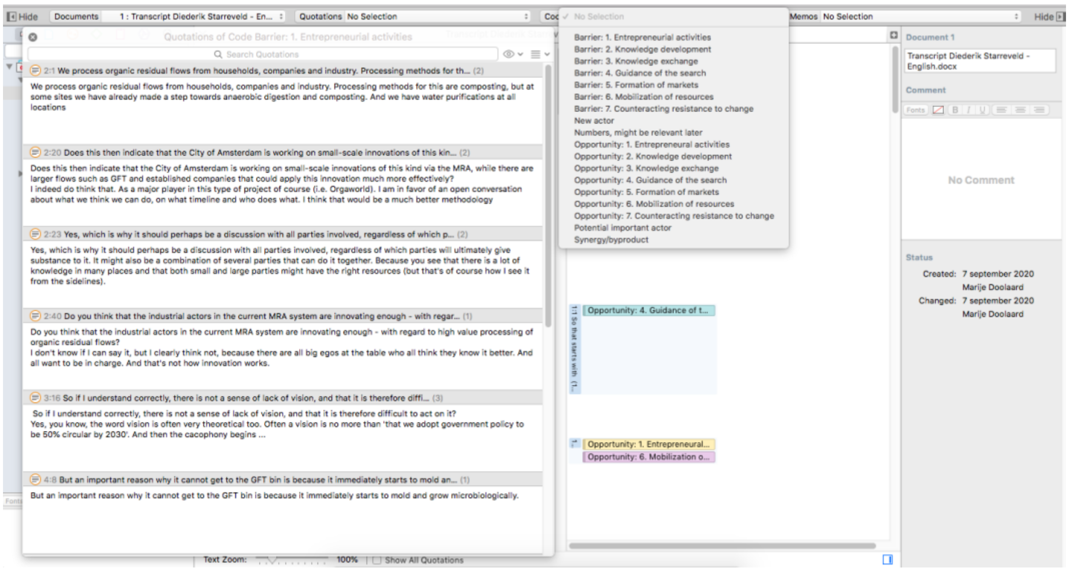
Figure 11. Data analysis for the socio-technical analysis. Labelling of interviews based on the seven system functions.



2:1 We process organic residual flows from households, companies and industry. Processing methods for th... (2)

We process organic residual flows from households, companies and industry. Processing methods for this are composting, but at some sites we have already made a step towards anaerobic digestion and composting. And we have water purifications at all locations

2:20 Does this then indicate that the City of Amsterdam is working on small-scale innovations of this kin... (2)

Does this then indicate that the City of Amsterdam is working on small-scale innovations of this kind via the MRA, while there are larger flows such as GFT and established companies that could apply this innovation much more effectively?
I indeed do think that. As a major player in this type of project of course (i.e. Orgaworld). I am in favor of an open conversation about what we think we can do, on what timeline and who does what. I think that would be a much better methodology

2:23 Yes, which is why it should perhaps be a discussion with all parties involved, regardless of which p... (2)

Yes, which is why it should perhaps be a discussion with all parties involved, regardless of which parties will ultimately give substance to it. It might also be a combination of several parties that can do it together. Because you see that there is a lot of knowledge in many places and that both small and large parties might have the right resources (but that's of course how I see it from the sidelines).

2:40 Do you think that the industrial actors in the current MRA system are innovating enough - with regar... (1)

Do you think that the industrial actors in the current MRA system are innovating enough - with regard to high value processing of organic residual flows?
I don't know if I can say it, but I clearly think not, because there are all big egos at the table who all think they know it better. And all want to be in charge. And that's not how innovation works.

3:16 So if I understand correctly, there is not a sense of lack of vision, and that it is therefore diffi... (3)

So if I understand correctly, there is not a sense of lack of vision, and that it is therefore difficult to act on it?
Yes, you know, the word vision is often very theoretical too. Often a vision is no more than 'that we adopt government policy to be 50% circular by 2030'. And then the cacophony begins ...

4:8 But an important reason why it cannot get to the GFT bin is because it immediately starts to mold an... (1)

But an important reason why it cannot get to the GFT bin is because it immediately starts to mold and grow microbiologically.

Transcript Diederik Starreveld - English.docx

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Marije Doolaard
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Marije Doolaard

Figure 12. Data analysis for the socio-technical analysis. Filtering the main opportunities and barriers of the socio-technical system under study.

4.3.3 Environmental assessment

Based on the water- and energy inventory data presented in the previous section, two scenarios were investigated in the environmental assessment. Scenario 1 includes the present-day food waste valorisation by means of anaerobic digestion, composting, incineration, and direct application for animal feed, whereas scenario 2 encompasses an addition of the three niche technologies investigated in this research (i.e. Chaincraft, AGC, FABULOUS-project). These niche technologies are complementary to the status quo technologies and quantities, since food waste flows currently ending up in residual waste or direct feed production are redirected towards these more high-value technologies, based on the outcomes of the MFA.

4.3.4 Social network analysis

The future vision, as provided to the participants, can be described as the *desirable future scenario* by defining the future of the system as one would prefer it. Determining this future and providing it to the actors of the system under study is of great importance, because visions can be regarded as 'pull factors' that have a strong motivating component, in comparison to the push factors of less desirable, or likely future scenarios from the point of current state (Quist, 2013).

For this research, the analysis for providing this future scenario was applied to the food waste processing system in the AMA by using the so-called *backcasting method*. Following the methodological framework of Quist (2013), five steps need to be performed: (1) strategic problem orientation, (2) develop future vision, (3) backcasting analysis, (4) elaborate future alternative & define follow-up agenda, and (5) embed results and agenda & stimulate follow-up. Within the scope of this research, steps 1-3 were executed, as the current scope does not include implementation and a participatory follow-up of the future vision.

By applying step 1-3 of this backcasting method, first (1) the target (objective) of the future state, and criteria to measure this objective are defined. Then, a (2) desired future is designed, after which (3) steps are determined from the future vision back to the present day to come to this desired future.

Due to its solid future orientation of sustainable innovations and transitions, backcasting can be regarded as highly relevant as a methodological tool. More specifically, backcasting had the function of unifying actors by forming their visions into one concrete narrative including all pros and cons. Also, backcasting develops an actionable plan' in which both short-, medium- and long-term actions are defined (Quist, 2013). In conclusion, this future vision describes which actor groups would be involved in the future system, their major role in the system, the main food waste processing routes, and the steps required to achieve this. The future vision can be found in section 7.2.

Furthermore, the Excel plug-in software NodeXL was used to process the data obtained with the quantitative surveys that were based on this future vision. The data collected was used as input for creating visualisations of the current and future actor systems that present the actors involved and their mutual relationships. This analysis was performed following the subsequent steps:

1. *Data inventory set up:*
   Results from the survey (Likert-scale score from 0-6 on frequency of interaction) was inserted into Excel, by connecting the right actors and defining the width of the edge by the frequency of interaction.
2. *SNA visualisation overall system:*
   Produce output visual to represent both current and future network on *actor level*, for comparison.
3. *Aggregation:*
   Aggregation of actor level social network systems into *actor group level* networks, for analysis on 'sectoral level' in F-E-W nexus context.
4. *Prevent double counting:*
   Double counting was prevented, by taking the average of two actor groups that stated different frequencies of interaction (e.g. current waste processors → chaincraft, chaincraft → current waste processors). Also, the edges were assumed bidirectional, and the system therefore undirected.
5. *SNA visualisation aggregated system:*
   Produce output visual to represent both current and future network on *actor group level*, for comparison.

Additionally, R studio was used for calculating statistical network metrics for the two aggregated social networks, as briefly touched upon in the conceptual framework (e.g. network density, betweenness centrality of actor groups). The nodes and edges (actors and their relations) were uploaded to R studio via a csv-file import, after which the 'igraph' library of R facilitated the calculation of the network metrics. The calculations behind, and meaning of these metrics are explained below (Buth et al., 2019):

- *Network density* is a metric often used in SNA to determine the level of interaction in a network. It calculates the ratio of the total number of edges in the network compared to all possible ties in the network, using the formula below, in which *T* is the amount of edges in the network, and *n* the amount of nodes:

$$\frac{T}{n(n-1)/2}$$

- *Betweenness centrality* provides insights on actor group level by calculating to what extent this actor group serves as an intermediary, which is closely related to the amount of resources going through this actor group (related to frequency of interaction also). It was calculated using the formula below, in which g_{ij} represents the amount of shortest paths to actor a_i, and $g_{ij}(a_k)$as the total amount of paths between actor group a_i and a_j, including actor a_k.

$$\sum_{i<j} \frac{g_{ij}(a_k)}{g_{ij}}$$

- *Eigenvector centrality* more specifically calculates the influence of an actor (group) in a network, by measuring how important the actors are that this actor is connected to. Doing so by calculating the centrality of these actors. It is calculated using the formula below, in which *G* is the overall network, "*with |V| vertices let A = ($a_{i,t}$) be the adjacency matrix. That means that $a_{v,i}$ = 1 if vertex v is linked to vertex t, and i = 0 if not*" (Buth et al., 2019, p. 197).

$$C_E(n_i) = \frac{1}{\lambda} \Sigma_{t \epsilon G} a_{i,t} C_E(n_t)$$

- Lastly, the *degree* measures the amount of edges that are connected to a node, thus indicating the influence of an actor group in the network.

4.3.5 Narratives

Finally, narratives employed in the current (nexus) governance system were uncovered by extracting storylines from the transcribed interviews, field notes, grey literature, and survey data. These narratives have the main goal to contribute to the outcomes of the opportunities and barriers analysis by comprehending how the main actors think a certain desired future state of the system should or could be accomplished.

4.4 Reflection on methods

Table 4 summarizes the focus of this research. The MFA and environmental analysis, as described in this chapter, are included as subsect of the first dimension. These analyses namely serve as a baseline assessment to provide a comprehensive overview of the relevant food waste flows present in the AMA to be used in fermentation biotechnologies, and their subsequent environmental impact to take into consideration. This to grasp a better understanding of the volume and relevancy of these different resources (i.e. food, water, energy) from a nexus perspective for increasing circularity. This baseline is therefore not directly part of one of the dimensions of the conceptual model in the previous chapter, but does assist important steps in this research.

Table 4. Overview of the dimensions of the conceptual model and the related focus, methods and research questions addressed in this research.

Dimension	Focus	Methods	Research question
Multi-level system & narratives	Describing the innovation system from a nexus perspective; the regime, landscape and niche level. Transition pathways and opportunities and barriers for the transition based on seven system functions and an environmental analysis.	Socio-technical analysis, environmental analysis, social network analysis: - Desk research - Semi-structured interviews - MFA for regime - EA for niche potential	RQ 1, 2 & 3
Network structure & relations	Mapping the current actor configuration, by representing actor groups as nodes and their relations as edges. Identification of actors on their position in the network and the content and quality of the relationships.	Quantitative network analysis: - Surveys Qualitative network analysis: - Additional interview questions	RQ 4

Additionally, below an overview is provided of the main advantages and disadvantages of the methods applied in this research, which should be considered when interpreting this research.

Table 5. Overview of the main advantages and disadvantages of the research methods deployed in this research.

Method	Advantages	Disadvantages	Anticipation on disadvantage
Semi-structured interviews	- The interviewer can align the main structure of the interview, ensuring that all required data is obtained, while still allowing sufficient space for the interviewee to insinuate new related topics.	- The challenge for the interviewer to redirect the interview structure based on the answers that are provided by the interviewee, while simultaneously continuing the interview (Bryman, 2016).	- Attempted to reduce this by recording the interviews, which allowed the interviewer to focus solely on the conversation, and therefore not also on taking notes.
Surveys & SNA	- The survey allows for explicit outcomes (Likert-scale) that can be quantitatively assessed. - SNA clearly shows the main leaders and bridges in an overall network structure, and potential future changes.	- Quantitative results can present a somewhat simplified picture. - Based on the personal expectations and visions of the respondents.	- Qualitative questions substantiated the quantitative outcomes of the surveys (i.e. narratives). - Validation of input from respondents via supplementing with interview outcomes and desk research.
Material flow analysis	- Providing a structured accounting method for insights in actual FW flows. - Sankey diagrams consolidate the former. - Ability to extend static MFA into dynamic MFA for monitoring purposes.	- Scope companies: based on classification of EWC codes. Difficult to divide organic- and FW. - Scope households: FW in residual waste based on normalisation with top-down method.	- Scope companies: Linked EWC codes to NACE codes. However, future adjusted and more precise classification of EWC codes and or field work on food waste types would be helpful for more precisely directing food waste processing policies. - Scope households: not to be dealt with in current research, more precise monitoring is recommended.
Environmental assessment	- Provides a baseline for understanding potential environmental consequences. - Allow a fair quantifiable comparison of technologies and different scenarios. - Create acceptance (social and political) for more environmentally friendly alternatives.	- Strongly relies on data inventory and related assumptions for new (ex-ante) technologies. - Requires a full life cycle- and all environmental impacts scope to make a fair comparison, which is often infeasible due to data constraints or multiple possible scenarios.	- Transparent documentation of data inventory and assumptions. - Comparison of scope under study in this research and qualitatively included additional (side)effects for nuancing the outcomes, rather than an often ‘black box’ LCA approach.

4.5 Research Flow Diagram

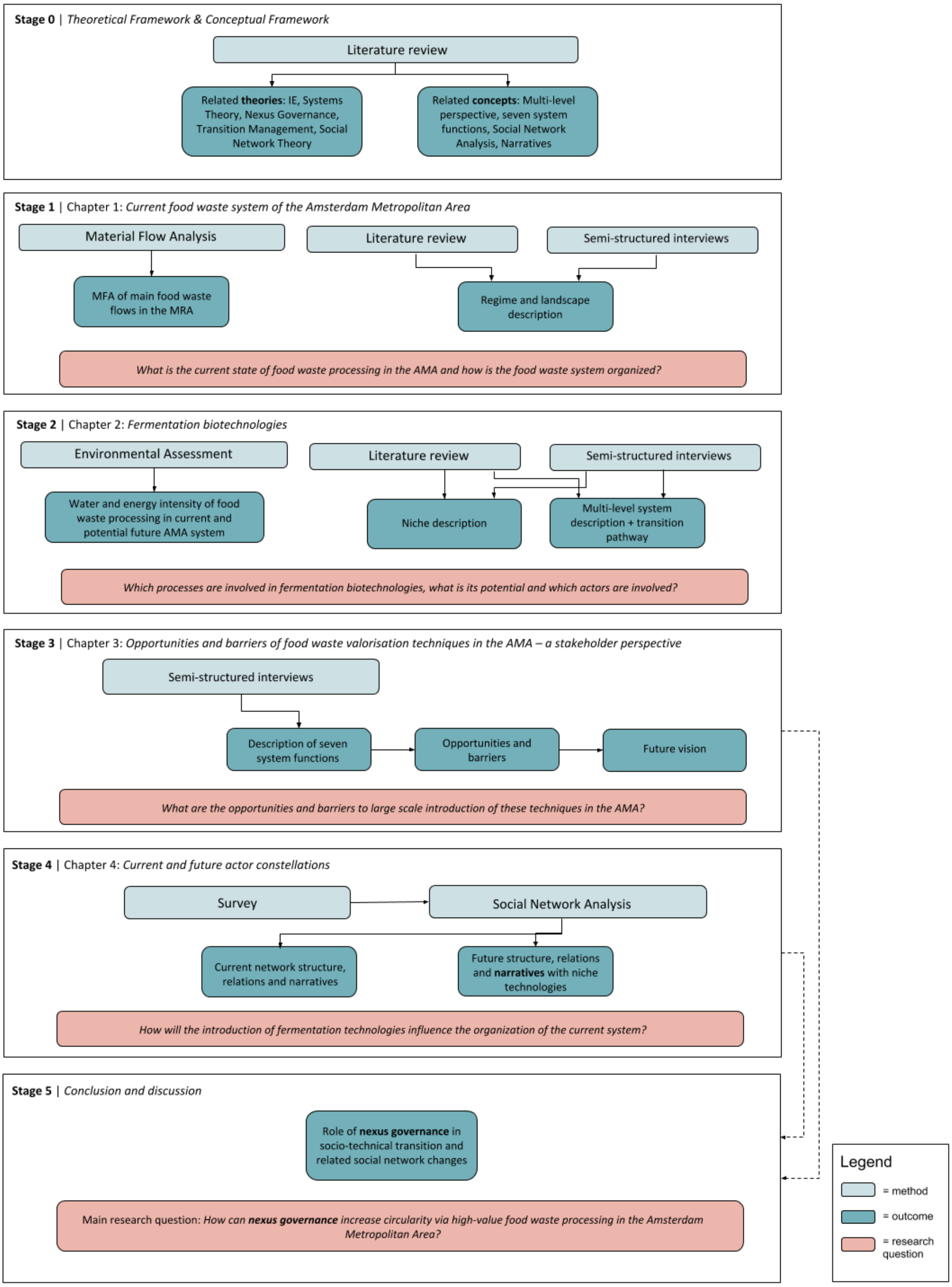

Figure 13. Research Flow Diagram of the present research.

5. Results I: Current food waste system of the Amsterdam Metropolitan Area

This chapter focuses on answering the first sub question of this research:

> *What is the current state of food waste processing in the AMA and how is the food waste system organized?*

First a baseline assessment of food waste flows in the AMA is provided. Subsequently, the current state of food waste processing is further explored by analysing it from a socio-technical perspective via an investigation of the regime- and landscape level of the multi-level perspective. Whereafter the subsequent chapter will more in-depth delve into the micro-level of the system under study (i.e. niche level: fermentation biotechnologies for fatty acids production).

5.1 Food waste in the AMA

Following the analysis of Geldermans et al. (2018) of food waste flows in the AMA in 2016, this research performed an updated material flow analysis for the year 2018. More specifically, it provides a more specified overview of currently available food waste flows for the fermentation biotechnologies investigated in this research. This higher specification was achieved by subdividing the food waste flows residing from households per food type. As stressed by Dahiya et al. (2018), "*the type of VFA* [Volatile fatty acids] *produced majorly depends on the composition and degradation of FW"* (p. 5). In other words, the type of food waste and thereby the quantities of proteins, carbohydrates and lipids in the food waste highly determine the potential output products of the anaerobic fermentation process (e.g. bioplastics, textiles, food). Which inevitably influences the viability of the biotechnology via its expenses and returns (Dahiya et al, 2018). Therefore, subdividing the food waste flows in different food types and their subsequent current collection and treatment routes is necessary for finding the most circular and sustainable fermentation biotechnologies in the context of the AMA. The table below provides a summary of the main results of the MFA.

Table 6. Summarized overview of food waste flows in the AMA by origin.

Food waste origin	**Food waste quantity (t/y)**	**Share (%)**
Households (including fw in residual waste)	145,708	53.1%
Agriculture	1,040	0.4%
Manufacturing	11,900	4.3%
Waste collection	17,000	6.2%
Wholesale and retail	71,500	26.1%
Food services	246	0.1%
All sectors (fw in residual waste)	26,900	9.8%
Total	**273,986**	**100%**

First, it shows that households and companies in the AMA have a virtually equal share in food waste generation, which substantiates the focus of this research on both households and companies. This can be explained from the fact that the AMA region - spanning from Haarlem to 'Gooi en Vechtstreek' and the polders of Flevoland -, is known for the grand magnitude of the agriculture sector and the food processing and -supply sector, but simultaneously for the large number of inhabitants, it being the densely populated 'Randstad'.

With regard to these equally major, but different food type flows, the investigated fermentation biotechnologies in this research (i.e. Chaincraft, FABULOUS project, AGC - see chapter 6) are able to process mixed- as well as more homogenous food waste flows. This offers potential for the bulk flow of food waste from households (mixed with organic waste in vfg), while for 'cleaner' food waste flows from processing and manufacturing companies, and companies in the food service sector, these fermentation biotechnologies also provide major advantages for processing from 'Food4Feed' of 'Food4Food' (van Stralen, personal communication, 2020; Persoon, personal communication, 2020, Suurmeijer, personal communication, 2020). A more in-depth elaboration on these techniques and their relevance for the food flows in the AMA can be found in chapter 6.

Furthermore, the study by Geldermans et al. (2018) shows "*that a small amount of companies produces more than half of the food waste*" that originates from companies (p. 98). 90% of this food waste is produced by these companies and are concentrated on 4 locations: "*1) the harbour of Amsterdam and Zaanstad to the north, 2) around Ijmuiden in the western AMA, 3) in and around Haarlem and 4) in Amstelveen*" (p. 98). This makes it attractive to collect these flows with few logistical movements and to process them locally with opportunities for industrial synergies for the in- and outputs of these processes. If, and how, these exchanges and synergies are currently already taking place - or might take place in the (near) future, is investigated by means of the socio-technical and social network analysis in the subsequent chapters of this thesis research.

With regard to these results, it should however be mentioned that in practice the 'food service' sector presumably has a larger share than indicated above. This is due to the fact that most of the fraction reported under 'waste collectors' entails different separate collected food waste fractions generated by different small companies (e.g. restaurants, catering), which are registered collectively by the collectors under their NACE code.

Moreover, it can be seen that the agricultural sector is included in the scope of the analysis. This was decided given the focus of the AGC project on the agricultural sector (beside the manufacturing and processing sector), and due to the lack of a thorough analysis of food waste from this sector in current research. Nonetheless, agriculture merely constitutes a relatively small share, for which it is assumed that this can be explained from the fact that food waste fractions are often directly reused for animal feed application and as nutrition for the soil within the farm itself, as was also indicated in one of the interviews (Suurmeijer, personal communication, 2020).

5.2 Food waste flows per type of food

Below, a more specified overview of food waste flows in the AMA is provided in Sankey diagrams, respectively for households and companies. This specification is provided by a direction of the flows of the current system per food type and per subsequent treatment method (see figure 14 and figure 15). This subdivision per food type is highly relevant for FW treatment, as certain treatment methods can only process certain FW types (e.g. fruit and vegetables for AGC). Also, the ratio of these different

FW types determines the quality of the collected (vfg) waste and how the subsequent treatment processes should be designed to obtain the right efficiencies. Let alone the fact that in the future other high-value technologies might develop that provide sustainable and circular solutions for FW treatment of specific FW flows (e.g. coffee residues, peels, bones).

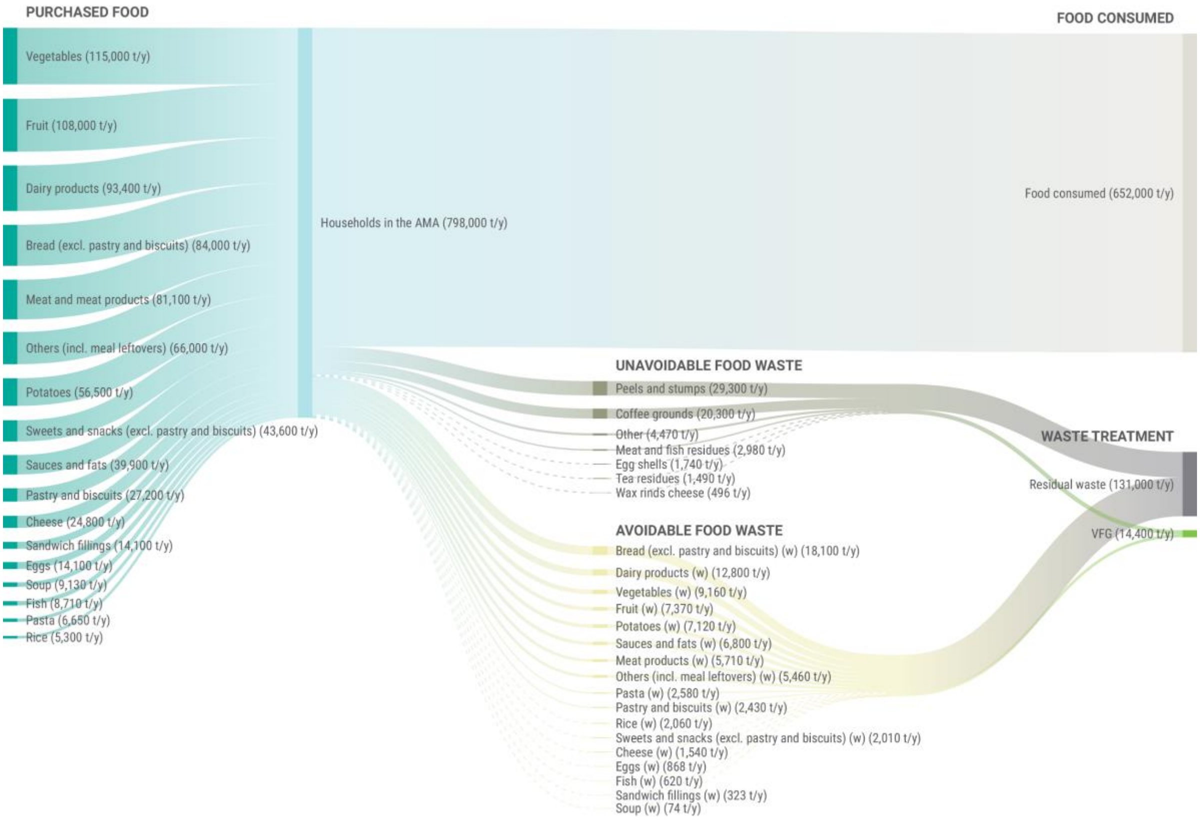

Figure 14. Sankey diagram of the food waste flows from households in the AMA sorted by food (waste) type and subsequent treatment method.

First of all, the Sankey diagram of household food waste shows that avoidable food waste from households in the AMA encompasses 84,923 t/y, whereas 60,785 t/y can be appointed as unavoidable food waste. Meaning that unavoidable and avoidable food waste from households have a virtually equal share in the AMA, and that the total share of food waste equals 145,708 tonnes annually. Most importantly, the equal share of unavoidable- and avoidable food waste stresses the necessity for high-value food waste valorisation, as the share of unavoidable food waste will always remain and demands appropriate circular and sustainable waste processing.

Interestingly, the main share of food waste (=90%) ends up in residual waste, indicating that it is not separately collected, and being incinerated (with energy recovery) at the point of valorisation. This despite the fact that almost all municipalities in the AMA separately collect vfg waste, hence indicating the bad state and quality of separate food waste collection from households.

Regarding the latter, it was also calculated how the numbers would change if the City of Amsterdam would collect vfg waste separately in the whole municipality (with the same share and quality compared to the other municipalities). This was determined based on the urbanisation rate and amount of inhabitants, and showed that total food waste ending up in vfg would increase to 26,075 t/y (+81%), and total food waste in residual waste would decrease to 119,634 t/y (-8.7%).

Additionally, the most prominent food waste types from households appear to be (in respective order) peels and stumps (ua), coffee grounds (ua), bread (a), dairy products (a), and vegetables and fruit (a)[9]. This presents interesting insights for treatment methods, as fruit and vegetables are for example more suitable as feedstock for the AGC technology, and the current application of Chaincraft.

Lastly, it should be mentioned that for sake of clarity and proportion the Sankey diagram also includes the amount of purchased food in the AMA by households per food type. From which it can be concluded that food waste constitutes 18% of the total amount of purchased food by households in the AMA, and more specifically, avoidable food waste constitutes 11% of total purchased food.

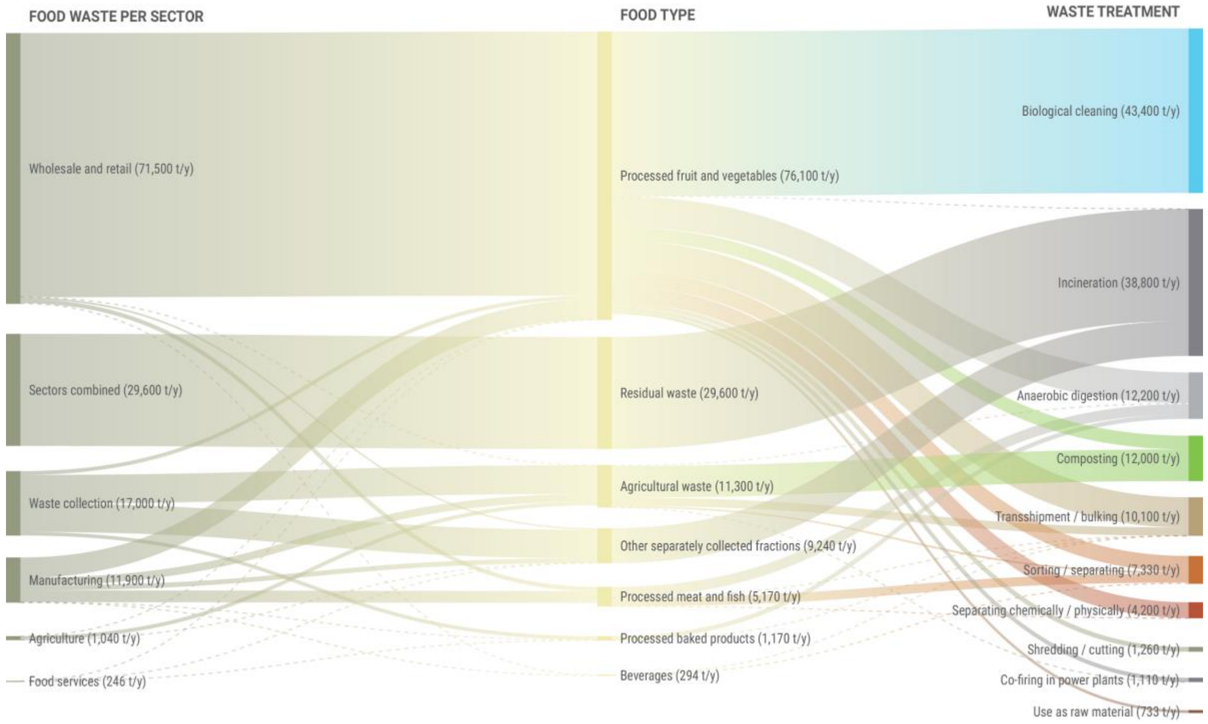

Figure 15. Sankey diagram of the food waste flows from companies in the AMA sorted by food waste type and subsequent treatment method.

Subsequently, the Sankey diagram of company food waste in the AMA indicates total food waste from companies to constitute about 131 kilo tons annually. It shows that the 'wholesale and retail' sector contributes the largest share to food waste from companies in the AMA (71,500 t/y), with 'processed fruit and vegetables' taking up the largest portion (76,100 t/y). Moreover, the main treatment method for these fruit and vegetables is 'biological cleaning', for which it is assumed that this entails cleaning with water for reuse of the fruit and vegetables as animal feed (San Martin et al., 2016). Mainly also because biological treatment is often used for treatment of 'sludges from washing and cleaning', however these were excluded from the scope of analysis.

Interestingly, the share of food waste from companies ending up in residual waste (23%), is of a completely different nature compared to the households MFA, where 90% of food waste currently ends up in residual waste. This might be explained from the fact that in most sectors food waste fractions are relatively 'clean', and provided in large quantities, making it attractive to collect them separately (think of cutting residues in manufacturing, or expired products of supermarkets).

Moreover, the quantities of food waste from companies being treated by means of anaerobic digestion or composting is of about the same magnitude as incineration (~30kt/y). The main food

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[9] (ua) = unavoidable food waste. (a) = avoidable food waste.

waste flows treated with anaerobic digestion into biogas are fruit and vegetables, meat and fish, and baked products (i.e. ordinary food composition of vfg waste), whereas composting mainly constitutes agricultural waste. This agricultural waste contains food waste fraction related to the primary production of crop products and animal products[10], which is mainly assigned to the 'waste collection' sector, as again, these waste flows are presumably only assigned at the level of the waste collectors' NACE codes, but might originate from the agricultural sector.

Overall, it can be concluded that anaerobic digestion and composting, being the current 'higher-value' valorisation options, constitute only a minor fraction of food waste treatment of companies. Whereby part of this can be allocated to the fact that a considerable fraction still ends up in residual waste and subsequently incineration, while it might additionally also be explained from the fact that a large portion of fruit and vegetables is processed by means of biological cleaning.

5.3 Regime overview of current food waste collection and processing

Following the baseline assessment of the quantities of food purchased in the AMA and food waste from households and companies, this section describes another important aspect of the current food waste processing system in the AMA. Namely, the involved actors, regulations and recent developments from a multi-level perspective. A clear overview of these socio-economic characteristics and developments of the system under study will help in understanding the required transition towards increased high-value and circular food waste processing, and to eventually come to (policy) recommendations to enhance this transition. For doing so, this section first describes the regime level, whereafter section 5.4 delineates the landscape level of the current food waste processing sector.

As discussed in section 3.2.1 of the conceptual framework, the MLP approach analyses radical innovations within the notion of the broader socio-technical system that is defined by multiple actors, activities, and rules and institutions. More specifically, within the three levels of the MLP, the regime level includes shared rules and institutions that define the interaction and perception of the actors within the innovation system under study. Furthermore, these socio-technical regimes consist of both tangible and intangible artefacts (e.g. knowledge, investments, material) that form societal functions, and induce realignments (with niche innovations) to be path dependent and incremental (Smith et al., 2010). The following paragraphs describe these substantive components and their mutual interaction of the current food waste processing system in the AMA from a MLP perspective.

5.3.1 Rules and institutions

The contemporary Dutch waste management system finds its origin in the 1970s, as it became a crucial part of environmental protection related to public health. The environmental issues of waste disposal caught increased attention due to the 'Limits to Growth' report of the Club of Rome in 1972, and the oil crisis in 1973. This concern was translated to legislation via the 'Hazardous Waste Act' (1976) and the 'Waste Act' (1977), which shifted the role of coordination towards provinces and the implementation of waste collection and disposal towards local authorities (i.e. municipalities) (Kemp, 2007; Geels & Kemp, 2007). Also, a new organisation called the 'Waste Management Council' was shaped. They closed borders for waste transport and put a ban on the expansion of municipal solid

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[10] See:
https://ec.europa.eu/eurostat/ramon/nomenclatures/index.cfm?TargetUrl=DSP_NOM_DTL_VIEW&StrNom=NACE_REV2&StrLanguageCode=EN&IntPcKey=18493724&IntKey=18493754&StrLayoutCode=HIERARCHIC&IntCurrentPage=1

waste (MSW), via a moratorium on incineration capacity, hoping this would induce new recovery initiatives to arise, and to reduce the amounts of waste landfilled and incinerated (Kemp, 2007; ; Geels & Kemp, 2007; Verhoef et al., 2006). However, the MSW targets per municipality were not met and it was not until the 1990s that "*the systematic collection of the bulk of recyclable waste and organic materials*" became institutionalized (Kemp, 2007, p. 3). This was implemented in 1996, when it was concluded to apply centralised waste management on the national level - in close cooperation with local governments. This came into force in 2002, and in 2003 - as part of the Dutch Waste Management programme (LAP) - avoidance of CO2 emissions, lifting the ban on high MSW incineration quantities, and opening the borders for waste transport (not until 2006) had to ensure that waste quantities decreased and was more efficiently processed (Verhoef et al., 2006). Interestingly, this shows how the Dutch government changed its approach from restrictions and bans on bad practices, towards the stimulation and rewarding of positive practices. These related laws and regulations in the benefit of environmental protection and public health provided important *regulative* rules forming the present-day Dutch waste management system.

Another important element that helped shape the present day (food) waste management system in the Netherlands is the 'order of preference' that is used by the national government to determine the most optimal way of processing with regard to environmental impact and public health. In respective order from most preferred to least preferred, it includes the following guiding principles: Reduce, Reuse, Recover, Dispose (see figure 16). In order to live up to this objective, the Dutch government uses several instruments to stimulate prevention and recycling: enforcement of legislation, financial instruments such as landfill tax and volume-based waste fee systems, separate collection infrastructure, and effective communication for public awareness and feedback on the current collection systems (Rijkswaterstaat, Ministry of Infrastructure and Water Management, n.d.).

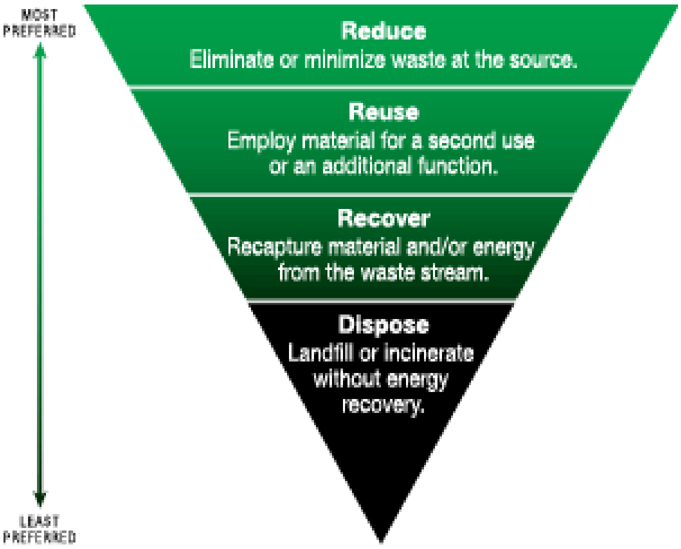

Figure 16. The order of preference used by the Dutch national government to implement waste management strategies (source: Rijkswaterstaat, Ministry of Infrastructure and Water Management, n.d.).

Moreover, Dutch waste policy is strongly linked to EU regulation, which has shifted over the years from a focus on management of disposal, towards recovery of wastes to meet new targets (Verhoef et al., 2006). This interdependency clearly reflects in Dutch and European waste management policies over the past 60 years. As mentioned above, this included a shift from closed borders for waste transport, to efficient waste processing due to open borders in the EU. A milestone that underscores this transition is the recent publication of the Circular Economy Action Plan as part of the European Green Deal (European Commission, 2020). This action plan includes a focus on recovery and circularity of waste streams such as electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, water and nutrients, and most interestingly in the context of this research; food. This action plan provides a combination of both *regulative* and *cognitive* rules, at which the regulative rules contain both binding sanctions or restrictions, and also general policy targets that aim to influence approaches and knowledge paradigms in waste treatment (i.e. the latter being cognitive rules and institutions). For example, related to food, the Commission will set a target on food waste reduction under the EU Farm-to-Fork strategy and it will '*consider specific measures to increase the sustainability of food distribution and consumption"* (p. 15). So, it firmly depends how binding the policy aims are per waste type, and for 'food' they are certainly not (yet) that binding in the near future.

Concluding on the regulatory and institutional context of the food waste processing system in the Netherlands, and thereby the AMA, there are 4 main processes in the regime under study, that thereby determine which actors are involved in the current regime of food waste processing in the AMA. These are in respective order of processing: (1) waste generation, (2) waste collection, (3) waste processing, and (4) usage and application of the commodities produced from the food waste.

5.3.2 Actors

Households and companies - producers of food waste

The first important actor group of the food waste processing system of the AMA are the **households** and **companies** that produce food waste. As became apparent from the MFA in the previous sections, households and companies are respectively responsible for approximately 145,708 and 128,278 ton of food waste annually in the AMA. The AMA constitutes 1.18 million households comprising circa 2.5 million inhabitants in 32 municipalities (Metropoolregio Amsterdam, 2020). More particularly, households deposit their food waste either in vfg assigned bins or mixed in residual waste, dependent on the collection system of the municipality and behavioural factors. Currently, all municipalities of the AMA separately collect vfg waste, except the municipality of Amsterdam. However, as stated previously, the City of Amsterdam aims to set up separate vfg collection in several neighborhoods of the city by 2030. Concerning the mentioned behavioural factors, research shows that behaviour plays an important role in the eventual quality and quantities of separate collection and processing of vfg waste - and thereby food waste. Currently, circa 30% of residual waste namely consists of vfg waste, which in its turn mainly constitutes food- and kitchen waste (Metropoolregio Amsterdam, 2019).

The companies that produce food waste in the MRA represent a wide range of companies in different sectors, but also produce a wide range of food waste types with different characteristics. In comparison to households that produce mainly mixed food waste flows (in vfg and residual waste), companies in the MRA produce both mixed and more homogenous food waste such as fruit peels, coffee residuals and cutting residues from vegetables as can be observed from the MFA in the previous section and became apparent in the interviews conducted for this research (Persoon, personal communication, 2019).

Waste collectors and waste processors

Secondly, other important actors in the regime of food waste processing in the AMA are the companies that collect and process (food) waste. Considering the scope of this research, **waste collectors** are not described in detail, as they do not play a major role in how food waste is processed and thus how food waste could be processed in a more high-value and circular way. These waste collectors comprise a wide range of both commercial and public organisations that provide transportation of (food) waste from the point of deposition (by households and companies) to the location(s) of processing (Coudard, 2019).

Regarding **waste processors**, the market analysis of waste processing of vfg *household* waste in the AMA shows that this is mainly processed by 5 waste processors (de Bruin & Nijmeijer, 2019):

- HVC (Purmerend)
- Meerlanden (Rijsenhout)
- Indaver (Alphen a/d Rijn)
- Orgaworld (Lelystad)
- Renewi (Nieuwegein)

These companies mainly process food waste (in vfg waste) via composting and anaerobic digestion into biogas and compost (HVC, n.d.; Indaver, n.d.; Starreveld, personal communication, 2020). In addition to this, Meerlanden obtains other products from the vfg waste besides compost and biogas, namely water for anti-skidding and street cleaning, and CO_2 and heat for greenhouses (Meerlanden, n.d.). Figure 17 provides a concise overview of the vfg (food waste) processing at Meerlanden. Moreover, Orgaworld not only processes household vfg waste in their anaerobic digestion plants, but also food waste from supermarkets and process waste flows from the food industry (Orgaworld, n.d.).

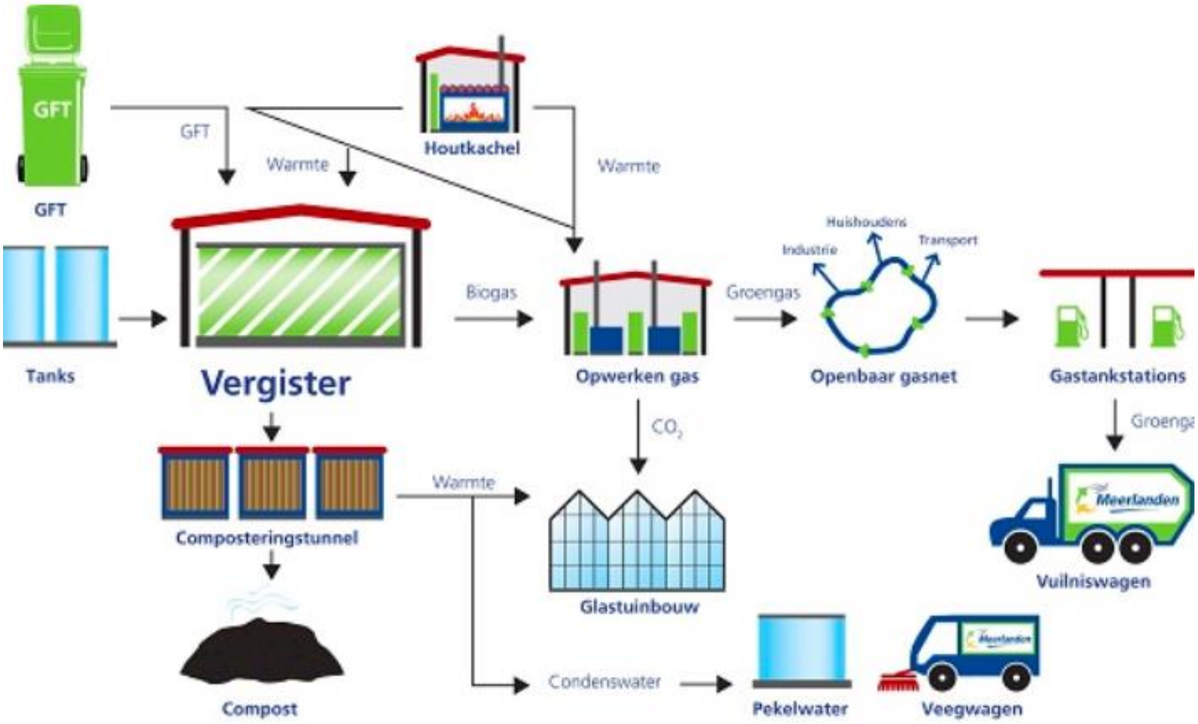

Figure 17. An overview of how vfg is currently processed in the AMA at Meerlanden. It produces biogas, CO2, compost, heat and water used in multiple sectors for diverse applications (source: Meerlanden, n.d.).

Nonetheless, as previously stated, still approximately 30% of residual waste consists of food- and kitchen waste, making the processors of residual waste in the MRA also relevant in the analysis of food waste processing. Either in terms of new processing technologies for the residual waste processors themselves, or collaborations with other (vfg) processors in the area. The analysis of de Bruin and Nijmeijer (2019) shows that 3 companies process residual household waste residing from the 32 municipalities in the MRA (see list below). At these plants, residual waste is incinerated and converted into heat and electricity (Circulus-Berkel, n.d.; HVC, 2020).

- AEB (Amsterdam)
- HVC (Alkmaar)
- Evi (Coevorden)

Interestingly, the webtool of the EU-funded CINDERELA project that was used for the data inventory of the company's food waste mfa also allows for a spatial analysis of the food waste flows originating from companies in the AMA respective to their location of treatment. From the map below it can be concluded that a significant share of the food waste produced in the AMA is treated outside the region's boundaries. This in contrast to the above-mentioned research of de Bruin and Nijmeijer (2019) which shows that household vfg waste is mainly processed within the AMA boundaries by 5 different processors. This can be explained from the fact that more homogenous streams of food waste from companies (e.g. from the processing and manufacturing or food services sectors) are either processed in more direct applications such as agriculture or animal feed, or processed together with other bulk flows from companies elsewhere in the Netherlands. For sake of the scope of this research, and due to the fact that still a large fraction of company food waste is processed within the AMA boundaries (e.g. large yellow flow to Lelystad), the subsequent chapters focus on the waste processors mentioned above.

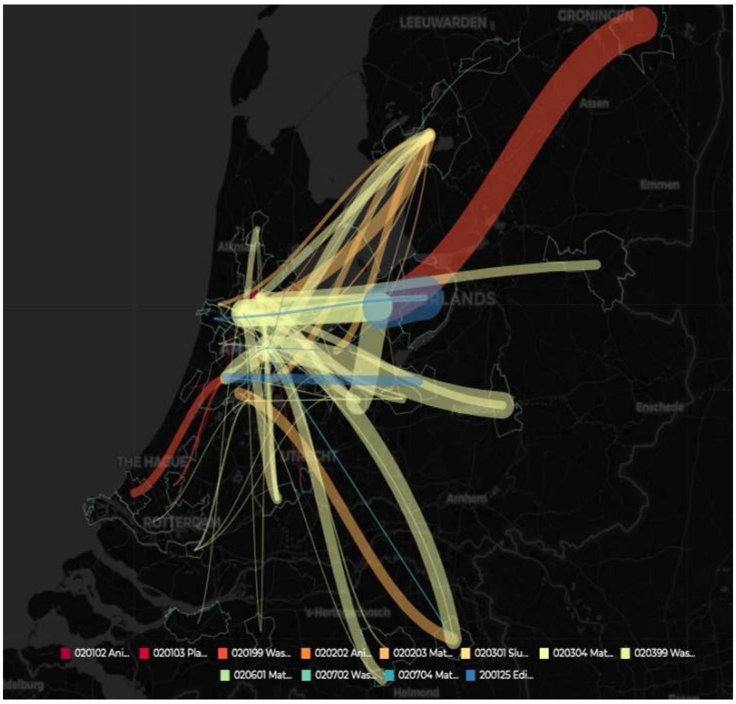

Figure 18. Map of the location of treatment in the Netherlands of food waste flows originating in the AMA (source: TU Delft H2020 CINDERELA webtool).

Governments

Thirdly, local, regional and national governments play a significant role in shaping policies and incentives that determine how waste is collected and processed within - or across - their geographical boundaries. The role of the national government was already described in the section on rules and institutions above, however both the regional and local level also play an important role in waste processing in the AMA.

Firstly, the **municipalities** in the AMA play a crucial role in how waste management is shaped and implemented. A map of the 32 municipalities in the AMA was provided in the methods chapter. The role of the municipalities in the food processing system of the AMA is rather significant, since the policies and incentives they provide, but also the companies they contract with, determine how the food waste is collected and processed. I.e. with relation to if the food waste is separately collected (via vfg waste), and what (high- or low-value) products are made from the food waste (e.g. compost, heat, electricity, bioplastics, feed, or even food additives).

More specifically, the recent developments in the City of Amsterdam regarding Doughnut Economy goals for 2030 and 2050 including the increased separate collection of vfg waste, reduction of food waste, and more high-value valorisation of food waste, provides a great example of the stretch and influence of a municipality on the practices within the area related to food waste processing. This accentuates an important and major change in waste collection in the City of Amsterdam, as separate collection of organic waste has been attempted earlier without success, and until recently it was regarded unremunerative[11]. Though interestingly, the implementation program mainly focuses on separate collection with local (low-value) valorisation methods fitting the concerning neighbourhood best (e.g. 'worm hotels' for composting and local (garden) composting), while recent research advocates that these techniques are less favourable from a socio-economic perspective due to their low-value outputs (see Tonini et al., 2020; Teigiserova et al., 2019; Tsang et al., 2019 Maina et al., 2017).

Moreover, the actual effect of these policies became apparent in the interviews conducted in this research. As the following question was answered in affirmative by Suurmeijer (personal communication, 2020) of Orgaworld: "*Does that also mean that projects such as the FABULOUS project do indeed need the support of the Municipality of Amsterdam and their vision behind it?".* With regard to this, van Stralen from Chaincraft also pointed out that the recently published plan of the municipality of Amsterdam states that it wants to support technologies such as the fermentation biotechnology of Chaincraft via investments and by fostering the separate collection of fruit- and vegetable waste as an input for these processes (personal communication, 2020). And that consequently "*the ecosystem has developed positively in this respect*".

This influence of municipalities not only influences the niches developing in the food waste processing system of the AMA in a positive manner, but also the other way around via the established order. As Suurmeijer from Orgaworld pointed out that municipalities have long-term contracts with waste processing companies that "*provoke that there is no incentive for innovation to process the flows in a high-value manner*" and that in contrast "*it really takes a long-term vision to achieve a higher goal",* that it currently lacking due to these long-term contracts with current (low-value) waste processors (personal communication, 2020).

Additionally, regional governments such as the **Province** of Noord Holland, the Province of Flevoland and the **AMA organisation** also play an important role. More specifically, as indicated in one the interviews, the role of the province with respect to food waste processing is to "*stimulate, boost, connect, and develop knowledge"* between governments on the one hand, and entrepreneurs and education/research on the other hand (de Vries, personal communication, 2020). Thus indicating the rather 'soft duties' the province has with regard to waste processing in the region. In addition, the province is also responsible for more 'hard/direct' instruments with regard to permits related to

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[11] See for example the statements of te alderman for Sustainability in this news article in 2016: https://www.parool.nl/nieuws/komende-10-jaar-geen-scheiding-gft-door-amsterdammers~b6ee7da0/

spatial planning, and it has several financial instruments at its disposal varying from subsidies to loans from commercial partners, and a sustainability fund to invest in knowledge development and pilot projects (de Vries, personal communication, 2020).

Lastly the AMA organisation is also a player on the regional political 'playing field', with goals related to circularity of biomass flows. More specifically, they state to agree with the policy goals in the previously mentioned 'biomass & food transition agenda' of the national government and are currently working on a 'biomass statement' and a working group called 'round table fermentation' has been set up.

Users of commodities produced

Other important actors in the current regime of food waste processing in the AMA are the **users** of the products produced by the waste processors. This refers to both products from vfg and residual waste processing (i.e. compost, biogas, heat). Meaning, if there is sufficient demand for these products, they will continue to be produced the way they are via conventional food waste processing technologies (i.e. composting and anaerobic digestion), while new demand for more innovative high-value products from fermentation biotechnologies might fall behind due to the novel character and the lack of sufficient testing material. This lock-in mechanism was pointed out in multiple interviews, as the interviewees all described the challenge of where a niche innovation has to produce enough product (e.g. bioplastics, animal feed additive) to 'convince' their client that it is a solid product, however in order to produce enough mass to provide this evidence, the innovation requires more investments for upscaling (Persoon, personal communication, 2020; Suurmeijer, personal communication, 2020; Mooij, personal communication, 2020). A more in-depth description of the niche innovation and the barriers and opportunities for upscaling this innovation can be found in the subsequent chapters.

The main commodities currently produced by the food waste processing system in the AMA are used by the agricultural- and agri-food sector, and the energy sector. The former uses the compost on agricultural lands, and CO_2 and heat in greenhouses. The energy sector facilitates as an intermediary before the biogas is used by households and companies to cook, heat buildings and as fuel for cars (HVC, n.d.; Meerlanden, n.d.). Figure 19 provides another overview of the commodities produced from vfg waste by Meerlanden including its end-users (note: this is the waste processor that processes vfg waste in a more diverse range of products than the other companies that only produce compost and biogas). Interestingly, the figure shows that Meerlanden is still looking for additional nursery gardens that can use their produced heat in their greenhouses. Currently only 34% of the 10 million kWh produced is used. While this concerns residual heat as a by-product of the composting process, from a circular perspective it would be a waste not to use it.

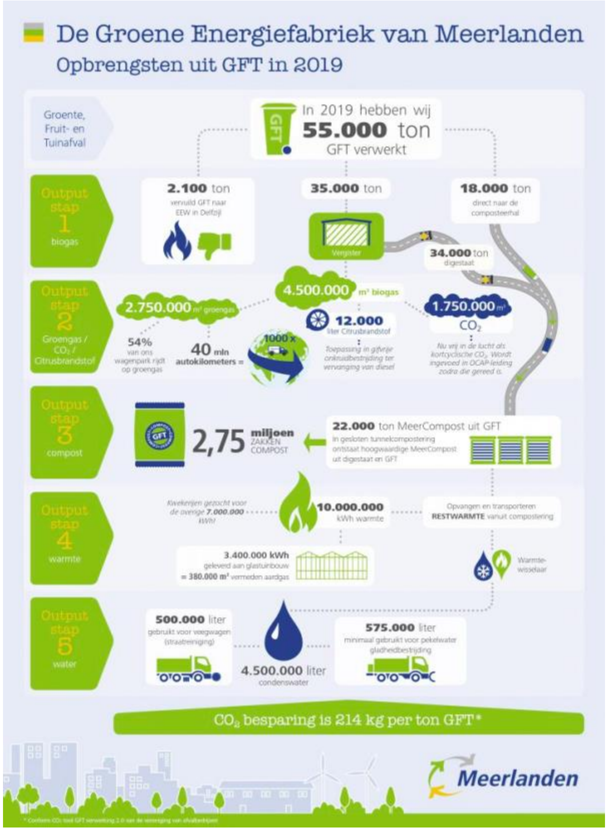

Figure 19. A more elaborate overview of how vfg is currently processed in the AMA at Meerlanden. It produces biogas, CO2, compost, heat and water used in multiple sectors for diverse applications (source: Meerlanden, n.d.).

Knowledge institutes

Other relevant actors in the context of this system are **knowledge institutes.** They aim to foster the circular and sustainable processing of food waste in the AMA via knowledge development and exchange through e.g. consortiums with companies and governments. These are, for example, Voedsel Verbindt, AMS Institute, Metropoolregio Amsterdam, Amsterdam Green Campus, but also collaborations of these institutes or niche innovations with universities (of applied sciences) like Wageningen University, Delft University of Technology or Hogeschool van Amsterdam. An example of such a collaboration is the FABULOUS project. This is a project of the AMS Institute in collaboration with TU Delft, Paques (a company in biological wastewater and gas treatment) and Orgaworld, partly funded by Rijksdienst voor Ondernemend Nederland (RVO) (Mooij, personal communication, 2020). The main purpose of the project is "*to produce high-value chemical building blocks from organic waste*" with a fermentation biorefinery technology (AMS Institute, n.d.). A further description of the particular processes of the technology and the development stage of this niche innovation can be found in the subsequent chapter about the niche level of this Multi-Level system. Interestingly, these knowledge institutes constitute an important actor for the development of fermentation biotechnologies in the AMA region. Whether it being via the improvement of established techniques (composting, anaerobic digestion), or the development of new technologies (fermentation biotechnologies). The latter both via theoretical knowledge development and practical application, ranging from lab scale to factory scale (Mooij, personal communication, 2020; Persoon, personal communication, 2020; Suurmeijer, personal communication, 2020).

Summarizing, figure 20 provides a concise overview of the actors involved in the regime of the food processing system of the AMA and their respective interactions as described above.

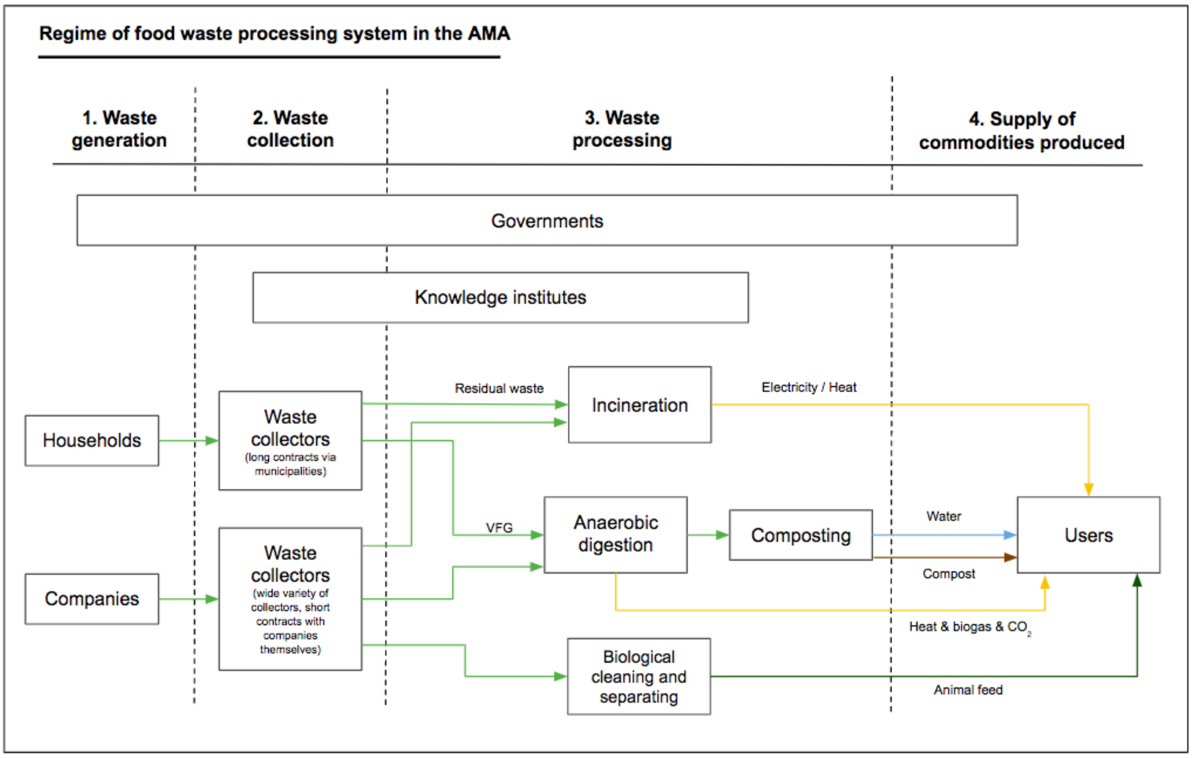

Figure 20. A concise overview of the actor dynamics in the regime level of the food waste processing system in the AMA.

From the figure above it can be observed that the government actor group has an influence in multiple phases of the food waste processing system of the AMA. Municipal governments namely determine policy for waste of companies and households via waste taxes that influence the types and volumes of waste generated. Also, contracts of municipalities with waste collectors and processors determine how it is processed, and which commodities are produced in the subsequent phases. On a more indirect level, the national government and the AMA organisation influence these actions of municipalities via the defined goals for circularity, waste management and the energy transition, whereas regional governments such as the two provinces aim to foster the development, and exchange, of knowledge around innovative technologies in accordance with spatial planning and permits. Moreover, knowledge institutes are currently mainly focused on researching both the benefits of separate collection, as well as technologies to valorise the food waste in a high-value manner. Indirectly, they thereby influence the transition in the sector and the eventual commodities produced via food waste valorisation.

5.3.3 Tangible artefacts

As mentioned in the introduction of this section, the regime level of a multi-level system entails both tangible and intangible artefacts. These intangible artefacts, such as rules and institutes, knowledge development and investments of companies and governments, have been described in the section above. Tangible artefacts however comprise all material and infrastructural components of the regime level. It is important to consider these tangible artefacts in a Multi-Level system, because they are part of the current dynamic structure of food waste processing in the AMA, and "*it is this dynamic structure which sustainable niches must overcome if they are to unsettle the regime and seed a transition"* as stated by Smith et al. (2010, p. 441). Moreover, it is argued in this research that these dynamic structures not only provoke potential barriers to be overcome, but also potential opportunities for collaboration and enhanced development of the transition of large-scale application of high-value fermentation technologies for a more circular economy.

As depicted by Verhoef et al. (2006), the tangible artefacts of the waste infrastructure in the Netherlands "*is the set of physical facilities*" [that] "*concerns the removal, disposal and recovery of municipal solid wastes (MSW)*" (p. 303). The first important tangible artefact to consider related to this waste infrastructure, in chronological order of processing, are the **'bins'** in which the food waste of both households and companies is collected. These material artefacts comprise an important aspect, since a certain regime of waste collection demands certain bins for separate collection of food waste (or not), separate transport, and in some facilities also sorting residual streams after collection. Importantly, Geels and Kemp (2007) state that "*once artefacts and material networks are in place, they are not easily abandoned"* (p. 443). When vfg waste for example is not separately collected, or homogenous food waste streams of companies are not kept 'clean' and homogenous, these tangible artefacts might further stabilize the existing systems such as the conventional technologies to process food waste in the AMA (i.e. composting, anaerobic digestion, or even incineration via residual waste) (Geels & Kemp, 2007). They thus define how easily the socio-technical regime is able to cope with required changes in this collection and processing system in the aim of more high-value waste processing. Regarding the system under study, all municipalities in the AMA (except the City of Amsterdam) separately collect vfg waste, which benefits certain fermentation biotechnologies as they will be able to process mixed food waste (in vfg waste) in the foreseeable future (i.e. Chaincraft, FABULOUS) (van Stralen, personal communication, 2020; Mooij, personal communication, 2020). However, these current material and infrastructural artefacts of this collection system also limits the potential of 'destabilizing' the current regime (i.e. diffusion of fermentation biotechnology on a larger scale), as the current development phase of the niche innovation also requires more homogenous, cleaner, flows of food waste. Such as expired products from supermarkets and cutting residuals from food processing companies (van Stralen, personal communication, 2020; Suurmeijer, personal communication, 2020; Persoon, personal communication). Here it should also be taken into consideration that using these flows for niche innovations demands more transport and cannot directly benefit from the material artefacts currently in place (bins and efficient collection system).

This links to the second important material/infrastructural artefact, which are the **vehicles** to transport the food waste from point of generation to processing. Importantly, since these vehicles belong to both public and private organizations. The private organizations are hired by the municipality, or part of the contract of the municipality with the waste processor, in these long-term contracts earlier mentioned. Again, the long-term character of these contracts induces a certain lock-in for the current regime to continue business-as-usual (Suurmeijer, personal communication, 2020).

Thirdly, the **processing plants** where currently vfg and residual waste is processed form another material artefact. Interestingly, these plants of, for example Orgaworld, Meerlanden or HVC, might provide both opportunities and barriers for niche innovations to develop. Opportunities might occur where the established order cooperates with niche innovation to experiment on new technologies, as is currently done by Orgaworld in the FABULOUS project (Suurmeijer, personal communication, 2020). However, often the material artefacts of the established order do not provide these direct benefits, as is the case with the Amsterdam Green Campus innovation (see subsequent chapter for a further elaboration of the technique). Here, a lack of proof of concept causes a lack of investments, and subsequently upscaling and proof of concept itself. Which in its turn causes the established order to be not interested enough to invest in the innovation technology (Persoon, personal communication, 2020).

Moreover, all the above-mentioned tangible artefacts include **sunk costs** that should not be overlooked, as they might induce that investments in new infrastructure for new collection methods or the new niche technologies are not made on the short-term before the return-on-investment of current infrastructure is met

Lastly, the **commodities** produced by the established order (i.e. compost, water, CO_2, biogas) form another material artefact. It is the demand for these products that can determine the (in)stability of the current regime to alter towards other commodities produced from food waste (e.g. bioplastics, animal feed, food additives). For example, if the demand for compost would decrease, this might provide opportunities to process the food waste in a more high-value manner, or similarly if another renewable alternative would decrease the demand for biogas.

5.4 Landscape overview of current food waste collection and processing

Lastly, from the multi-level perspective, the current food waste processing system in the AMA can be explained from its landscape level interactions and developments that are continuously shaping the regime and the niche innovation. As stated in the conceptual framework, these landscape factors can be regarded as factors that are out of control of the regime, "*which include both slow-changing developments (e.g. demographics, cultural repertoires, societal concerns, geo-politics, macro-economic trends) and external shocks (e.g. wars, financial crises, accidents, oil price shocks)*" (Geels, 2019, p. 190). These landscape factors can both enable and constrain the innovation of high-value food waste processing in the AMA and/or other innovations related to (food) waste management.

In the past, several landscape factors have influenced the (food) waste management system in the AMA up to present-day. First of all, the most historical and influential landscape factor that should be mentioned in this context is the disease called 'Bovine Spongiforme Encephalopathie' (BSE), also known as the mad cow disease, which caused a rapid nationwide epidemic in Great Britain in 1992. This epidemic was caused by the fact that livestock was fed with meat and bone meal that contained the remains of other cattle. Most importantly, this disease is the cause of a variant of Creutzfeldt-Jakob disease, a fatal brain disease for humans, for which humans can be infected with via consuming BSE infected meat or dairy products. In response to this epidemic, the Netherlands prohibited the import of this meat and bone meal, and living livestock from GB, and since 2001 all livestock ready for slaughter is checked on BSE (Wageningen University & Research, n.d.). But even more interesting in relation to the research topic under study, the mad cow disease and all legislative and policy responses, had a huge influence on the 'waste law' as we currently know it in the Netherlands. At present day, waste legislation in the Netherlands prohibits the usage of flows that are appointed 'waste' or could contain animal meat residues to be used for feed or food applications, in order to prevent another outbreak of BSE of similar diseases for the sake of human health concerns. As a result, high-value applications such as that of Chaincraft for animal feed or AGC for food additives, are only able to experiment with homogenous food flows not appointed as 'waste', and current techniques such as anaerobic digestion and composting are favoured (Varelas, 2019). This landscape factor might however also provide opportunities, as flexibility in this legislation - while safeguarding health concerns, offers opportunities to experiment for more high-value valorisation.

Secondly, the financial crisis of 2008-2013 is another landscape factor that influenced the regime of food waste processing. CBS data indicates that in 2008 municipal household waste per capita decreased, as consumption also decreased (and it can also be assumed that citizens dealt more consciously with food waste in this time of crisis) (CBS, 2019). Moreover, this economic crisis also caused a reduction in investments from (local) governments in innovative waste management strategies to collect waste (more) separately and process it into high value output products (especially in Amsterdam) (Cuomo et al., 2020). On the other hand, in the aftermath of the financial crisis, investments, attention and encouragement for circular and sustainable initiatives increased, especially in those industrial sectors that suffered the most from the crisis, for which "*new forms of collaboration between citizens, private companies, and municipal governments are fostered*" to provide new job opportunities and economic growth (Cuomo et al., 2020, p. 4). Overall, it can thus be concluded that the financial crisis slowed down the transition towards a more sustainable waste management system in the Netherlands, although this transition was pursued around the year 2013.

Furthermore, and also in relation to the latter, the increasing popularity of the term 'circular economy' (CE)[12] deriving from social concerns about sustainability, has influenced the food waste management regime seriously (see also Geels & Kemp, 2007). As previously explained, CE entails the optimal usage of resources via reducing material use, and reuse and recovery of materials (materials and energy). This is a slow changing landscape development that is formed by common ideologies accepted in society, given that the past 50 years have put increased attention on sustainability and related issues, starting with the Report of the Club of Rome in 1972, up to new policies on national and EU level (as explained in the rules and institutions paragraph). This landscape development influences food waste processing in the AMA, because both municipalities and food waste processing companies (i.e. Orgaworld, Meerlanden) feel the urgency to process food waste in a more circular manner (Suurmeijer, personal communication, 2020). This landscape development thus positively influences both the regime level and the niche level.

Another concrete example of this landscape development is the 'Grondstoffen Akkoord' of the Dutch national government, that contains agreements of the national government with other parties to enhance the transition to a circular economy. Among which the main goal is to come to 50% circularity in 2030, and 100% circularity in 2050. One of the 'transition agenda's' that is included in this agreement is the 'biomass and food' agenda that aims to undertake action for reducing food waste, and 'optimal valorisation of biomass and residual flows into circular, biobased products'. Thereby thus a positive influence on the development of the niche innovation under study in this research.

Lastly, an external shock (i.e. sudden change) in the landscape level that should not be left unmentioned, is the recent COVID-19 crisis. On the one hand, this crisis has shifted attention away from sustainable and circular practices, towards primarily and foremost dealing with the crisis. Thus causing a reduction in, or procrastination of, investments in sustainable technologies for waste management, and in research focussing on these technologies. On the other hand, developments in Dutch politics have also shown increased attention for a 'green recovery' after COVID-19, thereby showing a potential for increased investments and support on the short- to medium term for the fermentation niche technologies as sustainable alternatives for (food) waste processing[13]. Additionally, as denoted by Sharma et al. (2020), quantities of food waste might also be affected by the COVID-19 crisis. In the long term, these quantities could potentially reduce due to worries about food shortages. Nonetheless, in the short term it was also proven that quantities of food waste

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[12] See for example the previously mentioned 'Amsterdam Circular 2020-2025 Strategy' of the City of Amsterdam and the Circular Economy Action Plan of the European Commission, but also the increased tendency of companies to commit to circular economy targets.

[13] See: https://www.klimaatakkoord.nl/actueel/nieuws/2020/07/21/vijf-plannen-voor-een-groen-herstel

increased due to a ‘broken supply chain’, in which food did not reach its destination in time and was wasted as a result[14].

5.5 Concluding remarks: current status of regime and landscape level

In conclusion, the analysis of the food waste flows, and of the regime- and landscape level provided a first exploration of the current quantities, quality and status of food waste processing in the AMA. More particularly, it showed that both food waste residing from households ánd companies deserve equal attention for high-value valorisation options, based on their relative quantities. Especially the large fraction of unavoidable food waste from households, and the large quantities of both household and company food waste ending up in residual waste denote the necessity to explore high-value valorisation options for a circular economy.

Regarding the current regime structure, it is important that future investments, policies and technology developments take advantage of the opportunities that the overarching- and connecting position of governments and knowledge institutes have in the overall actor system, whereby steering via waste taxes for households, reconsideration of long term contracts with current processors and collectors, and carbon taxes to enhance the competitive position of biobased alternatives provide opportunities. Appropriate governance on a national, but more particularly a regional level could create this fair level playing field (e.g. AMA organisation for collaboration between organisations, directing investments, and exploring technological feasibility in pilots). Additionally, the opportunities and barriers related to existing tangible artefacts (e.g. experimentation in existing plants, redesigning collection bins merely for kitchen food waste in an urban setting) should not be underestimated for enhancing this transition.

Lastly, both landscape factors concerning the mad cow disease in relation to waste management legislation, and the current COVID-19 crisis, could destabilize the regime and the way we currently approach food waste management challenges, providing a window of opportunity for fermentation niche technologies for fatty acids. Think of flexible legislation for experimentation to increase biobased alternatives, or redesigning food supply chains to prevent food surpluses and have a more stable unavoidable food waste inflow.

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[14] See for example the large potatoes surplus that was caused by the closure of restaurants and the catering industry in the Netherlands: https://nos.nl/artikel/2334062-overschotten-door-corona-miljard-kilo-aardappelen-en-vrieshuizen-vol-vlees.html

6. Results II: An exploration of the fermentation biotechnologies

Following the baseline analysis in chapter 5 including a description of the regime and landscape level of the multi-level perspective, this chapter describes the third level of the multi-level perspective: the 'niche level'. This level includes the innovation system under study in this research, i.e. the fermentation biorefinery technologies in the AMA of Chaincraft, the Amsterdam Green Campus and the FABULOUS-project. By doing so, this chapters answers the following research question:

> *Which processes are involved in high-value fermentation biotechnologies, and what is its potential and environmental impact related to the status quo?*

First, this chapter provides a description of both biorefinery technologies in general and the three specific fermentation biotechnologies investigated in this research. Subsequently, the technologies are put in perspective by describing their prospects and expected transition pathway in the overall multi-level perspective. Thereafter, the final section of this chapter analyses the potential of the technologies from a holistic IE perspective by investigating the related environmental impacts and benefits of both large-scale application of the niche technologies and the status quo (e.g. water and energy inputs, by-products, substitution products).

6.1 The case of biorefinery technologies for food waste processing

As discussed in the previous chapter, mainstream food waste processing techniques in the AMA currently constitute anaerobic digestion and composting (either combined with post-composting, or separate) for producing biogas, biofuels and compost, and incineration of food waste present in residual waste. The niche biotechnologies under study in this research specify themselves by processing food waste into, biochemicals and -products via (volatile) fatty acids and medium chain fatty acids, sugars and bio solvents for applications such as bioplastics, biofuels, animal feed additives, or even food flavouring intermediates (Dahiya et al., 2018; Persoon, personal communication, 2020; van Stralen, personal communication, 2020).

Compared to the status quo of food waste processing (aerobic digestion, composting) these biotechnologies have the main advantage of providing (high) value added output products and chemicals, and that they can process both mixed and more homogenous food waste streams including some streams that are underexposed in current literature (Caldeira et al., 2020). However, as figure 21 from the research of Caldeira et al. (2020) denotes, the term 'biorefinery valorisation technologies' still entails a wide range of end products or chemicals. Additionally, figure 22 from Caldeira et al. (2020) summarizes the main technologies in biorefineries with whom the biobased products and chemicals are produced. Interestingly, it shows that the specification of 'fermentation biotechnologies' for food waste valorisation still entails a wide range of applications, including different end-products (e.g. Hydrogen, methane, Volatile fatty acids, bio-diesel).

This research focuses on a fraction of these applications by investigating the three earlier mentioned fermentation 'biorefinery technologies' for food waste valorisation currently present in the 'innovation system' of AMA (at both lab, pilot and factory scale). A further substantiation on the choice for these technologies can be found in the appendix and methods chapter. All in all, it is by all means interesting to see the position of the three investigated technologies in relation to other ‘biorefinery technologies for food waste processing’. Mainly, because these different technologies are often combinedly applied in biorefinery-like installations, and thus require the same transition and a “*holistic biorefinery approach with hybrid-integrated strategies for multi-purpose applications*” (Mohan et al., 2016, p. 9).

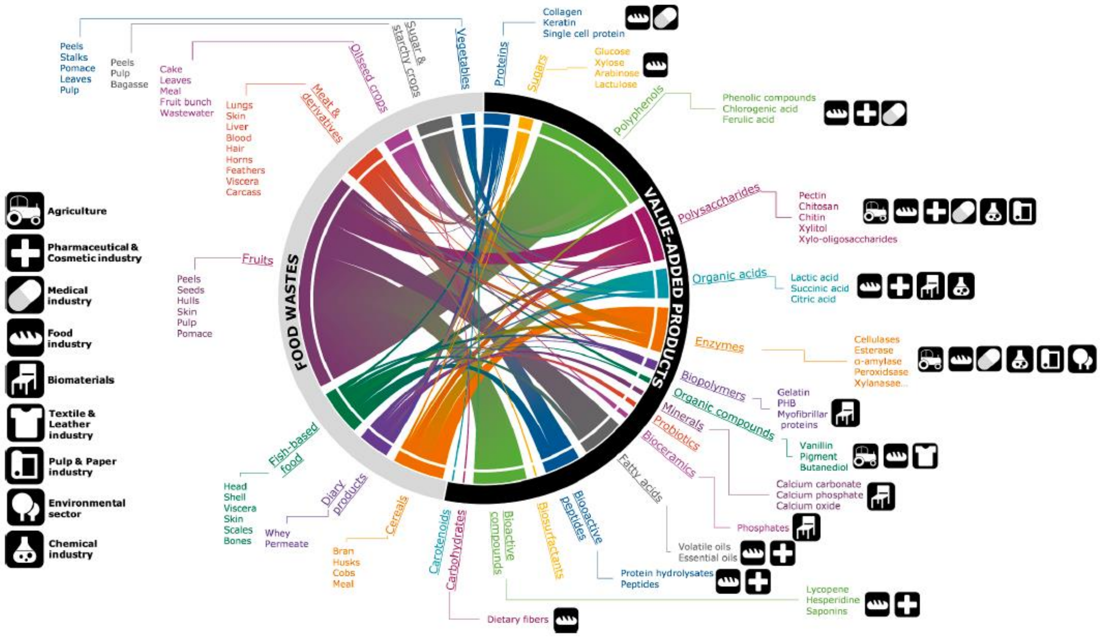

Figure 21. An overview of the wide range of valorisation pathways of food waste in current literature including the value-added output products and area of application (source: Caldeira et al., 2020).

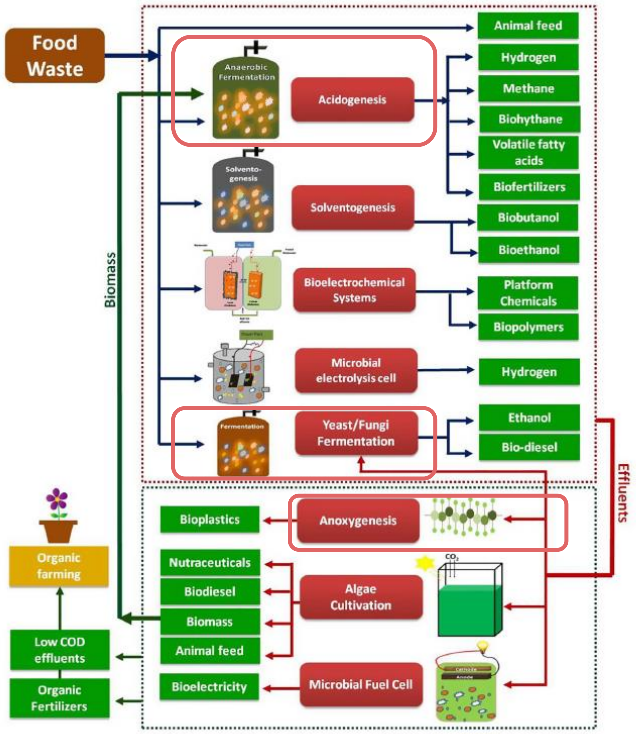

Figure 22. A concise overview of different biorefinery technologies to valorise food waste into different ‘value added’ products. The circled processes indicate the ‘fermentation biotechnologies’ that are present in the AMA and investigated in this research (source: Caldeira et al., 2020).

6.1.1 Three fermentation biotechnologies investigated

The fermentation biotechnologies investigated in this research are those of the Amsterdam-based organisations: Chaincraft, Amsterdam Green Campus and the FABULOUS-project of Orgaworld, TU Delft and Paques. All three technologies use a form of (anaerobic) fermentation to produce biobased products and -chemicals.

Chaincraft

Over the past 10 years, the Amsterdam-based company Chaincraft has developed a technology to process organic residual streams into medium chain fatty acids by means of a fermentation technology. These medium chain fatty acids can be used as valuable biochemicals for applications such as plasticizers, plastics, paint, solvents and herbicides. In these 10 years, the company has developed itself from a discovery at lab-scale at Wageningen University to pilot scale and now an "*operational and semi-commercial demonstration scale*" (Chaincraft *a*, n.d.). With this technology it now finds itself in a scale-up phase, as the concept was proven economically and technically viable (Chaincraft *a*, n.d.).

While the technology would be able to produce for all aforementioned applications in the future, it currently uses vegetable and fruit waste from fruit and vegetable processors to produce animal feed additives, which "*ensure that the pigs and cows need less food and serve as a natural and healthy alternative to antibiotics in animal feed*" (van Stralen, personal communication, 2020). These fruit and vegetable processes entail the major suppliers for supermarkets in the Netherlands, generating food waste flows from cutting losses or unavoidable food waste products that are not suitable for entering the supermarket (e.g. peels, apple cores). Moreover, Chaincraft currently also merely produces for animal feed applications, since their current scale of applications does not suffice to also produce for other applications (i.e 20,000 tonnes of organic material as input and 2,000 ton of fatty acids as output) (van Stralen, personal communication, 2020).

More specifically, as explained by van Stralen during the interview, the processes of Chaincraft consists of a fermentation process that is very similar to anaerobic digestion. Chaincraft does not produces biogas (methane) out of this process (as most vfg processors in the AMA do), but they dissolve the small fatty acids (i.e. acetic acid, propionic acid, butyric acid) into the liquid, after which in another fermentation process the short fatty acids are extended with ethanol to longer fatty acids (i.e. medium chain fatty acids). This so-called 'chain elongation technology' is the novel technology that Chaincraft has proven to be successful with on a commercial scale. The ethanol used in this process is a residual stream from brewers in the area that produce 0.0% beers. Subsequently, this still very watery product that also contains bacteria and solid matter (i.e. fibres) enters a downstream process in which the product is separated and concentrated into a pure and anhydrous product. The end product of this phase is a mixture of medium chain fatty acids.

Interestingly, van Stralen (2020) also denoted that the input of food waste streams from fruit and vegetable producers can in the future be replaced by food waste streams from households (i.e. vfg waste), and that they are in contact with the City of Amsterdam to discuss these opportunities. It should be noted however, that this waste cannot be used for animal feed additives due to laws and regulations, but they could be used for applications in plastics, lubricants or paint, where laws and regulations do not form a barrier.

Amsterdam Green Campus

The second fermentation biotechnology investigated in the innovation system is the 'Valorisation of residual flows from fruit and vegetables' project of the Amsterdam Green Campus (AGC). The AGC is a foundation that focuses on knowledge exchange, education and economic growth in the 'green sector', with projects about sustainable development and a circular society. Within this specific project, the AGC cooperates with Wageningen University & Research (WUR), University of Amsterdam (UvA), AERES Hogeschool, G.Kramer & Zonen B.V., Barendse-DC II B.V., GreenPort Noord-Holland Noord, and Oterap B.V.. It applies a fermentation technology on lab-scale in which homogenous 'clean' streams from fruit and vegetable processors, such as white cabbage, peppers, broccoli and tomatoes are valorised into various enriched vegetable powders that can serve as additives in soups and sauces (Amsterdam Green Campus, n.d.; Persoon, personal communication, 2020).

In particular, the technology of AGC entails a fermentation process in which a specific microorganism cultivates the food waste input material and provides an end product with added value in nutritional value for consumers[15] (Persoon, personal communication, 2020). Persoon specifically emphasized that this technology is intended to produce for human consumption, in contrast to for example the animal feed additive production of Chaincraft. He indicated that both are a high value application, and are concerned with strict laws and regulations when it comes to waste processing and feed/food production, however the main aim in this project was to use agricultural (and processing) food for human consumption (i.e. Food4Food).

With regard to this high added value, Persoon stressed that currently these cutting losses from the food processing industry are returned to cultivators of the vegetables, who process it in the soil (i.e. mixing it in the soil as compost). However, as Persoon argued, that is not always the highest application for using these residual streams, and sometimes also not the best way to till the soil, while the vegetable powders provide a higher value application more directly in the food industry itself for food consumption.

At the moment the project is fully developed on a lab scale and is aiming to produce several hundred kilos of 'starting material' to provide a proof of concept for potential clients. Moreover, the business model of this technology consists of two part: on the one hand for AGC to make the business profitable by keeping the cost price low, and on the other hand there's a business model for the farmers (i.e. cultivators) to value the remnant they offer in a new way. Concerning the latter, thus not regarding the cutting losses and avoidable food waste as 'waste', but as a new input source for a new system (Persoon, personal communication, 2020).

Lastly, it should be noted that this fermentation biotechnology thus processes 'clean' homogenous vegetable streams from the food processing industry and cultivators, and is not capable of processing mixed household food waste ending up in vfg waste. This is mainly due to the fact that all kinds of microbiological processes already happen when the food waste is gathered in the vfg bins, and the processes of AGC require pure streams that have not yet undergone these decomposing processes. By all means that also has to do with current legislation around treating (food) waste that states that 'waste' cannot be used for food applications for public health reasons (Persoon, personal communication, 2020).

FABULOUS: Creating Value from Organic Waste

The third fermentation biotechnology considered in the innovation system of this study, is the FABULOUS project of the AMS Institute, which is a collaboration between Orgaworld, TU Delft and Paques. The project focuses on "*high-value chemical building blocks from organic waste*" by applying

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[15] N. Pesoon could not go into much detail about this 'added value', the microorganism, and what it specifically is, due to the fact that the project that is now in the phase of being patented.

a fermentation technology in which organic waste is processed into chemicals for bioplastics (AMS Institute, n.d.; Suurmeijer, personal communication 2020; Mooij, personal communication, 2020). Suurmeijer from Orgaworld emphasized that the project first mainly focused on the production of bioplastics, but that this focus shifted towards a focus on producing fatty acids. These fatty acids provide a platform of diverse applications beyond bioplastics (e.g. the extension towards medium chain fatty acids as Chaincraft is doing), thereby taking into account potential changes in supply of the input material. Currently, the project is operating at pilot scale, since Orgaworld is able to provide the facilities and to experiment on this scale at their site.

This input material currently consists of both more homogenous streams from industry and businesses (i.e. food processors, restaurants, supermarkets), but also mixed vfg waste from households. Suurmeijer supplemented that he wants to put the main focus of the project on mixed vfg waste, since it is the largest flow in terms of volume. This despite the known difficulty of this waste stream as it contains both kitchen- and garden waste (personal communication, 2020). Mooij from TU Delft and AMS Institute complemented this statement by explaining that the composition of the vfg waste poses an interesting challenge, as it seems to have a different composition in an urban area (i.e. more kitchen waste). This makes vfg waste interesting with regard to this technology since the bacteria prefer food residues over garden waste, which makes the city very suitable for this innovation (personal communication, 2020).

Concerning the output material (i.e. bioplastics), Suurmeijer (personal communication, 2020) highly emphasized the necessity to use the produced bioplastics merely in applications that have an ‘added value’ compared to the alternative that is currently used, to accommodate an optimal reduction of environmental impacts with the application of the bioplastics. Meaning, it is a high-value product that should be applied in a high value application. For example, where the biodegradability of the bioplastics provides an added value to the business as usual (e.g. preferring the application of the bioplastic for coatings of slow release fertilizer over the application in plastic sandwich bags).

Following the description of the regime and landscape level in the previous chapter, and the investigated niche technologies above, figure 23 below provides a concise overview of the actors involved in the ‘food processing system of the AMA’.

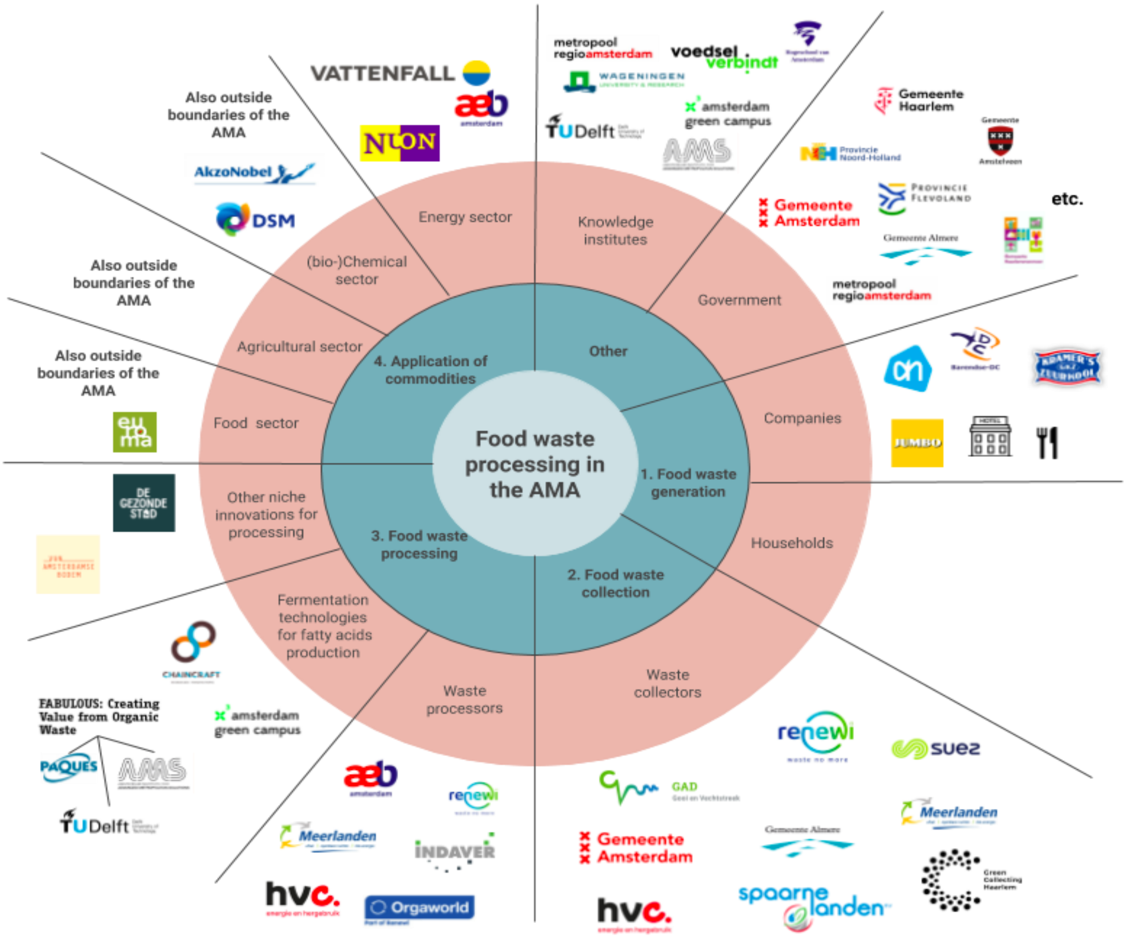

Figure 23. A concise overview of the actors involved in the ‘food waste processing system of the AMA’ in order of the different process steps.

6.2 Main advantages and prospects of fermentation biotechnologies

Following the explanations of the three investigated fermentation biotechnologies of Chaincraft, AGC and the FABULOUS-project, it can be stated that these technologies can be identified as biological anaerobic fermentation processes that produce multi-purpose applications via the production of short chain and medium chain volatile fatty acids (see Dahiya et al., 2018 and Mohan et al., 2016 for a classification of biorefinery technologies). See figure 24 for a more specific placement of these types of biorefinery technologies in the ‘integrated holistic biorefinery approach’ of Mohan et al. (2016).

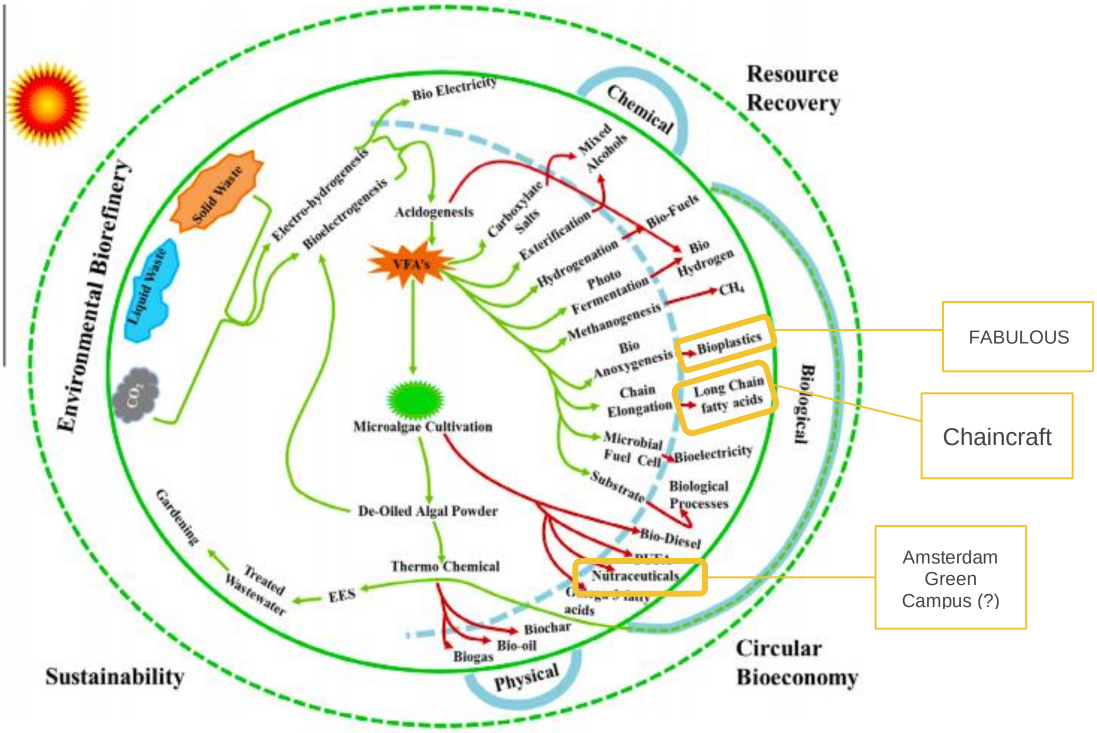

Figure 24. The three food waste fermentation biotechnologies in the AMA presented in the holistic biorefinery approach of Mohan et al. (2016). Note that AGC is indicated with a question mark because it is unclear which specific microorganism is used for what particular food additive (source: adjusted illustration of Mohan et al., 2016).

Considering these three technologies (i.e. for bioplastics, chain elongation for animal feed, and nutraceuticals), several main advantages compared to the status quo of processing food waste can be recognized. First of all, the overall process of anaerobic fermentation that is applied in all three innovations is highly suitable for using food waste as feedstock (as previously explained) because of its high nutrient availability, efficient biodegradable nature, and rich moisture content (Zhou et al., 2018). Which, consequently, "*makes the process relatively inexpensive*" (Dahiya et al., 2018, p. 3). However, it should be noted that the specific efficiency of the fermentation process of course depends upon the composition and thereby quality of the waste stream (e.g. ratio kitchen and garden waste in vfg waste from households) (Starreveld, personal communication, 2020). In relation to this, the research of Jiang et al. (2013) demonstrated that the VFAs acetate and valerate increased when the organic loading rate (OLR) increased, while the VFAs propionate and butyrate decreased when the OLR increased.

Secondly, by using the organic fraction of the food waste (lipids, carbohydrate and proteins) from the waste to produce bioplastics, and food and feed additives, it is claimed that direct carbon emissions to the environment are reduced (compared to status quo: incineration/composting/ biogas). Especially with regard to bioplastics, where carbon will be stored in the commodities produced from the bioplastics (Dahiya et al., 2018; Caldeira et al., 2020). Additionally, carbon emissions are also indirectly reduced due to the replacement of 'product alternatives'. Meaning, that the multi-purpose applications replace applications that use petroleum derived compounds in their production processes (e.g. bioplastics compared to petroleum based plastics, or the food additive of AGC compared to the use of palm oil as food additive).

More particularly related to bioplastics, recent research also showed that higher Polyhydroxyalkanoate (PHA) production was achieved when applying acidogenic effluents (from the second acidogenesis phase) due to the readily available VFAs (Reddy & Mohan, 2012). Thus indicating that integrating these fermentation processes into the production of bioplastics increases efficiency and consequently increases the economic viability of the innovation technology of producing bioplastics.

Lastly, with regard to the technology of Chaincraft where chain elongation is applied to produce medium chain fatty acids (MCFA) from the (short chain) VFA's, additional advantages are achieved as MCFA's have a higher energy density and lower solubility compared to ethanol, which is required for producing caproic acid (Dahiya et al., 2018). Caproic acid is one of the MCFA's produced by Chaincraft by means of the chain elongation technology (Chaincraft *b*, n.d.).

Following these advantages of the fermentation biotechnologies for food waste processing it is interesting to note that, with regard to the prospects of these niche technologies, both academic literature and current practice highlight an increased interest in them (see for example: Cristóbal et al., 2018). Particularly with regard to the 'order of preference' pyramid (reduce, reuse, recover, dispose) that was mentioned in chapter 5 in figure 16, as this niche innovation provides a technology that is higher situated on this pyramid and thereby contributes to higher sustainability and circularity targets. This was also remarked by Starreveld (program manager vfg at the City of Amsterdam) in the interview, as he stated: "*(Food) waste should be processed as high as possible on that value pyramid. And we [the Netherlands] are in fact always on the lowest steps. [...] and that is now seen as efficient waste management, but we [Municipality of Amsterdam] really want to go a few steps higher. So I really want to move towards bioplastics, insect farming, all those steps*" (personal communication, 2020).

Hence it is expected that the application of these technologies will increase in the AMA in the (near) future, dependent upon the advancement of the socio-technical transition that it is to encounter. Consequently, the subsequent chapter describes the main barriers and opportunities that this innovation system of 'fermentation biotechnologies for high-value food waste processing for VFAs production' faces in this socio-technical transition. But first, the following section concludes with a concise description of the MLP perspective including the interactions in the system, and the transition pathways it is expected to experience. Moreover, the final section of this chapter provides a more in-depth analysis of the specific advantages of the technologies with regard to their environmental benefits from a holistic Circular Economy and Industrial Ecology perspective. Doing so by calculating energy and water inputs when the technologies would be applied at large scale in the AMA, in relation to their by-products and compared to the contemporary practice of food waste processing.

6.3 Multi-level perspective and transition pathways

Concluding from the previous descriptions of the regime-, landscape- and niche level, several main conclusions can be drawn about the niche innovation under study (i.e. fermentation technologies for fatty acids production from food waste), in the context of the multi-level system. First of all, the niche innovation can be defined as a 'radical technology innovation', following the definition of Geels (2019) as presented in the conceptual framework. Therefore being an innovation that is market-based and focused on making profit with a commercial application.

Secondly, the description of the actors, rules and institutions, and the tangible artefacts of the regime level discovered certain lock-in mechanisms that currently hinder the innovation from further developing and diffusing (i.e. stabilizing) on a larger scale in the regime level (i.e. lack of window of opportunity). The first lock-in mechanism present in the current multi-level system is a regulatory one, defined by Geels (2019) as an ‘institutional and political’ lock-in mechanism. As shortly described earlier, regulations in the Netherlands concerning food waste processing state that material flows designated as ‘waste’ cannot be used in applications for food or feed. Therefore, the current applications of the niche technologies (Chaincraft, AGC, FABULOUS) and their handling of incoming organic flows, is highly determined by these regulations. Even more, mixed food waste flows can therefore merely be processed into applications such as bioplastics, paints, etc.. The food and feed applications of AGC and Chaincraft are dependent upon homogenous and ‘clean’ food waste flows from food waste processors. This regulatory lock-in mechanism is further described from the perspective of involved actors in the subsequent chapter.

Furthermore, another ‘techno-economic’ lock-in mechanism can be observed in the multi-level system as described above (Geels, 2019). As described before, both AGC and the FABULOUS-project are now aiming to upscale their production process from resp. lab- and pilot scale, to produce enough material to provide a proof of concept for potential clients. Both projects indicated that in the interviews this can be a bit of a hindrance, since upscaling production requires more investments, and more investments (i.e. money) can be obtained from selling the product, which in its turn requires upscaling. This lock-in mechanism is also further described from the perspective from the actors in the following chapter.

Nonetheless, windows of opportunity could be created for these lock-in mechanisms in the future via both external momentum (i.e. landscape pressures) or internal momentum from within the niche itself. One could think of a change in expectations in the (political) network at the regime level due to changes at the landscape level, that could induce changes in regulations or increase subsidies invested in these niche technologies. Also, internal momentum could be achieved by the niche technologies via finding investors themselves to upscale production processes. These potential windows of opportunities are further explained after the description of the opportunities and barriers of the niche innovation in the following chapter. Figure 25 provides a recapitulatory overview of these levels and their interactions.

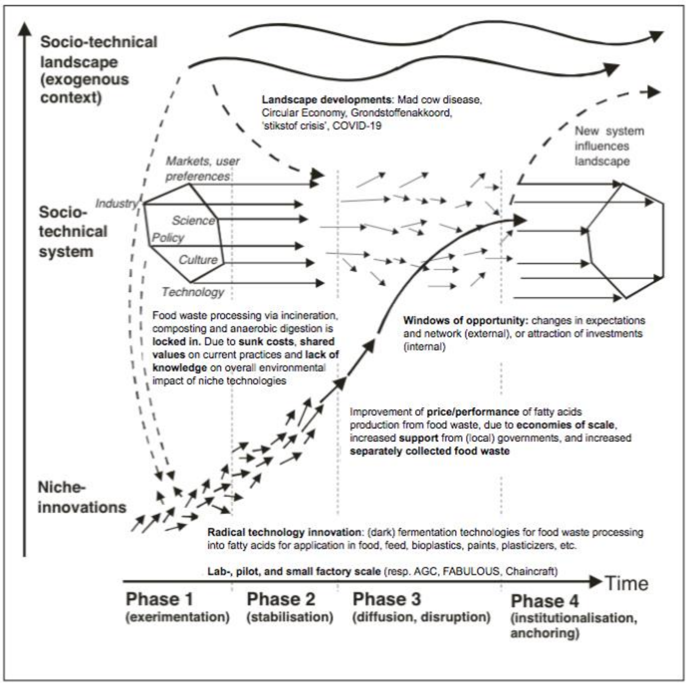

Figure 25. Overview of the multi-level system of the (dark) fermentation high-value niche technologies for fatty acids production (based on Geels, 2019).

Subsequently, the theory of Geels et al. (2019) on *transition pathways* as described in section 2.3.1 states that the interactions in this multi-level system combinedly define a certain transition pathway that this system is likely to follow, and that may help in enhancing a desired sustainable development. The trajectory of the niche innovation under study in this research can be described by the *transformation pathway*, since the fermentation biotechnologies are an improvement of existing technologies, by which they form a symbiotic relation with the current technologies for improvement. The existing technologies namely entail composting and anaerobic digestion, which contain similar processes as the (dark) fermentation for fatty acids, only the last steps are not executed in which methane is produced, but products in earlier processes are used to produce the short, and medium chain fatty acids. Also, it is expected that when the fermentation innovation technology would be applied at large scale, this would not substitute the current composting and anaerobic digestion technologies, but will be complementary (see figure 26 for a visualisation of the transformation pathway). Though it should be noted that the fermentation niche technologies do differ greatly from anaerobic digestion in that they require a whole different governance model, as novel high-value commodities (from fatty acids) are produced. This requires a new approach from a governance- and economic perspective. Still, it is expected that a transformation pathway applies, because it requires 'bending' of current legislation and regulations, for the technological processes to be implemented.

This transition pathway is characterised by its incremental nature, whereby the transition is performed in steps (see also development phases in conceptual framework and section 7.1). It should be noted however that, as stressed by Geels (2019), nonlinear processes can occur, causing a transition pathway to shift from one pathway to another. In the case of fermentation for fatty acids production from food waste, it can be argued that other technologies could develop in the (near) future, that are more efficient and environmentally friendly in dealing with food waste, thereby competing with this niche innovation. Consequently, the transition pathway might shift to a *reconfiguration pathway*, and the regime could slowly adopt several other niche technologies. One could think of the Black Soldier Fly technology, which now mainly encountering issues due to the same legislative obstacle to process food waste into feed products. Once this burden is (partly) overcome, this could open a window-of-opportunity for this niche technology to co-exist with the niche technologies investigated in this research (see figure 27).

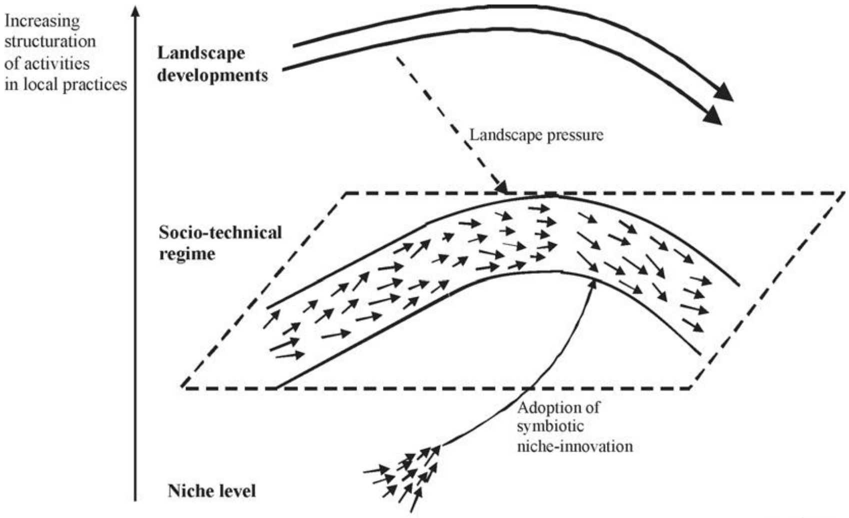

Figure 26. The transformation pathway that applies to the food waste fermentation for fatty acids production in the AMA (Geels & Schot, 2007).

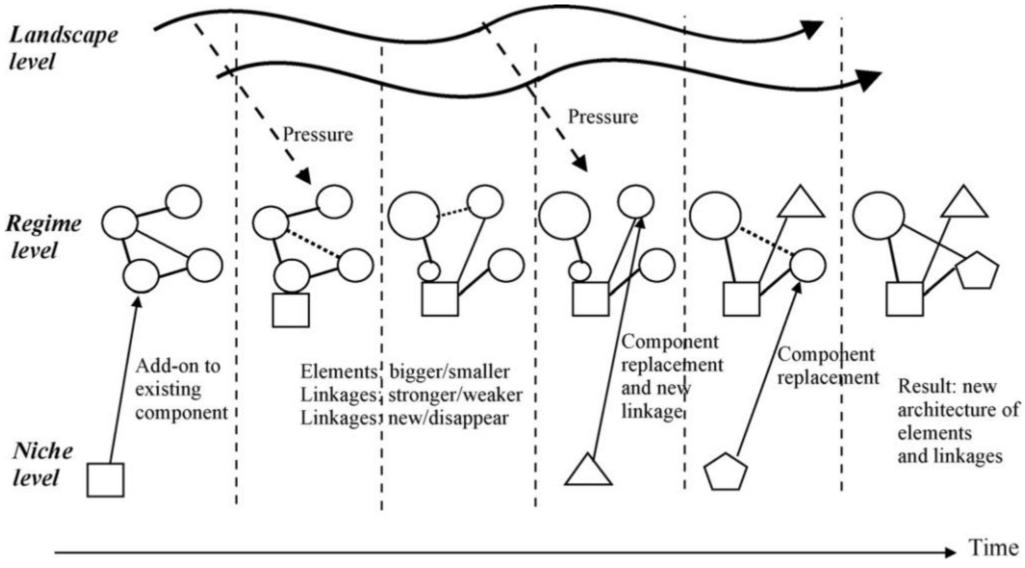

Figure 27. The reconfiguration pathway (Geels & Schot, 2007).

6.4 Environmental assessment of the niche potential

As stated in section 6.2.1, the concerned technologies in this study have the main advantage of reducing environmental impacts, but as denoted by Caldeira et al. (2020), this highly depends on the type of technology and (status quo) alternatives for determining if "*the additional impact caused by the valorisation processes can outweigh the environmental benefit derived from re-using a stream of FW that would otherwise be wasted*" (p. 12). This type of analysis was hardly found by Caldeira et al. (2020). The need for this type of analysis was also pointed out by Mooij in the interviews, who stated: "*it is also important in this system to think about what currently happens to the organic flows and what will potentially not happen anymore in the future, and what effect that has* [on the overall system]" (personal communication, 2020).

Therefore, this research provides an environmental assessment of large-scale application of the fermentation niche technologies relative to the status quo of food waste processing. An overview is provided of the energy and water inputs of the fermentation biotechnologies relative to their (high-value) economic and physical outputs (i.e. commodities and remaining by-products), and the-'fossil-fuel-based'-products they replace. This entails the direct water- and energy consumption of the technologies during the treatment processes in the AMA region. This thus not includes more indirect water- and energy impact related to embedded impacts (e.g. water and energy for food production) or, for example, land use changes.

This is also of great relevance for municipalities and regional governments, for understanding potential synergies within and between different biorefinery processes, because 'cycles' of water and energy can potentially be closed in the process itself or in industrial symbiosis with other industrial companies or processes. Thereby reducing the environmental impact of the processing of the food waste by applying high-value fermentation biotechnologies (Dahiya et al., 2018). More importantly, this necessity of conveniently (re)using water and energy flows once more emphasizes the nexus governance approach that it requires.

While investigating the energy- and water intensities of several food waste management options offers only a partial share of the environmental impact in the whole life cycle, it is still important for validating the impacts of waste processing technologies from a nexus approach and the waste hierarchy in the local context of the AMA.

The present research aims to go beyond the findings of Coudard (2019) by applying his energy- and water intensity characterization factors to the case of the AMA. Moreover, this research provides an additional nuance by investigating the by-products of the technologies and the environmental impact of the alternative products that these technologies replace (i.e. substitution), which should be taken into consideration when assessing environmental benefits from a holistic perspective.

In his research, Coudard (2019) concludes with a new 'Food Waste Management and Valorization' framework that provides possible strategies for food waste valorisation in the city of Amsterdam. It focuses on 4 technology strategies (that include the 12 techniques mentioned above), and presents them relative to their energy and water inputs, and economic output. Figure 28 below presents the framework concisely. With regard to biomaterial technologies (e.g. for production of bio-polymers, enzymes, organic acids) it shows, for example, the relatively high water requirements and the medium energy requirements, compared to the medium economic output value.

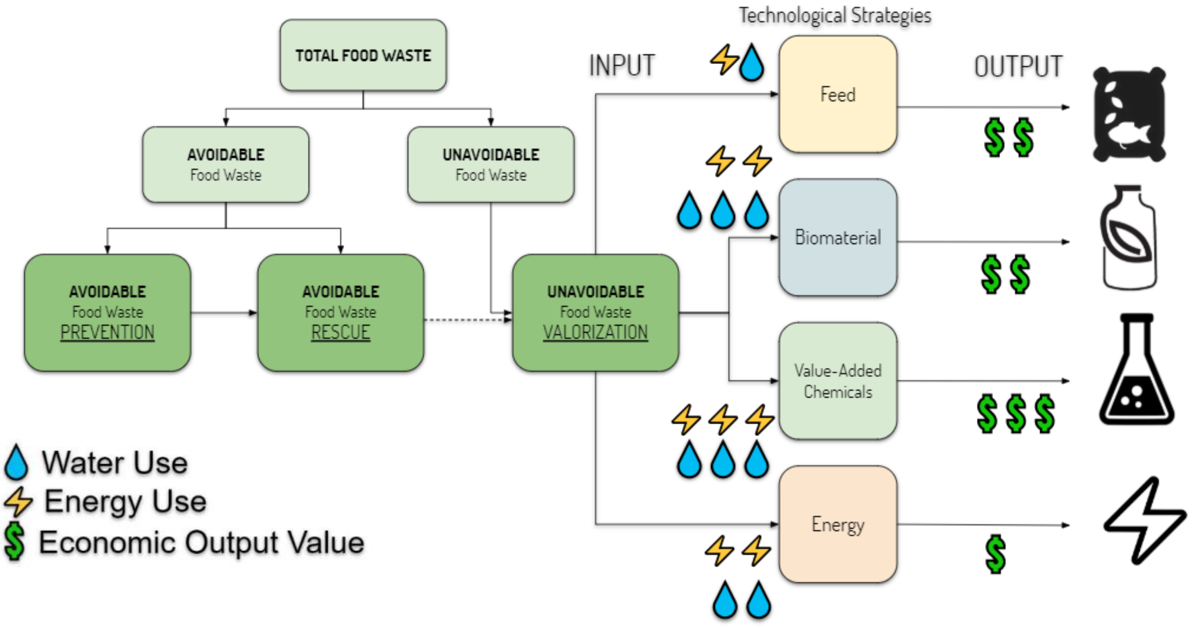

Figure 28. The new Food Waste Management and Valorization Framework of Coudard (source: Coudard, 2019).

In the present research, this framework of Coudard (2019) is used to determine the environmental impact relative to the economic and environmental benefits of the niche technologies under study. This analysis is performed based on the data and calculations behind the framework, as it presents the inputs and outputs of the 12 technologies investigated by Coudard (2019) (see the methods chapter for the specific inventory data used in this research).

6.4.1 Inputs and outputs in the AMA case

The previous chapter presented two material flow analyses that indicate the total food waste flows in the AMA from households and companies in the year 2018/2019. Based on these MFA's it can be calculated how these quantities of different food waste flows are (or will be) processed by different technologies at present day and in the future. Following the type of food waste flows and treatment methods presented in the MFA's, and the interviews, it is assumed that in the *status quo scenario*:

- Amsterdam also separately collects vfg waste, for which the changes in quantities of separately collected vfg waste are determined by the urbanisation factors applied in the MFA (i.e. 26,075 and 119,634 t/y of food waste from households collected resp. via vfg waste and residual waste in the AMA in total).

- All household and company food waste in residual waste, and a small fraction of organic company waste is incinerated with energy recovery.
- All household food waste in vfg waste is processed by combined anaerobic digestion and composting.
- 52% of food waste from companies is treated via biological cleaning and processing for direct application in animal feed[16].
- 33% of food waste from companies is processed by combined anaerobic digestion and composting and 12% is composted (assuming that 'transhipment / bulking', 'sorting / separating', and 'separating chemically / physically' are pre-treatment phases for anaerobic digestion).
- Wastewater effluent from all technologies is either processed on site in decentralized wastewater treatment facilities, or treated in a centralized wastewater facility, and therefore regarded negligible within the scope of this assessment.

This scenario results in the overview presented in figure 29.

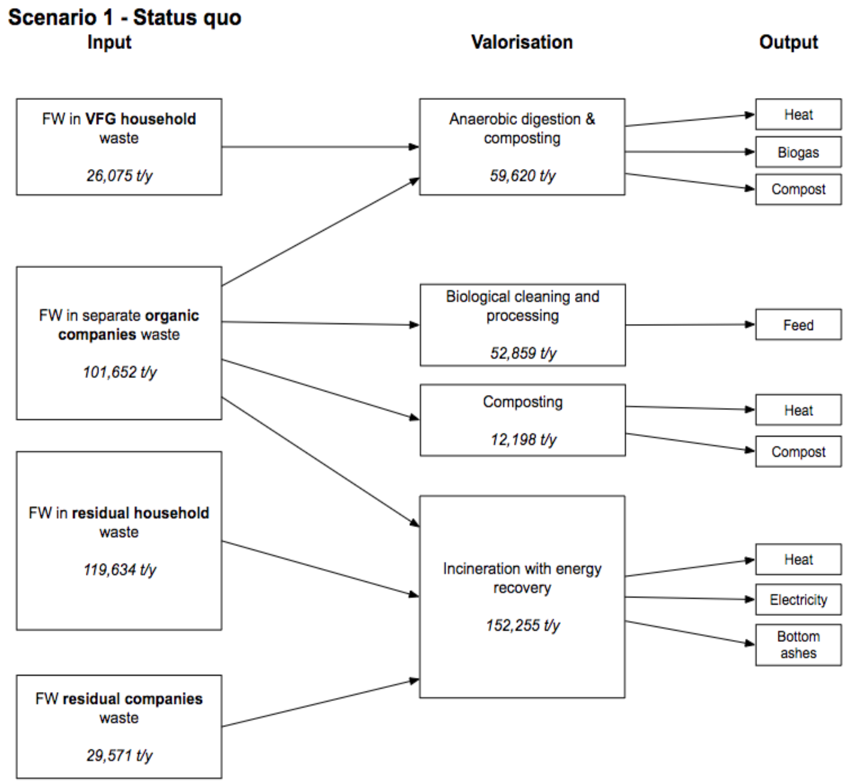

Figure 29. Scenario 1: status quo food waste valorisation in the AMA with corresponding quantities and output products

Additionally, the figure below presents an overview of the scenario if the three niche technologies would be applied on a large scale. This scenario is based upon their expected potential as described previously. Thus assuming that still a fraction of (household) food waste will end up in municipal

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[16] See the following research for share of application in animal feed from wholesale and retail in the Netherlands: https://edepot.wur.nl/499300

residual waste, and that the FABULOUS project is the only technology to process mixed-food waste flows in the short-, to medium-term future (i.e. Chaincraft produces for feed additives from homogeneous flows from companies and the food processing sector). Therefore, the following assumptions are taken into account:

- 25,000 of mixed household food waste (vfg) now ending up in residual waste will be treated by the FABULOUS project and/or similar 'bioplastic' process factories. Assuming that it will be operating at factory scale similar to current processes of Chaincraft at present day (i.e. 20,000 t/y), and that it is feasible to increase vfg collection rates in the municipality of Amsterdam and to increase collection efficiency in surrounding municipalities. Also, given the statements of two FABULOUS project employees that the techniques should be an addition to, and not substituting current anaerobic digestion and composting quantities.
- 100% of food processors' homogenous fruit and vegetable food waste flows now ending up in animal feed via biological treatment will be treated by Chaincraft (i.e. 52,859 t/y). Given that Chaincraft currently already processes 20,000 t/y and is currently upscaling production 'in competition with' the current animal feed-from-food waste sector. It should be mentioned though that it is not expected that Chaincraft will diminish the whole 'food waste to animal feed' sector, but given the realistic increase to ~52 kton for Chaincraft, and the fact that animal feed production direct from FW has a lower nutritional and economic value than the feed additives from Chaincraft (San Martin et al., 2016), this assumption is applied.
- 15,000 of food processors' homogenous fruit and vegetable food waste flows now ending up in incineration will be treated by AGC. Assuming this can be supplied separately by the food processors in the AMA (Persoon, personal communication, 2020), and that AGC will be operating at pilot scale.
- Residues/digestate from Chaincraft, FABULOUS and AGC will be used as input for composting processes, hence no residue/effluent remains (Suurmeijer, personal communication, 2020).

This can be summarized in the scenario in figure 30.

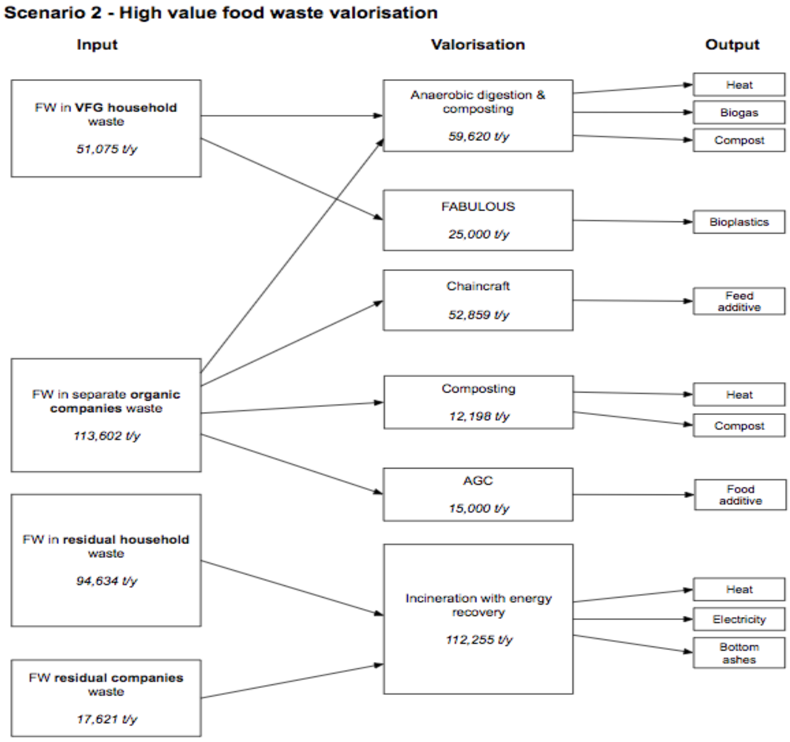
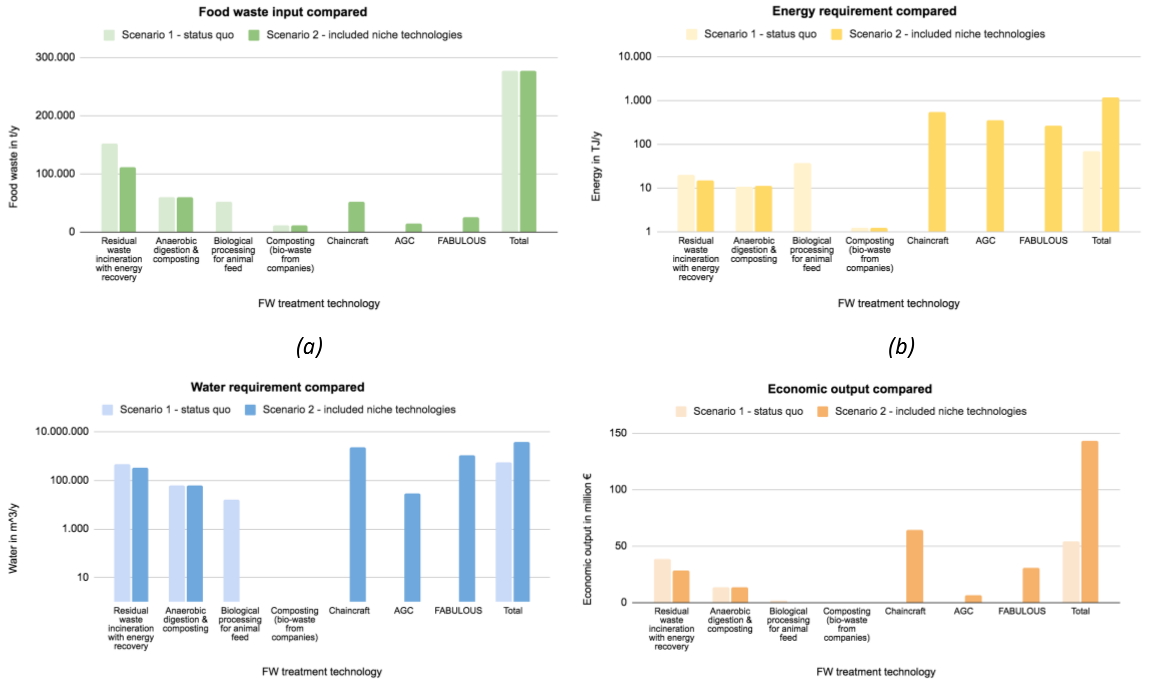


Figure 30. Scenario 2: status quo food waste valorisation in the AMA with corresponding quantities and output products.

Following these two scenarios, the figure below presents the overall water and energy inputs, relative to the food waste input and economic output of the technologies under study in both scenarios (see appendix and publications of the diagrams[17] for a specification on the numbers).



(a) *(b)*

(c) *(d)*

Figure 31. Energy- and water intensities, combined with the relative food waste input and economic output of the valorisation technologies applied in the AMA in the status quo and future scenario. Note the logarithmic scales in tables (b) and (c). (a) Total food waste input quantities for each technology corresponding to the scenarios, (b) total energy inputs for each technology corresponding to the scenarios, (c) total water inputs for each technology corresponding to the scenarios, and (d) total economic outputs for each technology corresponding to the scenarios

Again, it should be mentioned that the energy- and water requirements of the technologies entail the direct water- and energy consumption of the technologies during the treatment processes. Meaning that it thus not includes more indirect water- and energy impact related to embedded impacts (e.g. water and energy for food production) or, for example, land use changes. Also, the different units and scales used for the food waste, water, energy and economic quantities should be noticed. These graphs are mainly aimed to facilitate a comparison between the different technologies, not between water and energy within one technology. Besides, it also presents the overall energy and water requirements for comparison of the two scenarios.

Then, with regard to the status quo technologies some conclusions can be made. To start with, it can be observed that the energy requirements for animal feed production in the first scenario are relatively high compared to the food waste input and economic output of the technology, in comparison to the other technologies. This can be explained from the drying processes required for this technology (San Martin et al., 2016). Secondly, the economic output of food waste in residual waste incineration relative to the food waste input quantities, is virtually equal to this ratio for anaerobic digestion (green bar versus orange bar). In terms of economic efficiencies, this indicates a similar efficiency for these techniques. Note however, that the economic outputs merely reflect the revenue from the commodities produced, and thus not the overall profit. Nevertheless, for energy the

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[17] Food waste input: https://ap.lc/6MmEH. Energy input: https://ap.lc/Ru9sS. Water input: https://ap.lc/TYNcR. Economic output: https://ap.lc/Ts1Cd.

two technologies also demonstrate a relatively equal share, whereas the water intensity of incineration of food waste is relatively larger than for anaerobic digestion. Yet, considering the low water prices and high drinking water efficiency in the Netherlands and Amsterdam specifically, this effect can be deemed negligible on the profits and environmental impacts in the current system (Van Leeuwen & Sjerps, 2015).

Interestingly, the outcomes also demonstrate the relatively low economic outputs of the composting technique, whereas the animal feed technology is also relatively low in the first scenario in comparison to incineration and anaerobic digestion.

Comparing the results of scenario 1 and 2, it can be concluded that by applying the high-value niche technologies, the total economic output triples, whereas total water- and energy requirements are respectively sevenfold and seventeen-fold the quantities of the status quo. The increase in both water and energy intensity can mainly be attributed to Chaincraft, as it represents application at the largest scale (i.e. highest food waste quantity input) of a high-value technique in scenario 2. Relatively, it can be noticed that, while valorising merely half of the fraction valorised via incineration, the (assumed) Chaincraft technology has a 36 times higher energy requirement.

These relatively large energy requirements in comparison to the other technologies, should be put into perspective to energy prices in the Netherlands to demonstrate the profitability (i.e. economic output) of the high-value technologies compared to the status quo. This e.g. shows that the energy requirements of Chaincraft of 549 TJ/y equals approximately 6.1 million €/y in energy costs if this would be all electricity, and 0.31 million €/y if this would be heat produced from natural gas[18]. Both respectively comprise merely 9% and 0.4% of the economic output of the Chaincraft technology, hence validating the potential profitability of the technology despite its large energy requirements (not yet taking into account capital- and other operational costs, both those are deemed nearly similar to the status quo techniques).

Nevertheless, the seemingly worse environmental performance in terms of water and energy of the promising niche technologies should be put in context to provide a fair comparison and to come to recommendations for a sustainable and circular strategy for food waste treatment in the AMA. They should be put in perspective to the origin of the energy and water inputs, and the conventional commodities that the niche technologies replace, as will be further delineated in the subsequent section.

6.4.2 Renewable inputs & substitution of corresponding market products

As stated, it is important to put the relatively large water and energy quantities used by the high-value niche technologies in perspective. First of all, the higher energy requirements in the second scenario denote the necessity to consciously monitor these required inputs and to acquire them as much as possible from renewable resources. Given the current energy transition in the Netherlands and the goal of the national government to have a completely CO_2-free electricity system and a climate-neutral industry in 2050[19], one could argue that part of the energy demand will be obtained from renewable sources in the scenario for 2030. However, as the goal of the national government is stated on a longer

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[18] See the research of PWC: 'Vergelijking van gas en elektriciteitsprijzen 2017' for electricity and gas prices in the Netherlands compares to other EU countries.

[19] See: https://www.rivm.nl/onderwerpen/energietransitie#:~:text=Het%20doel%20van%20de%20Rijksoverheid,broeikasgassen%20aan%20de%20andere%20kant.

timeline than the expected lifetime of the niche technologies (due to expected FW prevention measures and reductions in homogenous avoidable FW flows), it is assumed that this national goal cannot be reflected one-to-one on the future scenario (i.e. 100% from renewable sources). Even more since the national government is currently off track for achieving the above-mentioned goals, according to Planbureau voor de Leefomgeving[20]. Following the projected pathway in this publication, it is more realistic to state that the total share of renewable energy will increase from 8.7 percent in 2019 to 25 percent in 2030. Moreover, it is assumed that the main share of the energy requirement can be attributed to heat demand, for which - especially for higher temperature heat sources - it currently remains a challenge to substitute this demand with renewable sources in industry. Even though new technologies such as 'high temperature co-electrolysis' or residual heat exchange with surrounding industries might solve this issue (Morgenthaler et al., 2020).

More specifically, the PBL publication states an expected increase from 18% in 2019 to 75% in 2030 for the share of renewable electricity, and an increase from 7% in 2019 to 13% in 2030 to the share of renewable energy for heat demand. Therefore, it is assumed that 19% of the energy requirements will be obtained from renewable sources in the second scenario in 2030, and 8% in 2019 for the first scenario. This is in line with the average predictions of the PBL, assuming that some demand is for electricity and the largest fraction for heat. This results in the adjusted graph below[21] for the energy requirements, when taking into account that *direct* environmental impacts from renewable sources are negligible. It shows that this provides a relatively minor decrease in total energy requirements of scenario 2 of 1187 TJ/y to 961 TJ/y (note the logarithmic scale). Though it could be argued that if Chaincraft, AGC and FABULOUS could guarantee to obtain their energy from renewable resources (no biomass, no indirect certificates, and potentially also compensate for embedded emissions for wind- and sun renewable resources), the energy requirements can be regarded close to zero, thereby making the niche technologies more promising compared to the status quo from an energy perspective. This thus remains very context specific, but simultaneously offers opportunities for governments to make clear agreements with the niche technologies about the origin of the energy, to increase the circular and sustainable potential of FW processing in the AMA.

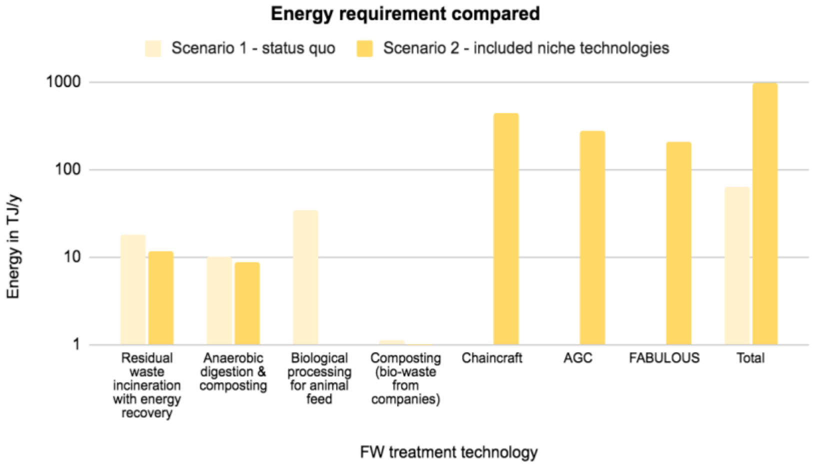

Figure 32. Energy intensities of the valorisation technologies in the AMA in the status quo and future scenario, adjusted to energy obtained from renewable sources. Note the logarithmic scale.

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[20] See: https://www.pbl.nl/sites/default/files/downloads/pbl-2020-klimaat-en-energieverkenning2020-3995.pdf

[21] Publication of graph for exact numbers: https://ap.lc/uA7qV

Besides, concerning the higher water requirements of the second scenario, a more nuanced conclusion should be formed. This refers to the previously mentioned statement that the City of Amsterdam scores high on topics such as 'water security, 'water quality', and 'climate robustness' in the 'Blueprint' assessment of Van Leeuwen and Sjerps (2015), thus indicating abundant water availability and quality. Together with the findings from the interviews that often waste processors facilitate wastewater treatment onsite, and that local wastewater treatment is also included in the project development of the new niche technologies, this sketches a positive picture of the current state of affairs in the AMA. It demonstrates the possibilities to treat and reuse these water flows in a decentralized manner. But more importantly, it could be argued that in the current situation these water impacts could be regarded negligible.

Nonetheless, for the future scenario this should be taken into consideration with great caution, as inappropriate wastewater management and increased water scarcity in periods of drought due to climate change, might threaten water security both physically and economically for FW management technologies in the near future (Koop et al., 2017). More particularly, as stressed by Van Leeuwen et al. (2018) wastewater treatment should not be limited to reuse of water, but should contain optimal nutrient and biomass recovery from a Circular Economy perspective. Subsequently, it is argued for the water impacts of the niche technologies that compared to the status quo, in which water scarcity and -security issues are not (yet) relevant in the AMA, the future scenario will demonstrate equal, or more negative environmental impacts from a water perspective. Where it is strongly dependent upon the eventual climate change effects and its specific consequences for the AMA water system (Bruggemann et al., 2013).

Moreover, it is not only the interpretation of the energy- and water requirements that allows for a fair comparison with the status quo. It should also be considered that the commodities produced by the new niche technologies (bioplastics, feed/food additives), have an (added) value from a system perspective in terms of minimising environmental impacts. These niche technologies namely substitute conventional product systems that would otherwise use additional energy, water and fossil-based materials (i.e. plastics from crude oil, food/feed additives from palm oil), while the niche technologies also provide waste treatment.

This substitution effect of the FABULOUS technology results in subducting the energy and water requirements of conventional plastics, assuming that the bioplastics are of the same quality as polypropylene. According to the Ecoinvent database plastic production requires 2.042 MJ of energy, and 0.00289 m^3 of water per kg produced polypropylene granulate[22]. Assuming that 13,800 ton bioplastics can be produced with the quantities of FW processed in the second scenario[23], this equals a substitution of 28 TJ energy and approximately 40,000 m^3 of water. Let alone the fact that conventional plastic production requires natural gas and crude oil, which has an additional damaging effect on the environment via natural resource depletion. The 28 TJ reduction in energy requirement of the FABULOUS technology due to substitution is 11% on the total of 260 TJ requirement of FABULOUS, and the substitution of the water is 4% on the total water requirements of FABULOUS.

For the feed and food additives of resp. Chaincraft and AGC it is not that straightforward to subtract the energy and water requirements of 'conventional' food and feed additive production for several reasons. First of all, because it is unknown what the specific nutritional food additive of AGC

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[22] Ecoinvent 3.7 database: 'polypropylene production, granulate - RER'.

[23] See Coudard (2019): 552 kg of PHB produced per ton of FW input.

is, which constrains this research to determine what conventional food additives it replaces. Secondly, for the feed additive of Chaincraft it was stated to replace the 'zootechnical value' of antibiotics in animal feed. However, since 2011 it is not allowed anymore to produce or sell animal feed including antibiotics in the Netherlands. These antibiotics were used to stimulate the digestive system of young livestock to increase growth rates. Currently, probiotics, yeasts and specific enzymes are used to achieve this[24]. In relation to this, it is assumed that the conventional way of producing feed and food additives, and thereby its energy- and water requirements, are similar to the processes of Chaincraft and AGC. The main additional benefit of Chaincraft and AGC is thus found in them using FW as an inexpensive feedstock, thereby facilitating waste treatment into circular products. Nevertheless, as the specific food and feed additives are unknown, it was not possible to calculate the specific water and energy substitution effects. As it is also dependent upon the specific 'commercial-scale' quality of these additives to replace the conventional market.

On the contrary, for a fair comparison, something can be said of the substitution effect of the commodities produced in the status quo, i.e. compost and biogas. First of all, these effects are deemed negligible for compost, because compost produced with the status quo technique does not have this high added value compared to its substitute (i.e. fertilizer). Due to the fact that it is known for only partly replacing fertilizer' quality, and adding to the current manure surplus problem of the Netherlands as farmers are often paid to use the produced compost, because the benefits of the compost are highly dependent upon local conditions and are mostly experienced on the long term (Tonini et al., 2020).

However, for biofuel production from anaerobic digestion, which equals a total of approximately 7,600 ton of biofuel production[25] in both scenarios, this corresponds to a replaced 0.1 TJ of energy requirements and ~93.000 m^3 of water requirements when assumed that this substitutes unleaded petrol production[26]. This effect thus shows to be negligible for energy inputs on the total of 11 TJ for anaerobic digestion techniques (i.e. 0.9%), whereas the water impact substitution effect accounts for 156% of total impacts of anaerobic digestion. The latter thus indicates that petrol production is relatively water intensive compared to biofuel production from FW via anaerobic digestion. Additionally, it should again be mentioned that petrol production requires crude oil, which has a more damaging effect on the environment via natural resource depletion than using FW as input. Overall thus making the water impacts of anaerobic digestion also in the future scenarios negligible.

6.5 Concluding remarks: the niche innovation potential

Following the analysis in this chapter, the second research question can be answered. First of all, it can be stated that the three niche technologies investigated in this research encompass similar, but at the same time different high-value biotechnologies. They can be regarded the same due to their resemblance in the fermentation technology that is similar to anaerobic digestion, at which the last step for methane formation is not executed, but fatty acids are produced. However, the three technologies include somewhat different processes with regard to 'chain elongation', 'bio anoxygenesis', and other acidogenesis processes to produce different fatty acids (ranging from C2 to

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[24] See: https://www.diervoederketen.nl/index.php/fact-sheets/antibiotica-in-diervoeders

[25] See Coudard (2019): 294 kg of biofuel production per ton of FW input.

[26] Ecoinvent 3.7 database: 'petrol production, unleaded, petroleum refinery operation - Europe without Switzerland'.

C18 fatty acids) for different applications (i.e. bioplastics, feed additives, food additives), and with different food waste flows inputs (homogeneous flows from food waste processing sector and agriculture, and mixed vfg from households). Concerning the latter, each food waste type presents its own challenges and issues, for example, with relation to the lead time before microbiological processes make more homogeneous flows unsuitable for high-value processing, and the ratio of kitchen- and garden waste in vfg flows that determines the efficiency of the high-value processing technique.

Furthermore, based on the description of the niche level, the multi-level perspective (MLP) analysis concluded upon two main lock-in mechanisms in the current system that hinder a window-of-opportunity for the niche technologies to diffuse. An 'institutional and political' lock-in referring to national and European legislation that determines that 'waste' cannot be used as feedstock for food and/or feed products, and a 'techno-economic' lock-in that describes the current situation in which upscaling is required for proof-of-concept and vice versa. Furthermore, it is observed that a *transformation pathway* applies to the MLP system under study, because the fermentation biotechnologies are an improvement of existing technologies, by which they form a symbiotic relation with the current technologies for improvement. However, it is not ruled out that a nonlinear pathway might change it into a reconfiguration pathway, including other high-value valorisation technologies such as BSF.

Even though the environmental analysis does not directly allow for a straightforward conclusion by counting all the environmental benefits and impacts quantitatively, it partly validates the relative advantages of the niche technologies compared to the status quo. All in all it can be stated that despite the niche technologies showing higher water and energy requirements compared to the status quo, when put in perspective to the higher economic output, the (circular, sustainable and nutritional) added value and substitution effect of the commodities produced (bioplastics), and the potential to use renewable resources as inputs, this presents some interesting opportunities these high-value valorisation techniques have to offer in the context of the AMA. Although strictly dependent upon the actual implementation with regard to usage of renewable energy sources and reduced/reused water sources. Thereby simultaneously highlighting the importance to closely monitor how these nuances will eventually be implemented in the AMA.

It should also be further explored though what the trade-off is of directing homogenous food waste flows from the food waste processing sector and supermarkets to either direct animal feed production via drying, or to animal feed additive production from Chaincraft. Both provide a lower environmental impact compared to composting or anaerobic digestion (San Martin et al., 2016), however it should be investigated which provides the better alternative. Given that direct animal feed production replaces conventional oatmeal production, but still requires nutritional additions such as yeasts and probiotics, whereas the animal feed additive of Chaincraft replaces these yeasts and probiotics, but still requires addition of the animal feed itself (e.g. oat- or soymeal).

All in all, the main advantages and disadvantages of implementing the niche technologies on a large scale in the AMA with regard to the environmental impact are summarized in the table below. Note that the opportunities and barriers of the socio-technical transition itself are addressed in the following chapters (e.g. knowledge development, level of experimentation).

Table 7. Summarized overview of the main advantages and disadvantages of large-scale application of the three niche technologies in the AMA.

Advantages	**Disadvantages**
- They produce more **high-value commodities** from FW (bioplastics, feed/food additives) from a circular economy perspective, compared to anaerobic digestion and compost (Ladder of Lansink). I.e. use for human and animal feed, and material recovery instead of use for nutrients and energy recovery[27]. - They have a **high economic output** compared to the status quo. - If **energy and water** requirements are guaranteed to be obtained from **renewable sources**, more sustainable and circular than status quo. - **Substitution** of PP (**plastic**) production and related environmental impacts. - **Substitution** of **conventional food/feed additive** production and related environmental impacts. - Current **compost** production and electricity production from residual waste is **not the most beneficial** option from an economic and environmental perspective, the niche technologies could provide a more circular and sustainable alternative/supplement.	- **High energy and water requirements** compared to status quo technologies (e.g. compost, anaerobic digestion). - Anaerobic digestion in status quo also **substitutes petrol production**: → Niche technologies should be an addition to the biogas production, not supplement it. - Decision-making should delve further into **mutual comparison of sustainable technologies** (i.e. anaerobic digestion, feed additives, animal feed, etc.) from both a circular and sustainable perspective.

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[27] See adjusted Ladder of Lansink in Teigiserova et al. (2020).

7. Results III: Seven system functions of the fermentation biotechnologies – a stakeholder perspective

In relation to the previously described MLP-levels and the potential of the innovation system, this chapter provides a more in-depth analysis of the functioning of the system and the related opportunities and barriers to the required socio-technical transition for large scale application. The previous two chapters already described several barriers and opportunities while describing the overall system properties, which became apparent from desk research (e.g. waste taxes, carbon tax, redesigning existing tangible artefacts, landscape development effect of COVID-19). This chapter aims to complement and validate these insights from the perspective of the experts in the system, structuring the insights by the technological innovation system analysis of Hekkert et al. (2011).

The main goal of this chapter is thus to understand what currently hinders the large-scale diffusion of the investigated niche technologies, after which the subsequent chapter elaborates on how to overcome these barriers from a nexus governance and social network perspective. Hence this chapter answers the third research question:

> *What are the opportunities and barriers to large scale application of these techniques in the AMA?*

This chapter provides a description of the seven system function of Hekkert et al. (2011) based on input from semi-structured interviews with key expert actors in the system. As Hekkert et al. (2011) namely emphasize that the functioning of an innovation system should be qualitatively evaluated by experts, as solely quantitative indicators (e.g. economic performance, output produced) do not suffice in providing this assessment, since technologies are highly dependent upon context specific factors (such as: location, time and competition).

7.1 Development phase

As stated in the conceptual framework, the functioning of the innovation system and the related opportunities and barriers for further diffusion of the technology, are dependent upon the development phase that it is in. More particularly, the phase of development determines the relative importance of the seven system functions (Hekkert et al., 2011). For the high-value fermentation biotechnologies in the AMA it can be stated that it is located in the second phase: the *development phase*.

Nonetheless, it should be noted that the fermentation biotechnologies investigated in this research comprise three technologies that are in different development stages. Chaincraft in the 'development phase' as it already commercially applies its technology in a factory, the FABULOUS-project in the 'development phase' at a pilot-scale, and AGC in the 'pre-development phase' currently testing its technology and product at lab-scale. Importantly, despite its current relatively large size of production and aim to accommodate a larger market in the near future, Chaincraft is not regarded a technology in the 'take-off phase', since they are currently producing animal feed additives from homogenous food waste flows from the food processing sector, while they aim to extend their business with using mixed food waste flows (from households) for a more diverse range of applications (e.g. bioplastics, paint, plasticizers). The latter relates more strongly to the research topic under study in this thesis and is assumed to reside in the 'development phase'.

Therefore, because this research also denotes the necessity to process (mixed) food waste streams from households, it is assumed that the innovation system under study currently resides in the development phase, since Chaincraft and the FABULOUS-project are aiming to process these food waste streams into a wide range of applications, and already operate at a larger scale than AGC.

In relation to this, Hekkert et al. (2011) indicate the most important functions of the seven functions in this development phase. For the *pre*-development phase, knowledge development is the most critical function, whereas knowledge exchange, guidance of the search, and resource mobilisation are subsequent important supportive functions to the former. In the development phase however, entrepreneurial experimentation is the most important function, at which all the other six functions have an important supportive function in that they can positively or negatively influence this experimentation and production. Therefore, all seven system functions are deemed important given the development phase that the technological innovation system is currently in, with an emphasis on knowledge development and entrepreneurial experimentation.

7.2 Seven system functions

7.2.1 Function 1: Entrepreneurial experimentation and production

The work of Chaincraft, AGC, and the FABULOUS project demonstrate an adequate presence of entrepreneurial experimentation, and in the case of Chaincraft also significant production. However, as denoted by almost all interviewees the question remains whether this innovation and experimentation is sufficient (Mooij, personal communication, 2020; van Stralen, personal communication, 2020; Starreveld, personal communication, 2020). More specifically, Persoon from AGC and Suurmeijer from Orgaworld even clarified that the level of innovation of the involved actors is currently not sufficient enough, due to the fact that it is very difficult to scale-up the fermentation technology from lab-scale to pilot-scale, which can be regarded a huge barrier for enhancing the innovation (personal communication, 2020). Persoon attributed this to a lack of financial resources, while Suurmeijer underscored that this also partly originates from an absence of decision-making, as he stated with regard to the AMA organisation: "*there are all big egos at the table who all think they know it better. And all want to be in charge. And that's not how innovation works*".

It was emphasized by several interviewees that the current level of innovation and experimentation is dependent upon multiple factors, such as legislation and regulations, financial constraints, availability of input material (i.e. type of food waste), and the stimulating role of governments (van Stralen, personal communication, 2020; Persoon, personal communication, 2020; Starreveld, personal communication, 2020). Also, the time span from deposition until processing determines the eventual application, as microbiological processes in vfg bins for example hinder application for human consumption (both biologically and from legislation), thus restricting the use of mixed household's food waste for food and feed additive applications (Persoon, personal communication, 2020). The subsequent function descriptions will describe these factors more in-depth.

Nonetheless, a positive 'shift in mindset' can be witnessed in the (food) waste processing sector that manifests itself in processing technologies. This was most clearly demonstrated by Suurmeijer and van Stralen that designated the historical steps in the transition in Dutch waste management from landfilling, to separately organic waste collection and processing with anaerobic digestion and composting, and now transitioning towards high-value processing for VFA's that have a wide range in application from plasticizer, to plastics, paint, solvents, herbicides and feed additives (personal communication, 2020). At which Suurmeijer expressed this entrepreneurial and experimenting attitude via FABULOUS' ambition to cooperate with waste processing companies like HVC and Meerlanden in the near future to combine forces in, and around Amsterdam to produce "*bioplastics with a high value in the market*" (personal communication, 2020).

Additionally, Starreveld (program manager GFT/E at City of Amsterdam) underscored the considerable influence, and level of experimentation, of appropriate collection on processing technologies (personal communication, 2020). In Amsterdam he is working on a pilot project where food grinders will be placed in new build apartments to separately collect the flows, and he is working on finding appropriate high-value processing methods for these flows. He stated that compared to underground containers (20%) and roll containers (70%), food grinders contain up to 90% food waste. Consequently creating a better efficiency and market for the high-value processing industry.

Lastly, van Stralen also underlined the potential role of biochemical companies in this transition: "*chemical companies are more concerned with fermentation techniques than waste companies. The latter focus more on energy production because it is a clear commodity that can be supplied to the grid. But making and supplying chemicals is really 'a different matter' than waste processing, which involves a completely different value chain in which you have to meet the requirements of your customers in the chain".* While simultaneously noticing that currently almost no biochemistry companies are involved in these innovations with regard to processing vfg municipal waste.

7.2.2 Function 2: Knowledge development

Concerning knowledge development, an overall positive attitude towards this innovation system function can be witnessed from the interviews. As Suurmeijer, van Stralen and Mooij indicated that there is good research performed at universities (of applied sciences) and other knowledge institutes on both the social components of the required transition and on the specific chemistry processes required to produce VFAs with high efficiencies (personal communication, 2020). More specifically, van Stralen stated: "*I think it is reasonably 'fast enough', and it is well coordinated; meaning the phase of research they are in and the phase of application that we are in*".

Furthermore, de Vries highlighted the important connecting role of governments, and especially the Province, in knowledge development, as their strength is really in connecting education, entrepreneurs and the government (i.e. also knowledge exchange) (personal communication, 2020). Whereas he also depicted that there is still a lack of knowledge on the circular economy among civil servants and officials that are assigned to work on the topic. Especially on the practical application of them, as often it is added on top of their daily work (e.g. housing construction, waste management). Logically, this forms a potential barrier to upscaling of the fermentation biotechnologies. However, recognition of the problem could be the first step in resolving it by enhancing knowledge development among these officials.

In relation to this, Persoon again emphasized the need for increased pilot scale application of their technology for further knowledge development on the Food4Food application of AGC, which they are currently aiming for together with Wageningen Research, to produce several 100 kilos of output. Here, Persoon stated that there is a particular lack of 'process technologists' in the professional field in the Netherlands that "*you really need to shape these types of processes*". More education and internships in this field of research might remove this barrier (personal communication, 2020).

7.2.3 Function 3: Knowledge exchange

First of all, it should be mentioned that the FABULOUS- and AGC project themselves are good examples of knowledge exchange between universities and the professional field/entrepreneurs (resp. TU Delft and Wageningen University). Chaincraft also stated to be involved with several universities via internships and research (van Stralen, personal communication, 2020). For such a cooperation to succeed, Suurmeijer explained that openness and transparency are key components. This necessity for openness was also shared by Starreveld, who stated that in order to eventually apply the food grinders on a larger (national) scale, there should be no "*competition-sensitive things in it,* [or] *it becomes a very difficult story*". Whereas Mooij added that there should always remain a sense of competition for the innovation to strive, under good and strict agreements (personal communication, 2020). One project that the City of Amsterdam is involved in, is the so-called 'Meetchain' project with Chaincraft in which ways to process the 'food waste soup' originating from the food grinders is investigated. Moreover, beside knowledge exchange between governments, knowledge institutes and entrepreneurs, Mooij explained that the three innovation system projects investigated in this research are also in close contact with each other (personal communication, 2020).

Furthermore, in addition to the previous statement that the province aims to exchange knowledge by connecting education, research and entrepreneurs, it is interesting to notice that there is also an important aspect of knowledge exchange between the municipalities in the AMA. Mainly given the targets set by the organisation 'Metropoolregio Amsterdam', and by the City of Amsterdam in relation to the AMA. Interestingly, Starreveld highlighted that knowledge exchange and collaboration on the topic of high-value food waste processing is much more performed on the level of the G4 municipalities in the Netherlands (i.e. The Hague, Rotterdam, Utrecht and Amsterdam) than between the municipalities of the AMA, because they face similar urbanisation challenges. Starreveld even stated that he does not "*have much hope for the AMA in this regard*", matching the sentiment of the quote of Suurmeijer about the 'big ego's in the AMA' (personal communication, 2020). Also, beyond the deficiency of decision-making in the AMA organisation, it was explained that the smaller municipalities in the AMA at present just simply do not have the time and (financial) resources to tackle the high-value (food) waste processing transition. Starreveld also emphasized that the City of Amsterdam is always open for collaborating with these smaller municipalities. Insights from the interviews with Persoon and van Stralen consolidated these statements about the geographical scale at which knowledge is exchanged. Where Persoon accentuated the need for regional over local cooperation on this topic in favour of economies of scale (both input and output), and van Stralen noted that they are mainly in contact with the City of Amsterdam, and no other regions in the AMA (personal communication, 2020).

Overall, it can thus be stated that knowledge exchange is high between knowledge institutes and the entrepreneurs of the technologies, and also between governments and the latter, however it is very centered around Amsterdam on a local level, and smaller municipalities in the AMA are more or less still lagging behind on the transition towards more high-value food waste processing. Most interestingly, the organisational body of the AMA as an 'administrative partnership of 32 municipalities' does not seem to take away this barrier.

7.2.4 Function 4: Guidance of the search

Hekkert et al. (2011) argue that regulations, visions and shared expectations are crucial factors for an innovation system to succeed. From the interviews it became apparent that both interviewed actors from governments and waste processors acknowledge the necessity of a transition towards high-value processing of (food) waste. A shared vision thus seems to be present. The support for this shared vision is predominantly demonstrated in the vision of Orgaworld, the recently published doughnut economy approach of the City of Amsterdam, the financial support of the RVO on the FABULOUS project, and the work of Starreveld as manager GFT/E at the City of Amsterdam where they are working towards pilot-scale application of grinders and high-value processing in collaboration with Chaincraft (Suurmeijer, personal communication, 2020; Mooij, personal communication, 2020; Starreveld, personal communication, 2020).

Nonetheless, this shared vision seems to be less present in the other (smaller) municipalities of the AMA due to the aforementioned lack of financial and human resources. Also, particularly the AMA organisation currently lacks vigour for translating this vision into concrete steps and practical application of high-value technologies. Hence, although a shared vision seems to be present, acting upon it is a difficult next step, especially translating it into a long-term vision and concrete actions (given the relative short term timeline of politicians). This is mainly manifested in the City of Amsterdam not yet separately collecting household vfg waste. Mooij suggested that governments should take a more active role to overcome this barrier, for example in the form of being a launching customer, providing an economic incentive (carbon tax on ‘fossil-based’ products), and via flexibility in regulations and legislation (personal communication, 2020).

Especially this ‘regulations and legislation’ factor was named by all interviewees as being a main barrier in the ‘guidance to search’ function, since labelling food waste as ‘waste’ now majorly limits the range of applications of VFA’s in for example food and feed due to public health safety restrictions. Starreveld noted that although the new LAP-3 (national waste management plan) already states that anaerobic digestion is not seen as ‘effective waste management’, and that the so-called ‘crisis- en herstelwet’ offers possibilities to opt for flexibility in legislation in favor of innovation, it is still a main barrier and that “*regulations take time*” (personal communication, 2020). Interestingly, Suurmeijer stated that this legislation regarding the waste status is currently the main reason for Orgaworld to not (yet) invest in companies such as Chaincraft (personal communication, 2020).

7.2.5 Function 5: Market formation

This function encompasses the current and expected future market size and whether it is sufficient to accommodate large scale diffusion of the technology. Quantitatively, this can be measured by the amount, and size of active projects. Qualitatively it can be supplemented by insights from key actors in the expected market size (Hekkert et al., 2011). The main image sketched during the interviews indicated that both the current and future expected market size is sufficient, however strongly dependent upon both the type of food waste input material, and the type of output for application. With regard to the former, Starreveld stated that “*the collection technique highly determines the composition of your organic waste”*, which was supplemented by a statement of Persoon: “*the availability of good residual flows may also become limiting at some point*”, referring to the current techniques that mainly focus on homogenous residual food flows from food processors over mixed heterogenous food waste flows from households. Therefore, in order for the technologies to be viable, they should be flexible in terms of the market size of their input material. Also, Suurmeijer explained that they shifted the focus of the FABULOUS project from solely bioplastics as output towards VFAs as output, as they “*provide a platform with which you can go in different directions”*. In line with this, Persoon opted for a ‘multi-functional factory’ on a regional scale (North West Netherlands) for the market size to be sufficient in the future.

Moreover, Persoon, Mooij and van Stralen both pointed out that before this multi-functional, regional scale will be achieved, the current lock-in of having enough material to convince clients to buy the products (i.e. create a market), and on the other hand having enough financial means to produce this material, as explained in the 'users of commodities produced' section in the previous chapter, should be overcome. According to Persoon, this requires a new value chain construction, which he tried to accomplish in an earlier project called 'Quisquiliae', in which a cooperative was aimed to set up. In this cooperative the members would be able to both produce and market the products due to its wide network of sectors, therefore overcoming the burden of scaling up before finding clients. Again, financial means were the limiting factor in succeeding this cooperative (personal communication, 2020).

It was also mentioned by Suurmeijer and Mooij that these new fermentation biotechnologies should not substitute the current market of composting and anaerobic digestion. Rather they should complement them, as it was argued that there is enough input material available, and since they are also much needed products (personal communication, 2020). Whereby again the challenge remains to separately collect household food waste in a high quality, and to process these flows for a wide range of high-value applications on a large scale.

7.2.6 Function 6: Resource mobilisation

This system function entails the availability of sufficient financial, physical and human resources for the innovation to diffuse. As already described in the previous functions, a lack of sufficient financial resources appears to be the main bottleneck with regard to resource mobilisation, and above all, for the whole innovation system to scale up (all interviewees except van Stralen, personal communication, 2020). This lack of financial resources indirectly also influences the 'entrepreneurial experimentation and production'-, and 'market formation' system function via a lock-in mechanism in which the latter could in its turn attract more financial resources. Surprisingly, van Stralen (Chaincraft) was the only interviewee that did not appoint a lack of financial resources, and even stated: "*the ecosystem is sufficiently developed for financing options from Europe or the Netherlands, or even at municipal or provincial level*. Although with the small remark: "*the biggest challenge occurs mainly in selling the product"* (i.e. market formation) (personal communication, 2020).

Secondly, physical resources seem not to be a main limiting factor, although it should be noted that the composition and quality of food waste flows highly influences the type of high-value fermentation processing applicable. Currently, mixed food waste flows collected from households in vfg waste, contain both kitchen and garden waste, while kitchen waste is the easily biodegradable waste, and for garden waste it is much more difficult to set up these processes (Suurmeijer, personal communication, 2020). Whereas in Amsterdam vfg waste is not even separately collected, as Starreveld pointed out: "*The chain is as strong as its weakest link. And that is really the collection at the moment. We are now at about 1-2% vfg collection in Amsterdam*" (personal communication, 2020). However, food grinders could potentially overcome this barrier, and it was appointed by both Suurmeijer and Mooij that vfg waste in an urban context provides good opportunities as the ratio kitchen-/garden waste is higher (personal communication, 2020).

Lastly, Persoon defined another physical bottleneck related to logistics. Stating that this could easily become too expensive when processing homogeneous flows from food processors, which could be overcome by developing a factory on an industrial location where both the inputs of food waste, and other utilities (i.e. steam, energy, electricity, water) are abundantly available (personal communication, 2020). Interestingly, hereby thus indicating the importance of a nexus approach on a regional scale.

7.2.7 Function 7: Counteract resistance to change

The current innovations of Chaincraft, AGC and the FABULOUS-project take, or have taken, a lot of time to scale up due to legislative and financial constraints. However, there is no direct resistance to fermentation high-value technologies, since all interviewees expressed that no one is 'against' high-value processing. Aside from the fact that composting and anaerobic digestion is still regarded the standard practice in the Netherlands and there could be a discussion around what is actually the highest application (i.e. Chaincraft, AGC or FABULOUS) (Mooij, personal communication, 2020). Mooij indicated that due to the current practices of composting and anaerobic digestion, there is currently no economic incentive to process food waste differently. Nonetheless, he hopes that the bioplastics of the FABULOUS project are able to change this, because they provide a more economic high value output product. Though Mooij also stated: "*But as long as there is no competition, and there is more than enough [organic residual flows], it can easily co-exist*" (personal communication, 2020).

Moreover, Starreveld explained that the main resistance might not be with processing the food waste, but rather with collecting it in an appropriate manner. With regard to the food grinders, the main resistance concerns the project development; i.e. how to adapt the buildings. With his pilots, he hopes to overcome this barrier (personal communication, 2020).

Lastly, Persoon also denoted consumer behaviour to be a potential resistance on the long term, since the products produced (especially food additives by AGC) should eventually also be embraced by the end-users, as it is produced from 'waste'.

7.3 Concluding remarks

As explained in the conceptual framework, Hekkert et al. (2011) provide three research steps to identify the functional barriers of an innovation system:

1. "Determine which system functions are forming a barrier;
2. Determine for each system function which structural component forms a barrier [...] (e.g. actors, institutions, networks, technology, knowledge, external factors);
3. Describe the relation between cause and barriers" (p. 13).

From the description of the seven system functions above, several main barriers for the innovation system to transit towards the next development phase can be concluded upon, thereby fulfilling the first research step of Hekkert et al. (2011). Below, figure 33 provides a concise overview of these barriers.

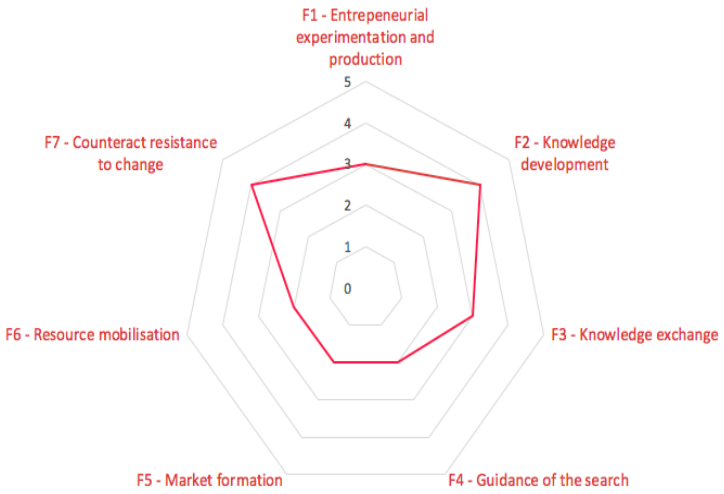

Figure 33. Overview of the system functions fulfilment of the 'fermentation biotechnologies for high-value food waste processing for VFAs production' innovation system.

Overall, it can be concluded that the **main barriers** of the innovation system under study are located in the functions: guidance of the search, market formation, and resource mobilisation. Moreover, for performing research steps 2 and 3 of Hekkert et al. (2001), these barriers are respectively caused by barriers from legislation around what is regarded as 'waste', difficulties with finding clients (i.e. creating a market), and limited financial resources for upscaling production. Consequently, these barriers influence the current situation around 'entrepreneurial experimentation and production' and 'knowledge exchange', since the main barrier of not being able to find the required financial resources (e.g. from governments or a profit motivated investor) obstructs to experiment on a larger scale (i.e. lock-in mechanism), thereby also to a lesser extent being able to exchange knowledge about the practical application of the technologies, i.e. beyond lab-scale or theoretical knowledge on the processes. Fewer knowledge exchange in its turn induces another negative feedback loop on guidance of the search and market formation, since less 'evidence' is available to convince governments and profit motivated investors to 'invest' in the technologies. The interplay of the main barriers and the most important functions in this development phase are visualised in the figure below.

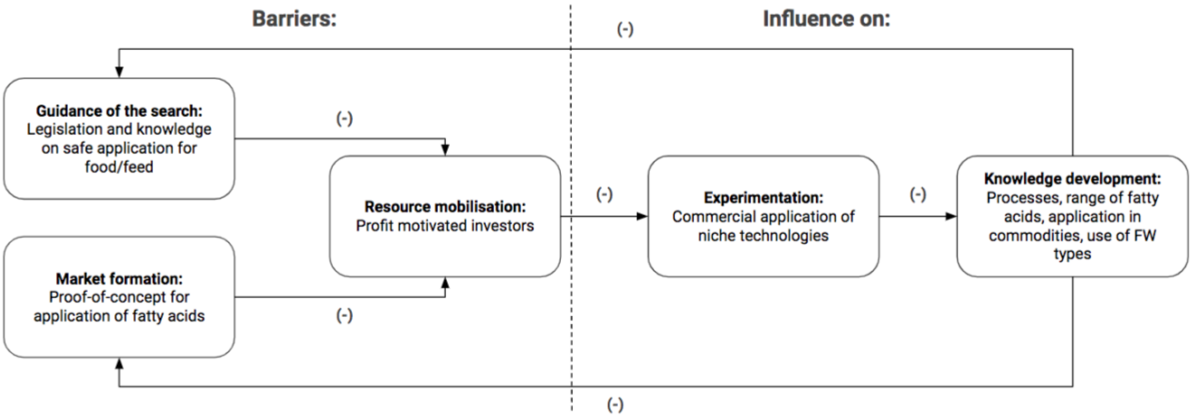

Figure 34. Structural causes of the main barriers of the innovation system with the most important system functions for transitioning to the next development phase.

Nonetheless, at the same time these 'barrier functions' provide opportunities to overcome these limitations to diffuse the technology. Namely, as stated previously, the mind-set of both governments and waste processors has clearly changed in a positive manner over the past decade. Namely shifting towards a preference for more high-value processing, including appropriate high-quality collection systems. This positive attitude could provide opportunities if governments would more actively demonstrate this preference by providing more economic incentive (e.g. subsidies, carbon tax, launching customers), flexibility in legislation (i.e. input not regarded as ‘waste’, but circular raw material), or increased regional cooperation.

Moreover, the level of experimentation and production, knowledge exchange and market formation, could potentially also be upscaled if biochemistry companies would take a more prominent role in the transition at the level of waste management. As expressed by several interviewees, these companies have a lot of knowledge on the practical application of fermentation technologies, and could potentially be the linking factor for an optimal design of the processes including optimal reuse of resources (e.g. energy, water, application of VFAs in bioplastics and other chemical applications).

8. Results IV: A pathway for large scale application

This chapter delves more in-depth into the opportunities mentioned in the previous chapter for understanding how the above-mentioned barriers could be overcome. This is done by means of the (1) backcasting method (Quist, 2013) that described the required actions to overcome the barriers, a (2) social network analysis that investigates actors, relations and potential collaboration structures for implementing these actions, and a narrative analysis to understand how the desired future (actor) state of the system could be accomplished. It thereby helps in answering the fourth sub research question of this research:

> *How will the introduction of fermentation technologies influence the organization of the current system and how could these changes help to remove the main barriers for large scale application?*

8.1 Future vision & backcasting a pathway

As described in the methods section, a future vision is sketched in this research based on the description of the multi-level system (i.e. regime, landscape and niche technologies), and the seven system function analysis, using the backcasting method. This future vision (i.e. normative scenario) serves two goals. First of all, it provides a first impression of the scale of implementation and type of applications that these niche technologies can provide in the (near) future, and what steps should be undertaken to achieve this. Secondly, the scenario was used as input for the surveys of the SNA.

Following the three steps of the methodological framework of Quist (2013), the *target* defined for the future system is: a food waste processing system in which (un)avoidable food waste is optimally reused while minimising impact on the environment. Several *criteria* to measure this target are: *efficient, renewable, circular, biobased, monitorable, and sustainable.* Meaning, the desired food waste processing system should be efficient in terms of energy and water usage, renewable in terms of energy inputs and commodities produced, circular by applying the most high-value valorisation option possible, biobased in relation to the output commodities produced, monitorable in terms of actual food waste flows (NACE codes) and environmental impact, and sustainable by minimising all environmental impacts related to water use, land use, GHG, biodiversity and resource depletion.

For the second step, the desired future vision was shortly defined as: *food waste processing in the AMA by means of large-scale application of high-value fermentation biotechnologies for fatty acids production.* This future vision is explained more in-depth below and was also presented this way to the survey participants. It focuses on the year 2030, in line with the objectives of the national government to use half less primary raw materials in 2030 (Rijksoverheid, 2018). Also, it is composed based on a comparison with a business-as-usual scenario. For this BAU scenario it is assumed that in 2030 quantities of food waste are virtually equal to the quantities observed for 2019 (see MFA in chapter 5). This assumption is based on the fact that with an expected increase in the AMA population size, it is expected not to have a significant influence on the overall quantities of food waste. This given the research of Soethoudt and Vollebregt (2019) that shows that in the period 2009-2017 food waste per capita in the Netherlands barely changed. However, based on population growth numbers for the year of 2020 that indicate that population growth in the AMA mainly occurred in Amsterdam and its surrounding municipalities[28], it is expected for the BAU scenario that urbanisation rates will increase. It is expected that this impacts the composition of food waste flows for 2030 by having a better kitchen/garden waste ratio, but at the same time to have more food waste being incinerated when BAU collection- and treatment methods are retained. Therefore, the future vision outlined below provides an improvement in relation to the BAU scenario.

The future vision

Collection

In the year 2030, all municipalities in the Amsterdam Metropolitan Area will collect organic / food waste from households separately. In addition, in all new buildings, built from 2026 onwards, a food grinder is present that collects kitchen waste efficiently and makes it suitable for high-quality processing. Inhabitants of older residences will dispose of kitchen waste separately from garden waste in 2030 via their own bin or underground waste containers. Additionally, current waste taxes for households will be adjusted to a system in which citizens are rewarded for producing less residual waste. E.g. by making a smaller bin for residual waste in peri-urban areas the default selection, at which citizens need to pay extra to have a larger residual waste bin. For more urbanised areas and high-rise (e.g. Amsterdam, parts of Haarlemmermeer) with mostly underground collective containers, this could be regulated by equipping them with chips and a personal card system.

Also, companies apply the highest efficiency to minimize cutting losses and thus save costs on waste taxes, and to make a profit with (free) residual products that other food products can be made with. Restaurants and supermarkets also efficiently handle their food waste products, because there is a lot to be gained in the (free) re-use of these food waste products in, for example, soups and drinks, and it also provides a reduction in their waste taxes.

Despite the fact that by 2030 wasting of avoidable food waste has been reduced enormously, which led to increased processing of unavoidable food waste (e.g. peelings, clock houses, coffee and tea residues, meat and fish residues), the amount of food waste collected separately is higher compared to 2020, because unavoidable food waste is now better collected separately.

Processing

Due to the higher quantity and quality of collected organic waste (i.e. more kitchen / food waste), high-value techniques can be used in a more economically profitable way. Processing no longer only takes place via incineration, composting and anaerobic digestion, but the vast majority of the food waste is processed with high-value fermentation techniques via VFAs to applications in the chemical sector. For example, bioplastics with added value, feed and food additives, plasticisers and paint. The processing into bioplastics, plasticisers, paints and solvents have the largest share, because this required less flexibility of laws and regulations with regard to 'waste' use for feed and food.

Nevertheless, by 2030 the legislation and regulations for the processing of food waste flows will have opened some space for experimentation for food and feed, if it can be demonstrated that no contamination occurs in the food waste flows and in the final food or feed product. Processing for feed applications will take place in 2030 in an upscaled factory that produces approximately one million

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[28] See: https://www.metropoolregioamsterdam.nl/sterke-groei-gemeenten-rond-amsterdam/

kilos of fatty acids output (e.g. Chaincraft - source Parool). Production for food will take place in 2030 in a first small-scale factory (beyond pilot experimentation), where it will process a small share of food waste from the local food processors, agriculture and the catering industry. With these new laws and regulations, these waste flows are therefore no longer regarded as 'waste', but as raw materials for making products that (indirectly) replace fossil products.

In the overall picture, the processing of food waste consists of 10% incineration via residual waste, 30% composting and fermentation and 60% of the aforementioned high-value fermentation techniques. At which the 30% composting and fermentation equals the amount of organic streams that were processed by these techniques in 2020, and the 60% high-quality fermentation techniques are due to the improved separate collection of (un)avoidable food waste that ended up in the incinerator in 2020. In other words, the new fermentation techniques are an addition to, and not a replacement for, the production of compost and biogas from organic waste.

With regard to both composting and anaerobic digestion, and the high-value fermentation techniques, the techniques are applied from a holistic system perspective to minimize environmental impacts. Meaning that in- and output resources are optimally utilized. One could think of recovery of waste water to drinking water quality to economize on high wastewater taxes and reduce environmental impact. Another example could be an industrial symbiosis with local industries on exchange of ethanol from beer brewers that produce alcohol-free beers, exchange of residual heat, or usage of the residual product for further composting and biogas production.

For applying the final step of the methodology of Quist (2013), it was determined which steps should be undertaken to achieve the desired goal (i.e. backcasting). This was done by defining each step by a ‘what’, ‘how, ‘who’, and ‘when’ question. For sake of clarity and the timeline, these steps were subdivided into 4 categories based on the ‘sector’ in which these actions have to be implemented: regulations & incentives, collection, infrastructure & fermentation technologies, and application. The table below provides an overview of the actions to be undertaken, and figure 34 summarizes these steps on their location over time.

Table 8. Steps required to achieve the 'future vision', subdivided per category. Describing 'what' needs to be done, 'how' - by what interventions, by 'whom', and 'when' concludes the actual temporal pathway of these steps.

	What	**How**	**Who**	**When**
Regulations & incentives	- **Flexibility** in food waste processing **regulations** to create room for safe experimentation for feed and food applications (Chaincraft, AGC, BSF[29]) - Adjust **waste taxation** schemes to incentivise higher quality waste separation - National or European **carbon tax** for fair level playing field of biobased commodities - Retain and increase **financial support** (subsidies) for high-value valorisation technologies at a regional scale in the AMA	Resp.: - National policies - Research - Municipal policies - European policies - Regional support and investments	Resp.: - Rijksoverheid together with knowledge institutes - 32 municipalities - EU - AMA organisation - Province of Noord Holland and Flevoland	As soon as possible, at which EU regulations (carbon tax) will likely require more time before implementation.
Collection	- Experimentation with **food grinders** - Experiment with **separate kitchen waste** collection in highly urbanized areas (Amsterdam, Haarlem, Almere) - Increase collection of **mixed food waste** streams from **companies** - Improve **monitoring** food waste from companies (NACE codes)	Resp.: - Research - Investments (pilot projects) - Improve mixed food waste processing with high-value techniques to incentivise companies - European/national policies (NACE codes)	Resp.: - Municipalities of Amsterdam, Haarlem and Almere via contracts with collectors and processors - Chaincraft, FABULOUS, other niche technologies - EU/Rijksoverheid (LMA[30])	All as soon as possible, but expected to take more time than regulations above (i.e. pilots). Also, mixed food waste companies will take more time as it is incentivised by the improvement of niche technologies.
Infrastructure & fermentation technologies	- **Upscaling** of fermentation niche technologies - **Efficient logistics** for more diverse landscape of processors - **Efficient** high quality **separate** (kitchen waste) **collection** in urbanized areas	- Experiment with niche technologies at current anaerobic digestion plants - Open space for experimentation in current long term contracts of municipalities with waste processors - Locate near companies food waste origin and collaborate at regional scale - Redesign waste bins and containers	- Current waste processors (Orgaworld, HVC, Meerlanden) - Chaincraft, FABULOUS, AGC - Municipalities - Food waste processing sector - Commercial collectors of companies food waste	By 2025: Starting now dependent upon the developments concerning the two categories above.
Application	- **Social acceptance** of	- Open and	- Food sector that	By 2030, and

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[29] Black Soldier Fly (BSF) food waste processing technologies would also benefit from this intervention.

[30] Landelijk Meldpunt Afvalstoffen.

	consumers for ‘waste’ in food products - **Market creation** for high-value biobased fatty acids produced	transparent storytelling of products for added value (e.g. Kromkommer, Verspillingsfabriek) - Upscale technology (see above) to provide proof of concept in bioplastics, feed/food additives, plasticizers, etc.	eventually uses the food additive - Chaincraft, FABULOUS, AGC - Biochemical sector that prepares fatty acids for application in commodities - Food, plastics, feed sector	beyond.

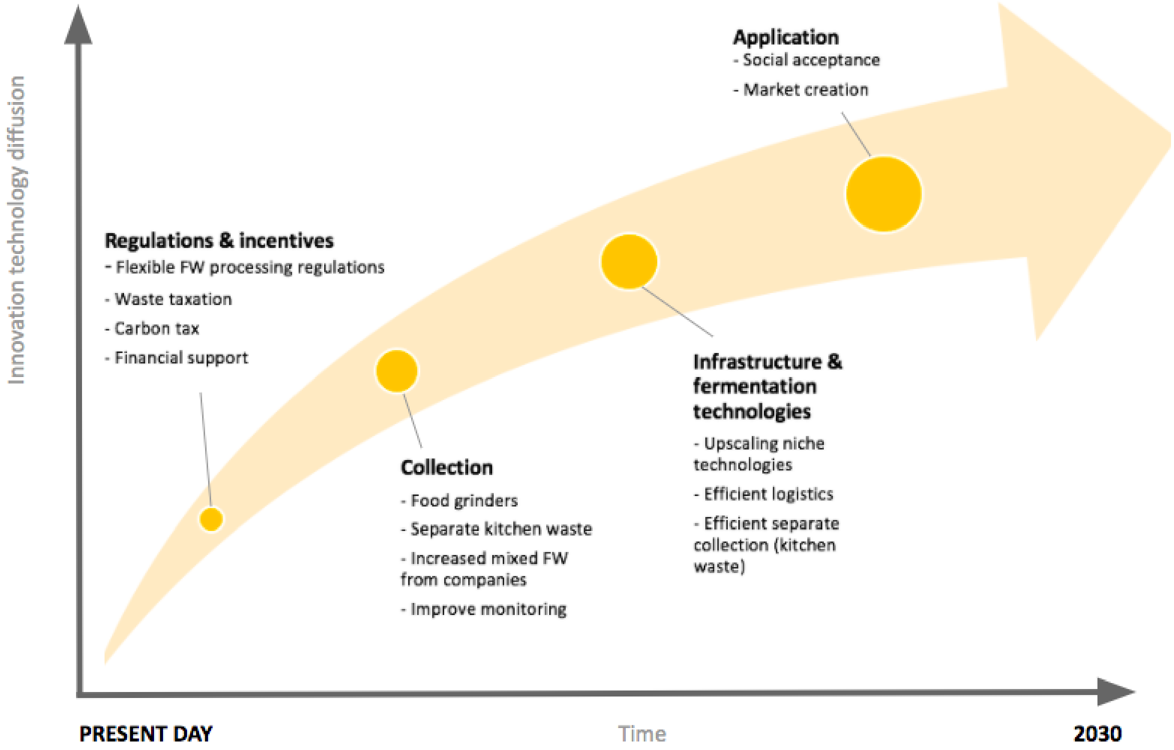

Figure 35. Overall temporal pathway of steps required to achieve the desired future vision as described above.

8.2 Current and future actor constellations

In addition to the backcasting analysis, a social network analysis (SNA) was performed based on the input of quantitative surveys to understand how the previously described required actions could be implemented in the actor network to arrive at the desired future vision. Therefore this section presents visualisations and a comparison analysis of the current and future actor system of the investigated innovation technology. The current actor system includes the current food waste processing system in the AMA as described in the previous chapters, and serves as a benchmark to compare the future actor system to. The future system entails the actor system if the fermentation technologies would be applied at large scale (i.e. the future vision).

Before delving into the specifics of the current and future actor system, a brief explanation of the outline of the SNA is needful. As explained in the methods section, both actor systems are explained via a visualisation of the actors (nodes) and their relationships (edges), and five statistical SNA metrics that describe the relative importance of the actors and their relationships over time. The table below provides an overview of these network metrics.

Table 9. Overview of the network metrics for the actor constellation analysis (source: adjusted from Buth et al., 2019).

Network level	**Metric**	**Visibility in network properties**
Overall	Network density	Cohesiveness of the network
Nodes	Betweenness centrality	N.A.
	Eigenvector centrality	N.A.
Edges	Strength of the relation	Width of the tie
	Degree	Number of connections

Moreover, it is worth noting that the representation of the actor groups in the network visualisations is based on the expert judgement and personal interpretation of one actor in that specific actor group. For the sake of nuance, for both actor systems first a less aggregated version of the actor networks, on the level of actors instead of actor groups, is presented. Note however that these visualisations do not provide a fair representation of all mutual relations of the actors in the system, as they are formed from the perspective of the four research participants in the surveys (i.e. province of Noord Holland, Orgaworld, AMS Institute, and Wageningen Research). Still, they are added to the results in this chapter, since they indicate which actors are represented by the actor groups, and the interactions at different governance levels (i.e. multi-level governance).

8.2.1 Current actor constellation

Note that all 4 network visualisations are presented at the end of this section, for sake of comparison. Firstly, the actor overview visualisation in figure 36 presents the current actor network on actor level. Each actor that was listed during the survey exercise is presented by a node in a colour that refers to the actor group in which the actor network is later aggregated to (see title; e.g. government, knowledge institutes, food waste generation). The edges (i.e. lines) between the nodes represent the frequency of interaction between these actors, at which a thicker line indicates a more frequent interaction (i.e. strength of relation - see survey in appendix for Likert scale). For this, the term interaction is defined as: exchange of knowledge, data, technology, products, services or financial resources. Also, the actors are sorted by governance level. The local level indicates actors active at the municipal level, whereas the regional level includes actors active across municipal levels but within the AMA boundaries. Lastly, the highest level contains actors active (or established) outside or across the AMA boundaries (with respect to food waste processing. For the current actor system, it was assumed that only Chaincraft represents the niche technologies, since it is the only of the three technologies to be operating at a commercial scale.

From this first visualisation of the current actor constellation, it can be concluded that Wageningen University and Research, AMS Institute and TU Delft are the main knowledge institutes, as they were mentioned most often by the respondents. Furthermore, the governments with a major role in this actor system are the City of Amsterdam and the AMA organisation. This indicates the formerly mentioned strong focus on Amsterdam in this 'AMA-focused' issue of food waste processing, which on the contrary might demand a more regional approach as was indicated by most of the interviewees. Also, the current (food) waste processors in the AMA (dark blue actors) appear to be in a strong relation (amount of connections and thick edges), as this was also underlined by the respondent from Orgaworld who stated that they are in good contact with each other, as they are also clients of each other. This can be an important factor for exchange of knowledge and practice of, and collaboration for, high-value food waste valorisation.

Subsequently, the outcomes of the surveys and the actor constellation in figure 36 were aggregated to the level of actor groups, which can be seen in figure 38. Chaincraft is still presented at actor level, as it represents the 'niche technologie(s)' for food waste processing in the AMA, and since it is the main research focus of this study. Also, the food waste generators (e.g. supermarkets, restaurants, etc.) are still represented at actor level, as their separate relationships with other actor groups in the network might indicate a specific sector focus for (high-value) food waste processing in the AMA, and the respective opportunities or barriers for handling these diverse types of food waste flows.

Node metrics

To conclude upon the main properties of the current actor constellation, table 10 provides a summary of its network metrics. To start with, based on the first network metric (i.e. betweenness centrality) it can be concluded to what extent actors serve as an intermediary in the actor system. The betweenness centrality metric namely measures to what extent an actor lies on the (shortest) path between two other actors, meaning the higher the betweenness centrality, the higher the extent to which the actor serves as an intermediary for resource exchange. As can also be seen from the network in figure 38, the current waste processors, governments and knowledge institutes have a central position in the actor network, which reflects in their betweenness centrality score (resp. 7, 8.5 and 12). This implicates that most resources are exchanged in the current network via these actor groups. Nevertheless, one should take into consideration that this includes for example both knowledge, physical, and financial resources. In the current analysis, these different resources were not weighted, though if one would put a higher importance to financial and physical resources (e.g. food was flows themselves and financial resources to commercially process them), it can be argued that the current waste processors would take a more central role and a higher betweenness centrality score than governments and knowledge institutes. As for the latter it is assumed their interaction with other actor groups is mainly determined by knowledge and information exchange.

Secondly, the eigenvector centrality adds an extra important dimension to the betweenness centrality, as it also measures the importance of the surrounding nodes. Therefore this metric indicates the importance and/or influence of the actors in the network. From the table below it can be derived that again the current waste processors, governments and knowledge institutes have the biggest influence in the system (i.e. resp. 0.963, 0.945, and 1), whereas Chaincraft now also shows a prominent score (i.e. 0.908). The latter can be explained from the fact that Chaincraft had a 'medium' score of 4.5 on the betweenness centrality, and the actor groups to which it is connected in their turn also have relatively many (i.e. degree metric) and important (i.e. betweenness centrality metric) connections, as Chaincraft is connected to all three formerly mentioned most important actor groups. On the contrary, the least important actors (groups) are households/citizens, as only knowledge institutes and governments (i.e. municipalities) are in direct contact with them to exchange knowledge and create awareness.

Overall & edge metrics

Lastly, the overall network density of 0.515 indicates that the network includes 51.5% of all actor connections possible between all nodes in the network. Whereas the degree metric and the width of the edges indicate respectively the amount and strength of the connections per actor group. Moreover, the degree of each actor group determined the location of the actor group in the network visualisation in figure 38. At which actors with a higher degree are located at a more central position, and actors with a lower degree are positioned at the periphery of the network, where less resources flow.

From the degree metric it can be concluded that the same four actors (groups) have the highest degree, which makes sense as the previously discussed metrics are connected to the degree of each actor. Though it is interesting to put these numbers of connection (i.e. degree) in relation to the strength of these relations as is visualized in figure 38. This shows that although governments, knowledge institutes and the current waste processors have almost equal scores on the node metrics and the degree metric, the waste processors show relatively stronger relations with the actors they are connected to (i.e. width of the lines). Also, Chaincraft has less connections (9), but those relations are stronger than the ones of the knowledge institutes and governments. From the assumption that for knowledge institutes and governments these interactions mainly entail knowledge and information exchange, this result seems logical, since food waste processors (both the status quo and Chaincraft) have more frequent interactions with their connections, as these concern physical resource exchange (e.g. waste, energy, water), and process optimisation on a daily basis. Also, from a nexus perspective, it is interesting to note the connections to the water, energy and biochemical sector, despite their location in the periphery. Especially the current relatively weaker relationship between current waste processors and the biochemical sector (in its broadest sense, e.g. for application of fatty acids in bioplastics or optimisation of fermentation processes).

Table 10. Overview of the network metrics in the current actor network.

Actor group	**Betweenness centrality**	**Eigenvector centrality**	**Degree**
Current waste processors	7.0	0.963	10
Governments	8.5	0.945	10
Knowledge institutes	12.0	1.000	11
Chaincraft	4.5	0.908	9
Restaurants	0	0.429	3
Food processing sector	0	0.563	4
Agricultural sector	0	0.563	4
Supermarkets	0	0.563	4
Biochemical sector	0	0.563	4
Energy sector	0	0.424	3
Water sector	0	0.563	4
Households/citizens	0	0.287	2
Overall network density	0.515		

8.2.2 Future actor constellation

The actor overview visualisation in figure 37 presents the future actor network on *actor level*, again first from the perspective of the survey respondents. The first thing that can be noticed from the future network system at actor level, is that it contains more actors and relations (nodes and edges) than the current system network. Most actors are added at the local and national level. The local level now also includes the other two niche technologies (AGC and FABULOUS), whereas at the national level more actors from the biochemical sector, and a ‘regional’ collaboration of 4 large municipalities in the Netherlands are included (i.e. G4 municipalities). The latter indicates the necessity of increased regional collaborations in the near future as these large municipalities face the same urban challenges with regard to (food) waste processing (Starreveld, personal communication, 2020). Also, in the future system the animal feed sector is included at the regional level (i.e. within the AMA boundaries), since it was claimed by the survey respondent from Orgaworld that fractions currently used for animal feed production could be used in the future by the current waste processors for more high-value applications such as bioplastics and animal feed additives.

Node metrics

Subsequently, given the aggregated future actor constellation in figure 39 and the metrics of this future system in table 11, several conclusions can be made in comparison to the current actor network. With regard to the node metrics, it can be observed that the betweenness centrality of the current waste processors and the niche technologies (now also AGC and FABULOUS) decrease, while it increased for the governments, and remained equal for the knowledge institutes. This implies that the governments (together with the knowledge institutes) gained a more prominent position as an actor that serves as an intermediary on 'the shortage' path to other actors in the system. Nonetheless, again in relation to the type of resource exchange (e.g. knowledge versus physical).

Moreover, the eigenvector centrality metric demonstrates the same proportional results compared to the current network system, since the knowledge institutes, governments, current waste processors and the niche technologies are deemed the 'most influential' based on these metrics. It should be noted though that the eigenvector centrality of the current waste processors and the niche technologies increased relatively more (resp. to 0.979 and 0.946) than the other two. This can be explained from the fact that the former is connected to almost all actors in the future system, whereas from a government perspective it was claimed by several respondents that the niche technologies and waste processors would require less intervention from government in the future system, because the current 'imperfection' in the market[31] would be solved by the large(r) scale application of the high-value valorisation techniques.

Overall & edge metrics

Whereas the node metrics do not present significant changes in the future network compared to the current network with regard to shifting importance and influence of actors, more interesting conclusions can be drawn from the network density and edge metrics. First of all, the overall network density shows an increase from 0.515 to 0.604, which does not necessarily coherent to the addition of the new actors in the system, since more actors can still mean a less dense (i.e. centralised) network. In other words, the newly introduced actors in the network are well connected to the other actors in the future network. This offers opportunities for a nexus governance approach, because this means the technologies will in the future be closely connected to e.g. the water, energy, food and biochemical actor groups.

Furthermore, the degree metric shows an increase of 2 connections for almost all actor groups (except restaurants), which logically can be explained from the addition of AGC and FABULOUS to the overall future network. Nonetheless, the most interesting changes can be witnessed from the changes in the strength of the relations (i.e. width of the edges). To start with, an increased strength of relation can be observed for the biochemical sector, especially with the niche technologies, but also with the current waste processors. This change in relations originates from the assumption of the respondents that with the increased interest for biobased products and chemicals from food waste, this implies more contact with the biochemical sector concerning both the processing of the fatty acids in e.g. bioplastics and feed/food additives, and the optimisation of fermentation processes. Hence indicating an increased intertwining of the waste processing sector and the biochemical sector.

Also, with regard to the water sector actor group, it can be observed that the degree metric increased, while the strength of the relation metric did not. This can be explained from the fact that in both the semi-structured interviews and the surveys it was indicated that current waste processors often process their wastewater on site. It is expected for the future system that when the niche technologies will be operating at a large commercial scale, this will account for them too, as it increases efficiency, but most importantly, it lowers the costs. Consequently, the relations with the water sector will not increase compared to the current system.

Moreover, in relation to the previously mentioned 'imperfection' in the market that causes a decreased connection of governments to waste processors, it can on the contrary be argued for

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[31] The 'imperfection' in the market refers to the fact that food flows are not optimally used, resulting in food waste, which in its turn is not processed most efficiently from a circular and sustainable perspective.

restaurants and supermarkets that the strength of these relations will increase in the future system. This can also be observed from figure 39. The survey exercise showed that restaurants (and supermarkets) require more support in correctly separating and processing food waste, as they are often small(er) companies that do not have the financial means to do so on their own.

Also, while the strength of relation decreased for governments (especially municipalities) with Chaincraft, this governmental relations with the niche technologies increased for the FABULOUS project. This change can be explained from the focus of FABULOUS on vfg waste as input for their processes, while AGC and Chaincraft focus on more homogenous food waste flows from the food waste processing sector. More specifically, the former currently (and in the near future still) requires close collaboration with the City of Amsterdam in particular to execute their newly set goals to separately collect vfg waste.

Table 11. Overview of the network metrics in the future actor network, including large scale high-value food waste valorization via fermentation technologies.

Actor group	**Betweenness centrality**	**Eigenvector centrality**	**Degree**
Current waste processors	6.0	0.979	12
Governments	9.3	0.947	12
Knowledge institutes	12.0	1.000	13
Chaincraft	2.9	0.946	11
Amsterdam Green Campus	2.9	0.946	11
FABULOUS	2.9	0.946	11
Restaurants	0	0.324	3
Food processing sector	0	0.638	6
Agricultural sector	0	0.638	6
Supermarkets	0	0.638	6
Biochemical sector	0	0.638	6
Energy sector	0	0.534	5
Water sector	0	0.638	6
Households/citizens	0	0.216	2
Overall network density	0.604		

Current actor system - actor level

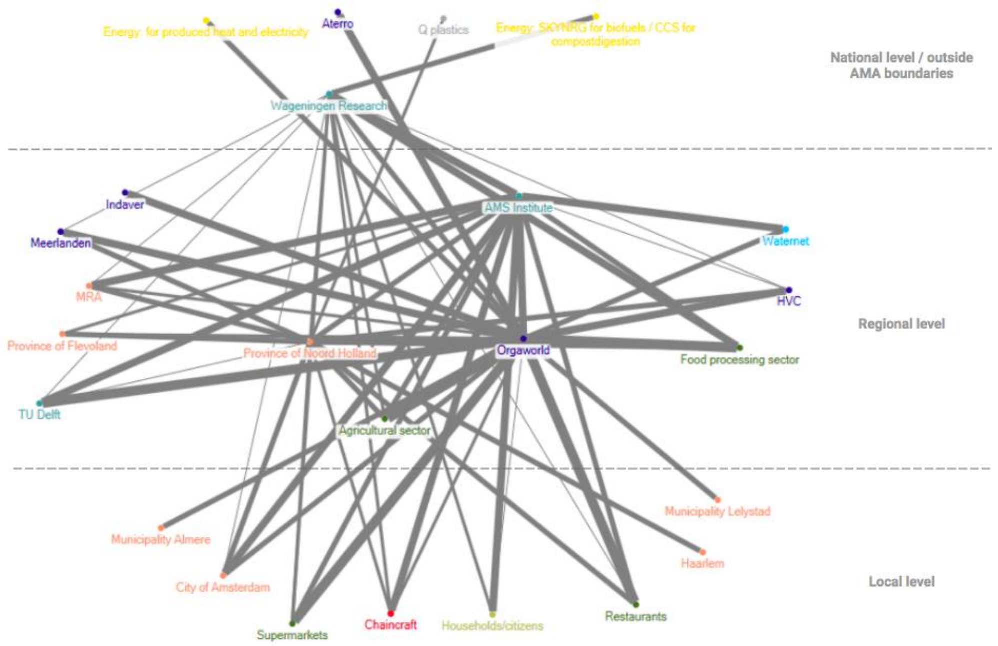

Figure 36. Actor constellation of the current actor system at actor level, presented from the perspective of the survey respondents (i.e. Orgaworld, Province of Noord Holland, Wageningen Research, and AMS Institute). Red: niche technologies, Yellow: energy sector, Grey: biochemical sector, Dark blue: waste processors, Salmon: Government, Dark green: Food waste generators, Light Blue: water sector.

Future actor system - actor level

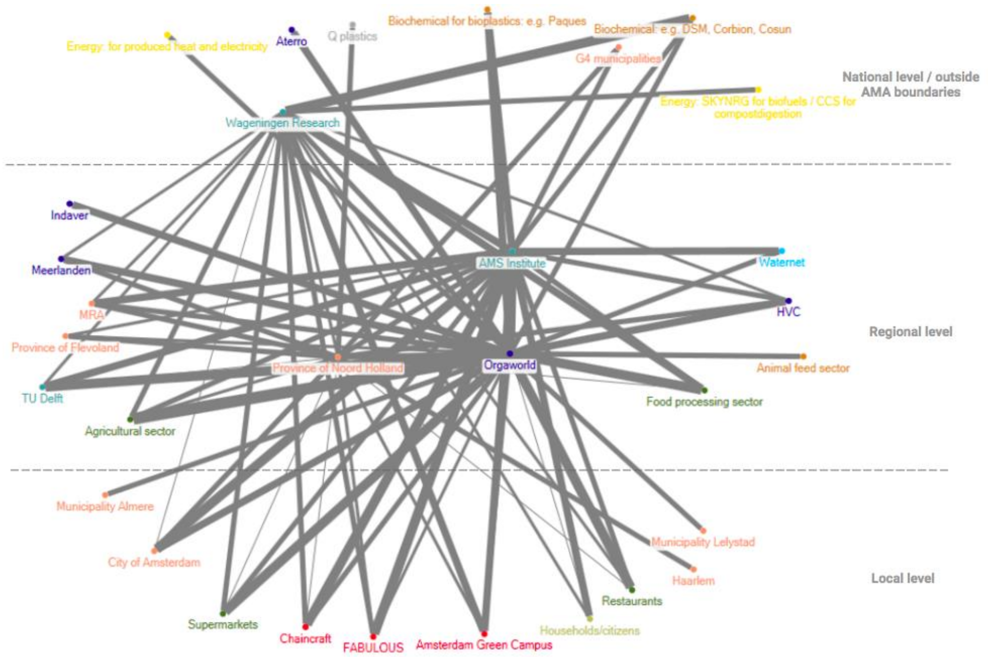

Figure 37. Actor constellation of the future actor system at actor level, presented from the perspective of the survey respondents (i.e. Orgaworld, Province of Noord Holland, Wageningen Research, and AMS Institute). Red: niche technologies, Yellow: energy sector, Grey: biochemical sector, Dark blue: waste processors, Salmon: Government, Dark green: Food waste generators, Light Blue: water sector.

Current actor system - actor group level

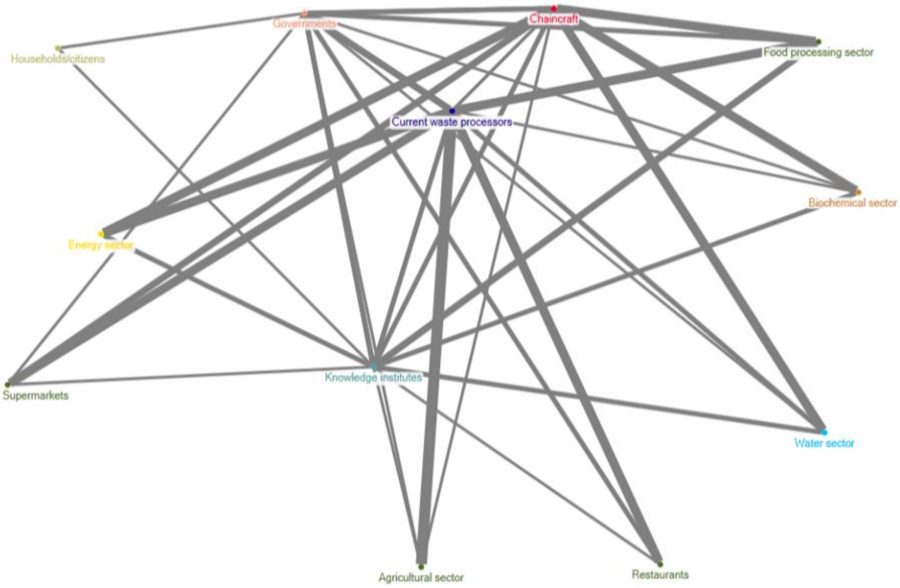

Figure 38. Actor constellation of the current actor system of food waste processing in the AMA at actor group level. Red: niche technologies, Yellow: energy sector, Grey: biochemical sector, Dark blue: waste processors, Salmon: Government, Dark green: Food waste generators, Light Blue: water sector.

Future actor system - actor group level

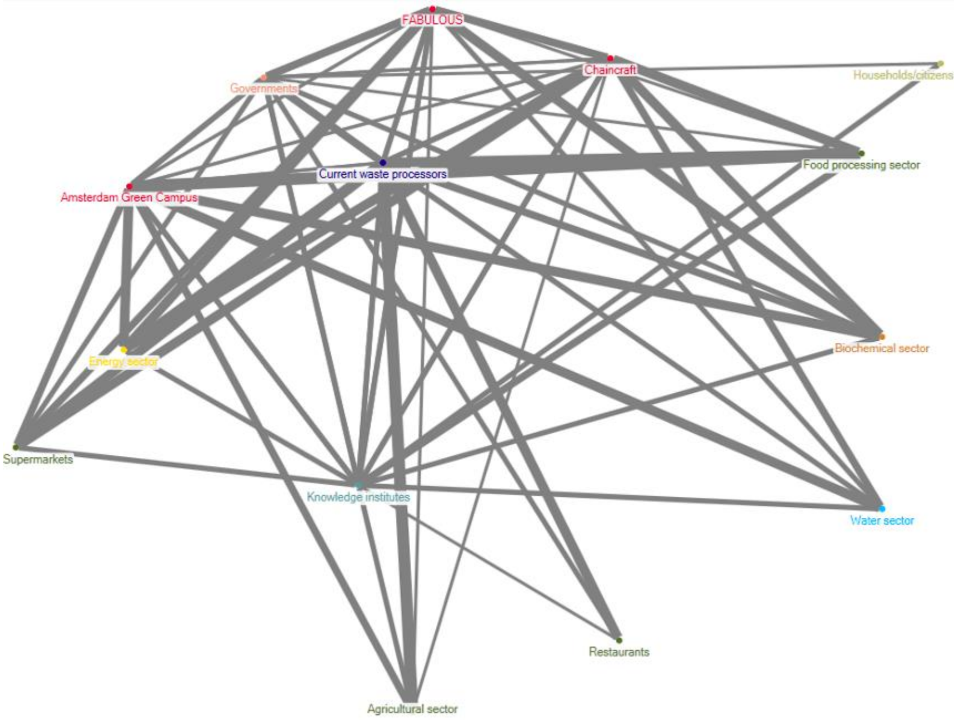

Figure 39. Actor constellation of the future actor system of food waste processing in the AMA at actor group level. Red: niche technologies, Yellow: energy sector, Grey: biochemical sector, Dark blue: waste processors, Salmon: Government, Dark green: Food waste generators, light Blue: water sector.

8.2.3 Conclusion SNA

Firstly, it is observed that the main changes in the actor system can be expected not so much with regard to changes in influence and importance of central actors (groups) in the system (e.g. becoming more decentralised), but more in relation to an increased complexity of the actor network and a shift in their functions, as new actors will be introduced within the actor groups. More specifically, it is expected that the biochemical sector actor group will include a more diverse range of actors in the future network (i.e. from processing of fatty acids into bioplastics, up to optimisation of fermentation processes themselves), since high-value fermentation technologies will become more interesting. Also, the introduction of all three niche technologies on a large scale, will add a noteworthy connection to the current animal feed sector, as current homogenous food waste flows from the food processing sector that are used for animal feed are expected to diverge towards more high-value applications such as the ones from FABULOUS for added-value bioplastic production. Moreover, with regard to the functions of the actors, a shift is observed for current waste processors from solely a 'waste processing' function towards also provision of a wide(r) range of biobased commodities such as bioplastics, feed/food additives and additives for paints and plasticizers.

All in all, for the current waste processors (Orgaworld, Meerlanden, HVC, Indaver) it is interesting to observe that in both systems they have a central position and a bridging function when it comes to exchange of both knowledge and information, and financial and physical resources (e.g. food waste flows, energy, water, output products). This indicates that their current central position in waste processing will still be present in the desired future system. Therefore, in the future system - from a nexus governance perspective - they can potentially serve as a bridging actor group between food waste flows and governments on the one hand, and the application of more high-value niche technologies, and their application in the water, energy and food (additive) sector on the other hand.

It should be noted however that due to the competitive position of waste processors mutually, the government (especially on a regional level - e.g. AMA organisation, G4 municipalities) could play a more prominent role in assessing the best combination of techniques and measures from a system perspective in which both circularity and sustainability are assessed over the whole life cycle of the food (waste) supply chain (i.e. LCA approach). Consequently, this requires an integration of an increased bottom-up (i.e. local/regional government system approach for the right techniques in the AMA context) and a top down approach (financing, economic incentives) by stimulating niches in combination with the established order.

Lastly, it needs to be mentioned that the outcomes of this chapter could turn out to be more nuanced than presented above. The results are namely based on the personal interpretations and expectations of the interviewed experts in the food waste processing system in the AMA. Therefore, the outcomes do not predict the future, and the actual future pathway might deviate, however it provides a first solid exploration of the potential shifts in connections, relationships and functions of actors in this system. Consequently, these insights provide valuable lessons for both policy makers, academia and actors in the field for desired development pathways and policy incentives.

8.3 Narratives

Lastly, these quantitative outcomes are complemented with a qualitative analysis in the form of a description of the main narratives present in the current actor system based on expert judgement. The narratives contribute to the third and fourth sub research question of this research by comprehending the way actors think a certain desired future state of the system should or could be accomplished. This analysis is based on the qualitative outcomes of chapter 7 on the seven system functions of the innovation system, and the quantitative outcomes of the social network analysis above.

As argued by Ingram et al. (2014), narratives are namely often shaped in coalitions of actors with certain interests. Knowing the position and relations of these actors that carry competing narratives contributes to understanding and enhancing a desired transition by understanding their competing interests that might be redirected by means of nexus governance. Below, an overview is provided of the main narratives of coalitions of actors in the food waste processing system of the AMA:

Table 12. Main narratives in actor coalitions in the food waste processing system of the AMA.

Coalition	**Narrative**	**Recommendation**
Academia	High-value food waste valorisation techniques offer possibilities for a more circular society, however they should always be taken into consideration with their environmental impact (overall sustainability). Current studies only provide these insights for anaerobic digestion and composting compared to incineration, or small-scale decentralized valorisation options (i.e. home composting).	**Research:** A full life cycle analysis of high-value valorisation fermentation techniques for bioplastics, and food/feed additives. Taking into consideration that they are complementary to current AD and composting volumes in the AMA case.
Current waste processors and governments	Given the national governmental goals of ‘100% circularity in 2050’, they are fully committed to these new high-value techniques (also BSF), as long as it is financially feasible in the current system compared to the status quo (e.g. bioplastics versus plastics, animal feed additives from biobased versus primary source). The holistic system perspective (see above) is often overlooked in this narrative, since the main focus is on ‘circularity’.	**Policy:** Better integration of what is desired from an environmental perspective for the ‘100% circular’ goal, with what is (financially) feasible (e.g. via carbon tax, incentives).
Companies (e.g. current waste processors, food processing sector, supermarkets)	Developments around high-value food waste valorisation are mainly driven by economic incentives. E.g. ‘get rid of’ waste and process wastewater as cheap as possible against yield from energy versus high-value output commodities.	**Policy:** Transition for high-value valorisation could be accelerated if the government would provide economic incentives, that would make these niche technologies also attractive to smaller waste processors, niche companies and smaller municipalities in the AMA. **Research:** These economic incentives could be maintained on the long term, if more insight on food waste flows that would still be susceptible in the future (e.g. what flows would disappear due to better prevention of food losses). **Companies:** Focus on those high-value commodities produced that have an added value compared to the status quo. E.g. bioplastics in slow-release fertilizers.
Users of (future) fatty acids/commodities	Commodities from high-value valorisation techniques should have a comparable or higher quality than currently used fossil-based commodities for the same, or lower price (unless higher value proposition due to added value).	**Research**: More research into the specifications of the output commodities of the niche technologies (range of fatty acids) for application in food, feed, bioplastics, etc.

In conclusion, beside the recommendations per coalition, a cross-coalition narrative analysis shows that for further diffusion (upscaling) of the niche technologies of Chaincraft, AGC, FABULOUS and other potential new high-value fermentation techniques in the near future, the overall environmental impact (both circularity and sustainability) should be included more thoroughly in decision-making. Moreover, the narratives also appear to be not so much 'competing', but more so mainly to be about different economic incentives of different coalitions. Both for the economic feasibility of the niche technologies, as well as the profitability and quality standards of the biobased fatty acids in commodities compared to the status quo products (i.e. plastics, food/feed additives). So, while these narratives are thus not so much competing in its focus (i.e. financial), still its conflicting nature on proving the worth of the new biobased commodities could be overcome by focussing on added value commodities (niche technologies), and knowledge exchange of e.g. current plastic producers from fossil based resources to demonstrate the quality of the new biobased commodities.

8.4 Concluding remarks

Based on the barriers found in the previous chapter, and the analysis in this chapter on opportunities and required actions, some conclusions can be drawn. First of all with respect to the influence of the niche technologies on the actor network of food waste processing in the AMA. But also with regard to how these changes in the actor network could provide opportunities for removing the main barriers by implementing the main actions found in the backcasting analysis. Hereby concluding upon how the desired future scenario could be achieved.

Table 13 summarizes the main outcomes of the separate analyses, whereas figure 40 visualises how the barriers for the socio-technical transition of large scale high-value food waste valorisation in the AMA could be overcome. It mainly shows that this requires:

- increased regional collaboration of waste processors, niche technologies and governments;
- flexible legislation and economic incentives from the national government for biobased alternatives;
- an overall more holistic- and system perspective including all environmental impacts to come to the most circular and sustainable regional (food) waste management strategy;
- and increased knowledge exchange and experimentation with regard to the quality, processes and added value of platform applications of the fatty acids.

The interrelations of these required actions and how they remove the barriers are more clearly visualised in the figure itself. The figure presents an adjusted version of figure 34 that presented the main barriers. The figure should be read from the bottom to the top, at which first the actor groups that present opportunities in the future system are presented, which are linked to the specific opportunities/required actions, which in its turn are linked to the barrier that it will resolve. Consequently, inducing an overall positive feedback loop for the system to come to the next development phase. Note that regional cooperation has an overall influence on the system, and thus is not connected to one specific barrier.

Table 13. Overview of the main outcomes of the entire 'opportunities and barriers' analysis.

Main outcomes barriers and opportunities analysis for large scale application of the innovation system			
>>>------------ 1 --------------------------------- 2 ----------------------------------- 3 --------------------------------- 4 -------->>>			
Seven system functions analysis	**Future vision & backcasting**	**SNA**	**Narratives**
What are the main barriers?	*What future state is desired and what steps are required?*	*What actors and relations provide opportunities to overcome barriers?*	*What current narratives should be altered to do so?*
- **Guidance of the search**: Legislation and knowledge on safe application for food/feed - **Market formation:** Proof-of-concept for application of fatty acids - **Resource mobilisation:** Profit motivated investors	- **Short term**: Flexible legislation food/feed, waste taxation, carbon tax, financial support - **Medium term**: Redesign urban collection system, improve monitoring, increase niche experimentation - **Long term**: Social acceptance consumer, market creation via increased supply	- **Waste processors** will have a more **diverse function** (also production of biobased products) - **Waste processors and governments** a **central and bridging position** in both systems - **Regional** government level is present but should have a **more prominent role** to connect cities with equal urban waste challenges.	- **Overall environmental impact** should be included more thoroughly in **decision-making**. - Proving the worth of the new biobased commodities by focussing on **added value** commodities, and **knowledge exchange** (e.g. with current plastic producers on quality of bioplastics, with government on providing safety for food and feed)

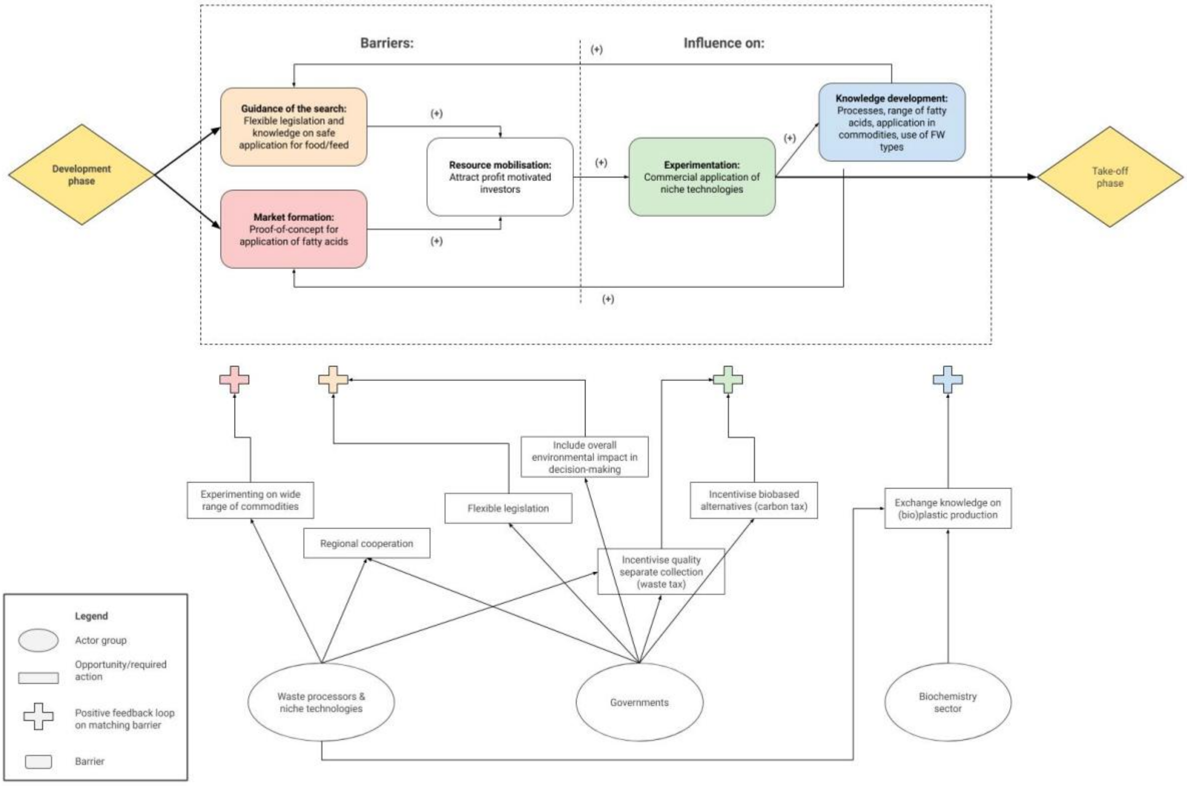

Figure 40. Overview of how the barriers for the innovation system transition could be resolved for large scale implementation of high-value food waste valorisation in the AMA.

9. Conclusion

The main goal of this thesis research is to provide more insight in the potential of high-value fermentation biotechnologies for food waste processing in the AMA, and what is requisite to achieve the related socio-technical transition for large scale application. The potential is discovered both in terms of its relevance to the quantified food waste flows in the AMA, the relative environmental impact, and more particularly in relation to the (nexus) governance system that it operates in by means of a socio-technical- and social network analysis. All in all, this research aimed to answer the main research question of this thesis: *How can nexus governance increase circularity via high-value food waste processing in the Amsterdam Metropolitan Area?* This chapter first recapitulates the main outcomes of the research by answering the four sub research questions of this research.

9.1 Sub research questions

sRQ 1: *What is the current state of food waste processing in the AMA and how is the food waste system organized?*

The material flow analyses showed that food waste flows from households in the AMA comprise 145,708 ton annually of which 60,785 t/y can be appointed unavoidable food waste, and 84,923 t/y avoidable food waste. Whereas companies in the AMA produced 128,278 ton of food waste in 2018. This virtually equal share proves that both FW origins deserve equal attention for high-value valorisation options, which is an important observation considering the difference between household and companies FW in terms of food types, quality and composition (e.g. mixed versus more homogenous, fruit and vegetables versus animal residues).

The 'wholesale and retail' sector contributes the largest share to food waste from companies in the AMA (71,500 t/y), with 'processed fruit and vegetables' taking up the largest portion (76,100 t/y), whereas peels and stumps (ua), coffee grounds (ua), bread (a), dairy products (a), and vegetables and fruit (a) constitute the largest fractions of household FW[32]. Though it should be taken into account that the division per sector is somewhat distorted by the broad definitions of the EWC codes, and the allocation of combined FW flows to 'waste collectors' in the NACE codes. The main portion of household FW currently ends up in residual waste and consequently incineration with energy recovery, whereas the main share of food waste from companies in the AMA is processed into animal feed, incinerated, or processed via anaerobic digestion and/or composting. Moreover, it was calculated that when the City of Amsterdam would also successfully separately collect vfg waste at full city scale, this would result in an 81% increase of separately collected vfg waste from households in the AMA to 26,075 t/y, and a remaining 119,634 t/y ending up in residual waste. Especially the large fraction of unavoidable food waste in household food waste, and the large quantities of both household and company food waste ending up in residual waste denote the necessity to explore high-value valorisation options for a circular economy.

Moreover, the regime- and landscape analysis uncovered the wide range of actors that are currently involved in food waste processing in the AMA (see figure 23). It shows the overarching and connecting role that governments and knowledge institutes have in the current regime, especially on a local (municipal) and national level. Additionally, the role of existing tangible artefacts (e.g.

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[32] (ua) = unavoidable food waste. (a) = avoidable food waste.

experimentation in existing plants, designing of collection bins in an urban setting) should not be underestimated for enhancing the transition towards more high-value processing. Lastly, landscape factors concerning the mad cow disease in relation to waste management legislation, and the current COVID-19 crisis in relation to current food supply chains and a green recovery were identified as important factors that influence the current developments of the regime and niche level for FW valorisation in the AMA.

sRQ 2: *Which processes are involved in high-value fermentation biotechnologies, and what is its potential and environmental impact related to the status quo?*

The description of the niche technologies in chapter 6 showed that the three niche technologies investigated are quite similar in terms of the technological processes they encompass, however differences can be observed with regard to the specific processes for different fatty acids production (e.g. chain elongation', 'bio anoxygenesis', and other acidogenesis processes for C3-C18 fatty acids). They also include different food waste type inputs, from more households mixed food waste flows to homogenous flows from agriculture and the food processing sector. Overall, the investigated technologies provide the main advantages of being relatively inexpensive due to the cheap feedstock of food waste and its high economic outputs, and the additional advantage of reducing carbon emissions via storing or substituting these emissions.

Moreover, an 'institutional and political' lock-in with regard to waste and food legislation and a 'techno-economic' lock-in relating upscaling and proof-of-concept was observed from the overall multi-level system, with regard to the niche potential. It was concluded that the current MLP system resides in a transformation pathway, although changing circumstances could push the system towards a reconfiguration pathway including other high-value niche technologies.

Importantly, the environmental assessment partly consolidated this generally positive potential. It demonstrated that despite its higher energy and water demand, the niche technologies could be promising if the higher economic output, the (circular, sustainable and nutritional) added value and substitution effect of conventional plastics and food/feed additives, and the potential to use renewable resources as inputs are dealt with within the specific context of the AMA.

sRQ 3: *What are the opportunities and barriers to large scale application of these techniques in the AMA?*

The seven innovation system functions analysis in chapter 7 complemented and validated the analysis for RQ 1 and 2, by indicating that that the main barriers for the niche technologies to diffuse to a large(r) scale are located in the functions: guidance of the search, market formation, and resource mobilisation. These barriers mainly originate from a lack of sufficient financial resources for upscaling, barriers from legislation around what is regarded as 'waste', and difficulties with finding clients (i.e. creating a market).

At the same time these 'barrier functions' provide opportunities to overcome these limitations to diffuse the technology. The positively shifted mindset of governments and current waste processors towards more circular and sustainable practices could provide opportunities if they are more explicitly expressed in terms of economic incentives from the government (e.g. carbon tax, launching customers), via flexibility in legislation, or by providing the infrastructure for experimentation with the technology (current waste processors).

This level of experimentation and production, knowledge exchange and market formation (being the most important functions in the current development phase), could potentially also be upscaled if biochemistry companies could take a more prominent role. Sharing their experiences and knowledge on the practical application of fermentation technologies with the niche technologies and current waste processors could potentially be the linking factor for an optimal design of the processes including optimal reuse of resources.

sRQ 4: *How will the introduction of fermentation technologies influence the organization of the current system and how could these changes help to remove the main barriers for large scale application?*

The previous opportunities and how they could be implemented, were further explored in the social network analysis by means of the backcasting method, a quantitative SNA and a narratives analysis. The social network analysis showed that by introduction of the investigated niche technologies, to a lesser extent changes will occur with regard to influence and importance of central actors (groups) in the system (e.g. the system becoming more decentralised), but to a bigger extent in relation to an increased complexity of the actor network and a shift in their functions. The 'biochemical sector' actor group will namely include a more diverse range of actors in the future system, and a shift of functions in the actors can be observed for the current waste processors from merely processing waste towards provision of a wider platform of commodities from fatty acids such as bioplastics, plasticizers, paints, and food/feed additives.

Moreover, a central and bridging position was witnessed for the waste processors and governments. Whereby the former has a leading and central position regarding both knowledge, information and physical and financial resources exchange. Whereas governments could play a more prominent role in assessing the best (sustainable) combination of techniques and measures from a system perspective due to the competitive nature of waste processing companies.

The additional cross-coalition narrative analysis denoted the need that the overall environmental impact (both circularity and sustainability) should be included more thoroughly in decision-making to align academia, companies, and governments. Also, not all coalitions seem to have the same interest in applying the niche technologies (i.e. policy goals for government, profitability and future viability for companies, quality of commodities for users). Therefore, more experimentation with, and knowledge exchange of fatty acids production from food waste and application in added value biobased products could overcome these differences.

All in all, the following opportunities and required actions were found to be able to remove the main barriers for large scale application of high-value fermentation food waste valorisation in the AMA: (1) increased regional collaboration of waste processors, niche technologies and governments; (2) flexible legislation and economic incentives from the national government for biobased alternatives; (3) an overall more holistic- and system perspective including all environmental impacts to come to the most circular and sustainable regional (food) waste management strategy; (4) and increased knowledge exchange and experimentation with regard to the quality, processes and added value of platform applications of the fatty acids.

9.2 Final remarks

Subsequently, the main research question of this research can be answered: *How can nexus governance increase circularity via high-value food waste processing in the Amsterdam Metropolitan Area?.* The nexus governance approach applied in this research includes a 'multi-level systems dimension' and a 'network structure and relations dimension'. It helps to identify the main opportunities and barriers of the multi-level innovation system, the main influences on the future actor constellation, and more particularly how the latter could help in resolving the main barriers for applying niche innovation at a large scale. This research thus validates that this approach can increase circularity via high-value food waste processing in the AMA, by designating the most important aspects that should be taken into consideration for achieving this circularity. With regard to the high-value valorisation techniques investigated in this research, the most important aspects to take into account for achieving circularity are about (1) resolving legislative, financial and market creation barriers, (3) carefully mapping out the sustainable and circular benefits of the technologies with regard to renewable energy- and water use and substitution of market products, and (3) showing how the changing actor network might resolve the main barriers (see sRQ4). Overall, it can be concluded that from a system thinking perspective, the main leverage points for upscaling and diffusion of the high-value fermentation technologies are simultaneously found in the barriers of the system, as mentioned under sRQ 4 (i.e. interventions in the legislative and financial domain).

However, as for any research approach, limitations and shortages were also indicated. One main finding emphasizes that it is not just intersectoral nexus governance that is required to boost this transition, but much more transboundary governance that more systematically and with binding legislation, binds different municipalities and provinces in the AMA and applies the niche technologies at a regional scale (e.g. more active role for the AMA organisation).

Moreover, it should not go unmentioned that prevention of food waste via efficient logistics and redesigning supply chains should always be the overall aim to reduce related environmental impacts on the long-term. Nonetheless, the investigated technologies offer a solution for reduced environmental impacts from FW on the medium term by dealing with present bulk FW flows and providing high circular- and economic outputs while environmental impacts could be reduced.

10. Reflection and recommendations

10.1 Reflection

Lastly, some remarks can be made about this study with regard to its limitations. First, concerning the methodology of the research, the socio-technical and social network analysis is based on expert judgement from the main actors in the innovation system. This might have restricted the eventual results of the research to the personal outlook of these actors, whereas extra interviews and/or surveys could have shed light on other important aspects that are now overlooked.

Data for the environmental assessment was obtained from available academic literature and the Ecoinvent v3.7 database. While it is supposed that this is the most recent data available with regard to energy- and water intensities, and yields and efficiencies of the technologies, more valid conclusions and recommendations could be made when more exact data on the Chaincraft, AGC and FABULOUS project themselves would be included. Also, data for the companies MFA was collected from Landelijk Meldpunt Afvalpunt based on EWC and NACE codes. Hence, the definitions used by the EWC and NACE codes determined at what level of detail data could be collected, which was found to be somewhat restricting, as general categories such as 'not suitable for consumption and processing' comprise a large share of the organic FW flows. Overall, assumptions have been made for both the EA and the MFA, and while it was attempted to do this at best, it is possible that some things were overlooked which affected these assumptions.

Moreover, this research aims to contribute to the field of Industrial Ecology by performing research at the intersect of its three pillars: the environment, the technosphere, and society. While the environmental assessment, the MFA, and the analysis of the required socio-technical analysis respectively cover and assemble them, it does not include the social aspect related to awareness and behaviour of citizens to separately collect FW. Mainly, because the scope of this research is on treatment of FW, still appropriate collection has a large influence on subsequent treatment methods.

The focus of this research is on the high-value fermentation valorisation techniques presented in the AMA, however other high-value valorisation techniques (such as BSF conversion) are available, that could potentially also provide a more circular and sustainable solution to FW processing than the status quo. Also, these technologies could be applied more centralized or decentralized, both presenting its own advantages and disadvantages.

Lastly, this research investigates the novel theory of nexus governance to see how it might provide solutions for decision-making to come to circular and sustainable solutions. Although an adjusted methodological approach to investigate nexus governance is presented in this research, other important governance aspects from, for example, multi-level governance or quadruple helix governance could potentially also provide other valuable insights for how to achieve the required circular socio-technical transition.

10.2 Recommendations

10.2.1 Recommendations for policy

Following the conclusions and reflections, several recommendations for policy are proposed to accelerate the transition towards circular and sustainable food waste processing in the AMA. First, maintaining and increasing financial support for niche technologies such as Chaincraft, AGC and FABULOUS to experiment with circular high-value food waste processing and to eventually be able to commercially upscale their processes is key in enhancing this transition. Especially, increasing the visibility via clear notification of the possibility for such financial support for niche technologies is key. Instruments one could think of are direct financial support via subsidies, or more indirect investments via investments in research and/or collaboration platforms that bring ideas into action. Specifically, more actively focussing on regional collaborations was considered one of the main requisites for this transition, and at the same time the missing factor in the context of the AMA. Whereby smaller municipalities could profit from the larger expertise and resources of a bigger municipality such as Amsterdam, and the niche technologies would benefit from economies of scale.

Another more visible and important financial instrument that would boost circularity and sustainability with regard to food waste processing is a European carbon tax to create a fair level playing field for biobased products that are produced by the niche technologies. This in comparison to status quo commodities such as bioplastics and compost that were found only profitable due to subsidies. Consequently, increasing the economic viability of the high-value technologies. The present research proved that environmental benefits of, for example, bioplastics or feed/food additives are currently not (economically) outweighed enough to provide a solid business case and incentives to enhance the circular transition of food waste processing.

Moreover, reconsidering more flexible legislation with regard to use of food waste in feed and food applications could open up one of the main barriers that currently hinders large(r) scale commercial application of circular processing technologies. Instead of assuming that processing in food and feed has adverse effects on human health until proven differently, this could be redirected into policies that open up some room for experimentation under strict agreements and guarantees for the producer, which offers the possibility to prove differently (when using homogenous, ‘clean’ streams of food waste).

Further, in relation to decision-making to achieve a circular economy in 2050, governments (both local and national), should more carefully and clearly consider what technologies could benefit this transition from a holistic system perspective. More specifically, this means including both the circular achievements of the technologies, as well as its overall sustainability impact in comparison to the status quo and other processing technologies (e.g. GHG emissions, land use change, energy- and water intensities). As it became clear from the EA that the overall sustainability of the high-value niche technologies is very context specific, but simultaneously offers opportunities for governments to make clear agreements with the niche technologies about the origin of the energy, to increase the circular and sustainable potential of FW processing in the AMA.

With regard to both national and European policies, it is recommended that the NACE- and EWC codes are updated in terms of definitions and allocation of commercial activities. Meaning that for the EWC codes definitions are further specified than ‘plant tissue waste’, and ‘not suitable for consumption and processing’, as the latter makes it difficult to distinguish between organic- and food waste. This allows for a more truthful baseline representation of FW flows. Also, allocation of commercial activities (i.e. waste generation) of NACE codes should be more specifically appointed to the right sectors.

Although collection of (food) waste is not the main scope of this research, the research showed that it is an important component of the supply chain that highly influences the food waste processing technologies, since it determines food waste composition, quality and quantities. Therefore, it is recommended to include a form of a new waste taxing system for households in municipalities of the AMA. That incentives citizens to produce less residual waste (e.g. smaller bin default, and chip/personal pass system for collective bins). Though this should be implemented in close consultation with citizens to prevent resistance and incomprehension. Secondly, redesigning the collection system to increase the quality of separately collected vfg waste should be further investigated and experimented with (e.g. grinders, kitchen waste separate from garden waste in urban context).

10.2.2 Recommendations for further research

While this research aimed to provide a more in-depth starting point for sustainable decision-making in the interest of circular high-value food waste processing in the AMA, it is presented in relation to its own limitations and shortcoming. Therefore, below several recommendations are provided for further research to strengthen the outcomes of this thesis research.

First of all, for deciding upon the most sustainable and circular pathway of food waste processing in the AMA a more in-depth and full life cycle analysis should show the true potential of the niche technologies. The environmental assessment merely focused on the processing part of the supply chain, and direct environmental impacts (no transport, quantifiable substitution effects, no embedded emissions) due to data and time constraints. However, if more context specific data would be available on the energy and water intensities of the niche technologies on a commercial scale, this analysis could be improved, including the qualitatively assessed nuances of this research.

Moreover, the scenario investigated in the environmental assessment should be enlarged to other scenarios, including different composition and quantities of food waste flows, but also other technologies, or a different composition of the technologies for food waste processing, because this research solely included the selected three niche technologies and the predicted future vision.

Additionally, in line with the recommendation for policy above with regard to the EWC and NACE codes, a fair baseline assessment could also be improved by a bottom-up method such as randomly measuring and weighing food waste flows in specific sectors/companies. This would enable to more effectively monitor FW flows and match it to the most appropriate high-value and sustainable processing technologies.

Also, future research should more clearly demonstrate the composition of unavoidable food waste in the (near) future. Prevention of avoidable food waste should always have the highest priority, while unavoidable food waste flows will remain and will require appropriate circular and sustainable processing technologies if we are to meet the national and local circular goals of the AMA, the City of Amsterdam and the Rijksoverheid, while simultaneously minimising GHG emissions.

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Appendices

Appendix 1 - Guiding research questions seven system functions

Table A1. Guiding research questions based on the seven system functions approach of Hekkert et al. (2011), used for the layout of the semi-structured interviews.

Functions and indicators	Diagnostic questions
F1 - Entrepreneurial Experimentation and production - Actors present in industry (from structural analysis)	- Are these the most relevant actors? - are there sufficient industrial actors in the innovation system? - do the industrial actors innovate sufficiently? - do the industrial actors focus sufficiently on large sale production? - Does the experimentation and production by entrepreneurs form a barrier for the Innovation System to move to the next phase?
F2 - Knowledge Development - Amount of patents and publications (from structural analysis)	- Is the amount of knowledge development sufficient for the development of the innovation system? - Is the quality of knowledge development sufficient for the development of the innovation system? - Does the type of knowledge developed fit with the knowledge needs within the innovation system - Does the quality and/or quantity of knowledge development form a barrier for the TIS to move to the next
F3 - Knowledge exchange - Type and amount of networks	- Is there enough knowledge exchange between science and industry? - Is there enough knowledge exchange between users and industry? - Is there sufficient knowledge exchange across geographical borders? - Are there problematic parts of the innovation system in terms of knowledge exchange? - Is knowledge exchange forming a barrier for the IS to move to the next phase?
F4 - Guidance of the Search - Regulations, Visions, Expectations of Government and key actors	- Is there a clear vision on how the industry and market should develop? - In terms of growth - In terms of technological design - What are the expectations regarding the technological field? - Are there clear policy goals regarding this technological field? - Are these goals regarded as reliable? - Are the visions and expectations of actors involved sufficiently aligned to reduce uncertainties? - Does this (lack of) shared vision block the development of the TIS?
F5 - Market Formation - Projects installed (e.g. wind parks planned, site allocation and constructed)	- Is the current and expected future market size sufficient? - Does market size form a barrier for the development of the innovation system?
F6 - Resource Mobilization - Physical resources (infrastructure, material etc) - Human resources (skilled labor) - Financial resources (investments, venture capital, subsidies etc)	- Are there sufficient human resources? If not, does that form a barrier? - Are there sufficient financial resources? If not, does that form a barrier? - Are there expected physical resource constraints that may hamper technology diffusion? - Is the physical infrastructure developed well enough to support the diffusion of technology?
F7 - Counteract resistance to change/legitimacy creation - Length of projects from application to installation to production	- What is the average length of a project? Is there a lot of resistance towards the new technology, the set up of projects/permit procedure? - If yes, does it form a barrier?

Appendix 2 - Background on valorisation techniques in academic literature and practice

Valorisation techniques in academic literature

Current most consolidated techniques for food waste valorisation in Europe and the Netherlands primarily consists of anaerobic digestion, composting, use for animal feed or incineration (with and without energy recovery) (Imbert, 2017; Vandermeersch et al., 2014; Manfredi et al., 2015; Tonini et al., 2020). While many studies have performed analyses of food waste valorisation techniques by means of life cycle assessment and life cycle costing (see for example: Slorach et al., 2019; Yeo et al., 2019; Vandermeersch et al., 2014; Martinez-Sanchez et al., 2016), a more holistic approach is required for providing a comprehensive picture of sustainable valorisation techniques.

More specifically, Tonini et al. (2020) and Tonini et al. (2019) aim to do so by including both an environmental, economic and social perspective in their analysis of the AMA. Tonini et al. (2020) investigate home composting, centralized composting, centralized anaerobic digestion (with and without post-processing), mechanical-biological treatment and the status quo in which most of the food waste is incinerated with mixed residual waste. They conclude that anaerobic digestion is the favorable technique from an environmental perspective. Tonini et al. (2019) subsequently state that these rather conventional (low-value) valorisation techniques are unavoidable due to the present low quality of collected household (and SMEs) mixed food waste in the AMA. However, due to the low agronomic and market value of the products of anaerobic digestion, an analysis of several so-called 'eco-innovative solutions' (EIS) is performed. These EIS include both mixed food waste flows and homogenous food waste flows (e.g. vegetables and fruit, bread) to increase this quality and market value of food waste valorisation products. The techniques include, for example, coffee grounds for biofuel production, bread for beer production, bread for animal feed, and fruit & vegetables to animal feed. They conclude that further research should however still consider EIS that (potentially) enhance the market value of food waste (products), such as "*high-value N and P fertilisers, animal feed, biomaterials (e.g. bioplastics) and biochemicals*" (Tonini et al., 2019, p. 22).

Additionally, recent research analysed high-value recovery of food waste in biorefineries by focusing on homogenous, unavoidable (mainly inedible) food waste from pre-consumer food waste (i.e. food processing companies) (Teigiserova et al., 2019). This flow provides a constant and stable flow for the future, inducing no potential rebound effect on waste generation, as might be the case for avoidable and edible food waste. In conclusion it is stated that biorefineries for food waste valorisation have great potential for processing homogenous food waste flows into high-value products due to low costs for the feedstock, its stable flow and composition, and the potential to bind carbon opposed to other techniques. Nonetheless further research should investigate its environmental (LCA) and social impact from a more holistic perspective. And more importantly, high-value techniques for household food waste should also be provided beside these pre-consumer focused techniques, given the current largest food waste flows in the AMA (i.e. household, post-consumer food waste).

Furthermore, Coudard (2019) did analyse food waste flows in the city of Amsterdam from a holistic perspective by including both a stakeholder overview and embedded energy and water resources in food waste flows. He mapped the quantities and composition of food waste flows from companies and households, and the theoretical potential of valorisation technologies within the city. Doing so by mapping the water and energy intensities, and the amount of recovered resources of several bio-based technologies. From a 'food waste management and valorisation' framework the author concludes "*anaerobic digestion, Black Soldier Fly bioconversion, and composting as potential FEW-efficient solutions for Amsterdam's unavoidable FW*" (p. 5).

All in all it can be stated that both (mixed) post-consumer and homogenous pre-consumer food waste flows require appropriate valorisation techniques for dealing with both (un)avoidable and (in)edible food waste in the AMA. Given the bulk waste flow of food waste in the AMA from households and companies, processing of both (mixed) post-consumer and pre-consumer food waste flows currently contain a high relevancy. In addition, current academic literature shows the need for more high-value valorisation techniques to be able to scale up potential techniques, such as Black Soldier Fly Conversion and biomaterial & -chemical production (i.e. biorefineries) (Tonini et al., 2019; Coudard, 2019). Beside this selection for a high-value valorisation technique that deals with both pre-consumer, and mixed post-consumer household food waste, the selection process of the case for this research is also dependent upon policy- and technological momentum in the AMA, as is explained in the following section.

High-value valorisation techniques in practice

The recently published innovation and implementation program of the City of Amsterdam[33] states that it aims to stimulate (experimental) initiatives that process food waste into high-value products, on the level of the AMA. Two projects mentioned there are (1) the Amsterdam Green Campus that is developing a fermentation process in which residual streams of fruit and vegetables are fermented into new high-value products, and (2) Chaincraft that is developing a fermentation processes in the Port of Amsterdam that converts both homogenous and mixed organic waste into medium chain fatty acids that can be used as raw material in the chemical industry (e.g. bioplastics). Both promising niche techniques respectively at lab scale and just beyond pilot scale.

Furthermore, although not in the AMA, Protix is a company in the Netherlands that produces feed (for fish, pets and chickens) from larvae of the Black Soldier Fly. The Black Soldier Fly is known for effectively digesting low-grade food waste into high-value proteins and fat. This technology provides great potential for processing low-grade mixed household food waste into a high-value product (see for example: Lalander et al., 2019, and also mentioned in Coudard, 2019).

Lastly, the 'Ontwikkelplan Circulaire Economie MRA'[34] (development plan circular economy AMA) that addresses the period until the end of 2020, highlights a specific action point for 2025 for the biomass track. This action point states that together with waste processing companies, the MRA will clarify how organic waste and vfg waste can be processed into products and materials with viable business cases. Technologies mentioned are green gas, the biochemical sector and digestion. Herewith denoting thus one specific high-value valorisation technique, namely the biochemical processing of post-consumer household food waste.

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[33] See the website of the municipality for both documents: https://www.amsterdam.nl/bestuur-organisatie/volg-beleid/ambities/gezonde-duurzame-stad/amsterdam-circulair-2020-2025/

[34] See the ontwikkelplan in Dutch: https://www.metropoolregioamsterdam.nl/wp-content/uploads/2019/10/Ontwikkelplan-Circulaire-Economie-MRA.pdf

Appendix 3 - Template semi-structured interview questions

Introduction research

This interview is part of the Thesis Research Project of Marije Doolaard for the joint-degree master programme Industrial Ecology at the Delft University of Technology and Leiden University. For this research project I am investigating the potential of biorefinery technologies, and more specifically the fermentation biotechnology of the Amsterdam based company Chaincraft.

Urban Food Waste constitutes 25 to 30% of municipal solid waste in high-income countries, and is expected to grow 35% until 2025[35]. Also, recent monitoring research of Wageningen University & Research shows that since 2013 there has been no significant reduction in food waste flows in the Netherlands[36]. This data highlights that prevention and reduction is often infeasible in the Netherlands, which can be explained from multiple technical, economic or behavioural reasons. Also, currently food waste in the Netherlands is not yet processed in the most circular manner, i.e. creating high-value outputs and recovering available resources without burden shifting potential environmental impacts.

Therefore, this research investigates the drivers in the transition towards high-value processing of food waste in the Amsterdam Metropolitan Area via the fermentation biotechnology, from a nexus governance perspective. Doing so, by investigating the opportunities and barriers of transitioning this innovation to large scale implementation in the current system, and the influence this technique might have on the current actor configuration. This is respectively analysed by means of a socio-technical analysis and social network analysis.

The present research thereby helps to unravel potential pathways of the transitions towards more high-value valorisation of food waste in the AMA and what is requisite to achieve this transition in a sustainable manner.

Introduction interview

For understanding these opportunities and barriers, I am interviewing several experts from within the current food waste processing system to unravel these opportunities and barriers based on expert judgement from within the current system. Therefore, I would like to ask you some questions about the current status of the system itself, and the position of the biotechnologies of Chaincraft therein. These questions are based on seven components of an innovation system, with which it can be determined what the status of the system is and thus what the opportunities and barriers are[37]. These include, for example, the degree of experimentation, knowledge development or the mobilization of (financial) resources.

It is possible that not all questions can be answered from your position in the network, but I would still like to ask all questions, for the most complete picture of the system.

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[35] See: Adhikari et al. (2006); Adhikari et al. (2009).

[36] See: Soethoudt & Vollebregt (2019).

[37] See: Hekkert et al. (2011).

Questions

Note: a prior selection was made of the interview questions below, matching the focus of the specific interviewee.

F1 - Entrepreneurial Experimentation and production

<List of actors>

1. Are these the most relevant actors in the MRA for the processing of food waste and the associated policies?
    a. If not, which are missing?
2. Do you think that the industrial actors in this MRA system are innovating enough?
    a. If so, can you give some examples?
    b. If not, why do you think that and could you identify the possible cause?
3. Do you think that the industrial actors in this MRA system focus (enough) on large-scale production?
4. Do you think that the experimentation and production of (small) entrepreneurs is a possible barrier to the innovation of Chaincraft/high-value food waste valorisation, and to transform into a next phase?

F2 - Knowledge Development

1. In your opinion, is the **amount** of knowledge development sufficient to develop Chaincraft's high-quality processing technology and / or other biorefining technologies in the MRA?
2. In your opinion, is the **quality** of knowledge development sufficient for the development of the high-quality processing technology of Chaincraft and / or other biorefining technologies in the MRA?
3. Does the type of knowledge that is available match the knowledge required to promote and apply these techniques on a large scale?
    a. If so, why?
    b. If not, what knowledge is missing / what is the misfit?
4. Does the amount and / or quality of knowledge development in the MRA with relevant actors hinder the growth of Chaincraft (or similar) biotechnology?

F3 - Knowledge exchange

1. Is there enough knowledge exchange between science and industry with regard to, for example, the technological processes, environmental impact, socio-technological transition that is required, etc.?
2. Is there enough knowledge exchange between the users of the technology (eg the industry that can use Chaincraft's products) and the industry (both Chaincraft and current processing techniques)?
3. Is there enough knowledge exchange between the various sub-areas / municipalities within the MRA?
4. Are you aware of other problematic parts of the current system with regard to the exchange of knowledge (e.g. difficult contact, lack of consortium, resistance from a certain angle)?
5. In general, do you think that knowledge exchange is a barrier to Chaincraft's technology to innovate and be applied more widely?

F4 - Guidance of the Search

1. Is there a clear vision in the MRA regarding the high-quality processing of food waste about how industry and the market should develop?
    a. In terms of growth
    b. In terms of technological design
2. What are the general expectations with regard to Chaincraft's technology and similar biobased technologies for processing food waste?
3. Are there clear policy goals regarding the high-quality processing of food waste through technologies such as Chaincraft?
    a. Are these goals regarded as reliable?
4. Have these goals, visions and expectations been aligned enough for all actors in the system (e.g. user, Chaincraft, other processors, MRA, municipality)?
    a. Possible: Does this lack of a shared vision block the development of Chaincraft (or similar techniques)?

F5 - Market Formation

1. Is the current, and expected future, market size sufficient for the development of Chaincraft? Both with regard to input (food waste) and output (users)?
    a. Does the market size form a barrier for the development of the innovation system?

F6 - Resource Mobilization

1. Are there sufficient human resources?
    a. If not, does that form a barrier
2. Are there sufficient financial resources?
    a. If not, does that form a barrier?
3. Are there expected physical resource constraints that may hamper technology diffusion?
4. Is the physical infrastructure developed well enough to support the diffusion of technology?

F7 - Counteract resistance to change/legitimacy creation

1. Is there a lot of resistance towards the new technology, the set up of projects/permit procedure?
    a. If yes, does it form a barrier?

Appendix 4 - Overview of contacted and interviewed interviewees and respondents

Table A2. Overview of all contacted persons for the interview.

Name	Organisation & position	Interviewed (x)
Claire Teurlings	Amsterdam Economic Board - Challenge lead circular economy	
Mara van der Kleij	City of Amsterdam - Adviseur Circulaire Economie	
Juan Carlos Goilo	City of Amsterdam - Senior information specialist	
Diederik Starreveld	City of Amsterdam - Project manager GFT/GFE	X
Marten de Vries	Province of Noord Holland - Project manager Biomass, Circular Economy and area development	X
Joop Suurmeijer	Orgaworld - Manager strategic accounts & innovation	X
Angeline Kierkels	Meerlanden - CEO	
Diederik Notenboom	Meerlanden - Strategisch adviseur	
Niels van Stralen	Chaincraft - Director and co-founder	X
Niek Persoon	Amsterdam Green Campus - Director & project manager	X
Peter Mooij	AMS Institute - Research fellow	X
Annick Mantoua	De Gezonde Stad - Director	
Arnold van der Valk	Food Council MRA - Co-founder	

Table A3. Overview of all contacted persons for the survey.

Name	Organisation & position	Response to survey + interviewed
Claire Teurlings	Amsterdam Economic Board - Challenge lead circular economy	
Mara van der Kleij	City of Amsterdam - Adviseur Circulaire Economie	
Juan Carlos Goilo	City of Amsterdam - Senior information specialist	
Diederik Starreveld	City of Amsterdam - Project manager GFT/GFE	
Marten de Vries	Province of Noord Holland - Project manager Biomass, Circular Economy and area	X

	development	
Eveline Jonkhoff	City of Amsterdam - Strategic advisor sustainability	
Joop Suurmeijer	Orgaworld - Manager strategic accounts & innovation	X
Angeline Kierkels	Meerlanden - CEO	
Diederik Notenboom	Meerlanden - Strategisch adviseur	
André Bout	HVC - plant manager gft	
Niels van Stralen	Chaincraft - Director and co-founder	
Niek Persoon	Amsterdam Green Campus - Director & project manager	
Roos van Maanen	Amsterdam Green Campus - project manager	
Judith Kreukels	Amsterdam Green Campus / UvA - Project manager	
Peter Mooij	AMS Institute - Research fellow	X
Jeroen Hugenholtz	Wageningen Research - Fermentation expert	X

Appendix 5 - Inventory data household MFA

Table A3. Inventory data household food waste MFA (source: Voedingscentrum, 2020).

Food (waste) type	**Quantity** (kg p.p.p.y. in 2019)
Food purchased	
Meat and meat products	32.68
Fish	3.51
Cheese	9.98
Dairy products (excl. Cheese and butter)	37.63
Eggs	4.67
Vegetables	46.55
Fruit	43.57
Potatoes	22.79
Bread (excl. Pasty and biscuits)	33.88
Rice	2.14
Pasta	2.68
Sweets and snacks (excl. Pastry and biscuits)	17.58
Sauces and fats	16.06
Pastry and biscuits	10.95
Soup	3.68
Sandwich fillings	5.69
Others (incl. meal leftovers)	26.60
Avoidable food waste	
Meat and meat products	2.3
Fish	0.25
Cheese	0.62
Dairy products (excl. Cheese and butter)	5.14
Eggs	0.35
Vegetables	3.69
Fruit	2.97
Potatoes	2.87

Bread (excl. Pasty and biscuits)	7.28
Rice	0.83
Pasta	1.04
Sweets and snacks (excl. Pastry and biscuits)	0.81
Sauces and fats	2.74
Pastry and biscuits	0.98
Soup	0.03
Sandwich fillings	0.13
Others (incl. meal leftovers)	2.2
Unavoidable food waste	
Peels and stumps	11.8
Wax rinds of cheese	0.2
Egg shells	0.7
Coffee residues	8.2
Tea residues	0.6
Meat- and fish residues	1.2
Others	1.8

Appendix 6 - Specification of environmental assessment

Scenario 1:

Table A4. Total energy and water inputs, and economic output of the status quo food waste processing technologies in the AMA.

Technology	Input food waste (t/y)	Energy requirement (TJ/y)	Water requirement (m^3/y)	Economic output (million €/y)
Mixed residual household and companies waste incineration with energy recovery	152,255	20	456,765	€ 38.52
Anaerobic digestion + composting (vfg household waste)	26,075	7	26,075	€ 5.84
Biological cleaning and processing for animal feed	52,859	38	15,858	€ 2.11
Composting (bio-waste from companies)	12,198	1	-	€ 0.24
Anaerobic digestion + composting (companies waste)	33,545	4	33,545	€ 7.51
Total	**276,932**	**70**	**532,243**	**€ 54.23**

Scenario 2:

Table A5. Total energy and water inputs, and economic output of the potential future food waste processing in the AMA, including the three niche technologies.

Technology	Input food waste (t/y)	Energy requirement (TJ/y)	Water requirement (m^3/y)	Economic output (million €/y)
Mixed residual household and companies waste incineration with energy recovery	112,255	15	336,765	€ 28.40
Anaerobic digestion + composting (vfg household waste)	26,075	7	26,075	€ 5.84
Composting (bio-waste from companies)	12,198	1	0	€ 0.24
Anaerobic digestion + composting (companies waste)	33,545	8	33,545	€ 7.51
Chaincraft: for animal feed additive via VFAs	52,859	549	2,272,937	€ 64.44

AGC: for food additives via VFAs	15,000	347	30,000	€ 6.60
FABULOUS: for bioplastics	25,000	260	1,075,000	€ 30.48
Total	**276,932**	**1187**	**3,774,322**	**€ 143.51**

Appendix 7 - Template survey

Introduction survey

For understanding the **current and expected future actor configuration**, I would like to gain insights by means of **surveys** into the current, and expected future, **interactions and relationships** between actors in the **'food waste processing' system of the AMA**. Doing so, by asking all actors in the system about the frequency of interaction with the other actors in the system. With the eventual aim to see if nexus governance could enhance the transition by providing a stimulating role for different sectors to collaborate and interact more frequently, to enhance industrial symbiosis and synergies, minimising environmental impacts.

Survey current system

Explanation

Please indicate in the table below how often you (meaning: the organization you work for) interacts with the organization mentioned, **with regard to the processing of food-/organic waste**. The term interaction is defined as: exchange of knowledge, data, technology, products, services or financial resources. For an explanation of the likert scale, see below:

Never = 0
Yearly interaction = 1
Twice a year interaction = 2
Monthly interaction = 3
Weekly interaction = 4
Daily interaction = 5
Almost constant interaction = 6

You can highlight your answer in the table or make it bold (or both), as in the example below:

Highlight:

Gemeente Amsterdam	0 1 2 3 4 5 6

Bold:

Gemeente Amsterdam	0 1 2 3 **4** 5 6

Actor	**Frequency of interaction**
Fermentation technology for high-value VFA (volatile fatty acids) output products	
Chaincraft	0 1 2 3 4 5 6
Amsterdam Green Campus	0 1 2 3 4 5 6
FABULOUS-project	0 1 2 3 4 5 6
Knowledge institutes	
AMS Institute	0 1 2 3 4 5 6
Wageningen University	0 1 2 3 4 5 6
TU Delft	0 1 2 3 4 5 6
Other knowledge institute, namely: ...	0 1 2 3 4 5 6
Waste processors	
Meerlanden	0 1 2 3 4 5 6
Orgaworld	0 1 2 3 4 5 6
HVC	0 1 2 3 4 5 6
Indaver	0 1 2 3 4 5 6
Governments	
MRA organisation	0 1 2 3 4 5 6
Province of Noord Holland	0 1 2 3 4 5 6

Province of Flevoland	0 1 2 3 4 5 6
City of Amsterdam	0 1 2 3 4 5 6
Other municipality of MRA, namely: ...	0 1 2 3 4 5 6
Other municipality of MRA, namely: …	0 1 2 3 4 5 6
Users of products (think of: bioplastics, food additive, feed additive, other VFAs applications)	
Namely: …	0 1 2 3 4 5 6
Namely: …	0 1 2 3 4 5 6
Industry that produces food waste	
Restaurants	0 1 2 3 4 5 6
Food processing industry	0 1 2 3 4 5 6
Agricultural sector	0 1 2 3 4 5 6
Supermarkets	0 1 2 3 4 5 6
Other, namely: …	0 1 2 3 4 5 6
Households	0 1 2 3 4 5 6
Companies from the biochemistry sector, namely: *<name company and type of collaboration>*	0 1 2 3 4 5 6
Waste water sector, namely: *<name company and type of cooperation>*	0 1 2 3 4 5 6
Energy sector, namely: *<name company and type of cooperation>*	0 1 2 3 4 5 6
Collaboration with another sector, namely: *<name company and type of*	0 1 2 3 4 5 6

collaboration>	

Normative scenario / future vision

See section 7.2

Survey future actor system

Explanation

Please indicate in the table below how often you (meaning: the organization you work for) would interact with the organization mentioned, **with regard to the processing of food-/organic waste**, in the outlined **future scenario**. The term interaction includes: exchange of knowledge, data, technology, products, services or financial resources.

<repetition of first survey for future vision>

Appendix 8 - Interview transcripts

The interview transcripts can be found in a supplementary document.