MSc thesis in Engineering and Policy Analysis

A QUANTITATIVE APPROACH TO THE VALUE-BELIEF-NORM THEORY

CREATING ENVIRONMENTAL VALUE IN SYMBIOTIC BIODEGRADABLE WASTE NETWORKS

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A quantitative approach to the Value-Belief-Norm theory.

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Preface

I have thoroughly enjoyed my learning journey of the past two years. With this thesis I will be concluding my Master of Science in Engineering and Policy Analysis at Delft University of Technology, Netherlands, with my specialization at ETH Zürich, Switzerland.

I would like to thank my graduation committee: Martijn Warnier, Gijsbert Korevaar and Kasper Lange, for the time and motivation that they have shown guiding me through the past half year. It was extraordinary being both a 1st and 100th graduate student. Thank you for all the different ideas and let us be permanently curious. Additionally, I would like to thank the people involved with the NDSM wharf and Re-StOre project for their enthusiasm and insights about the topic.

What is more, this thesis concludes an exhilarating student time. I would like to thank the people of the World Solar Challenge team supporting me through the deserts of Australia, I would like to thank my fellow Young Future Leaders in Abu Dhabi and in Brussels for their insights and support to push boundaries, and I would like to thank my fellow UNITECH students for their never ending motivation.

I also would like to thank my friends who helped me with their humour, encouragements and needed distraction from the thesis.

Lastly, I would like to thank Max and my family for their endless confidence and their daily messages of love, tranquillity and inspiration.

Sabine Kerssens
Overveen, July 2019

Executive Summary

In the Netherlands 2 million tons organic bio-waste is not fully sorted and ends up burned or landfilled. This process is unnecessarily harming the health of people, animals and our planet every year. With our waste quantities only increasing, this is an important topic on the European agenda.

The creation of user-driven, self-organising, and decentralized networks is supported to make better use of the remaining value in bio-waste. The behaviour of people in these networks is critical for its environmental impact and long-term survival. This research proposes a quantitative set-up to increase the bio-waste separation rate of small and medium-sized enterprises (SMEs). To research the potential environmental benefit in a symbiotic network for bio-waste separation the following research question was posed:

What is the influence of different groups of human behaviour and policy interventions in the development of bio-waste sortation networks for environmental benefit in symbiosis?

The Value-Belief-Norm theory is a social theory that is based on the altruistic intentions that drives people to behave in the interest of the planet, rather than their own benefit. The set-up offers a new approach to combine the Value-Belief-Norm theory with Industrial Symbiosis. This approach is applied in an agent-based simulation model and case study of the NDSM wharf Amsterdam.

In this approach four different steps of general bio-waste separation behaviour are identified: the recognition of bio-waste, the willingness to walk to a central waste container, the social experience with the container and the more practical difficulty of disposal. The different values, beliefs and norms that participants of the network hold will influence the decision that they make at every step of the bio-waste separation. Creating the more altruistically-oriented approach to predict the total quantities of sorted bio-waste and non-sorted bio-waste. The main KPI that will be used in this model is the percentage sorted bio-waste (the sorted bio-waste divided by the total quantity of bio-waste). Furthermore, the knowledge and happiness of the participants with the symbiotic network will be studied.

Three steps of analysis will together answer the main research question, first the influence of policy interventions on the main KPI, secondly the effect of different groups of human behaviour on the main KPI, and thirdly the overall environmental impact.

This study found that by the introduction to bio-waste separation facilities a sortation percentage of 30% is achievable. By researching different policies in this model the expected bio-waste separation rate has risen up to 70% correct sortation. It was shown that individual bio-waste separation policies are often limitedly capable of changing the behaviour in the system. Rather, a combination of increasing knowledge and supporting the processing capabilities of the system can introduce a significant sortation rate growth. A single policy implementation can reach a percentage sorted bio-waste around the 38%. This percentage can be reached by reducing the discomfort and inconvenience of a full central waste container, by implementing an on-demand waste collection scheme. To increase the sortation rate further, a combined two-part policy can result in a percentage sorted bio-waste of 54%. The on-demand waste collection scheme in combination with a feedback loop in the network connects the waste percentage to the knowledge and interest of the participants, and can create these levels of bio-waste separation.

Secondly, it is found that the types of participants in the network can have a significant impact on the total quantity and the percentage sorted bio-waste. A deviation of 10 percent sorted bio-waste is predicted when different types of agents dominate the symbiotic network. External pro-environmental and/or altruistic agents can increase the behaviour up to 15% without any further policy implementations. A majority of hedonic agents can even cancel out the policy effects. A good analysis of the accorporating parties and the support of complex network supporting policies can therefore improve the environmental output of the model.

Thirdly, the percentage sorted bio-waste is an important indication to the environmental impact of the symbiotic bio-waste sortation network. This is largely due to the relatively limited capabilities and reducing usage of post-sortation techniques to sort highly contaminated residual bio-waste streams and the production of subsequent residual streams that could be even more difficult to process than non-post-sorted bio-waste streams. In a situation where the sorted bio-waste quantities could be processed to bio-gas, the introduction of bio-waste separation could equal the electricity consumption of 130 households. When implementing policies, a 60% sortation rate would meet the electricity demand of 260 households. However, there are more indicators needed to predict the total environmental impact.

First of all, the current Amsterdam processing facilities are not capable of processing sorted bio-waste in an environmentally friendly manner. At first, it would seem that in the current situation, bio-waste separation behaviour would result in zero added environmental value unless contracts are adapted and environmentally friendly bio-waste processing methods are introduced. Since the further processing of bio-waste falls out of the scope of this research, further research is advised.

Yet, a self-sustainable and valuable network of bio-waste separation can reduce the wetness in the general waste stream. In this study it was found that this positively impacts the separation of other recyclable waste streams, such as paper, as well as reduce the environmental incineration costs (in terms of electricity and heat generated) of residual waste burning. Also, this study finds that it is likely that the sortation and processing of other recyclables will be endorsed and pro-environmental behaviour will be stimulated, due to the close geographical proximity in the network. Furthermore, the creation of a self-sustainable symbiotic bio-waste sortation network in collaboration with international initiatives could introduce a positive global awareness for bio-waste separation.

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1 Introduction

In the Netherlands 2 million tons generated organic bio-waste is unnecessarily harming the health of people, animals and our planet every year. This chapter will discuss the consequences of this problem, and the difficulties in finding holistic solutions (1.1). Chapter 1.2 describes the specification of this research, through its societal relevance and the objectives within this study. Concluding with the specifications and structure of the study (1.3).

1.1 Background of the Problem

In natural circumstances organic materials are in a closed loop system where decomposition and life are in constant balance. Yet, the big quantities of waste worldwide are not fully sorted and this non-sorted organic waste is processed in polluting thermal conversion methods (burning of waste), which bring adverse human health outcomes, or stored in our scarce landfills, which creates an overall in-balance in the ecosystem (Haas, Krausmann, Wiedenhofer & Heinz, 2015; Tozlu, Özahi, & Abuşoğlu, 2016; Khalid, Arshad, Anjum, Mahmood & Dawson, 2011; Wiedinmyer, Yokelson, & Gullett, 2014; Al-Yaqout, Koushki & Hamoda, 2002). With ecological sustainability enhancement high on the global agenda a better waste processing is desired to decrease this hazardous link (Scalco et al., 2017). The research for technical innovations in waste sortation and waste processing techniques has seen a great growth in the past decades (Polprasert, 2017). Also, social efforts have been made to raise awareness and teach about bio-waste and the consequences of (un)successful processing, thereby aiming to increase the source-separation rates. For example, the EU Landfill Directives from 1999 and 2014 aim at phasing out landfilling by 2025 for recyclable waste (including plastics, paper, metals, glass and bio-waste) in non-hazardous waste landfills.

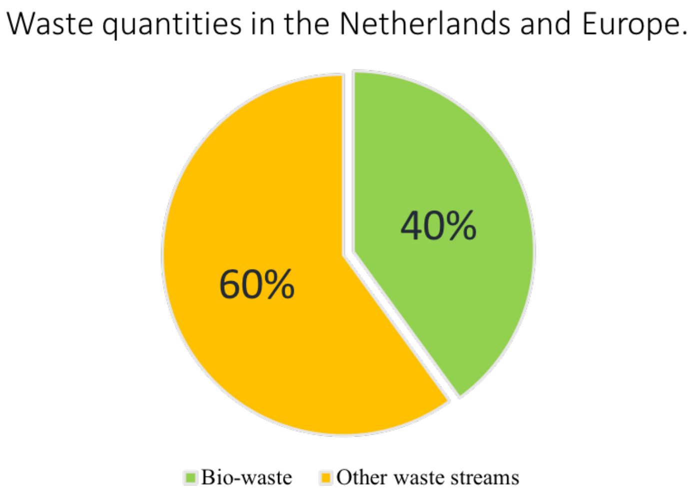

Figure 1- European and Dutch bio-waste distributions.

Even with these technical and social initiatives, organic waste in the Netherlands still adds up to 2 million tons per year and is expected to grow (Smits & Linderhof, 2015; AEB, 2019). As shown in Figure 1, 40% of Europe's total waste could potentially re-enter a sustainable ecological system loop (Cornelissen, & Otte, 1995; European Compost Network, 2016). However, two-thirds does not re-enter the energy loop on average, due to bad waste management processes. A lack of knowledge and social participation, and bad technical sortation techniques result in polluted bio-waste that cannot be recovered anymore. Furthermore, the percentage polluted bio-waste is currently increasing (Rijkswaterstaat, 2018).

The continually adapting network of participants, technologies and interests in the organic waste debate can be considered a complex system, incorporating both social and technical aspects on all parts of the waste management process (Dijkema & Basson, 2009). Hence, in this race against the clock a solution is needed that combines both technical and social initiatives to answer the problem in a holistic manner.

There are currently developments happening towards the processing of bio-waste on centralized and decentralized levels and towards technical capabilities of bio-waste post-sortation within the Re-StOre project (Centre for Applied Research Technology, 2019). Also, in literature technical developments such as sustainable improvements in transport, recycling techniques or post-sortation through Material Recovery Systems are studied, but leave for limitations of respectively, waste storage and hygiene regulations, high operational costs and highly contaminated generated digestive (Angelo, Saraiva, Clímaco, Infante & Valle, 2017; Bassi, Christensen & Damgaard, 2017; Münster et al., 2015, Münster & Meibom, 2010).

To prevent these limitations in waste management, solutions are needed in the earlier waste management process steps of waste separation and collection. This field is seen as one of the most uncertain processes in the chain, due to human behaviour interacting with waste technologies, creating a socio-technical problem (Bassi, Christensen & Damgaard, 2017).

1.2 Research Specification

As a response to the limitations in waste sortation and recycling, the EU encourages industrial symbiosis (EU Landfill Directive, 2014). This concept focusses on mutualistic interaction of industrial stakeholders in user-driven, self-organising, and decentralized symbiotic networks towards closing the energy or material loops in the local urban areas in an economically, environmentally and societally benefiting manner (Weijnen, ten Heuvelhof, Herder & Kuit, 2004; Hajer & Dassen, 2014). With several successful practices industrial symbiosis is seen as a practice that can reduce the ecological impact of industrial processes (Boons, Chertow, Park, Spekkink, & Shi, 2017). But, because of difficulties in technology transitions and adaptations, divergences in production cycle times, unavailability of low cost transport systems, lack of environmental consciousness, government's role in formulating and implementing regulation, and uncertainty in outcome, performance or cost benefit ratio it is difficult to predict if a network will contribute to economic, environmental or societal value on forehand (Aparisi, 2010; Chertow, 2007; Islam, Rahman & Islam, 2016). Successful practices of industrial symbiosis remain therefore difficult to organize (Gibbs, Deutz & Proctor, 2005).

1.2.1 Societal Relevance

With waste quantities expected to grow over the upcoming decades, the burden it plays on society continues to increase (Smits & Linderhof, 2015; AEB, 2019). Separation can be done at the source, as well as later retrieval from the total waste stream. Companies such as AEB are currently active in post-sortation of many recyclables. However, in conversation with AEB (2019) it was found that the sifting of organic material results in highly contaminated residuals. Microplastics are an example of contaminating materials that end up in the organic waste streams if not source separated. These different separated waste streams are largely unfit for successful composting or the creation of biogas according to current legislation. What's more, when post-sorting valuable materials from the general waste streams, residues can arise that are even more difficult to dispose of (Richard & Woodbury, 1992; Van Renssen, 2012). The percentage post-sorted bio-waste has been decreasing over the past decade (CBS, 2019)..

Networks in which bio-waste sortation at the source is promoted can therefore offer an important positive influence on the health of our planet and our people. It should be noted that technologies in sustainable waste processing are developing fast. It is not unthinkable that post-sortation of organic waste will become a more feasible method in the future. However, these developments are not available to us yet, and are not expected to reach a 100% sortation rate (AEB, 2019). Furthermore, with the high sunk costs of waste separation and processing, the introduction of good post-sortation processes shall have a long implementation time (AEB, 2019). Therefore, when regarding organic waste, there is a benefit in separation at the source.

In order to reach the goals as set in the EU Landfill Directive (2014) an improvement of source separation is necessary.

1.2.2 Objective

Regarding the stated problem and the displayed lack of research, this paper has the following objectives:

- To analyse the dynamics of bio-waste separation and its impact on symbiotic networks.
- To create recommendations to improve the sortation rate and therewith the environmental output of a network for bio-waste recycling.
- To increase debate around improving organic waste separation and recycling in the Netherlands.
- To scientifically contribute to our understanding of ecological sustainability.

1.2.3 Scope

This research focusses on the effect of policies in a Dutch symbiotic network around biodegradable waste separation. A perspective has taken hold that addressing environmental concerns can support economic and social value creation (Paquin, Busch & Tilleman, 2015). A symbiotic network is therefore considered to bring economic, environmental and societal value. Examples for this economic, environmental and societal value could be, respectively, cost saving through more efficient materials and energy use, a reduction of the environmental impact of industrial operations and improved public awareness or public health (Geng, Zhang, Côté & Fujita, 2009).

To limit the complexity and increase the quantifiability of this research success will be measured in the environmental factor of total quantity of sorted bio-waste, and the percentage sorted bio-waste on the total quantities.

1.3 Thesis Structure

In Chapter 2 a literature study is conducted to get a better understanding of state of the art research on the topics of Industrial Symbiosis and waste separation management literature. In Chapter 3 the methodology of the research will be explained. In Chapter 4 a connection is made between industrial symbiosis and waste separation management literature. Chapter 5 describes the case study that is used in this research, together with the different possible policies and scenarios, to research the robustness. Chapter 6 describes how the model is conceptualized. Chapter 7 shows the results of the experimentation and Chapter 8 offers an analysis of these results. In Chapter 9 the results of the model are compared to the literature again to create a useful discussion and underline the added value of this research. Chapter 10 the research is concluded and further research is proposed.

2 Literature review

In this chapter the state of the art research is described when it comes to Industrial Symbiosis and the application of social theories in this field. Industrial symbiosis as a field is originated in the study of industrial ecology and often go hand in hand, meanwhile also biology, social and complex adaptive system theory are getting interconnected in the field (Chertow & Ehrenfeld, 2012). This chapter will focus on the developments in the fields of Industrial Symbiosis (2.1, 2.2 & 2.3) and social theories (2.4). This chapter will conclude with two paragraphs highlighting the knowledge gap (2.5) and the accompanying sub-questions (2.6).

One of the next big step forward in achieving the sustainable development's goals are found at the level of local communities, since they offer a great opportunity for innovation and transition. As can be seen in the interest from the EU Landfill Directive (2014). User-driven, self-organising, and decentralized symbiotic networks are emerging, in which stakeholders are aiming to create economic, environmental, and societal value by closing energy loops in urban areas (Weijnen, ten Heuvelhof, Herder & Kuit, 2004, Hajer & Dassen, 2014).

2.1 Industrial Symbiosis

Industrial Symbiosis is a way of looking at traditionally separate entities in a collective approach to achieve environmental, social and economic benefits by the exchange of materials, energy, water, and/or by-products (Chertow, 2000). When the traditionally separate entities are involved together, positive contributions are anticipated to the skills, research and innovation and identity of the region (Martin & Harris, 2018). These regions are considered symbiotic networks.

To get a better sense of the general implications of this study it is important to have a thorough understanding of the network at hand. Boons et al. (2015) distinguished three different types of industrial symbiose networks: process-oriented networks, residue-oriented and place-oriented networks. Process-oriented networks relate to network participants which are highly knowledgeable about material transformation, residue-oriented networks are described as open-ended groups working towards economically beneficial resource conservation, place-oriented networks have a diverse range of geographically proximate participants aimed to bring environmental, economic and/or societal value to the community.

2.2 Symbiotic Networks

Within Industrial Symbiosis, every network is different and behaves differently. Long existing trends, such as openness to innovation, might influence the players' sensitivity towards new approaches such as industrial symbiosis (Baas, 2011). Once a solid network is constructed, the network is expected to see a growth in the number of jobs, and a growth of economic, environmental and societal value (Martin & Harris, 2018; Weijnen, ten Heuvelhof, Herder & Kuit, 2004, Hajer & Dassen, 2014).

This research will focus on place-oriented symbiotic networks, due to its focus on community involvement and its regular occurrence in the Dutch context (Boons et al., 2015). In place-oriented symbiotic networks the geographical proximity creates an opportunity to collaborate on more than solely bio-waste separation flows, and puts a greater emphasis on logistical questions. While this is considered out of scope for this research, Chapter 10.4 - Further research will outline future research possibilities.

2.3 Central Topics in the field of Industrial Symbiosis

Every person, small, medium or large company, public party or institution with a desire for environmental impact could be able to join a symbiotic network and therefore the possibilities are endless. Since the development of industrial symbiosis has taken a flight again in the beginning of the century, several key topics are central in the discussion of symbiotic networks and their development (Van Renssen, 2012). Topics, such as social cohesion, embeddedness and trust, are often mentioned variables in the value creation of symbiotic networks (Uzzi, 1996; Doménech & Davies, 2011a; Hewes & Lyons, 2008; Boons et al., 2015). These topics are often interlinked in research around industrial symbiosis, and are useful to recognise the long-term added value created by a symbiotic network compared to a normal collaboration (Doménech & Davies, 2011a; Uzzi, 1996; Velenturf & Jensen, 2016). Figure 2 displays the interpretation of the industrial symbiosis research field in this study. A green arrows represents a positive influence from one topic to the other, whereas the red arrow indicates a negative influence in this figure. As an example, a high level of embeddedness will influence a higher level of trust. It should be noted that the legitimacy of pure causality is questionable in this structure, rather a positive influence will increase the chances of.

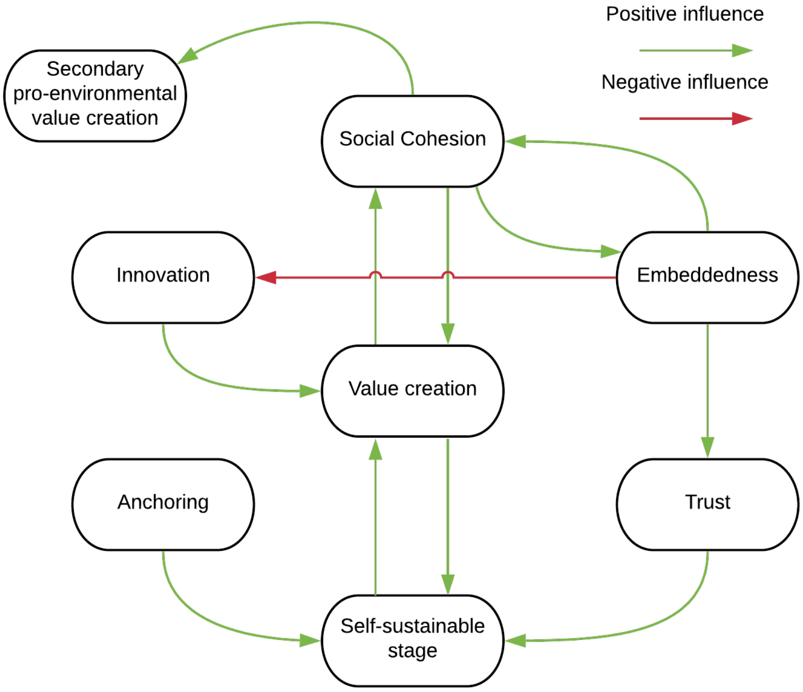

Figure 2 – Key topics within the industrial symbiosis domain as used in this study

Social cohesion and embeddedness are closely interlinked to the topic of industrial symbiosis (Doménech & Davies, 2011b). Hereby focusses social cohesion on shared values, where embeddedness describes the effect of social relations in a network (Boons et al., 2015; Lombardi & Laybourn, 2012; Uzzi, 1996). Figure 2 shows how social cohesion is strengthened by a highly valuable symbiotic network, as well as its influence in the increase of value creation. Additionally, it offers the opportunity for secondary pro-environmental behaviour to arise at the participants of the network, such as an increase in plastic separation in a symbiotic bio-waste sortation network (Barr, 2007). There are social mechanisms leading towards a state of social cohesion, respectively transparency, mental proximity, networking, knowledge of industrial symbiosis and intimacy (Sacchi & Remmen, 2017). However, the complexity of these mechanisms falls out of the scope of this research.

Focussing further on embeddedness, the social relations result, both in a network setting, as well as through ecological ambassadors, in positive experiences that lead to trust (Hewes & Lyons, 2008; Williamson 1996). Figure 2 shows this through a green link, describing a positive influence. The combination of both can create long-term value through a reduction of opportunistic behaviour in the network (Hewes & Lyons, 2008). For example, a social relation can create a feeling of trust that both parties are collaborating fairly, therewith reinforcing its own assumption (Doménech & Davies, 2011a).

However, an excessive amount of social embeddedness (or over-embeddedness) in a network can create rigidness and a vulnerability to react to changes of the network composition (Doménech & Davies, 2011a). Examples of these changes might be the departure of an agent from the network, or also an interruptive innovation. A rigid network can be harmful as innovation and entrepreneurship are central topics in symbiotic networks and have a great influence on the economic and environmental value creation of the network (Baas, 2011; Deutz, 2009; Gouldson & Murphy, 1997). Figure 2 shows this by the negative influence from embeddedness to innovation (red arrow). This study will look further into the effects of rigidness in the model experimentation.

Additionally, the rigidness of too many embedded links within the network can prevent organizational survival (Doménech & Davies, 2011a; Uzzi, 1996). In this study, organizational survival discusses the long-term improvement of the environmental impact of bio-waste network through sortation methods. Sacchi & Remmen (2017) also mention this as the topic of self-sustainability. Value creation on its own is seldomly enough to refer to a project as truly successful, for this to be true it is important that a network continues to create value over time (and in its operational phase). Through embeddedness and trust the long-term survival of a network can be ensured, creating an example for international collaboration and globally improved environmental impact (Fisher, 2012; Sacchi & Remmen, 2017). This long-term survival is described by Sacchi & Remmen (2017) as self-sustainability.

Furthermore, several topics have come to light around the provision of a critical mass for the self-sustainable development of industrial symbiosis, including, but not limited to, self-organization, anchoring, anchor tenants, coordinating bodies, leadership and ownership (Boons, 2008; Boons et al., 2015; Mirata, 2004; Van Renssen, 2012; Sun, Spekkink, Cuppen & Korevaar, 2017). Figure 2 shows anchoring as the focus in this study. The main idea behind all topics is the creation, evolution and stable continuance of a stage where the symbiotic network continues to create value over time.

In this study the definitions of Sun, Spekkink, Cuppen & Korevaar (2017, pp 12) are used. They describe two sub-types of anchoring; self-organizing and orchestrated. Whereby, self-organizing anchoring dynamics describe a self-motivation from participating industrial actors, and orchestrated anchoring dynamics describe "a coherent set of very deliberate, top-down, efforts". Both can be seen as different ways of creating a context for a symbiotic network to develop. Often, a party should incentivize a beneficial environment for a symbiotic network to arise. This can be done by public or private organizations, research institutes, NGOs or others (Mirata, 2004). After the creation of a network, one of the weaknesses of industrial symbiosis is the maintenance of the self-sustainable stage, created by a lack of ownership / anchoring (van

Renssen, 2012). Whether this ownership is institutional or physical is dependent on the specific symbiotic network, however in the Dutch context as chosen in this study a private party is often leader and owner in the network (Boons, 2015; Sun, Spekkink, Cuppen & Korevaar, 2017).

2.4 Social Theories for Industrial Symbiosis

Pan et al. (2015, pp. 416) writes that "A community is made up of a spectrum of different viewpoints and should be treated as such instead of a collective whole." To include these different actors in a structured and repeatable manner the general conceptual process is in need of a social theory that can help predict the behaviour of agents in a symbiotic bio-waste sortation network. Several theories have been used in pro-environmental settings, such as the Theory of Reasoned Action, Theory of Planned Behaviour (TPB), the New Environmental Paradigm (NEP), the Norm Activation theory and the Value-Belief-Norm theory (VBN).

The Theory of Planned Behaviour is an extension of the theory of Reasoned Action, and includes people's incomplete volitional control (Ajzen, 1991). It describes how attitude towards the behaviour, the subjective norms and the perceived behavioural control are interlinked and creating an intention. According to the TPB, people perform a behaviour with positive environmental outcomes if they hold a positive attitude to them, if other people expect them to act in that way and support them in doing so, and if they perceive themselves as being able to implement their intentions (Klöckner, 2013). This theory is based in the Rational-Choice theory, where individuals are expected to make fully-informed decisions, weighing the costs and the benefits, to optimize self-interest (Abrahamse, Steg, Gifford, & Vlek, 2009; Wiidegren, 1998). With this origin, the TPB had its limitations from the start. Ajzen (1991 pp. 184-185) states that "perceived behavioural control may not be particularly realistic when a person has relatively little information about the behaviour, when requirements or available resources have changed, or when new and unfamiliar elements have entered into the situation". With the climate being highly complex, and bio-waste separation just playing a small role in it, the underrepresentation of morality in this model has been criticized (Klöckner & Blöbaum, 2010). However, the theory also brings benefits. The theory explains 19 - 38% of the variance of behaviour on average (Sutton, 1998). Over the past 30 years hundreds of empirical papers have supported the usability of the theory (Ajzen & Driver, 1992; Albarracín, Kumkale & Johnson, 2004; Armitage & Conner, 2001; Beck & Ajzen, 1991; Hagger et al., 2016), but the use of correlations as proof for validity is questioned and therewith the validity of TPB's existence (Sniehotta, 2009; Sniehotta, Presseau & Araújo-Soares, 2014; Weinstein, 2007).

Alternatively, the Value-Belief-Norm theory links to Schwartz' extended Value theory (de Groot & Steg, 2007), Dunlap & Van Liere (1978) their New Ecological Paradigm and the Norm Activation Theory (Stern, 2000). Figure 3 shows how these different theories are interconnected to create personal norms that influence behaviour.

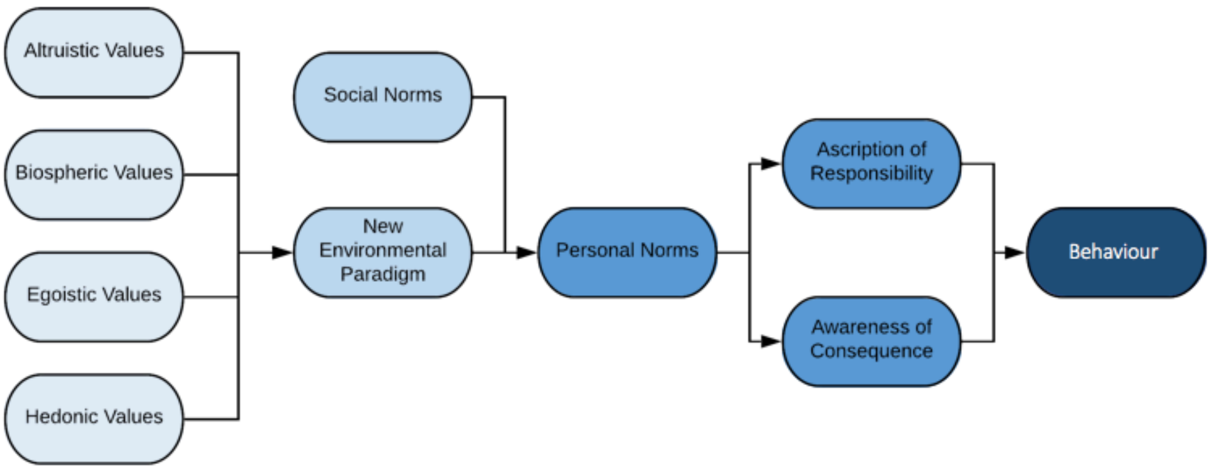

Figure 3 - Illustration of the Value-Belief-Norm theory.

On the far left side of the figure the Value theory is incorporated. Schwartz' extended Value theory reports four types of values that influence the behaviour of an actor. Altruistic values are for example aspirations of equality, world peace, social justice and helpfulness. Biospheric values refer to values such as respect for the earth, unity of nature and low pollution. Egoistic values refer to desires towards wealth, power and ambition. Finally, Hedonic values can be seen as pleasure and enjoyment of life.

Moving to the right, the New Environmental Paradigm is incorporated. The NEP offers a scale to measure environmental attitudes (Dunlap & Jones, 2002; Dunlap & Van Liere, 1978). In this research a questionnaire is used, adapted by Luzar & Henning (1993) to simplify the incorporation of this parameter in the social theory. Together with the feedback loop stakeholders receive from their peers as social norms, the NEP parameter results in the personal norms of agents. A high NEP parameter will lead to more ecologically oriented personal norms.

Thirdly, the social and personal norms of the Norm Activation Theory are included. According to this theory, people construct self-expectations regarding prosocial behaviour and this is called norm activation. These behavioural self-expectations are termed 'personal norms' and are experienced as feelings of moral obligation (Harland, Staats & Wilke, 2007). The exact factors that influence the personal norms have been known to change over the years. Including and excluding varying influences from "awareness of need", "situational responsibility", "efficacy", "ability", "awareness of consequences" and "denial of responsibility (Harland, Staats & Wilke, 2007). Over a wide range of studies, Awareness of Consequence and Ascription of Responsibility were chosen to be included in the model and give a good translation from norm to behaviour (Schwartz & Howard, 1981; De Groot & Steg, 2007; Golob, Podnar, Koklič & Zabkar, 2019). Altogether, this results in the Value-Belief Norm theory (Stern et al., 1999).

2.5 Problem Statement and Knowledge Gap

To expand the number of successful symbiotic networks, the Ulsan EIP centre created a "research and development into business" (R&DB) framework for a systematic design of symbiotic networks. For the effective expansion of symbioses in the industrial complexes the framework includes methods "(i) to develop the symbiotic networks through a feasibility study, (ii) to negotiate with the stakeholders to reduce the risks of networks failing, and (iii) to attract tenants by overcoming barriers and an equivalent benefit sharing among the participants in the synergy networks" (Behera, Kim, Lee, Suh & Park, 2012, pp. 106). The framework assesses feasibility through individual investigation teams, where networks, monitoring and business models are central, but is limited in reaching robust and comprehensive methods to quantify economic and environmental benefits to understand the relative merits of symbioses (Behera, Kim, Lee, Suh & Park, 2012).

Industrial symbiosis offers an opportunity to decrease the percentage of biodegradable waste that is unnecessarily filling up landfills or being burned, but leaves for a quantification void. To increase the number of successful symbiotic networks there are three qualitative methods named. The method for symbiotic networks, in combination with a social theory can qualitatively describe human behaviour to systematically bring a network into operation. But, qualitative methods of human behaviour solely do not solve our bio-waste processing problem. As stated by Behera, Kim, Lee, Suh & Park (2012) the method leaves a void in quantifiable metrics to understand the underlying dynamics of symbiotic network design.

This study looks for practical and quantifiable solutions in waste separation for small and medium sized enterprises (SMEs) in Amsterdam area to turn the problem of organic bio-waste into a successful collaboration. This type of waste includes, but is not limited to fruit waste, vegetable waste, leaves, meat waste and sewage sludge (Appendix A – Bio-waste). Depending on the organic waste processing method that should be determined in further research, meat waste and sewage sludge might be excluded from this list. According to the Re-StOre project (Centre for Applied Research Technology, 2019) circularity of bio-waste has so-far been a missed opportunity to reach the Dutch circular goals.

To fill in on the above mentioned gap in quantifiable understanding of symbiotic dynamics the following main research question has been established:

What is the influence of different groups of human behaviour and policy interventions in the development of bio-waste sortation networks for environmental benefit in symbiosis?

2.6 Questions

The above sections describe the possibility of social theories and industrial symbiosis in the context of biodegradable waste processing. The societal problem and the research gap help to develop the relevant research question and the sub-questions for the Re-StOre case. The main research question, broken down into sub-questions here, is:

What is the influence of different groups of human behaviour and policy interventions in the development of bio-waste sortation networks for environmental benefit in symbiosis?

1. How can the theory of Industrial Symbiosis be connected to social theories for the conceptualization of a symbiotic network?
    a. What social theory is chosen in this study?
2. How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?
    a. How does the waste separation behaviour affect the environmental output of the network?
    b. How can qualitative entities be represented in a quantitative agent-based model?
    c. How do human values affect the bio-waste separation output of the network?
3. How can a symbiotic bio-waste sortation network be modelled?
4. What is the effect of scenarios and sortation policies on the sortation outcome of participants in the NDSM wharf?

a. What is the behaviour within the symbiotic bio-waste separation model about the Re-StOre NDSM wharf project?
b. What can be said about the validity of this model?
c. What is the effect of an agent leaving the symbiotic network?
d. What is the effect of different agents on the model and policy implementations?
e. What is the influence of individual policies?
f. What is the influence of combining several policies?

5. What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?

Entities in this research will include both public parties, industrial actors and knowledge institutes or universities. In order to create societal value through this research, a collaboration is created with partners in the NDSM wharf case study (further explanation is found in Chapter 5). Therefore, big corporates are excluded from this research. In this context, industrial actors are the economically and organizationally discernible units (with some discretionary decision-making power) that undertake activities that transform inputs into outputs intended for further transformation or consumption (Boons, Chertow, Park, Spekkink & Shi, 2017).

Table 1 – Methods of answering the sub-questions & main research question.

Sub-question		Methodology	Chapter
1	How can the theory of Industrial Symbiosis be connected to social theories for the conceptualization of a symbiotic network?	Literature review	Ch: 4
2	How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?	Literature review & case study Re-StOre	Ch: 4 & 5
3	How can a symbiotic bio-waste sortation network be modelled?	Design Agent-Based Model based on literature review.	Ch: 6
4	What is the effect of scenarios and sortation policies on the sortation outcome of participants in the NDSM wharf?	Perform experiments based on Agent-Based Model.	Ch: 7
5	What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?	Reflection on experiments through cross-referencing state of the art.	Ch: 8 & 9

2.7 Engineering & Policy Analysis

This study will be done in partial fulfilment of the requirements for the degree of Master of Science in Engineering and Policy Analysis (EPA) at the Technology, Policy and Management faculty of Delft University of Technology. This interdisciplinary engineering masters aims to "Model the Grand Challenges". The central focus of this degree is on analysing and solving complex international problems that involve many parties with conflicting interests, combining both technical knowledge and social interaction skills. This study will combine the modelling nature of the EPA degree with the grand challenge of a responsible usage of the planet's resources. It will aim to improve the value of bio-waste and reduce the negative impacts of bad sortation to the health of the people, the animals and our planet.

3 Methodology

This chapter lays out the methods used in answering the sub-questions. A possible way of solving this void and supporting the understanding of the dynamics behind symbiotic networks is the use of Agent-based Modelling (ABM). ABM is attractive to use in research about the evolution of complex human-technical systems because of the flexibility and the level of detail to describe the behavioural of the system (Rai & Robinson, 2015). The ABM approach offers great possibility in quantifying real-world validated data. Notably, on the topic of Industrial Symbiosis Dynamics the number of ABMs is currently limited (Lange, Korevaar, Oskam & Herder, 2017). In this research literature study (3.1), a case study (3.2) and an agent-based simulation model (3.3 & 3.4) in Netlogo (3.5) complement each other to assess the different criteria and possibilities of successful symbiotic networks. Finally, the experimental design will be laid out (3.6).

3.1 Literature Review

In the first phase a systematic literature study will be conducted to dive further into the details and main research outcomes of the affiliated research. Core concepts such as industrial symbiosis, symbiotic networks and waste management will be studied, Table 2 gives an overview of the search terms that have been used in this study. To incorporate a diverse range of information several online scientific databases such as Scopus, Google Scholar and the TU Delft Library were used to collect papers. Additionally, a snowballing method of looking at references increased the number of papers identified. The number of citations and publication in respected journals have been used to verify the trustworthiness of the literature and to guide the use.

Table 2 - Search terms for literature study

Industrial Symbiosis	Biodegradable Waste Separation	Social Theory
Symbiotic Networks	Bio-waste separation	Value-Belief-Norm theory
Symbiosis dynamics	Ecology	Theory of Planned Behaviour
Eco-Industrial Parks	Organic waste	Value Theory
Energy loops	New Environmental Paradigm	Norm Activation Theory
Waste loops	Sustainable organic	Theory of Reasoned Action
Collaboration	Altruistic behaviour	Social Theories
Bottom-up initiatives	Water levels	Decision-making
Anchoring	(An)aerobic composting	New Environmental Paradigm
Self-Sustainable stage	Public participation	Waste separation behaviour
Value Creation	Recycling	SME Behaviour
Embeddedness	Decentralized / Centralized	Social behaviour
Trust	Motivation	Explained Variance
TPB / VBN Theories	Sortation in symbiotic networks	Social behaviour in waste separation

The findings from the literature study will be used to (partially) answer questions 1 and 2: *How can the theory of Industrial Symbiosis be connected to social theories for the conceptualization of a symbiotic network?* and *How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?* Afterwards, the findings of the experimentation phase will also be compared to state-of-the-art literature, aiming to answer the last question: *What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?*

3.2 Case Study

To better understand the implications of the literature and the model, the results of the simulation will be cross-validated with the help of the Re-StOre NDSM case study. Interviews are conducted to better understand the practical possibilities for social and technical interventions within the Industrial Symbiosis domain. This case study aims to identify key factors in increasing bio-waste separation rates, and (partially) answer the questions: *How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?* and *How can a symbiotic bio-waste sortation network be modelled?*

On February 1st, 2019 and April 12th a workshop was organised with the participants of the NDSM case study. The first workshop at the HvA was hosting the strategic advisor corporate waste management optimization and the strategic advisor municipal waste management of the municipality of Amsterdam, the project leader of the NDSM Energie cooperation, the managing director of the NDSM wharf foundation, program manager of the ROC Top and researchers 'circular logistics' and 'urban technology and engineering' of the University of Applied Sciences of Amsterdam. The second workshop was hosted on location, and included the same participants from NDSM Energie, NDSM wharf foundation, ROC Top, Amsterdam University of Applied Sciences, and myself as graduate student at the TU Delft.

The goal of the first workshop was a semi-structured event where the technological and social aspects of the NDSM wharf were identified to get a clearer image of the overall system and its capabilities for bio-waste separation and processing. The goal of the second workshop was the identification of possible interventions to setup an economically, socially and environmentally valuable network for bio-waste separation and processing within the NDSM wharf. Both of these goals have succeeded, resulting in a clear image of the involved agents, their focus and desires, the technical capabilities within the system and the possible interventions that are deemed appropriate in this case.

Semi-structured interviews have been done with the project leader of the NDSM Energie cooperation, an organic waste business developer at AEB (Amsterdam Energie Bedrijf, a waste processing company for Amsterdam & region), a customer-service employee of Avalex (a waste processing company for the Hague & region) and a sales & marketing manager of solid waste at Indaver (a Belgium waste processing company that processes organic waste streams for smaller Dutch waste processors). Appendix F – Interviews gives an overview of the different questions that have been asked during these interviews. The goals of these interviews have differed from understanding the waste management domain and historical decision-making procedures to specific implementation impacts, consequences and limitations

To discuss various policy interventions possible in the NDSM wharf, brainstorm sessions have been conducted with the NDSM participants and another 7 people living, working and/or studying in the neighbourhood of Amsterdam and 3 outsiders. Varying in age, gender and ethnicity, from international students till retired inhabitants of Amsterdam. One Dutch student living and studying in Amsterdam, one Dutch student studying in Amsterdam, three inhabitants living nearby Amsterdam and frequent visitors of the NDSM wharf, two elderly frequently visiting the NDSM wharf and three international students and engineers, unknown with the specifications of NDSM and the Dutch waste separation business. The results of these brainstorm sessions are described in Appendix G – Policy Discussions.

3.3 Simulation Modelling

This research analyses people to predict environmental behaviour. According to Thøgersen (1996) this type of behaviour belongs to the moral domain, and therefore is not solely represented by cost–benefit analysis, but also by the moral beliefs of right and wrong.

To make the data found in the literature review more relevant and useful this research makes use of simulation modelling (Holland, 1995). This type of assessment is four steps removed from reality and therefore creates a generalized view of the situation. This is useful because of the flexibility a modeler gets in the creation of policy interventions (Bonabeau, 2002).

The case study, which will be described later in detail, offers great possibilities to broader scientific research, because of its various inputs, external factors and the available policies that have to be taken into account. Simulation modelling can support informed decision making in the mentioned case or others. While simulation modelling can be time-costly, it is a very cheap way of researching a wide range of scenarios, testing robustness and testing resilience (Capano & Woo, 2017). Due to the current state of decision-making there is an open window of opportunity for the Re-StOre project at this point in time. The use of a modelling technique aims at answering question 3 and 4, and have the practical goal to contribute to an informed decision for the NDSM participants.

3.4 Agent-based Modelling

The Re-StOre project in de NDSM wharf includes many stakeholders, with a wide variety of opinions and goals, different technical aspects and natural uncertainties. These factors all have to be aligned in some sorts, for the waste processing to be an environmental success. The agents in the network behave in a dynamic and complex manner. This research uses Agent-based modelling (ABM) to model this environment, because of its capacity to model complex behaviour (Macal & North, 2005).

The Re-StOre project is not governed top-down, but rather all the individual agents make decisions based on their own properties and states. This lack of central control is a typical aspect that can be well modelled with ABM (Siebers, Macal, Garnett, Buxton & Pidd, 2010; Jennings, Sycara & Woolridge, 1998). ABM shows the emergent behaviour that arises when agents make their decisions decentralized and based on their limited world view & capabilities (Bonabeau, 2002; Jennings, Sycara & Wooldridge, 1998).

An important aspect in modelling the Re-StOre NDSM network is the change of the agents properties during the simulation. As an example, the knowledge of an agent will change over time, affecting his or her behaviour. Agent-based modelling offers the possibility to include this complexity, whereas methods such as system dynamics or discrete event simulations would have trouble formulating and/or solving the complex equations over time (Axtell 2000; Davis, Nikolić & Dijkema, 2009).

3.5 Tools

In accordance with current research at the TU delft, this system will be modelled in Netlogo. This is “a multi-agent programming language and modelling environment for simulating natural and social phenomena” (Tisue & Wilsensky, 2004, pp. 1). Netlogo offers an insight into the agent behaviour through simulations in an easy understandable interface (Gilbert & Bankes, 2002). It is useful because as it is a freely available program that simulates highly complex human behaviour (Macal & North, 2005).

On the other hand, there are several alternatives available. Simple models could be modelled in Excel or Spreadsheets. To increase the mathematical power it could be useful to use General Computational Mathematics Systems such as Matlab or Mathemetica, but these are often expensive and difficult to code (Macal & North, 2005). Lately, freely available programs are developed to increase scalability such as REPAST Py, SWARM, ASCAPE or MASON (Gilbert & Bankes, 2002). Also, MESA offers a promising new environment to model agent-based environments in python, which increases scalability, mathematical power and introduces simultaneous modelling.

It has to be noted that MESA and the Large-Scale Agent Development Environments are still in their development phases. The current research aims to contribute to the ABM community. Netlogo comes with a big community and a great influence into the ABM domain. Therefore, Netlogo will be the tool used in this research.

Summarizing, this research will primarily make use of Agent-Based Modelling in Netlogo. The agent-based model is used to observe how the technical and socio subsystems of an infrastructure co-evolve (Van Dam, Nikolic, & Lukszo, 2013). The drawback of this approach is that our model will include “human agents, with potentially irrational behaviour, subjective choices, and complex psychology—in other words, soft factors, difficult to quantify, calibrate, and sometimes justify” (Bonabeau, 2002, pp. 7287). To limit the effects of this issue a literature study will be used to further substantiate the model assumptions. Additionally the research will be validated through expert interviews for the Re-StOre project.

3.6 Experimental Design

Experiments are designed in order to substantively answer the main research question. These experiments will provide insight in the effect of the different policy options for the NDSM wharf. Many different factors play a role in determining the output. For every experiment most parameters are kept stable, according to their default setting. Varying a few variables each time, their impact on the output parameters is measured. The different designs used in this research are described in Appendix H – Experimental Design.

3.7 Conclusion

In conclusion there are three types of methodologies used to answer the different sub-questions as posed in Chapter 2.6. Figure 4 shows these figures on the top bar, the literature review, case study and the agent-based simulation model in Netlogo. As mentioned before, these are used to help

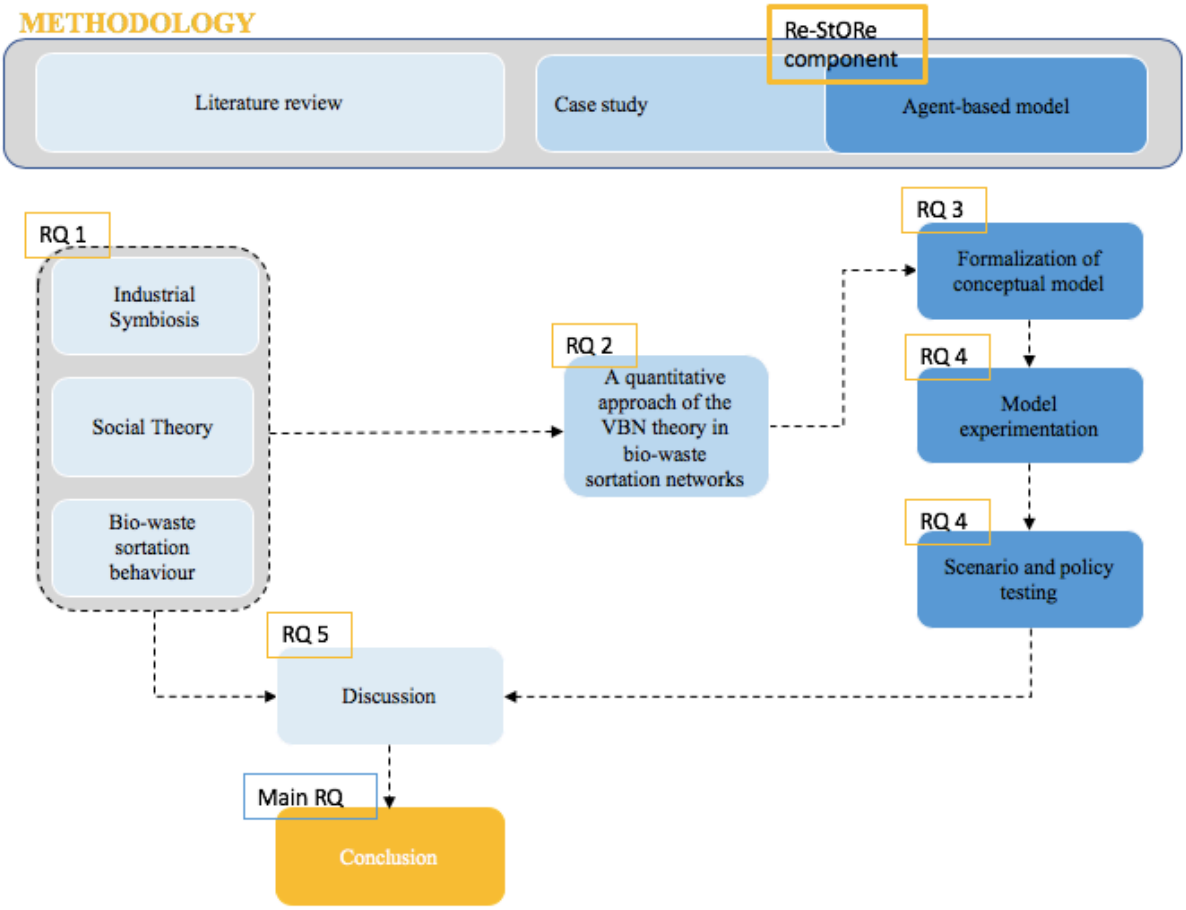

Figure 4 - Usage of different methodologies for the sub-questions.

4 Behaviour patterns in waste recycling

This chapter will combine the insight found in Chapter 2 with general waste separation behaviour literature. A social theory will be chosen (4.1) together with a new approach to translate the IS & VBN literature into a setup ready for agent-based modelling (4.2). To further specify the scope of this research, the general theories of waste separation behaviour are discussed (4.3). The VBN theory is found in Chapter 4.4 with its an environmental values, beliefs & norms and their impactful on this behaviour.

This chapter aims to partially answer questions 1 & 2:
1. How can the theory of Industrial Symbiosis be connected to social theories for the conceptualization of a symbiotic network? 2. How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?

4.1 Social Theory Decision

While the Theory of Planned Behaviour has been previously used in the topic of Industrial Symbiosis and waste separation (Chan, 1998; Ghali, Frayret & Ahabchane, 2017) the VBN theory offers the possibility to include normative factors in explaining sustainable attitudes and behaviour (Stern et al., 1999; Stern, 2000). To conclude the first sub-question, recycling behaviour is characterized as "highly normative behaviour" (Barr, 2007, pp. 435) and Industrial Symbiosis is influenced by "a high level of shared norms" (Ashton & Bain, 2012, pp. 70). Therefore, it is the underlying assumption of altruistic behaviour based on social satisfaction rather than an ultimate personal analysis, which drove the choice towards the VBN theory. Evidence has shown that the VBN model explains 19% to 35% of its variance (Stern et al., 1999). This is comparable with the explained variance of the Theory of Planned Behaviour.

4.2 Representation of Actors for Agent-Based Modelling

To translate the social theory to a generalizable agent-based model different groups of people are distinguished. To generate these profiles the four values, altruistic, biospheric, egoïstic and hedonic values, are used to distinguish the spectrum of human behaviour.

While research on the significance of the different values often includes heterogeneity in the connection between values and individual behaviour (De Groot & Steg, 2007; Steg, Perlaviciute, Van der Werff & Lurvink, 2014). In papers that apply the Value theory, one value is often seen as a homogenous indication of what people find most important in life in general, in other words: People will base their choice on the value that they consider the most important to act on (Steg, Bolderdijk, Keizer & Perlaviciute, 2014; Schultz et al., 2005). In this research a new approach is taken. Human action is ordinarily oriented to a plurality of values, none of which can be fully realized without injury to some others (Cohen & Ben-Ari, 1993). For example, a person may reduce car use because the costs are too high (egoistic), because it endangers the health of fellow citizens (altruistic), or because it harms plants and animals (biospheric) (Sánchez-Maroño et al., 2017).

To include the influence of all values, not just the dominant one, 16 profiles are constructed. For simplicity reasons the profiles represent an equal balance of all four values. Figure 5 gives a schematic overview of these profiles.

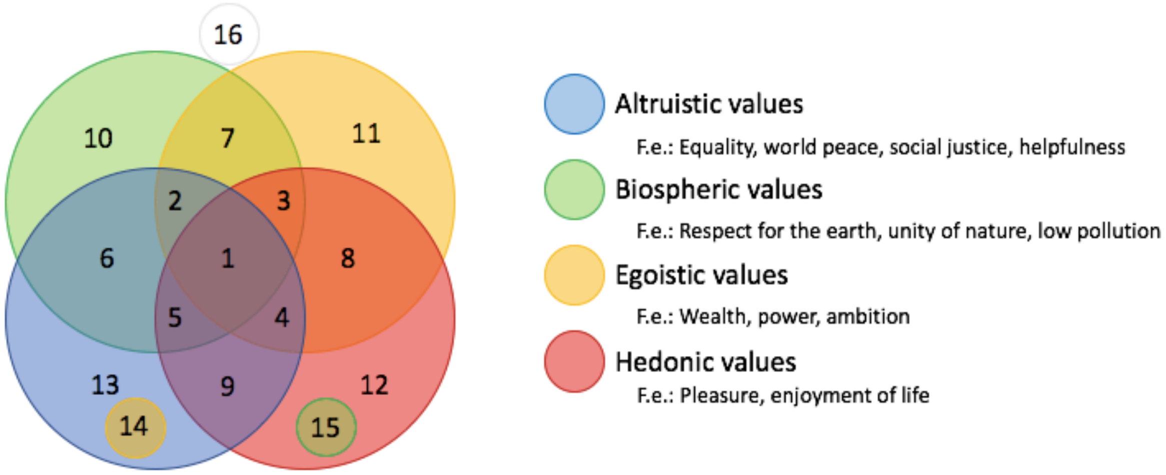

Figure 5 - Value profiles

Through extensive research of online documentation of the involved Re-StOre NDSM parties, 5 profiles have proven to be important players in the network. More information about these players can be found in Chapter 5.1. These profiles are useful in combination with agent-based modelling to standardize the idea that "people with different worldviews may react differently to certain economic incentives and scientific information." (Pan et al., 2015, pp. 416).

4.2.1 Type A

This profile shows Biospheric & Hedonic values. Actors with this profile live for self-fulfilment in harmony with mother nature. An example of this profile might be an organic restaurant that solely works with water-saving or vegan dishes.

4.2.2 Type B

This profile shows Hedonic values. Actors with this profile strive towards personal enjoyment of life. Private parties with a profit motive are often an example of this profile.

4.2.3 Type C

This profile shows Biospheric & Egoistic values. Actors with this profile have the ambition to be a trailblazer when it comes to environmental issues. An example of this profile might be Greenpeace.

4.2.4 Type D

This profile shows Biospheric, Egoistic & Hedonic values. Actors with this profile balance the intention towards unity of nature with an active approach to include their own fulfilment and that of its neighbours. An example of this profile might be a local association for a greener living environment.

4.2.5 Type E

This profile shows Altruistic, Biospheric & Egoistic values. Actors with this profile launch initiatives for the greater good of the planet and its inhabitants. An example of this profile might be a public agent or a knowledge institute.

4.3 General Waste Separation Behaviour

In this chapter the general behaviour from buying biodegradable products to disposal of bio-waste is described. First off the knowledge of recycling materials in the local area, processing means and recycling locations are described as a critical first step in waste separation (Gamba & Oskamp, 1994; Vining & Ebreo, 1990). An individual has to recognize the bio-waste in front of her and make the step to throw it in a local separation bin, it is therefore a prerequisite for the knowledge level to be above a certain standard (Barr, 2007). In this factor one clearly sees the effect of awareness campaigns.

Once disposed in a local waste bin Barr, Gigl & Ford (2001) mention that time, convenience and space to store are factors influencing the local storage, in addition to the visual impact of recycling bins (McDonald & Oates, 2003). Taken together, type of storage, sight and accessibility are possible factors to influence the "convenience". Additionally, health regulations limit the malfunctioning of proper waste management in SMEs and depending on the size of the business waste processing contracts are constructed publicly, waste care becomes therefore a concern of businesses (Aphale et al., 2014; Lebersorger & Beigl, 2011). This has the possibility to limit bio-waste separating behaviour, since throwing biological materials away in the regular waste bin is easier.

Later the locally separated waste has to be transported to a central collection location. The distance and time it takes to reach this central collection point, the convenience for the user and the space for storage before disposing the waste are factors that lead to non-sorted bio-waste (Tonglet, Phillips & Bates, 2004). Once stored the containers continue to have odour problems, rodent and insect problems, noisy and become "hanging" places, leaving them to be unattractive to visit (Lang, Binder, Scholz, Schleiss & Stäubli, 2006; Gil, & Kellerman, 1993). Xiao, Zhang, Zhu & Lin (2017) found in their research that waste disposal costs often go unnoticed and are therefore limitedly influencing the daily recycling behaviour.

Finally the collection of the waste by a private or public waste processor can be subject to technological and capacity capabilities (Lang, Binder, Scholz, Schleiss & Stäubli, 2006). Waste disposal in small businesses and households can be predicted for a small ¾th (Lebersorger & Beigl, 2011). With commercial waste being less predictable and more subject to seasonal changes the complexity for processors can increase.

4.4 Grouping of Behaviour

Schultz, Oskamp & Mainieri (1995) associate the environment and personality constructs of an individual with his/her separation behaviour. In this research the environmental attitude and personality constructs of individuals are represented through the earlier mentioned Value-Belief-Norm theory profiles. In future case studies this assumption is in need of revision.

In this chapter, first the effect of the personality construct is discussed (Altruistic, Biospheric, Egoistic & Hedonic behaviour patterns) and secondly the effect of the environmental attitude (NEP, Awareness of Consequence, Ascription of Responsibility).

Going through the literature one sees that people with altruistic values are likely to recycle when they can (Hopper & Nielsen, 1991). They feel a moral obligation to act responsibly. The feeling of being good for the world makes people be more willing to learn about recycling and incorporate it in their behaviour. Similarly, people with biospheric values are motivated to create a better biosphere (nature and environment) without a personal benefit (Steg & De Groot, 2012). People with a biospheric profile are likely to recycle when needed because of the personal satisfaction. When combined with values to be a trailblazer and to be in an innovative environment they could also easily be seen as someone that spreads this idea and initiates recycling throughout the neighbourhood (De Young et al., 1986). On the other hand, people with hedonic values are less interested in recycling behaviour as it takes time and effort of the participant. Egoistic values can both influence the recycling behaviour of a network to the good and to the bad as they look at being a central power in the network.

In this research a focus is set on place-oriented symbiotic networks. Due to the geographical proximity in these networks, neighbourly feelings create behaviour that is richer than simply personal norms, the perception of the problem and its effect on the agent make for complex decision-making (Baldassare & Katz, 1992). Therefore, if awareness of consequence and ascription of responsibility are high this can impact the behaviour towards more waste separation. Oppositely, participants may believe that their individual contribution is too insignificant when compared with the problem magnitude (Xiao, Zhang, Zhu & Lin, 2017).

4.5 Conclusion

In the previous four chapters the decision for the VBN theory is explained and the adaptation to the values in the model has been described. Together, this has led to a new quantitative approach of the VBN theory for the agent-based model in this research. Figure 6 shows how the approach is conceptualized, whereby the behaviour and the impact of the model on the behaviour has been described in Chapter 4.3 and 4.4, giving the needed focus on a symbiotic bio-waste sortation network.

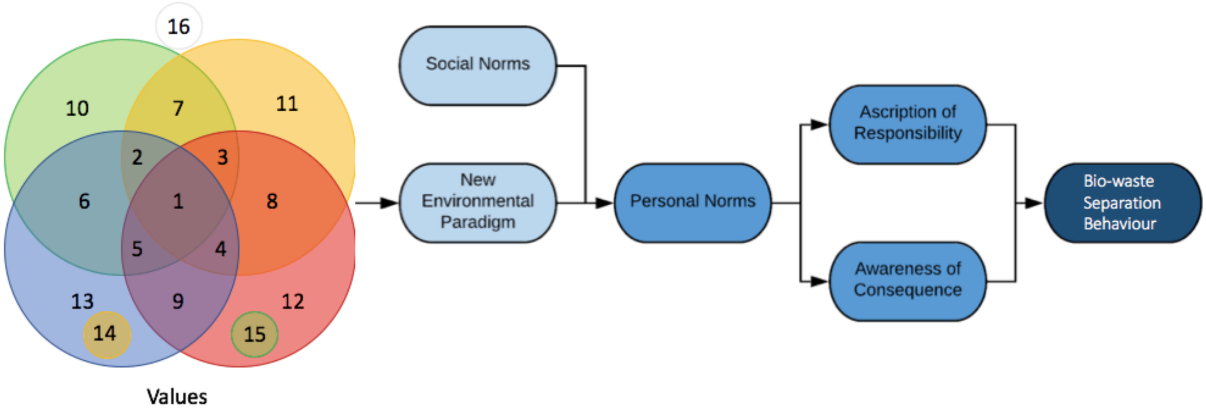

Figure 6 - New quantitative approach of the Value-Belief-Norm theory

5 Case Description and Application

In Chapter 4 a new conceptual model is developed incorporating the Value-Belief-Norm theory in the field of agent-based modelling. To test the viability of this model a context setting is created to test the model and be able to analyse the results. To do so, a case study is used. In the next paragraphs this case study is described and the current agents involved in the case study have been identified (5.1). This research aims to get a clearer image of the context and the possibilities of scenario testing and policy interventions (5.2 & 5.3). Hereby it is very important to also note the scenarios and policies that have not been taken into account for several reasons (5.3.2).

This chapter aims to partially answer question 2:
How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?

5.1 The Application of Re-StOre Amsterdam

From 2016 till 2018 the University of Applied Sciences in Amsterdam did research on the decentralized processing of organic waste flows at urban farms through the project Re-Organise. This project resulted in the design of several technical solutions and prototypes for corporate small-scale processing of organic residual flows at urban farming locations. The knowledge of the Re-Organise project is underlying the follow-up Re-StOre.

Since 2018, Re-StOre (Centre for Applied Research Technology, 2019) is developing a measuring system and simulation model that gives companies and municipalities more insight into the financial, ecological and social effects of various composting and bio-digestion forms, on a small and large scale. The system must enable municipalities and businesses to make better decisions on issues like "which solution for the processing of organic waste fits best in a specific situation".

In light of this research, the NDSM wharf has emerged as a potential focal point on the topic of a symbiotic network for bio-waste processing. From the 1920s until the 1980s, the NDSM-wharf was one of the biggest shipyards in the world. Recently it has become a home port for creative pioneers. These things combined it offers an innovative and vast-developing community where ecological interest is high. This user-driven and bottom-up network with many heterogenous actors spread over the wharf has shown an interest in sustainable waste management and therefore offers an interesting scientific and societal test location for new ideas on the topic of bio-waste separation.

At this point in time, the main actors in the project are:

- Foundation NDSM wharf (Stichting NDSM-werf)
    - A foundation responsible for the physical management of the wharf, which hosts ±400 businesses.
- NDSM Energie
    - A corporation representing ± 60 parties located in the wharf to sponsor sustainability of the business park.
- Municipality of Amsterdam – Departments of waste management
    - Strategic advisory department for the Amsterdam area.
- ROC Top
    - A small-scale practical education institution with a focus on circular economy.

- Amsterdam University of Applied Sciences – Urban Technology
    - A research and education institute for urbanization in Amsterdam.

A group of 20 participants has already invested time in the Re-Organise project, and hence are eligible to include in the conceptualization. These participants have each been represented in an agent type based on their social media presence, this data is available upon request.

In addition, all 400 businesses on the wharf are likely to be affected by the new bio-waste processing. This makes for a highly fragmented location, which many differently oriented stakeholders. Potentially, the agents involved in Re-StOre can change over time. As an example it is likely that the 60 represented parties by NDSM Energie would increase their efforts to separate bio-waste once a project is in place. Since the specific actors in this model may vary over time, the next chapter will describe a concept to create a generalizable model for waste separation research.

5.2 Scenario Application

This study has researched several impactful or highly likely situations that can be inflicted upon the system. Several external effects that are likely to occur can seriously impact the behaviour in the model. One of these changes is the external decision of a member to leave the network. As discussed earlier, rigidness and a vulnerability to react to changes can be a problem in symbiotic networks (Doménech & Davies, 2011a). This change in network composition is tested in the first scenario. As second scenario analysis the number of agent types in the model is tested on its impacts. This is a likely scenario as applying the model to different cases can make a big difference on the number of agent types that should be modelled.

5.2.1 Leaving Scenario

Shortly recapping earlier topics of symbiotic networks. The networks are creating value through collaboration, whereby an over-embeddedness of the system outweighs the benefits by creating a system which is too rigid to create organizational survival (Hewes & Lyons, 2008; Doménech & Davies, 2011a; Uzzi, 1996). Organizational survival in this study means improvement of the environmental impact of bio-waste through sortation methods and the creation of a self-sustainable stage (Sacchi & Remmen, 2017). To test how the leaving scenario impacts the behaviour and output of the model it is implemented in the shape of a scenario. Testing the robustness of the model with and without the individual policies, and measuring the effects of policies with or without a leaving party.

5.2.2 Agent Type Scenario

In Chapter 4.2 the different agents that are represented in the NDSM case have been modelled in five different agent profiles. However, as shown in the description of Chapter 5.1, it is likely that the number of agents in the model can change depending on the interest of fellow NDSM members, and more importantly, when using the aforementioned approach of combining IS with VBN theory for a different case study, the initial number of agents can differ. To test if this results in significant differences in the model behaviour and model output the agents are modelled in quantities of the original number, 15 and 50 members with the other variables remaining the same.

5.3 Policy Application

Countries around the world waste enormous amounts of food, and good strategies are needed to convert this waste into useful resources. (De Clercq et al., 2017). Through a literature study of world-wide used policies, brainstorm sessions and workshops with the Re-StOre participants, locals and outsiders, several policies came to light. Several of these policies have been implemented and tested in this simulation model (see 5.3.1), while others have been left for various reasons (see 5.3.2)

5.3.1 Disclosed Policies

Five of the found policies have been studied further because of their frequent reoccurrence in the discussions; Information stimulus through group feedback, promotion of social diffusion, on-demand central collection, improvement of container interaction in central waste disposal and information stimulus through campaigning.

5.3.1.1 *Information stimulus through group feedback*

Education was highlighted to bridge the gap between "having the right attitude and actualizing that in behaviour" (Neo, 2010; Massawe et al., 2014). Through knowledge ones' intentions can be better translated to successful waste separation. Education campaigns can change recycling behaviour of people to the better (even though offering the information alone (flyering) will not lead to significant effects (Dennis et al., 1990; Vining, & Ebreo, 1989)).

A more extended version of information stimulus is to incorporate the effects of people's own behaviour. An example of this type of feedback can be through the dispatching of cards with a geographical display of the effects of their individual bio-waste separation behaviour. Specifically, in the case of Re-StOre a renewed private waste processing contract is needed to be able to make environmentally friendly use of the sorted waste. This leaves room for possible future communication strategies. These exchanges create a circle of the first set of actors (Chertow & Ehrenfeld, 2012).

5.3.1.2 *Promotion of social diffusion*

Not only the individual environmental behaviour of a citizen determines the decision-making process, also the environmentally friendly behaviour of family and friend can improve sustainable waste separation (Xiao, Zhang, Zhu & Lin, 2017). Seeing people around you actively engage in waste separation can cause a snowball effect on neighbours (Scalco, Ceschi, Shiboub, Sartori, Frayret & Dickert, 2017). Adapting the way the participants behave is by increasing the promotion of positive experiences.

This promotion of new bio-waste innovation can be a productive way of changing the behaviour. Possible policies are publicizing key trend setters; promoting salient, high-profile success stories; and capitalizing on existing social networks (Dennis et al., 2017). Research by Hopper & Nielsen (1991) showed the success of a so-called "block leader", someone that interacts with the group increasing their knowledge about recycling (what to recycle, when to recycle) or their motivation to be involved. In other researches so-called "opinion makers" or "initiators" play a similar role.

5.3.1.3 *On-demand central collection*

A second possibility to reduce personal efforts in bio-waste separation is to make the experience of people better. On-demand central waste collection could reduce the smell and bad aesthetics of a central collection point compared to the scheduled waste collection method. Beyond the scope of this research it could also reduce the operational costs of central waste collection.

Improvement of container interaction for agent engagement

There are numerous of possibilities that make the interaction with a central container bin a negative experience. It is estimated that 90 percent of the environmental impact of a product (waste container) is determined by design (Hosey, 2012). The combined research of ecological modernisation and industrial ecology states the importance of technological innovation and entrepreneurship in the creation of economic and environmental gains (Gouldson & Murphy, 1997; Deutz, 2009). A literary research has shed light on several of the causes that make people refrain from separation.

Difficulty in the social interaction of people with the waste management environment can occur in various sorts of forms. For example, waste separation will be more complicated if citizens have to throw different waste compositions at different times, or in different sites or trash bins (Xiao, Zhang, Zhu & Lin, 2017). This increase in personal effort can reduce the successfully separated bio-waste. Secondly, “bad” design can nudge people into wrong separation behaviour such as throwing waste in an incorrect bin, hereby polluting the previously correctly separated waste, glass from a nearby container can rip bags with bio-waste leaving the container environment dirtier. Thirdly, waste entries that are too small can cause unhygienic waste interaction and increase the risk of disturbing the cleanliness of the environment. Fourthly, waste bins have an interaction with their social and natural environment. Central sortation locations that are too easy to interact with can be subject to garbage-eating animals, when animals learn to effectively interact with their potential food sources (Peltola, Heikkilä & Vepsäläinen, 2013).

There are several ideas improving human engagement proposed to counteract this personal investment. Examples are “poka yoke” design (fool proofing), lean design (efficiency & simplification) or six sigma design (error reduction). Experiments can be done incorporating Environmental Internet of Things (EIoT) to ease the way people move their locally collected waste to a more central collection unit (Wang, Zhang, Quan & Dong, 2013). For example, electronic devices at central collection points can increase the capabilities of people to unload their waste. Furthermore, colours, shapes and sounds, child friendliness and ease of use are frequently mentioned factors that can be altered to directly induce successful recycling behaviour of people (Hosey, 2012). For example, currently glass and plastic central collection points in Amsterdam have different colours to stimulate recycling in the correct bin.

5.3.1.5 *Information stimulus through campaigning*

Since this growth of knowledge was deemed important (5.3.1.1), an optimal way of information disposal was explored for Re-StOre. Campaigning represents the simplest, least expensive, and least intrusive way of distributing information (Schultz, Oskamp & Mainieri, 1995). In the creation of this policy the intellectual property of Dennis et al. (1990) shows the different aspects of information disposal that are needed to make the knowledge growth a success. The most important aspect for effective stimulus through campaigning is for people to recognize the problem as their own. There are several means to obtain this goal.

Firstly, the type of information that is distributed can be very influential based on your audience, this goes hand in hand with the manner of presentation. Presenting information in long and difficult to read tables with lots of numbers, will not spark a learning process for everyone.

Additionally, the type of channel and the credibility & salience of the message are of utmost importance.

The latter two are more easily achievable in the case of Re-StOre, due to its geographical proximity and the central roles of cooperatives such as the *NDSM Stichting* and *NDSM Energie*. Also, the "NDSM culture" creates a homogeneity in its participants and therefore the manner of disposal can also be tailored to specific wishes.

5.3.2 Policies Not Modelled

Due to the limitations of time and the chosen modelling method, not all policies mentioned in the literature and brainstorm sessions are useful to be implemented in the model. For the completeness of this report, these policies are discussed in the following chapters.

5.3.2.1 *Legislation*

It was noted that legislation could force environmental behaviour through law. However, the effects of this policy are thought to be trivial in comparison to the policies increasing citizen knowledge or social motivation (Xiao, Zhang, Zhu & Lin, 2017). Also, due to the relatively small reach of the NDSM case study on the whole of the Netherlands, this possibility has not been taken into account further.

5.3.2.2 *Financial compensation*

The idea of rewarding positive behaviour through financial compensation, or punishing negative behaviour through fines or higher bills is thought to be of lesser importance than the before mentioned policies. Through a thorough literature study two reasons stand that invalidate the use of financial compensation.

First, there is the idea of "buying off". The book "why we work" by Schwartz (2015) describes how people's good behaviour can be undermined rather than enhanced through financial compensation. It describes the idea of people that buying off bad behaviour is equally good as behaving correctly in the first place, resulting in less social obligation and more economic optimization.

Secondly, as stated previously, the price of waste is a monthly reoccurring expense. Changes in this bill often go unnoticed and are therefore limitedly influencing the recycling behaviour (Xiao, Zhang, Zhu & Lin, 2017). If the financial compensation is big enough to be noticed by the participants this will directly lead to an increase sorted bio-waste without any of the dynamics in the behaviour pattern changing.

5.3.2.3 *Packaging*

Food labels, quality marks and food packaging can be improved to increase the ease of users to separate these correctly (Halloran, Clement, Kornum, Bucatariu & Magid, 2015). However, this is not in the hands of the actors associated to the Re-StOre project and needs an approach on a bigger scale. When implemented this could lead to an easier understanding of people while throwing away their waste.

5.3.2.4 *Pledges*

Initiating commitment through pledges and written support will increase the dedication of participants to be involved in the symbiotic network (Schultz, Oskamp & Mainieri, 1995). Haldeman & Turner (2009) predict a 7-9% increase in the bio-waste recycling rate through a face-to-face scheme. With limited financial costs, it could be a good idea for the NDSM participants to implement this policy. Because this policy does not influence the dynamics of waste separation as much as it will increase the separation behaviour in general, it will not be modelled in this research. Since it is shown that there is room for this policy to lead to an integral improve of bio-waste separation, implementation is suggested.

5.4 Conclusion

In conclusion there is a standard NDSM case that will be modelled over half a year. Additionally, there are 5 policies that will be tested on their effectiveness of changing the sorted bio-waste quantities. These are, information stimulus through newsletters or through specific feedback flyers, an increase in ease of use through design of central disposal units, an on-demand collection for better service and a highlighting of positive social behaviour. Furthermore, two scenarios will be modelled to test the resilience of the model and the different individual policies, the leaving scenario and the agent type scenario. Finally, the five different policies will also be modelled combinedly. This is summarized in Figure 7.

It is important to note that the policies described in this research are limitedly implementable in different case studies. One of the examples showing this difference is the common practice in Western Europe to improve the percentage sorted waste through education, however, in China the go to policy is more often legislation (Xiao et al., 2017). Also, the idea of "good" design can be very culturally dependent.

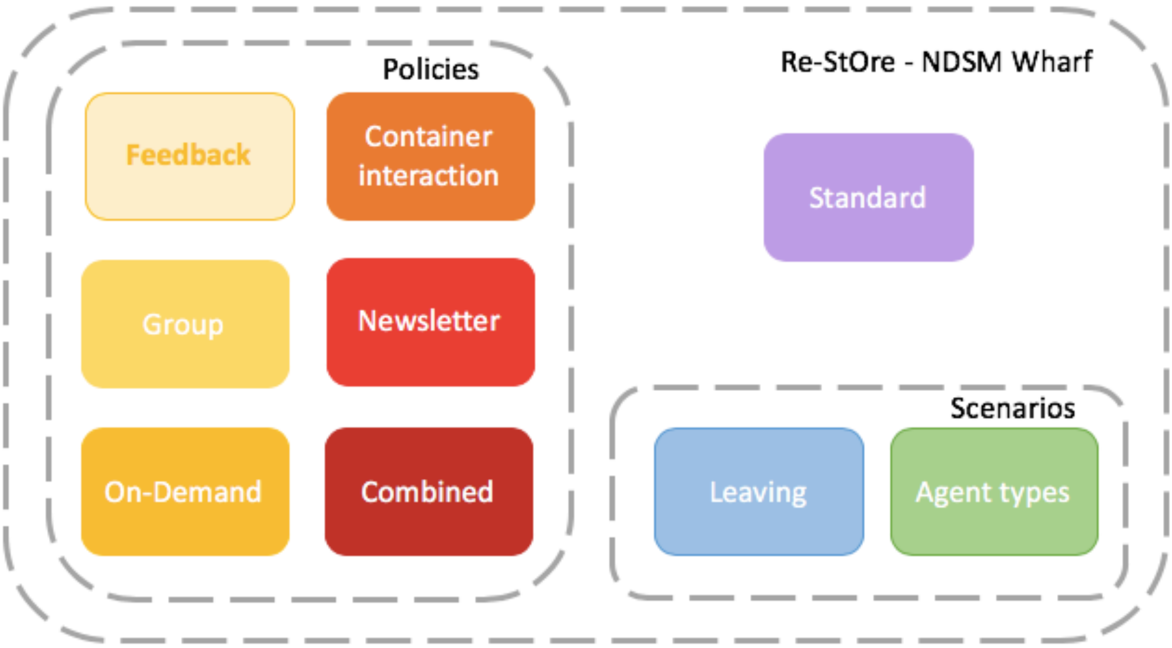

Figure 7 - Case Application

6 The Model

To create a model that can analyse bio-waste separation 20 agents are bread based on the agent types as discussed in Chapter 4.2. Type A, B and C create (non-)separated waste according to the steps in Chapter 6.1.1. Their values, beliefs and norms are included as discussed in Chapter 6.1.2, to make the general waste separation behaviour personal. Chapter 6.1.3 gives an overview of the whole model. The randomness of individual behaviour and the boundaries of this system are discussed in Chapter 6.1.4 & 6.1.5. Chapter 6.2 describes the assumptions made in this model and in the policies described in Chapter 5.3.1. A sample run in Chapter 6.3 gives a convenient overview of the model. Concluding with a verification in Chapter 6.4.

This chapter aims to answer question 3:
How can a symbiotic bio-waste sortation network be modelled?

6.1 System Identification and Decomposition

This chapter will look at the behaviour of the different agents included in this model and the different inclusions of behaviour modelling.

6.1.1 General Waste Creation

General waste management literature starts with the generation of bio-waste inflow. In their paper on the complexity of food waste behaviours Quested, Marsh, Stunell & Parry (2013) discuss the inflow of bio-based products and their process to separation. The quantities here are based on the previously collected waste quantities of the businesses at the NDSM wharf.

First, the bio-waste separation of the actor is called upon. The recognition and successful sortation of bio-waste is dependent on the time and reachability, the knowledge and biospheric values of the actor. Based on these values the bio-waste is collected in a local bin or thrown into the general waste. The local disposal of waste is on average 21.9 kg each time, with a standard deviation of 2.8 kg, and a five time disposal per day, based on previous research by the Waste Transformers in the NDSM wharf (2017). While the bio-waste storage bin has space and does not smell, this process shall continue.

When the bin is ready to be centrally collected the actor has three factors to take into account: willingness to walk the distance, previous container experiences and difficulty of disposal (see Figure 8). The first factor includes the distance to the container, the time it takes to get there and biospheric values of the actor. The second value includes the safety, the hygiene and the social atmosphere of the container. The third value includes the capacity of the container and the ease of container interaction.

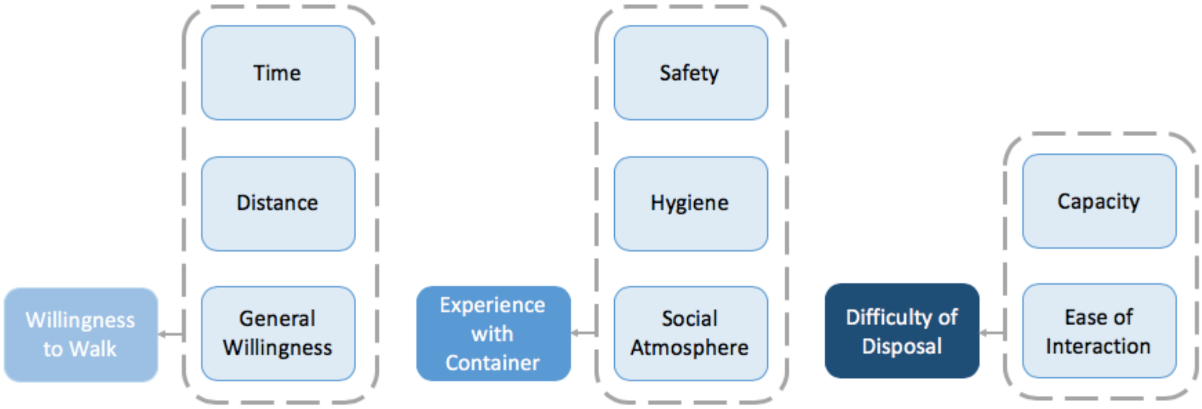

Figure 8 – The factors that are included in each of the decision-making steps of the model.

Figure 9 shows how the different factors are a barrier from the local to the central bio-waste storage and how these quantities add up, since every agent owns a personal storage bin, while the central bin is a shared location.

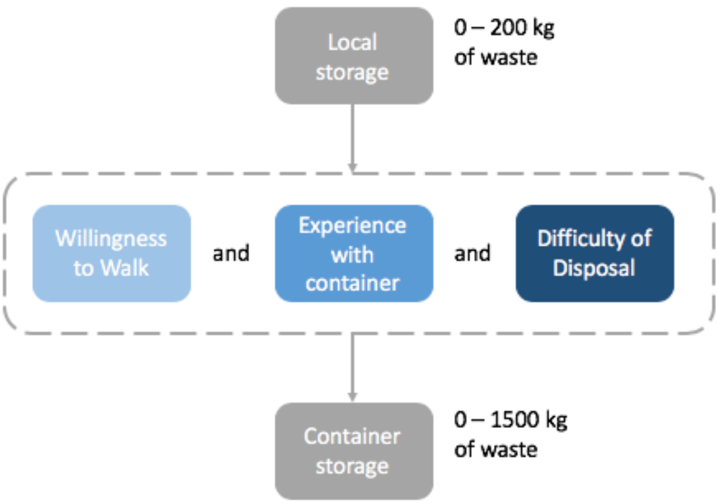

Figure 9 – The three decision-making steps necessary to move bio-waste from the local to the central storage container.

Finally the bio-waste has (or has not) reached the central container. In accordance with the waste processor these will be emptied and the bio-waste is transformed from individually-owned bio-based product to centralized and sorted bio-waste outflow. Lang, Binder, Scholz, Schleiss & Stäubli (2006) note three boundary conditions to the driving forces in centralized bio-waste transformation: Technological development, Environmental awareness, Processing capacity of the treatment facilities. In this model the environmental awareness is included in the profile-specific behaviour of the actors. The remaining boundary conditions are bundled in one function of the ABM model to limit the abilities of the behaviour space.

In summary, the creation of this model has led to a decision making process as described Figure 10. Where
Figure 8 gives more detail on the topics including the middle three steps. Furthermore, it should be noted that the percentage sorted bio-waste is still subject to correct municipal behaviour in the model.

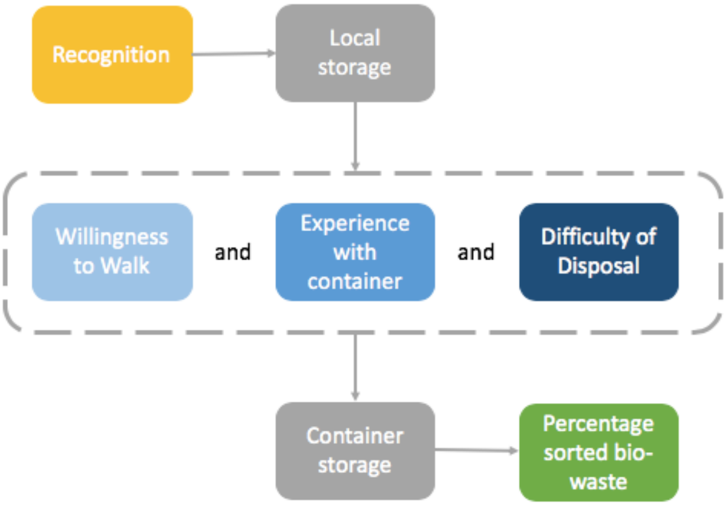

Figure 10 - Agent decision-making steps for general bio-waste separation behaviour in the symbiotic network.

6.1.2 Inclusion of Behavioural Profiles

To predict the behaviour of people this research underlined the inclusion of Value-Belief-Norm profiles. Figure 11 represents how the behavioural profiles (agent types) are a part of the agent, together with its other properties.

Chapter 4.2 highlights the different behavioural patterns, Hopper & Nielsen (1991) found that the norms of people do not change when the knowledge about recycling does, while the knowledge about recycling can alter the behaviour. However, Rideout (2005) found (limited) fluctuations that are possible in the NEP score of people. Therefore a dichotomy is made within the Value-Belief-Norm profiles for static and dynamic values. First of all, five different breeds of turtles are hatched, to include the agent types with their values, NEP & Awareness of Consequence value and an Ascription of Responsibility value. Secondly, the turtles receive a knowledge of bio-waste separation which is based on their NEP value. These have an initial similar value, however the bio-waste knowledge starts to change over time.

Furthermore, the agent has an initial the happiness with the symbiotic network and local waste bin are zero at the beginning of the simulation. These will adapt over time together with the knowledge of people and the personal willingness to walk the container distance. Finally, the behaviour of the agent and the network impacts the knowledge, local bin and happiness throughout the simulation.

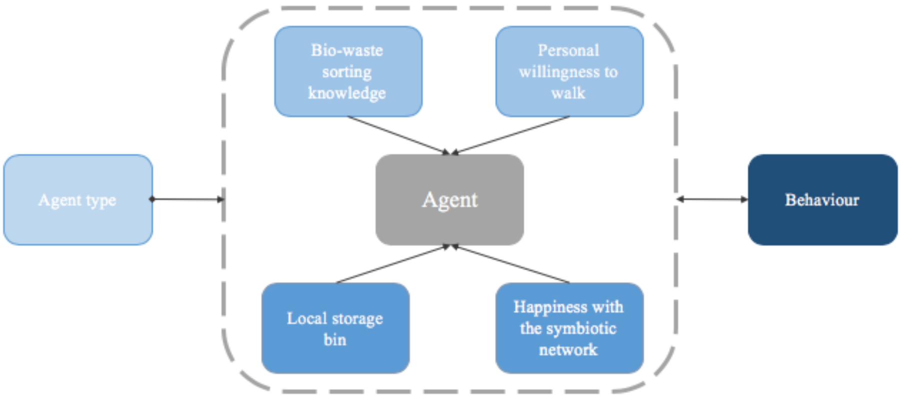

Figure 11 – The inclusion of the behavioural profiles, and other intrinsic value that the agent carries.

6.1.3 Full Model

A model is constructed including not only general waste management literature, but also includes the new application of the VBN theory to symbiotic networks. Therewith, it answers the third sub-question: *how can a symbiotic bio-waste sortation network be modelled?* The full model as shown in Figure 12 offers an inclusive representation of real-time waste separation behaviour.

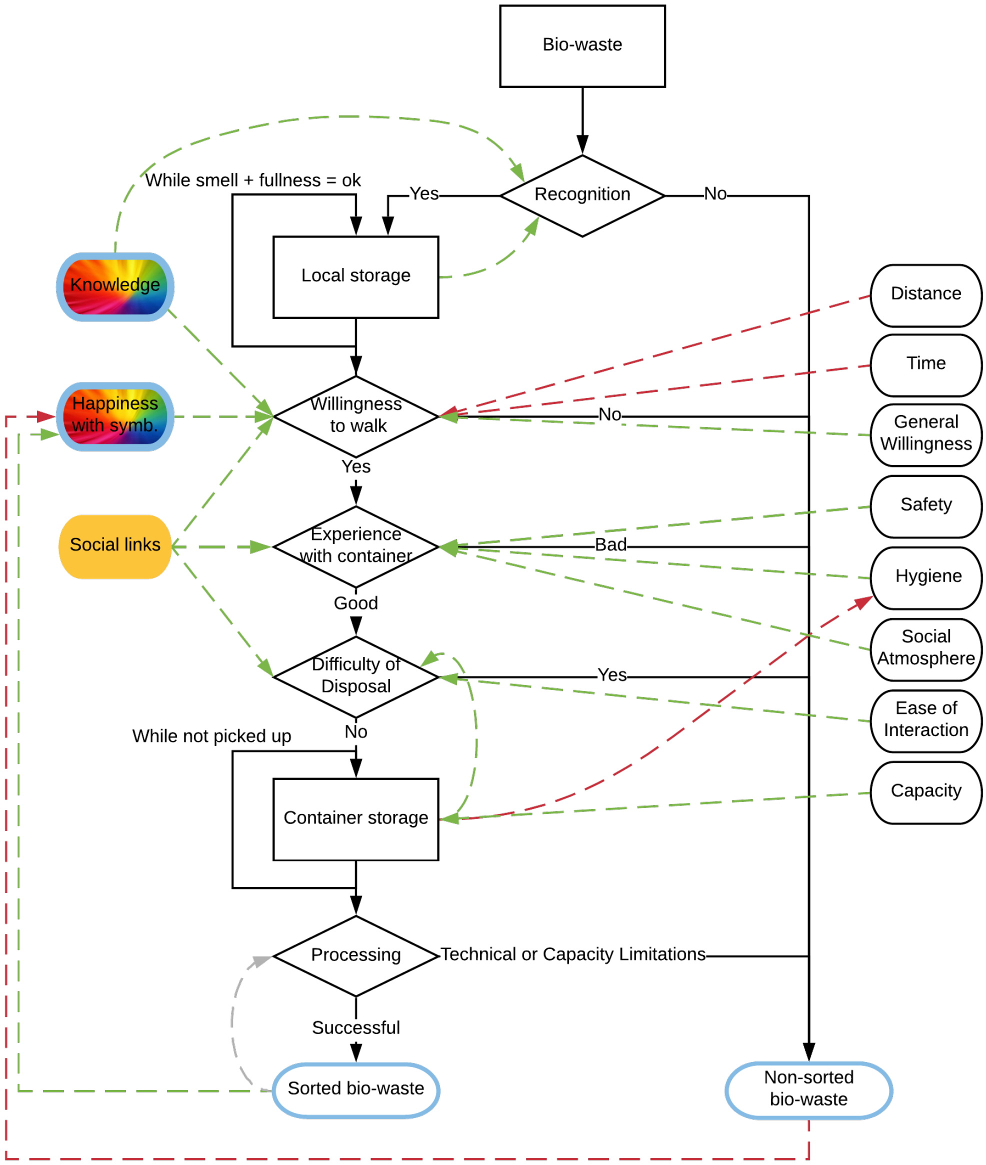

Figure 12 – Logic of the computed model

General waste separation behaviour is illustrated through the white boxes illustrating decisions (diamond shape) and storages (rectangles). By using the VBN theory in this model decisions are made based on the values, beliefs and norms of agents. At each of the decision-making steps the distribution between the two arrows is determined by the decisions made through the VBN approach.

Additionally, green dotted arrows represent a positive effect on the sortation behaviour similarly to Figure 2 (e.g. if knowledge about bio-waste separation is high the willingness to walk the distance will increase), whereas red dotted arrows represent a negative effect on the sortation behaviour (e.g. a high level of non-sorted bio-waste will lead to a low symbiotic attitude).

Not all five types of agents that are mentioned in Chapter 4.2 behave in such a way. By review of the NDSM case it was found that the Type D & E agents are involved in the network, but do not produce bio-waste. Therefore their roles have been altered from the other agents. The yellow box is enforced by a Type D agent that creates social links altering other agents' decisions. For example, a bio-waste producing agent might not be willing to walk the distance in this time step, but is convinced through social norms to do so anyways. The Type E agent only influences the model in combination with specific policy implementations (the newsletter policy).

The grey dotted arrow represents a limiting value of the sorted bio-waste that is processable. This research assumes a maximum of 84% sortation rate, to ensure a minimum unavoidable percentage of bio-waste (Exodus Market Research, 2008). In all runs with plausible values for this model (including policy and scenario runs) this limitation is not reached.

6.1.4 Inclusion of Randomness

When it comes to behavioural patterns several variables are known to be somewhat randomized. First, the values, beliefs and norms of people will not be exactly the same when one is assigned to a specific profile in the model. To include this deviation the New Environmental Paradigm parameter, the Awareness of Consequence and the Ascription of Responsibility factors will be included in the model as a normal random distribution. A questionnaire is distributed to be able to realise a mean and standard deviation value for each turtle.

Secondly, people will have different types of knowledge and a different opinion on what they consider as much effort for disposal. Therefore, the biological waste separation knowledge and the distance to the container have varying values for each turtle.

Most importantly, a person will not behave similar each and every day. For example, when it comes to the recognition of bio-waste it is assumed that having a biospheric attitude will increase the probability of someone sorting their waste in a local bin, still leaving for a chance that the waste will not be properly recycled. The same is true for the willingness to walk to a central disposal place, the way he or she will experience the environment and the capacity to interact with a container. Finally, the amount of bio-waste a person collects and the needed frequency of disposal from local to central bin will differ over time based on the normal distribution described in Chapter 6.1.1.

6.1.5 System Boundaries

The considered system is geographically bounded in the Netherlands with its Dutch culture. These boundaries are of importance when defining the parameters numerically, but also have implications to the generalizability of the network, as Boons et al (2015) showed great national differences.

Secondly, the model is bounded to waste separation behaviour of the Re-StOre participants. Everything outside of the waste separation border is considered the environment. Interaction with the environment appears when waste streams disappear from the model. This is the case when the participants have (or have not) sorted their waste. The contracts and collection and processing methods associated after the waste has been sorted are not taken into account. The effect that these methods have on the motivation of a participant have not been taken into account.

The model is also bounded to half a year of modelling, after this time period the roles of people in this process can have changed, and therefore a different setup might be needed. Also, over time the chance of extremities increases, which is not taken into account in this model.

6.1.6 Policy and Scenario Implementations

This chapter describes the model implementations of the five policies and the two scenarios.

The Leaving scenario requires a random agent to die, and cancels the knowledge and the symbiotic network feeling that has built over the first part of the simulation. The agent scenario simply increases the initial agent settings to include the original number of agents, 15 agents or 50 agents.

In the model the feedback policy affects the symbiotic feeling of the participants. Based on the awareness of consequence and the ascription of responsibility a person is affected by the feedback of the percentage sorted bio-waste. When the percentage sorted waste exceeds an agent's expectations, the turtle is set to "positive". Once positive, a turtle will put more effort in local waste storage, as well as increase its maximum container disposal distance.

The Group policy is constructed through links. Incorporating the value profiles as discussed in Chapter 4.2, the Type D actors in the model create links with one of each waste generating agent. In regular scenarios it will ask one of the connected agents to increase their happiness with the symbiose and to separate their waste for one tick correctly. In a group scenario the number of connections made is based on the slider "num-links".

The On-Demand policy will no longer use a scheme to collect the waste based on the number of participants, rather it will measure the quantity of waste in the bin and collect the waste accordingly. Every tick the quantity is measured and a decision is made whether or not to empty the central storage space. It should be noted that the cleaning of the container still happens on a regular basis.

The Newsletter policy is incorporated in the model based on research by Rideout (2005) that shows an x% knowledge growth is reduced to ½ x% growth in one year. The function that implements the effects of knowledge over time is extended with a "Newsletter" option. It is assumed that the effect of a newsletter is based on the number of type E participants in the model. Meaning, that 2 participants with a non-selfish profile can induce 80% of the participants with a 2% growth of knowledge when the newsletter is distributed.

The Container Interaction policy is implemented to affect the difficulty of disposal. In the model the design variables have been kept very simplified. It is assumed that with proper design, the difficulty of disposal reduces with 80% and will therefore be less of a barrier to separate waste.

6.2 Underlying Assumptions

The model used is a stylized version of reality. Both on the standard model and on the scenario and policy implementations assumptions have been made to make a representable version of the case study., including but not limited to topics of the environment, the waste quantities, the actors, the knowledge gathering, the disposal of bio-waste. These assumptions can be found in Appendix L – Modelling assumptions.

6.3 Example Run

To give a structured overview of the overview of the model, the design concepts and details an example run is described. In Appendix I – ODD+D Protocol one can find a structured description of this example run (Müller et al., 2013).

The focus of this model is to measure bio-waste separation rates in a symbiotic network. Figure 13 shows the setup consists of 6 type A agents, 6 type B agents, 5 Type C agent, 1 Type D agents and 2 Type E agents. Each have their own norms, values and beliefs to determine their actions. As the ticks start running the type A, B and C agents start creating bio-waste streams.

Figure 13 – Representation of agent types

Over every step an agent calculates its own recognition of a given piece of waste, its willingness to bring the local garbage bag to the central collection point, the experience it has that and its capability of disposing the waste. If bio-waste is not treated as such, it will automatically be disposed of and measured as non-sorted bio-waste.

Over time the waste gets collected from the central waste collection point and is recognized as sorted bio-waste. Figure 14 shows the distribution of sorted and non-sorted waste. In the given example around a third of the bio-waste is being sorted.

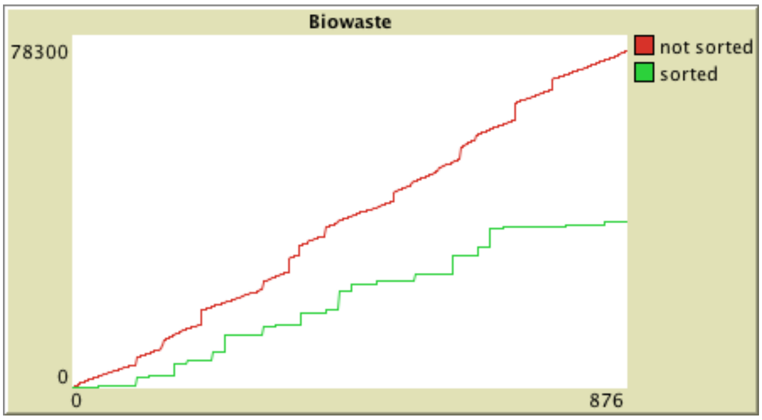

Figure 14 – Bio-waste sorted and not sorted in kg over one run.

The start-up values for this model are described in Table 3. They represent the NDSM case values when technological and capacity limitations of the waste processor are solved.

Table 3 – Initial values

Name	Model name	Value
Type A Profile	N_BW	6
Type B Profile	N_P	6
Type C Profile	N_NP	5
Type D Profile	N_NH	1
Type E Profile	N_NS	2
Waste Schedule	startschedule	15
Container Hygiene	startchyg	200
Policies	policies	Off

6.4 Model Verification

The objective of verification is for the model to be free of errors and it ensures the correctness of the conceptualization to computational model implementation (van Dam, Nikolic, & Lukszo, 2013; Xiang, Kennedy, Madey & Cabaniss, 2005). It is important to ensure that the values and relations in this model offer a good representation with reality, to be able to make sound conclusions and recommendations. According to Van Dam, Nikolic & Lukszo (2013) there are four tests available to check various aspects of a model's correctness: recording and tracking of agent behaviour, single-agent testing, minimal model testing and multi-agent testing.

The first test looks at the intentioned and reported behaviour of agents. This is tested by looking at the intrinsic decisions of agents. As the name suggests, the second tests the model with only one agent in normal and extreme conditions. In the minimal model of this research one agent of each type is included and tested in normal and extreme conditions. Finally, the model is run with the general setup as suggested in the NDSM case study.

The full model verification can be found in Appendix J – Verification analysis. Naturally, in further research this verification can be questioned and improved. One of the topics under revision could be the connection of knowledge on bio-waste to the VBN theory.

7 Results

In this chapter the results produced by the agent-based model are described through graphs and tables. The results are presented in three sections. The behaviour of the model as result of the NDSM case study is described in section 7.1, the sensitivity testing in section 7.2, scenario testing in 7.3 and the policy testing in section 7.4. Experimentation of all scenarios is designed and described in Appendix H – Experimental Design, a summary is shown in Table 4. This chapter aims to project the results in an easy interpretable and un-biased way. Further analysis of the effects of the results on the system can be found in Chapter 8 - Analysis.

This chapter aims to answer question 4:
What is the effect of scenarios and sortation policies on the sortation outcome of participants in the NDSM wharf?

To create a good understanding of the output dynamics of the model, several experiments are done creating different outputs. Table 4 shows the experiments that have been done to reach the results as described in this chapter. The left column describes the name of the experiment, and each row describes a variable that will be changed from the original NDSM setup. How it will be changed can be seen in the values-column, followed by the number of replications.

Table 4 - Summary experimental designs

Experiment	Changing variable	Values	Replications
NDSM standard	No variable changes		1000
Sensitivity 1	duration	875 8750	100
Scenario 1	Leaving	True / False	100
Scenario 2	Leaving	True / False	100
	policies	"off" 1 2 3 4 5 "all"	
Scenario 3 (people)	N_BW	6 15 50	30
	N_P	6 15 50	
	N_NP	5 15 50	
	N_NH	1 15 50	
	N_NS	2 15 50	
	policies	"off" 1 2 3 4 5 "all"	
Policy 1	policies	"off" 1 2 3 4 5 "all"	100
Policy 2 (all combined)	newsletter	True / False	100
	feedback	True / False	
	HumanEngmt	True / False	
	ondemand	True / False	
	group	True / False	
Policy 3	group	True / False	50
	N_NH	1 5	
	num_links	2 1 5	
Policy 4	newsletter	True / False	50
	num_readers	60 100	
	N_NS	2 5	

Experiment	Changing variable	Values	Replications
Policy 5 (Combined 1 & 3)	N_BW	6 15 50	200
	N_P	6 15 50	
	N_NP	5 15 50	
	N_NH	1 15 50	
	N_NS	2 15 50	
	policies	13	

The data in this chapter is generated through the behaviour space of Netlogo and the ggplot library in R. For replication of these results the datasets and visualisation codes are available upon request. In several plots only the last 25 ticks in the data have been included to give a sensible representation of the effects and to limit the computational power necessary.

7.1 Model Results

In this chapter the NDSM standard data set will be used to answer the sub-question: *What is the behaviour within the symbiotic bio-waste separation model about the Re-StOre NDSM wharf project?*

First the results will be shown in bar plots, a standardized way of showing the counted number of a certain value represented in the dataset. Secondly, to avoid overplotting a density plot is used to plot the percentage separated waste. Thirdly, boxplots will be used. These graphs are a standardized way of easily showing the median, 25th and 75th percentile. The white area represents the inter-quartile range, with the median value somewhere in the middle. A 1.5 rule is used to determine the upper and lower whiskers and the outliers. Taken the lower or upper quartile and respectively subtracting or adding 1.5 times the inter-quartile range leads to the used representation of the data points.

7.1.1 Bio-waste Percentages in the Standard Model

To get a good idea of what the program is doing in its NDSM setting the percentage sorted bio-waste is calculated based on the total quantity of waste (sorted + non-sorted). Over the simulation of half a year an average sortation rate is reached of 30%. Figure 15 represents the percentages of bio-waste that have been sorted towards the end of the simulation.

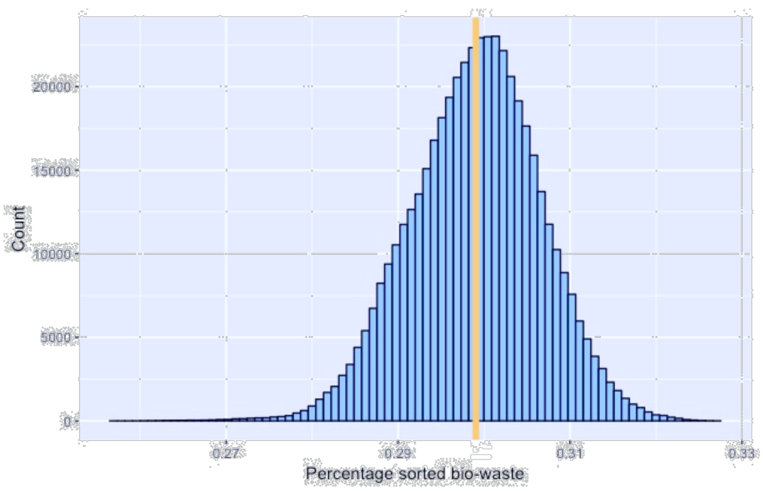

Figure 15 – Histogram of the percentages sorted bio-waste

Figure 15 shows a range of bio-waste separation rates towards the end of the simulation (the last month) in a histogram to give a clear image of its distribution. The percentage bio-waste sorted ranges from 26% to 33%, with an average and a median of 30% at the end of the simulation. The vertical yellow line shows the average value of 30%.

Figure 16 shows a scatterplot with the percentage of sorted bio-waste in comparison to the percentage of non-sorted bio-waste over time.

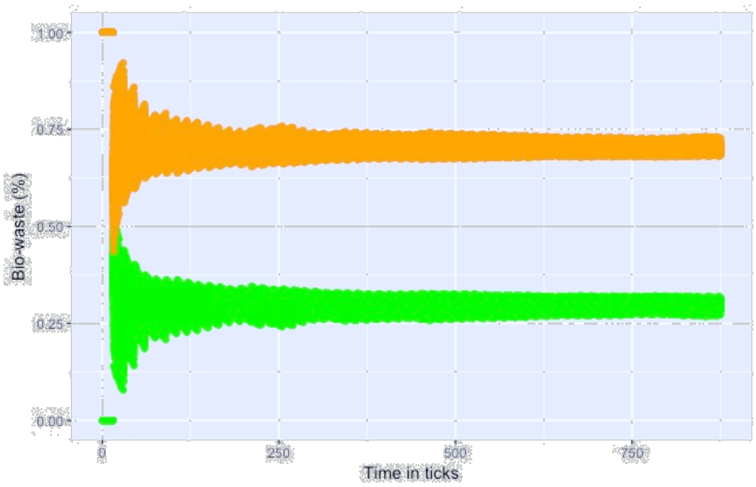

Figure 16 – Percentages sorted bio-waste (green) and non-sorted bio-waste (orange) over half a year.

The time is displayed on the x-axis in ticks, where 875 is equal to half a year of simulations. The y-axis shows the percentage. It portrays a wider range of values over the beginning of the simulation, averaging-out from 250 ticks (50 days) towards the end of the simulation. The average sorted bio-waste over half a year is 30% as mentioned earlier, which leaves the non-sorted bio-waste percentage at 70%.

7.1.2 Bio-waste Quantities in the Standard Model

Over time the total quantity of sorted bio-waste behaves as mentioned in Figure 17.

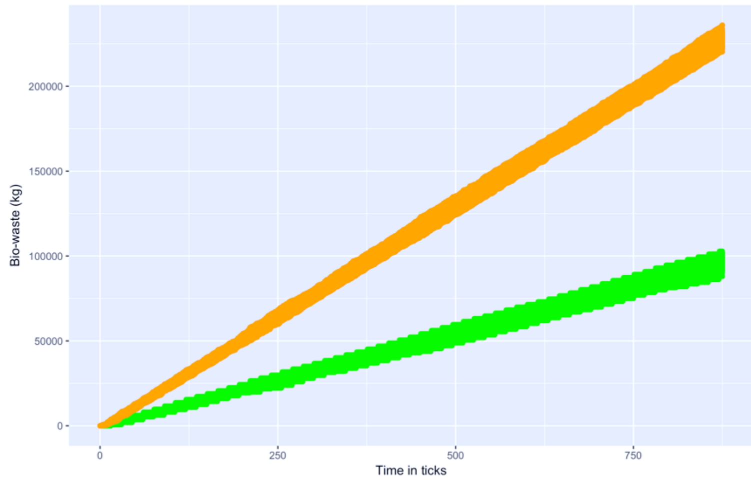

Figure 17 – Total quantities of bio-waste over half a year.

In Figure 17 875 ticks represent half a year of bio-waste separation. The y-axis represents the quantity of bio-waste in kilograms. In the end of the simulation a little over 200.000 kg is not sorted (206.226 kg on average), whereas a little under 100.000 is sorted (± 93.700 kg on average). As mentioned before, the average percentage sorted waste towards the end of the simulation is therefore 30%.

Figure 18 shows a density plot, where the height represents the quantity of waste-producing participants with that normalized knowledge level of bio-waste sortation throughout the simulations. A density plot is used to show how often different values of bio-waste separation knowledge appear in the simulations. On the x-axis the bio-knowledge is shown standardized from 0 to 1, on the y-axis the standardized count of values.

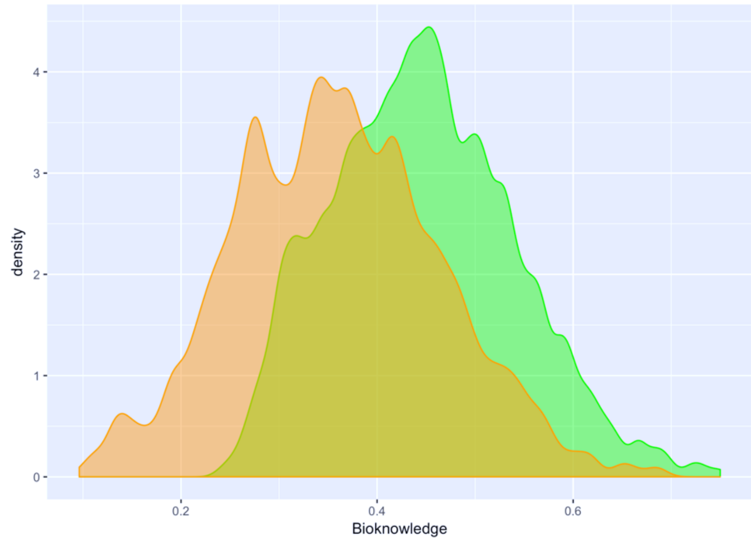

Figure 18 – The impact of knowledge about bio-waste separation on the sorted (green) and non-sorted (orange) bio-waste.

The green area represents the percentage of sorted bio-waste, whereas the red lines represent the percentage of non-sorted bio-waste. This figure shows that at a bio-waste separation knowledge level of 0.3, more waste is not sorted than sorted, whereas at a bio-waste separation knowledge level of 0.5, more waste is sorted than not sorted. Showing an impact of bio-waste sortation knowledge on the separation rate. More of these results will be discussed in Appendix M – Additional results and analysis.

7.2 Sensitivity Testing

In the sensitivity analysis the duration of the model run is tested, to be certain that the model is not biased because of an early termination. The Sensitivity 1 data set is used to partially answer the sub-question: *What can be said about the validity of this model?*

A sensitivity analysis is additionally useful as a validation of the model (Xiang, Kennedy, Madey & Cabaniss, 2005). The bio-waste quantities sorted and non-sorted are shown together with the knowledge of the different participants.

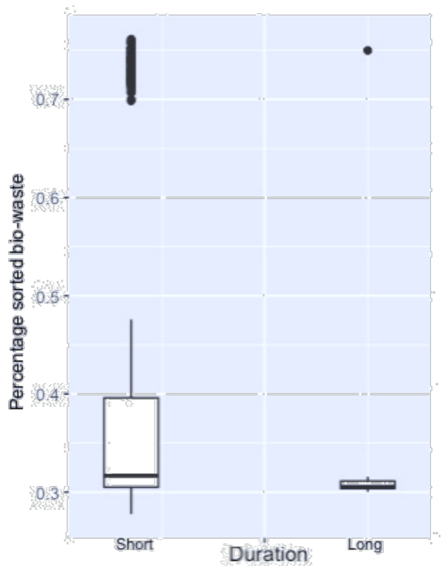

Figure 19 - Sensitivity Analysis duration

In Figure 19 the sensitivity analysis shows the percentage sorted bio-waste just before the end of the simulation (respectively tick 850 & 8500). It shows the percentage sorted bio-waste in with all individual policy implementations. As the figure shows the effect of all policy implementations, which originally ends up above the 70%, now becomes way more precise. Also the effects of the on-demand & container interaction policy, which previously ended up around the 40% are less visible after running the model for five years and the median value concentrates just above the 30% sorted bio-waste due to a lesser variation and representation throughout the simulations. The further analysis of these values will be done in 8.4 Validation.

7.3 Scenario Testing

In this chapter two different scenario are tested. First of all, the possible leave of one of the participants can disturb the behaviour of the network. The effects of this scenario are tested in the NDSM case and in combination with the different individual policies. Making use of the "leaving" data set to answer the sub-questions: *What is the effect of an agent leaving the symbiotic network* and *What is the effect of different agents on the model and policy implementation?*

7.3.1 Leaving Scenario Testing

What is the effect of an agent leaving the symbiotic network?

Figure 20 shows the density (y-axis) of the percentage bio-waste (x-axis). Over a large part of all simulations the percentage sorted waste is around 30%, therefore a high peak is shown in the figure around this x-value. The figure makes a distinction between the leaving and the not-leaving scenario by respectively the blue and red areas plotted.

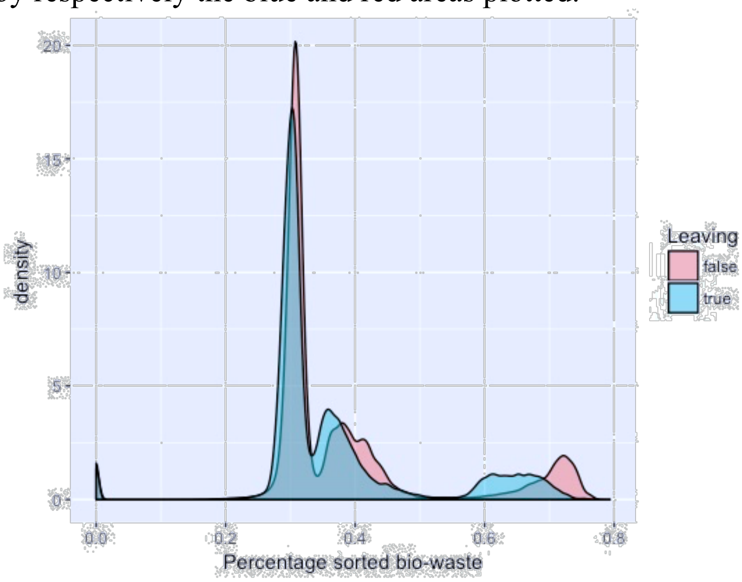

Figure 20 - Leaving scenario percentage sorted bio-waste.

The figure shows that when the leaving scenario is true, the different peeks that have been shown in the not-leaving scenario are represented now with a lower percentage sorted bio-waste on average. Presenting the idea that the leaving scenario results in lower sortation rates, that are more extremely influential in the higher percentage regions.

To understand this phenomenon further, Figure 21 makes use of boxplots to determine the difference of the leaving scenario over different policy implementations. The left figure shows the percentage sorted bio-waste over the second half of the simulation when no policies are implemented, the right displays simulation results with all policies. In both cases the interquartile ranges of the boxes do not overlap. Therefore, it can be said with a 95% confidentiality that the median value of the policy with or without the leaving scenario has a significant difference. The right side shows that the leaving impact is bigger when policies are implemented than when not.

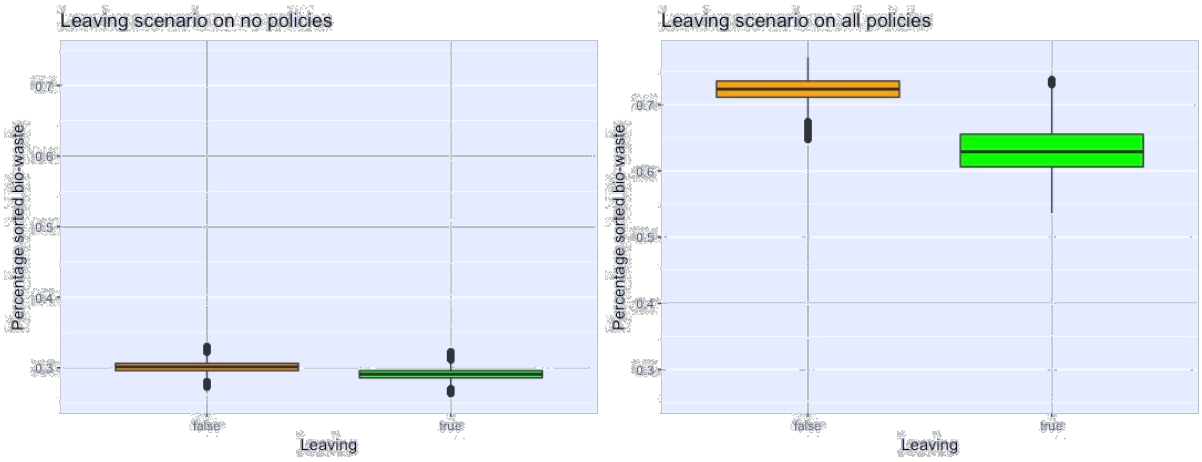

Figure 21 - Leaving scenario percentage bio-waste with no policies (left) and all policies (right).

In Appendix M – Additional results and analysis the impact of the leaving scenario on each individual policy is described. A summarizing table is given to compare the policy values and the effects of a leaving party. It was shown that the leaving scenario affects the different individual policies negatively with < 1 – 4%.

7.3.2 Agent Type Scenario Testing

What is the effect of different agents on the model and policy implementations?

The model is constructed based on 5 different type of agents. These agents have different interests and make different behavioural decisions in the model. In this was they affect the percentage sorted bio-waste of the whole system. The people dataset (Scenario 3) and separate r-code are used for this chapter.

Figure 22 shows the effect of a growth of each profile to 15 or 50 people, when no other policies are implemented.

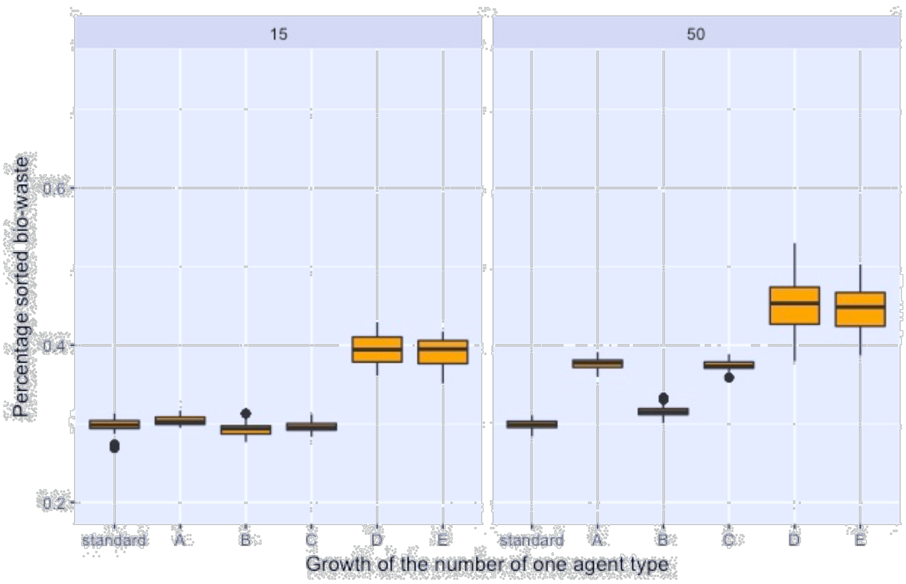

Figure 22 - Impact of a growth of the agent type in a network without policies.

The figure shows that an increase of the number of a certain profile or agent can increase the percentage sorted bio-waste. On the left side this increase is 15 agents, whereas on the right this increase rises to 50 agents. The "off" stays roughly the same, as it displays the NDSM case without the scenario in its standard form. A big increase in type A and type C (biospheric values) increase the percentage sorted bio-waste with roughly 8%. Whereas a small increase in type D & E agents can already cause this effect, and grow even towards the 45% sortation rate. Most interesting is the behaviour of type B agents. This odd behaviour has been mentioned when describing Table 5 As expected a slight growth of hedonic valued agents decreases the percentage sorted bio-waste. However, a bigger increase can cause a higher percentage sorted bio-waste. An explanation for this could be the adaptation to the waste collection scheme, when adapting the number of agents, the regularity of waste collection is recalculated. This might have given the type B agents a slight improvement of the bio-waste separation rate.

In Figure 44 the absolute values are a lot higher, ranging from 50% to more than 70% sorted bio-waste. The behaviour or the agents is quite different from that in Figure 22. A growth of the number of type D and type E agents can still slightly improve the percentage of sorted bio-waste (from 68 to 72% roughly), but most of all an increase of 15 or 50 type B agents can cause a far more significant drop of respectively, 6% and 18% sortation rate. Also, the increase of type A & type C agents does not improve the bio-waste separation rate any more.

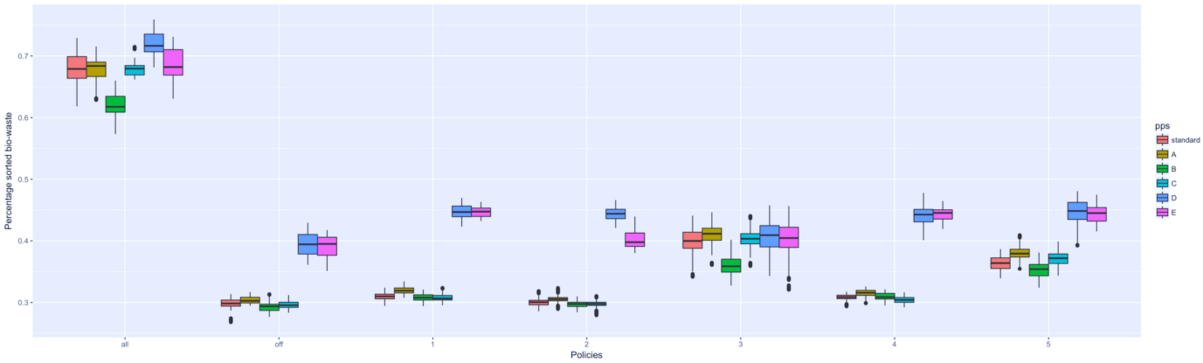

Figure 23 - Impact of individual scenarios based on the people involved.

Figure 23 shows the five individual policies on the x-axis, together with a base run without policies and a run with all five policies taken together. On the y-axis the boxplots show the median and inter-quartile ranges of percentage sorted bio-waste (perc). On the right side a legend shows six possible set-ups in which the number of agent types differs. The colours in the legend are related to the colours in the plot, giving an estimation of each policy over each agent type setup.

Comparing the agent type scenario "off" as a baseline, an increase in type A agents correlates with a percentage sorted bio-waste that is higher than the base run (15 versus 6 type A agents). Type B agents are often stable, not increasing nor decreasing the percentage sorted bio-waste (policies off, 1, 2 & 4). However, implementing policy 3, 5 or "all" the increased number of type B agents dampers the percentage bio-waste sorted. In the third policy it is even a decrease from roughly 40 to 36%.

Taking the policies off simulation as a baseline, it is clearly visible that the number of type D & type E agents positively affect the percentage sorted bio-waste. Over the different policies the correlation between type D and E and the percentage sorted waste grows, hereby is the second policy extraordinary due to its uneven growth of both types and preference to type D agents.

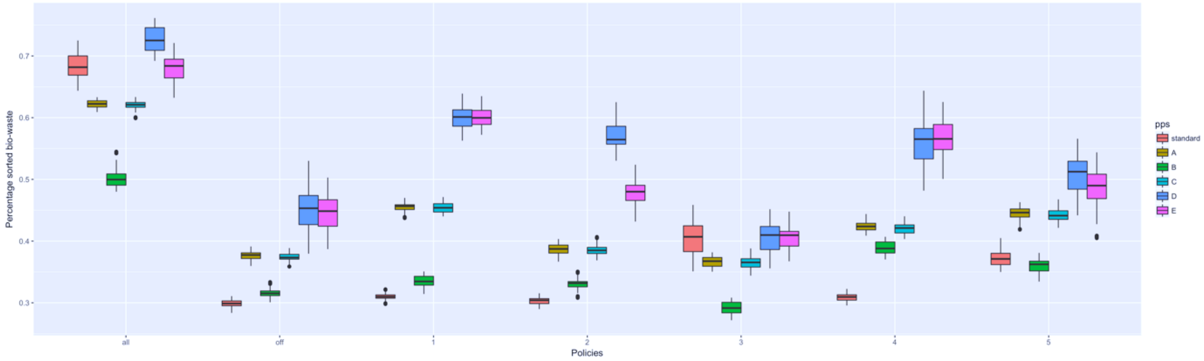

Figure 24 - Impact of individual scenarios when 50 of one agent type participate.

Figure 24 shows the same setup as Figure 23, except this time not an increase to 15, but to 50 participants is measured. The left figure showing the percentage sorted bio-waste when the given agent type is raised to 15 members, and the right figure showing the percentage sorted bio-waste when the agent type is raised to 50 members for each policy.

This figure shows that an extraordinary growth of participants type D & E will introduce great differences in the policy "feedback", the policy "group", the policy "newsletter", the policy "container interaction". An extraordinary growth of participants type B will decrease the percentage sorted bio-waste significantly in the "on-demand" policy and "container interaction", and when all these policies are brought together compared to the scenario "off" base run.

If a newsletter is distributed, even an extraordinary growth of type B agents will not stop a growth in sortation rates. While, if the waste is retrieved on-demand instead of on schedule, the number of type B agents has a big negative influence on the percentage bio-waste sorted.

7.4 Policy Results

In this research bio-waste separation within the scope of the NDSM case study has been described together with 5 individual possibilities to improve the sortation rates. This chapter will go through the individual policy implementation results and the joint effect of combining these policies together. Once more, the analysis of these policies will be done in the next chapter.

This chapter per policy the effects of implementation on the percentage sorted bio-waste, the average knowledge of bio-sortation in the model and the happiness with the symbiotic network. This is done by using a data set for all individual policies (policy 1). Chapter 7.4.2 shows the results of all combined policy interactions, the most complete of the used datasets (policy 2). This chapter aims to answer the sub-questions: *What is the influence of individual policies* and *What is the influence of combining several policies?*

7.4.1 General Results

What is the influence of individual policies?

Figure 15 showed the percentages sorted bio-waste that occur when no policies are implemented, centred around the 30% sorted bio-waste. The range of bio-waste separation rates that is found during the simulation is wider when all policy implementations are tested. The next figure displays a histogram of the percentages sorted bio-waste throughout the simulations of all the different policy implementations (no, only policy 1/2/3/4/5, or all policies).

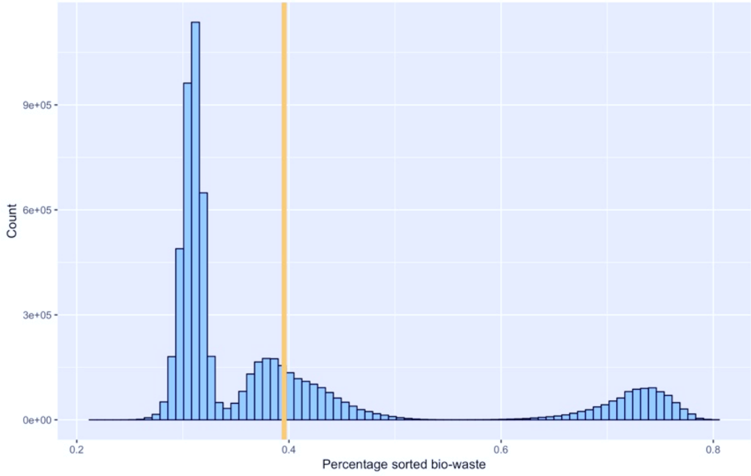

Figure 25 - Histogram of the percentage sorted bio-waste over all simulations including one or more policies.

Figure 25 shows a range of bio-waste separation rates towards the end of the simulation. The percentage bio-waste sorted ranges from 28% to 78%, with an average of 47% and a median around the 30%. There is a higher count around the 30%, the 45% and a steady distribution between the 50% till 70% before dropping down. The vertical dark green line shows the average value of 47%.

The next figure looks at the knowledge of bio-waste separation throughout the simulation runs.

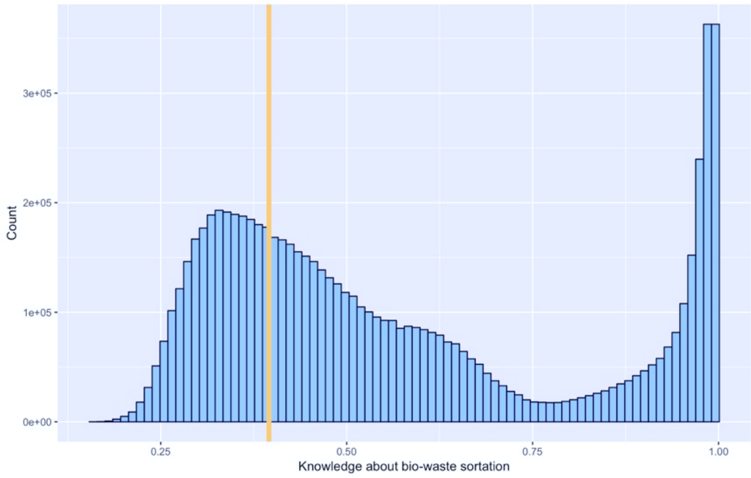

Figure 26 - Density plot about the knowledge level over all policy simulation time steps.

Figure 26 shows that the knowledge about bio-waste can drop lower than its initial value, which is estimated based on the intrinsic values of the agents. While there are also two regions that seem to have a higher bio-waste density, around 68% and 90% bio-waste knowledge levels.

Figure 27 will look at the happiness with the symbiotic network that is measured throughout all simulations.

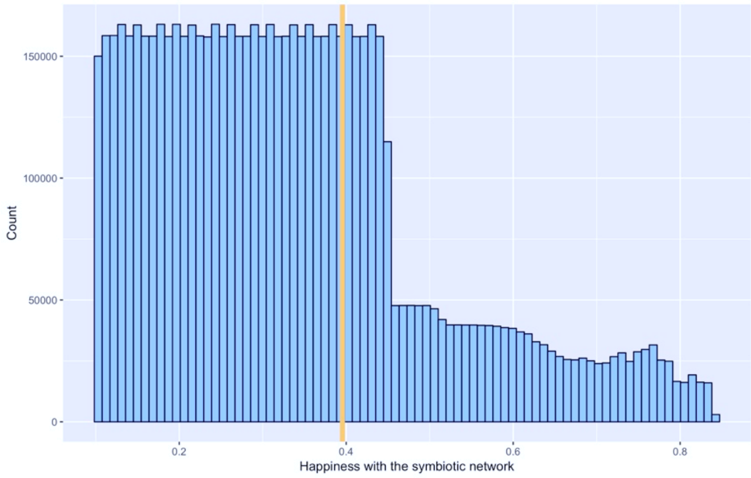

Figure 27 - Density plot of the happiness of all turtles on the symbiotic bio-waste sortation network throughout all policy simulation time steps.

Figure 27 shows a high density at low happiness levels, and a stepwise decrease of higher levels. However, at the highest number of happiness, just below 80% another increase is seen. To get a better understanding of these values the happiness with the symbiotic network will be discussed at the level of influential policies.

Figure 28 shows boxplots of the different container quantities over all simulation steps, and separated through the various individual policies, no policies and all policies. The “o” on the x-axis stands for “only” and denotes that no combined policies have been considered for the modelling of these results.

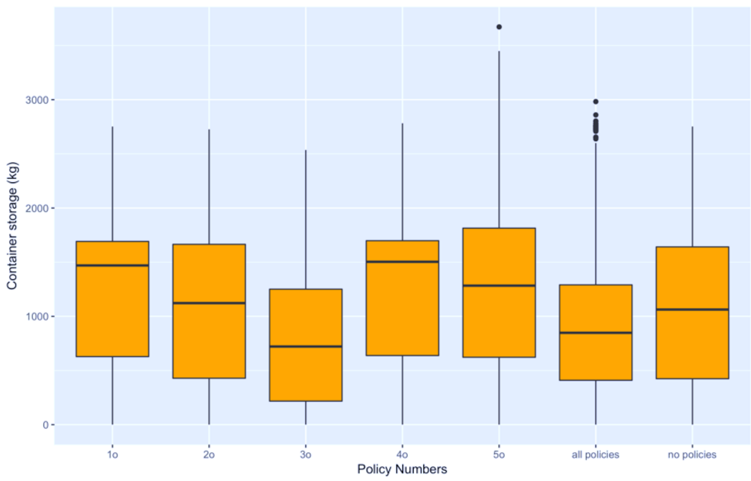

Figure 28 - The impact of different individual policies on the container storage over time.

The figure shows the five individual policies on the left, whereby policy 3 (on-demand waste collection) results in the lowest median waste storage in a central container, whereas the median of policy 4 (Newsletter) creates a high level of container storage most often, and the human engagement policy creates the most extreme container storage quantities, ranging up to 3500 kg. If container storage is high, it is more likely that there is no room for a person to dispose waste, and therefor separate correctly. It should be noted that a container storage of 1500 kg is a threshold from which on agents will feel like they could not separate their waste properly and will take this into account the next timestep, when they decide to separate their waste.

7.4.2 Feedback Policy

This policy shows the effect of communicating the percentage sorted bio-waste with the participants of the network. Figure 29 shows the impact of the feedback policy when all other policies are simulated on or off. This results in an expected growth of the percentage sorted waste. However, the boxes are not excluding each other, therefore there are scenarios where the implementation of a feedback policy will not necessarily improve the percentage sorted bio-waste.

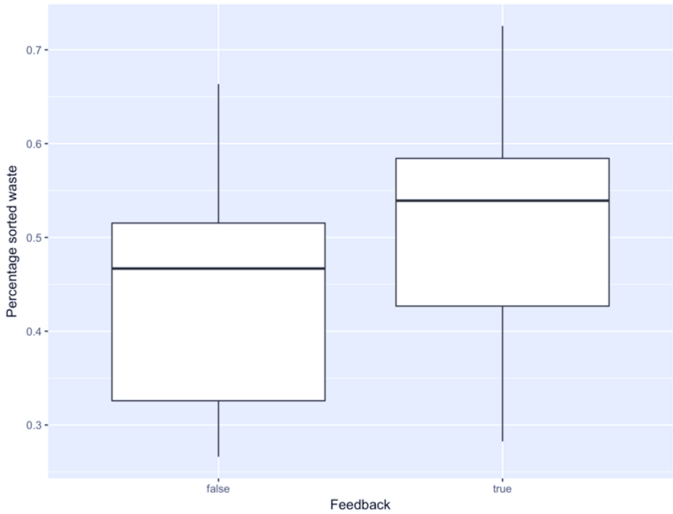

Figure 29 - Impact Feedback on the percentage sorted bio-waste

To get a better feeling of when this might be the case, it is important to understand the underlying dynamics of the feedback policy. In this study the feedback policy has a direct impact on the knowledge of turtles about bio-waste separation. This behaviour is plotted against the percentage sorted bio-waste in Figure 30.

This figure shows the different levels of knowledge of bio-waste sortation for all agent types. The black cloud of values is difficult to understand without an indication of how many dots are at each location. Density lines (contours) are therefore added to visualise the distribution of points through a multitude of small fragments. The closer together the lines, the higher the density. Additionally, a distinction is made between points retrieved from runs where the feedback policy was true or false (blue / red).

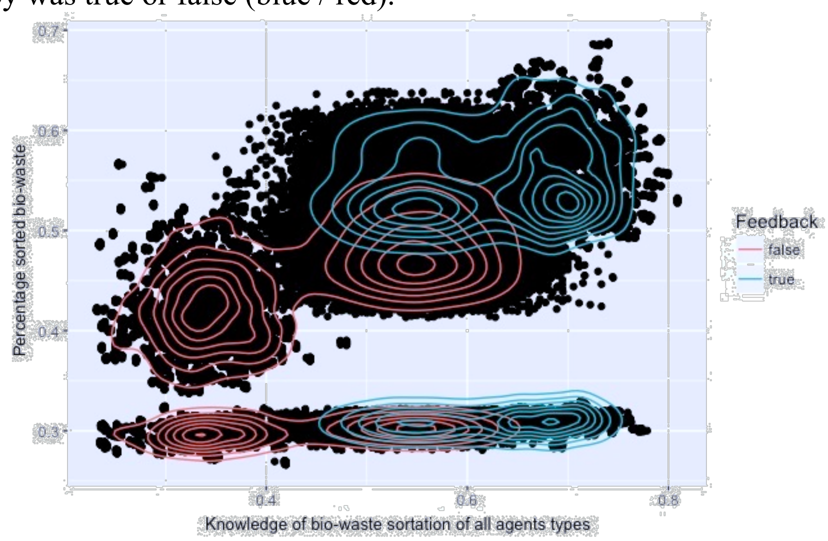

Figure 30 - Percentage sorted bio-waste based on the level of knowledge about bio-waste separation, tested over the implementation of the feedback strategy. In this figure the effects of the Newsletter policy have been excluded from the model.

In this figure the feedback policy has a strong presence at the higher levels of knowledge about bio-waste separation for all agent types as described in Chapter 4.1. There is a step-wise development visible between the knowledge levels of agents and their sortation rate. The density plot that is layered on top of the individual data points shows seven centre points where the number of simulation results are high.

The first three centres that are discussed are located on the lower end of the plot. At the 30% sortation rate the centres are found around the 0.35 standardized knowledge level, the 0.55 and the 0.65. Slight growth of the lower data points indicates that there is a weak link between the knowledge growth and the percentage growth in this domain. While the feedback policy excludes the average knowledge levels around the 0.35, it overlaps with simulations that lack the feedback policy and result in similar behaviour (0.55). A possible explanation for partially increased knowledge levels could be the implementation of the Newsletter policy (Chapter 7.4.5). However, the percentage sorted bio-waste is not necessarily increased by the implementation of the feedback policy. To get a better understanding of the dichotomy of lower and higher bio-waste sortation rates, Chapter 7.4.8 will discuss the combined policies.

The other four centre points are distributed over a bigger area. At a 0.35 knowledge level a 43% sortation rate is measured. While at the 0.55 knowledge level this sortation rate has grown to respectively 48% sortation rate and the 52% sortation. An even higher increase of the knowledge level results only in a minimum growth. The middle of the sortation rate seems to stick at 52-53%, though the results show higher possibilities of outliers up to 68% growth rate. Meaning, that the feedback policy can introduce bio-waste sortation levels above the 48%.

Concluding, there is a clear distinction visible of simulations where the feedback policy reaches high sortation percentages and outperforms simulations without this policy implemented. It is therefore interesting to further examine what conditions might bring about these model results in comparison to the high knowledge low percentage spectrum.

7.4.3 Group Policy

This policy shows the effect of a group tendency increasing the symbiotic network the percentage sorted bio-waste with the participants of the network. Figure 31 shows the impact of the group policy when all other policies are simulated on or off. This results in an expected growth of the percentage sorted waste. However, the boxes are not excluding each other, and therefore there are scenarios where the implementation of a feedback policy will not necessarily improve the percentage sorted bio-waste.

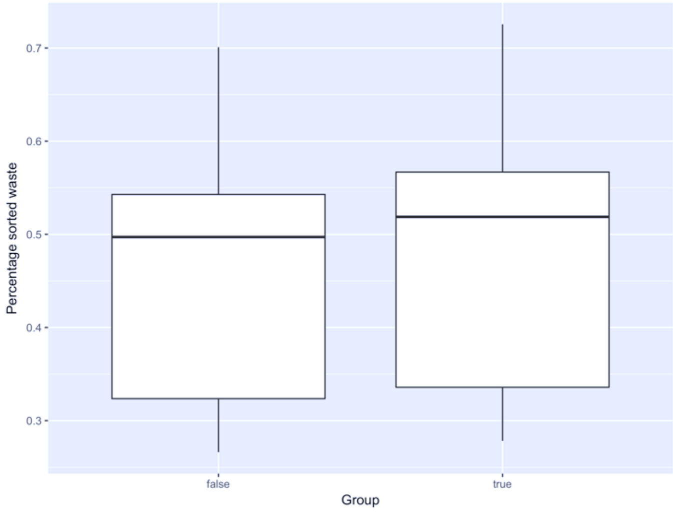

Figure 31 - Impact of Group policy on the percentage sorted bio-waste

Concluding, Figure 31 shows a slight increase of the median from 49% to 52% sorted bio-waste, when the group policy is implemented with 2 links and 1 type D agent. In Appendix M – Additional results and analysis the data set of policy 3 is used to further look at the number of links and agents in the model. However no indication has been found that the introduction of the group policy would much effect the percentage sorted bio-waste.

7.4.4 On-Demand Policy

This policy shows the effect of the collection of bio-waste when the container is full as compared to a logistic schedule to the percentage sorted bio-waste with the participants of the network. Figure 32 shows the impact of the group policy when all other policies are simulated on or off. This results in an expected growth of the percentage sorted waste. Only in a minimum number of simulations are the 75th quartile and the 25th quartile of respectively, the policy switched on and off overlapping.

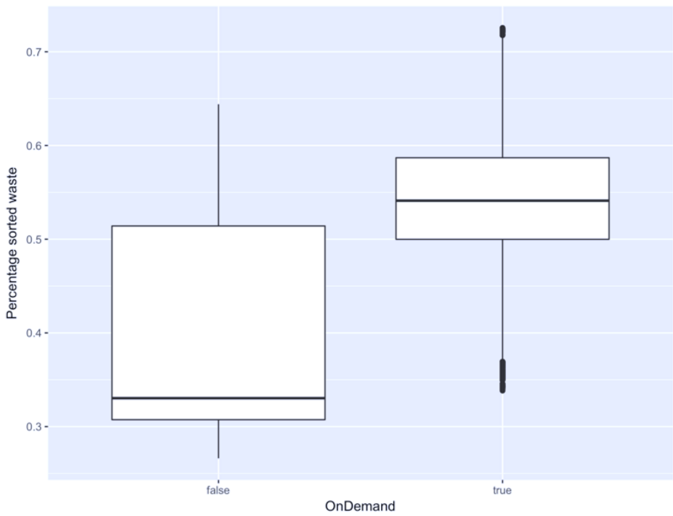

Figure 32 - Effect of the On-Demand policy on the percentage sorted bio-waste.

Figure 32 shows a noticeable growth of the median percentage sorted bio-waste from 33% to 54%. To get a better feeling of the behaviour in the model, Figure 33 shows how the container storage is behaving throughout each simulation.

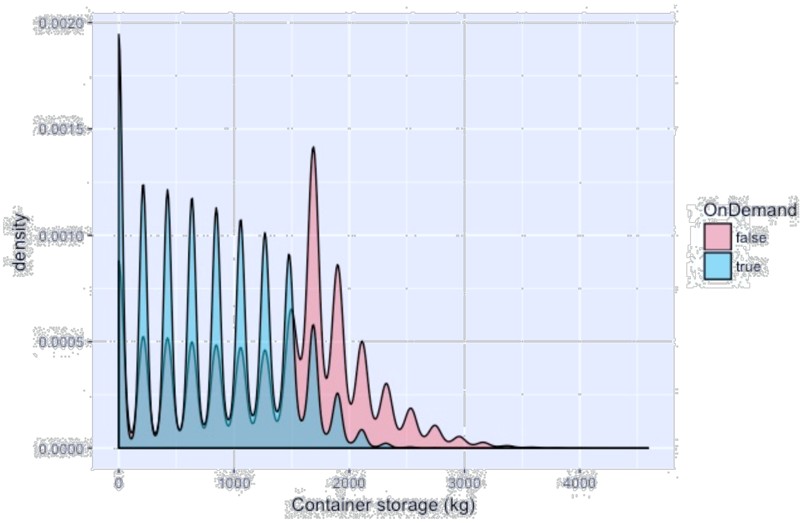

Figure 33 - Density plot of the quantities of waste stored in the central container with the on-demand policy implemented or not.

Figure 33 shows two high peeks when it behaves according to a waste collection schedule. At the end of the run the container is empty, or towards the full end. The values in between show peeks over certain values due to the size of local storage bins and the number of agents separating their waste at the described location. In case of a waste collection schedule an excessive quantity of waste in the bin happens more often than when an on-demand schedule separates the bin.

Concluding, the on-demand policy is successful in reducing the number of times that the container is over its max capacity. This results in a higher change of people being able to dispose their waste and a significantly higher total percentage sorted bio-waste. This makes for an interesting policy implementation.

7.4.5 Newsletter Policy

This policy shows the effect of the distribution of a newsletter to increase people's knowledge about bio-waste separation on the percentage sorted bio-waste with the participants of the network. Figure 34 shows the impact of the group policy when all other policies are simulated on or off. This results in an expected growth of the percentage sorted waste.

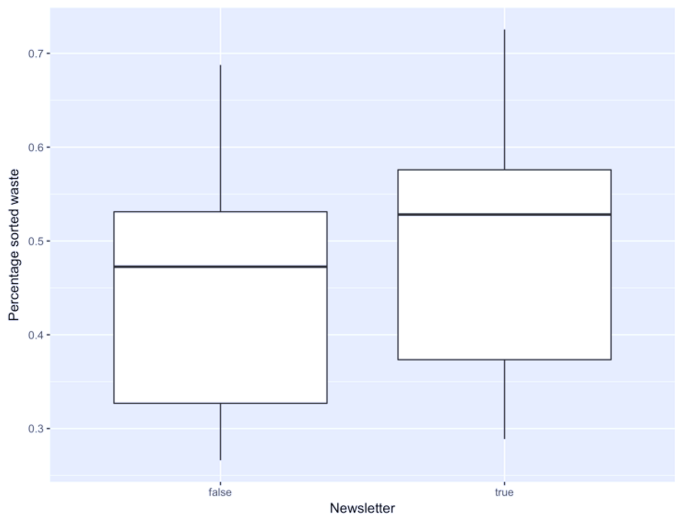

Figure 34 - Impact newsletter policy on the percentage sorted bio-waste over all implementations

Figure 34 shows a median increase when the newsletter is distributed from 47 % to 53% over all policy implementations. The boxes are not excluding each other, therefore there are scenarios where the implementation of a newsletter policy will not necessarily improve the percentage sorted bio-waste. To understand the effects of the policy better M.3 Additional Policy will discuss respectively, the effect of the number of readers and the effect of the number of theory spreaders (type E agents). For this study the additional data set for policy 4 is examined.

Figure 35 represents the effect of the mean knowledge of agents on the percentage sorted bio-waste in a density plot over the implementation and lack thereof. This has been tested for all types of bio-waste creating agents (Type A, B & C), whereby types A & C show similar behaviour and are therefore represented only once. The lines represent contour lines to show the density of results through the closeness of the lines (to prevent overplotting, as previously mentioned).

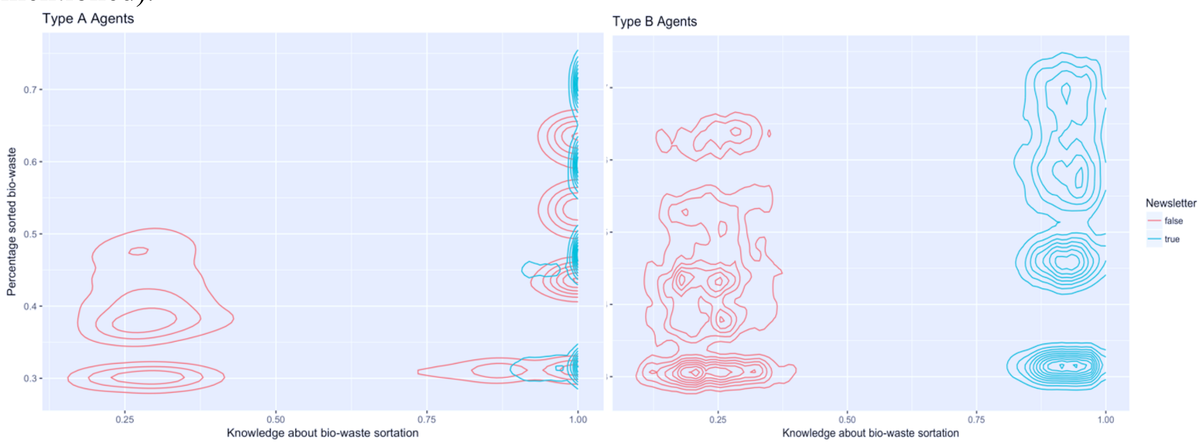

Figure 35 - Impact of the knowledge about bio-waste separation on the percentage sorted bio-waste, density plot over the implementation of the Newsletter policy

The figure shows that Type A agents in the newsletter implementation almost directly end up at the high end of the spectrum. Especially when combinations of policies are implemented to reach separation rates of 0.6 & 0.7 percent the knowledge is often around the top percentages for type A agents.

On the right side of the spectrum both red and blue density plots are shown, representing the effect of other policies on the bio-waste separation knowledge apart from the Newsletter. These red lines are not showing in the type B agents. This is likely due to the fact that profiles with a hedonic view are less interested in the effects of their behaviour on the environment (as tested with the feedback policy) rather than the increase of efficiency of their own separation knowledge through a newsletter. Looking at the type A agent plot, the effect of the increased knowledge through a newsletter on bio-waste separation seems to be higher through the newsletter than through the communication of environmental footprints.

Concluding, the Newsletter policy can offer an opportunity for increasing the knowledge levels of type B agents, where other policies have a focus on people with a focus on the biosphere.

7.4.6 Container Interaction Policy

The last policy shows the effect of reducing the complications of throwing away bio-waste in a central bin. Figure 36 shows the effect of this policy, while switching on and off the other policies.

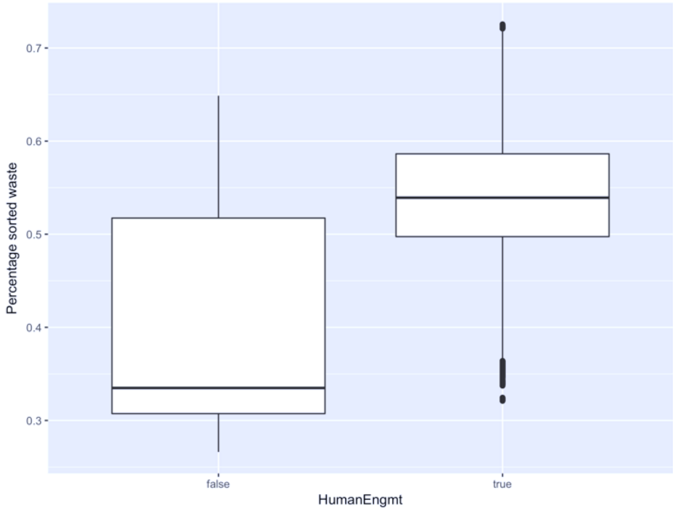

Figure 36 – Impact of the Container Interaction policy on the percentage sorted bio-waste.

In Figure 36 the implementation of the Container Interaction policy heightens the median from 34% to 54%. An increase just slightly lower than that of the On-Demand policy implementation. Once more, a small overlap is noticeable in the lower and higher quartile of the two boxes, indicating that there are simulations where the median value of the implementation of the container interaction policy does not differ significantly.

Concluding, the container interaction policy has a positive influence on the percentage sorted bio-waste in a large number of simulations and offers a possibility to improve the environmental output of the network.

7.4.7 Conclusion individual policies

The knowledge of turtles has shown to differentiate over different policy implementations, and to affect the percentage sorted bio-waste. The increased bio-waste knowledge has little effect when implementing no policy, or policy feedback (1), group (2), newsletter (4). An increased knowledge does impact the model if the on-demand policy (3), the container interaction policy (5) or all policies are implemented. This is an interesting lesson, since the policies actually affecting the bio-waste knowledge directly (1 & 4) have therewith a secondary reinforcing effect on the percentage sorted bio-waste.

7.4.8 Policy Interrelations and Overview

What is the influence of combining several policies?

In the previous chapters the policies have been implemented either individually, in a research with each policy being not implemented, individually implemented or all five policies being implemented together or in a simulation where each policy is being switched on and off in a matrix of 32 different policy combinations. The effects of this last research are discussed in this chapter. Figure 37 shows that a far wider range of percentage sorted and non-sorted bio-waste are reachable.

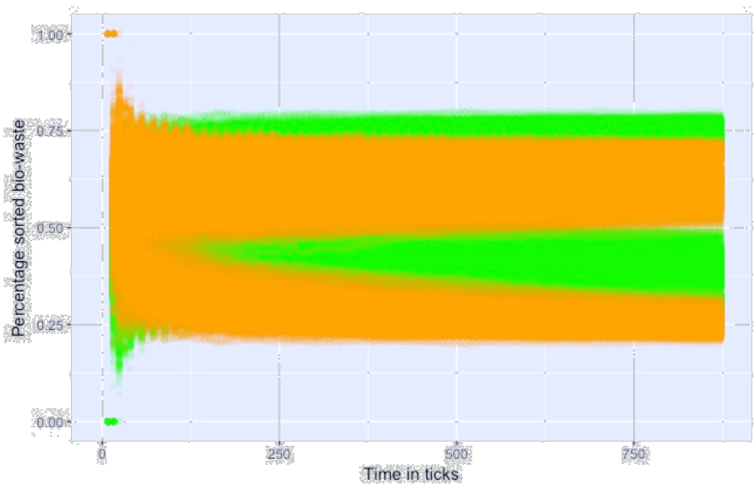

Figure 37 - Percentages of bio-waste over time (half a year)

Including all the different policy implementations, a far wider range of percentages sorted and non-sorted bio-waste are shown. In Figure 37 it becomes visible that the percentage non-sorted waste can differ from 74% to 24%, and the percentage sorted bio-waste can differ from 26% to 76%.

Starting with the impact of all the policy combination on the percentage sorted bio-waste in Figure 38. An overview is created of the policy effects.

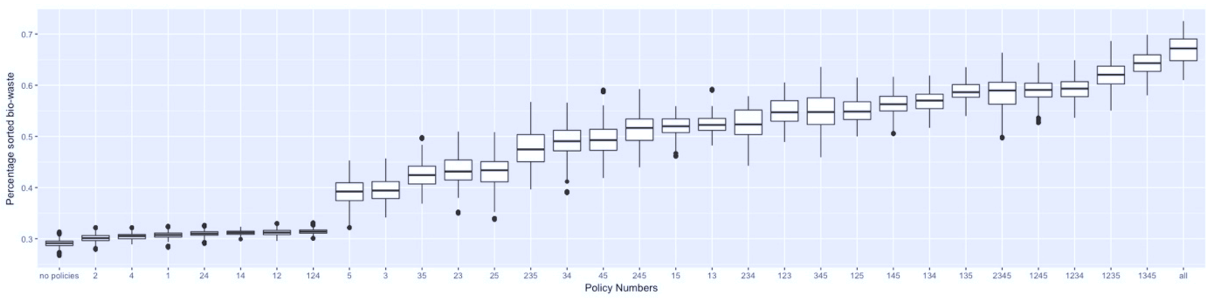

Figure 38 - Overview of the percentage sorted bio-waste over the combined policies

The figure shows how the implementation of each policy and their combinations can influence the percentage sorted bio-waste. On the right side of the spectrum are many of the individual policies as they have little effect independently, whereas the most right boxplot represents the implementation of all policies. Several things stand out, the implementation of policies “24”, “14” and “12” and even “124” (including the feedback, group & newsletter policies) have very little effect when implemented together. While the implementation of “15” (feedback and container interaction) and “13” (feedback and on-demand) reach levels of 54% with only two policy implementations. Leaving “135” and “1345” to create the highest sortation rates for their policy quantities. Similar to the findings of the individual policies, has policy 2 (group) limited impact.

To get a better idea of what the model does when several policies are implemented together (from the 32 possibilities as shown in Figure 38). Figure 39 displays the effect of the knowledge about bio-waste separation on the percentage sorted while including all the different policy interactions. To increase the readability of the plot, prevent over-plotting and reduce the computational power needed for the creation of this plot, the decision was made to reduce the number of points plotted to the highly dense areas. This results in empty spaces implicating that there are no simulations with e.g. a 0.5 standardized bio-waste separation knowledge and a 50%

sortation rate. These simulations are present, but represent a lower density, as can be seen in the appendix and Figure 65.

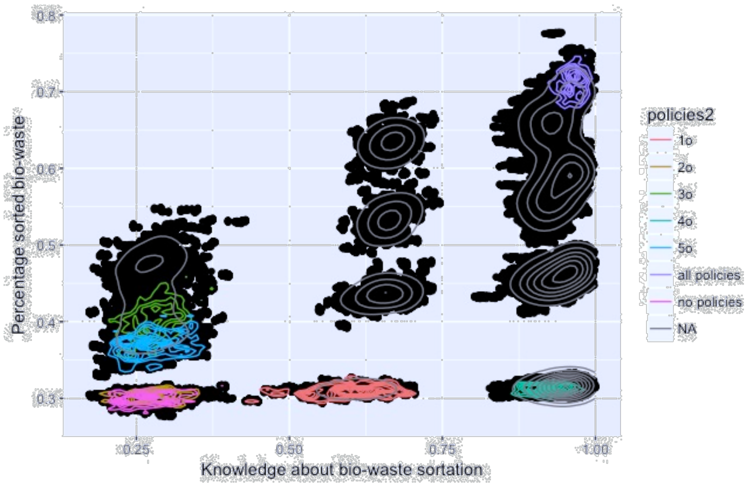

Figure 39 Percentage sorted bio-waste as an effect of the knowledge about bio-waste including all policies and policy interactions. It is important to note that values that are shown in figure only represent the highly dense areas to limit the effect of over-plotting and therewith give an unreadable representation of the data.

Figure 39 shows three levels of knowledge that the agents often reach on average, a reduction of the initial knowledge through no interest in the topic, a continuum of the average knowledge, and an increased level of knowledge through learning. In the first example, the maximum percentage of waste that is shown is just around 55% sortation, and with an increase of the knowledge level the percentage sorted bio-waste also seems to make a stepwise growth.

As discussed earlier, a growth of knowledge can still lead to a low percentage of sorted bio-waste, but with the implementation of another policy the effect of knowledge growth can have a secondary positive effect on the percentage sorted waste. This is clearly visible due to the high number of grey density plots representing combinations of individual policies, closing with all the policies implemented at the right top corner.

Since a stepwise behaviour has been found in the knowledge influence on the percentage sorted bio-waste (Figure 30), a distribution of boxplots has been made in Figure 40 to show the effect of each policy interaction on the knowledge level from 0 to 1.

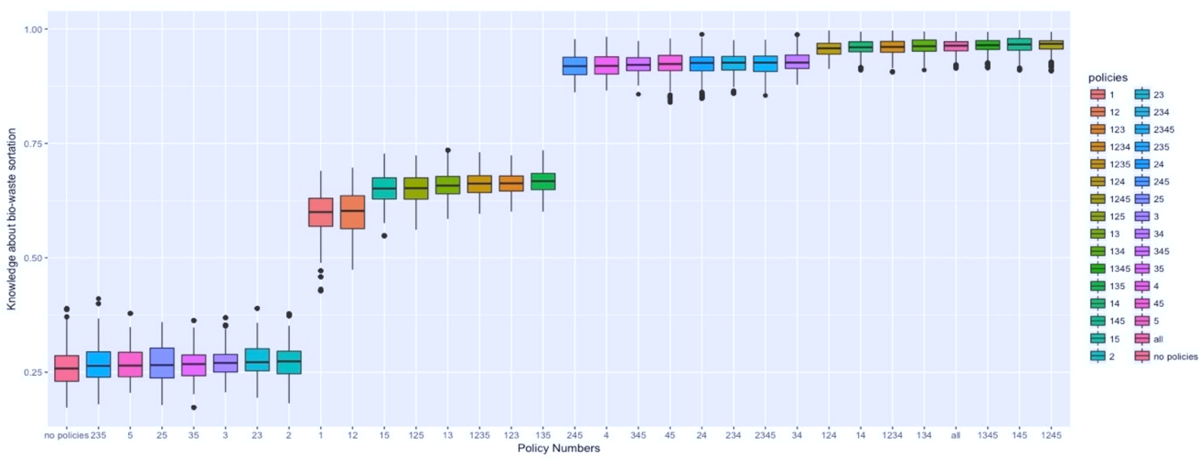

Figure 40 - Impact of different combinations of policies on the knowledge about bio-waste separation. A "12" policy number indicates the implementation of exclusively policy 1 (feedback) and 2 (group).

In Figure 40 there is a clear indication of the effect of four types of policy combinations, the combinations without policy 1 (feedback) and policy 4 (newsletter) levels around 0.26, the combinations including policy 1 but excluding policy 4 reaches an average value of 0.62, exclusively implementing combinations with policy 4 reaches a knowledge average of 92%, and combinations that include both policy 1 and 4 reach a 96% standardized knowledge level about bio-waste separation. Each of these four steps increase the knowledge about bio-waste separation as an average over all agents significantly.

A very interesting behaviour is seen in the combination of policy 1 and 3, which shows a significant increase of 59% to 66% bio-waste knowledge, compared to only implementing policy 1. This is interesting since policy three as such has only indirectly an influence on the knowledge levels of turtles. The additional implementation of policy 3 can influence the knowledge level of agents through communication of an increased percentage sorted bio-waste.

Therefore, the happiness about the symbiotic network will be further discussed. Figure 41 shows an image of all happiness levels compared to the percentage sorted bio-waste.

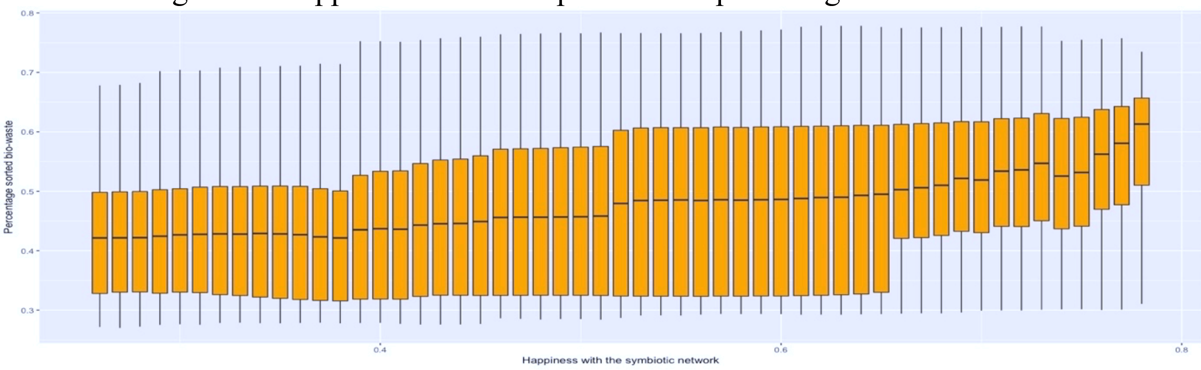

Figure 41 – Boxplot of the impact of the happiness about the symbiotic network on the percentage sorted bio-waste.

The graph shows a slight increase of the median value over the different values of happiness with the symbiotic network from 43% to 62%. Most importantly though the interquartile range of the values is relatively large, and the outliers span all ranges of bio-waste separation rates over each happiness level, narrowing down a little bit in the end indicating a stronger correlation of high happiness values with sortation rates above 45%.

The happiness agents feel over the symbiotic network is therefore moderately predicting for the percentage sorted bio-waste, and at high happiness levels only is an increased sortation rate likely. To further investigate in what policy combinations can influence these levels of happiness, Figure 42 will illustrate the simulation results through boxplots per policy combination.

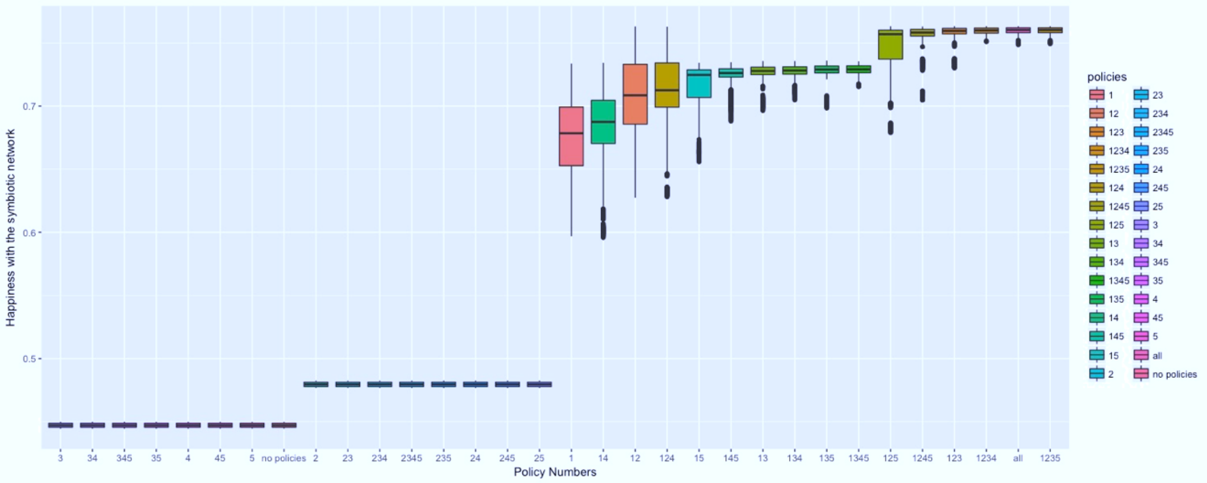

Figure 42 - Impact of the different policy combinations on the level of happiness with the symbiotic network. A "12" policy number indicates the implementation of exclusively policy 1 (feedback) and 2 (group).

Figure 42 shows that policies including the second policy (group), can result in a slightly higher happiness with the symbiotic network of 48% versus 45%. According to Figure 41 an increase of this quantity will not make a significant increase in the median percentage sorted bio-waste, even though a slight improvement from just below to just above a 45% sortation rate is measured in the run simulations.

7.4.9 Conclusion of the Results for the NDSM case

It is found that the implementation of a standard bio-waste sortation network at the NDSM wharf (see Table 3) can result in a 30% sortation rate. Secondly, the implementation of the combined policy of Feedback and an On-Demand waste collection scheme has shown to be extra interesting. It is predicted to create a significantly higher percentage sorted bio-waste of 54%, increasing the knowledge level, while remaining few in number. Thirdly, the highest ranges of bio-waste sortation (69%) are reached when all policies are implemented. Essentially, this research has shown that agents are influential when it comes to the height of this percentage sorted bio-waste. To get a good understanding of these three applications the results of the different agents are shown in Table 5.

Table 5 - Impact of agent types in standard model run and in combination with no policies, the combined policies feedback & on-demand waste collection, and all policies on the percentage sorted bio-waste.

	Standard	15 profiles	50 profiles
No policies			
Type A	0,30	0,30	0,38
Type B	0,30	0,29	0,32
Type C	0,30	0,30	0,38
Type D	0,30	0,39	0,46
Type E	0,30	0,39	0,45
Policies 1 & 3			
Type A	0,54	0,55	0,49
Type B	0,54	0,44	0,33
Type C	0,54	0,54	0,49
Type D	0,54	0,58	0,60
Type E	0,54	0,53	0,54
All policies			
Type A	0,69	0,68	0,62
Type B	0,69	0,62	0,50
Type C	0,69	0,68	0,62
Type D	0,69	0,71	0,73
Type E	0,69	0,69	0,68

Table 5 shows the expected percentage sorted bio-waste when there is no difference in the number of agents from the standard run, when the number is increased to 15 profiles and to 50 profiles. In each run only one type is increased and the other types remain equal to the standard initial values. The three blocks show the effects of implementing no policies, a combined implementation of policies 1 and 3 and all policies.

As seen before, the standard model results in an average of 30% bio-waste sorted. This number increases when agent types with biospheric values are present in higher numbers with no policy implementations. Oddly, Type B agents, with a hedonic focus, first decrease and later increase the percentage sorted bio-waste significantly when no policies are implemented, as mentioned before the schedule recalculation to empty the container might have favoured this small increase in sortation. Otherwise, Type B agents have a higher negative effect when implementing policies. When implementing policies 1 and 3, a high number of people with hedonistic values can decrease the added sortation percentage to a mere 3%.In an implementation of policies the added value of a biosphere-oriented agent type reduces, a small increase of Type A & C agents might still be beneficial / not-harming. But as policies take over the role of pro-environmental stimulus, the added bio-waste quantities put a strain on the model. The role that has been given in this research to the type D and E agents can greatly influence the network in the standard setting, however with all policies implemented this positive impact reduces to a couple of percentages.

To get a more visual understanding of this table, Figure 22 (see Chapter 7.3.2), Figure 43 & Figure 44 show the different blocks of “no policies”, “combined policies feedback & on-demand waste collection” and “all policies”. Figure 43 shows the implementation of the combined policies 1 and 3 on the percentage sorted bio-waste. On the left a growth of 15 agents per agent type is shown, on the right a growth of 50 agents per agent type. The deviation varies from 14 – 27%.

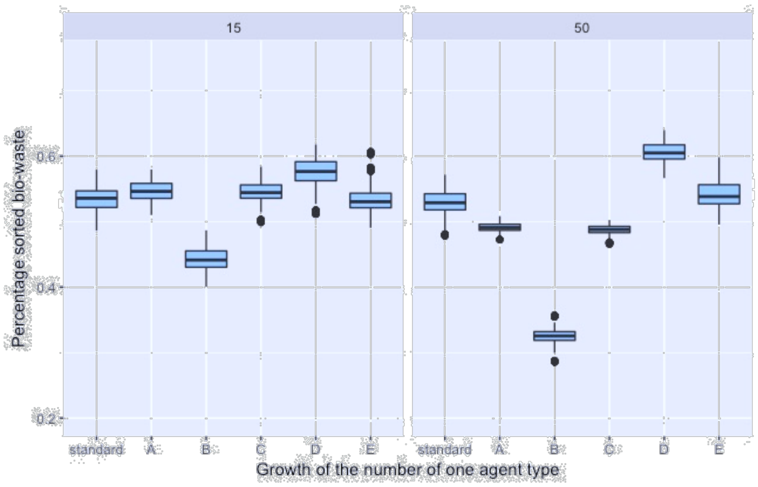

Figure 43 - Impact of the growth of the number of an agent type on the percentage sorted bio-waste, when the combined policies “feedback” and “on-demand waste collection” are implemented.

Figure 44 shows the same figure, but then if all policies are implemented. The deviation of the agents is slightly lower (9 - 23%), but behaves in a similar manner.

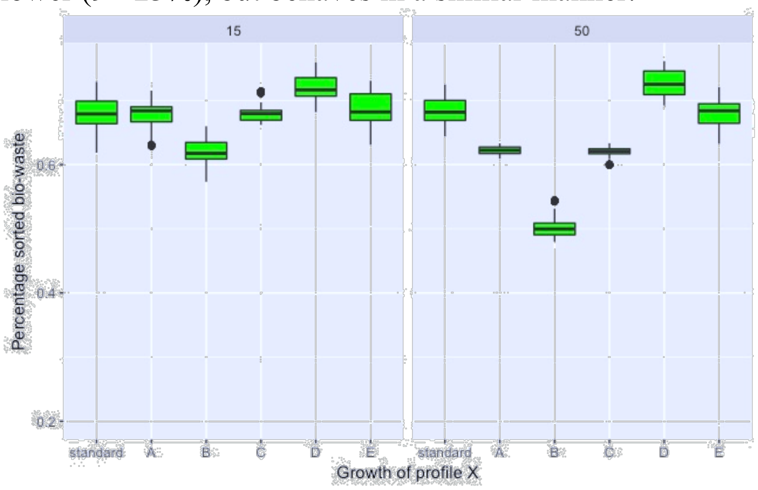

Figure 44 - Impact of the growth of the number of an agent type on the percentage sorted bio-waste, when all policies are implemented.

8 Analysis

In Chapter 7 the results of the model simulations have been displayed together with a guide to standard interpretation. This chapter aims to further dive into the results and give meaning to the numbers. This is done in four steps. First, the model is analysed in its standard settings mimicking the NDSM wharf case study (8.1). Secondly, the possible scenarios and policies as described in Chapter 5.2 & 5.3.1 and their implementation as described in Chapter 6.1.6 are analysed (8.2 & 8.3). Thirdly, the model is validated based on three types of validation: face validity, scenario analysis or parameter variability and predictive validation (8.4). In this analysis it is also important to note the limitations of the model in our study (8.5), an analysis of further reaching limitations of the entire study is given in the Discussion Chapter (9).

This chapter aims to partially answer question 5:
What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?

8.1 Model Analysis

The general bio-waste separation rate is shown in the first model results. The general bio-waste separation behaviour, as shown in Figure 15 shows that without any policy implementations, just by enabling the network to sort bio-waste through local and central containers, after half a year of simulations 30% of the bio-waste can be sorted. This is in line with the predictions of the European Compost Network (2016). It can be recognized that through knowledge levels and symbiotic interests the types of agents influence the percentage of bio-waste sorted. A high level of symbiotic network collaboration happiness is also positively correlated with the percentage sorted bio-waste, resulting in a connection between the beliefs and norms of an agent and its behaviour.

The system shows a difficult to predict start-up, ranging from sortation percentages from 0 to 50%. This can be regarded logical as the initial attempts of agents are highly unpredictable. After 200 ticks (or 40 days) the system seems to stabilize and give a pretty accurate prediction of the percentage sorted bio-waste over time, with little to no disturbances in a regular setting.

8.2 Sensitivity & Scenario Analysis

To get a better understanding of what external forces can influence the model behaviour and outcomes, the different results as represented in Chapter 7.2 and 7.3 will be further analysed in this subsection.

The implementation of a leaving scenario was linked to the literature about embeddedness in symbiotic networks. In the literature an optimum level of embeddedness is recognized to make practical use of the benefits of embedded links within a symbiotic network, but not the drawbacks of being too strongly connected. The dynamics of a strong interlinked network are however complicated, ongoing efforts are necessary to uphold relationships (Boons et al., 2015).

This reduction to the bare minimum bio-waste separation behaviour is understandable compared to existing literature, because of the topic of serendipitous network processes. These processes describe the slow growth of networks when the gains are evident, creating a long-lasting resilient network (Paquin & Howard-Grenville, 2012; Uzzi, 1996). It describes how timely interorganizational collaborations in networks create a network of trust, which remains stable over time (Gulati & Gargiulo, 1999). While the added benefit of recent policy implementations might deteriorate, the bottom line behaviour of partners remains stable.

8.3 Policy Analysis

To get a better understanding of what deliberate forces can influence the model behaviour and outcomes, the different results as represented in Chapter 7.4 will be further analysed in this subsection. Several outcomes will be taken under further consideration: the knowledge of turtles throughout the simulations, their happiness about the symbiotic network, the threshold of the central container storage, and the percentage sorted bio-waste.

8.3.1 Individual policies

Looking at the impact of individual policies in the model, a growth of the percentage bio-waste can be found that ranges from an insignificant amount to around the 10%. The model shows that these first steps of sortation rate improvement can be done through the reduction of technological failures. The policies that create the most values, have in common that they are less socially interruptive than the other policies. The On-Demand waste collection policy simply prevents users from encountering a full container where disposal is failing. The improvement of the container interaction for users through ecological modernisation is once more a reduction of the efforts of people to dispose of their waste easily. The other policies, distribution of a newsletter, the introduction of a feedback system and the creation of a group discussion have a more social impact. They improve knowledge levels, their happiness with the symbiotic network and create links between agents. However, simply implementing these policies results in an overload of the system.

The knowledge of agents changes over time based on their agent type, a higher level of bio-waste separation knowledge results in a better separation behaviour than in a situation with lower levels of bio-waste separation. However, a higher level of bio-waste recognition through knowledge seems to overload the system, resulting in more bio-waste separation losses later on in the system. If the container storage is not adapted to this behaviour, little positive impact on the percentage sorted bio-waste will show.

This overload in the system is seen in the modelling of the container storage over time. A large number of simulations steps, the container is able to effectively store the kilograms bio-waste. However, the container shows that a general level of bio-waste separation can be processed, the median value of the container lays below the maximum level in which successful storage takes place. However, in a large number of cases this threshold is overstepped and agents report negative feedback, impacting their next behavioural decision. When it comes to happiness with the symbiotic network this connection is slightly different. An increased value in the happiness with the symbiotic network will improve the percentage sorted bio-waste only at a later stage. A more extreme value is needed to improve the individual behaviour of the agents, a further effect in the model is therefore less than with the knowledge impact.

8.3.2 Combined policies

To make use of the knowledge level growth while preventing blocks in the system, the implementation of an on-demand waste collection scheme is researched as a solution. This results in an immediate percentage sorted waste growth of 20%, giving a total of more than 50% sorted bio-waste on the total bio-waste quantities.

In researching the combined policy implementations this effect once more shows. The implementation of policy 1 and 3 compared to the implementation of exclusively the on-demand (3) policy raised the percentage sorted bio-waste approximately five times as much.

Another way to support the system better on the increased level of sorted bio-waste through increased recognition is by improving the container interaction. By adding an improvement of container interaction as a policy the total percentage sorted bio-waste reaches up to a median of 60% bio-waste. Though it is not until four or even all five policies are implemented together that this model reaches bio-waste separation rates higher than 60 or even 70%. The maximum percentage of sorted bio-waste in over 10.000 simulations was 75 percent sorted bio-waste.

8.3.3 Connection VBN theory with ABM

The combined policies of feedback and on-demand waste collection (1&3) has been cross-referenced with the agent types in Chapter 7.4.9. This demonstrated big negative impacts on the percentage sorted bio-waste when type B agents are a majority in the system. The positive effects of the agents in the scenario testing are damped when policies are implemented, however the negative effects of type B agents are inflated. The implementation of policies 1 & 3 in the NDSM standard case is expected to result in a total of 54% sorted bio-waste, however when the number of hedonically-oriented participants get the upper hand the rate is expected to drop down to an unremarkable 33%.

8.4 Validation

The conceptualization and results as described in the chapters before are focused towards the NDSM case study. This results in a very practical goal for this study to support research for the participants in Re-StOre. To enrich the usability of this study, this chapter will look at the validation of the research and the possibility to generalize the findings towards a broader context. Aiming to inspect the idea of "did we build the right thing?" and to answer the sub-question: *What can be said about the validity of this model?* (Van Dam, Nikolic, Lukszo, 2013, pp. 127).

There are several possibilities to validate the model, this study makes use of three types of validity testing. In this study face validity has been used on the conceptual model, scenario analysis has been used on the model and predictive validation will be used in this chapter. Xiang, Kennedy, Madey & Cabaniss (2005) describe the validity measures for agent-based models as follows: Face validity is the activity of questioning experts in the bio-waste processing domain. Scenario analysis or Parameter Variability is the adaptation of chosen input values to determine its effect on the output. Predictive validation is comparison of the model output values to system behaviour as researched by peers.

In this study, face validity is achieved through interviews, questionnaires and a workshop with domain experts on the conceptual model. The setup for these can be found in appendix E, F & G. Before analysing the results, domain experts were asked their professional opinion about the inputs, relationships and other dynamics of the model. Experts asked for this research are an organic waste business developer from the AEB Amsterdam, a strategic advisor from the municipality of Amsterdam, participants of the Re-StOre and Re-Organise project and researchers at the HvA and TU Delft.

When analysing the sensitivity analysis in Chapter 8.2, it is shown that all values of the regular model settings are also presented in the longer running version. However, over time the variation decreases. This is logical as over time stochastic variables will average out. Therefore, it is shown that running the model for five years instead of half a year will not lead to any significant changes in the percentage bio-waste. Since increasing the time span will open up opportunities for external uncertainties that have not been modelled in this study, it is not recommended to run the model for this amount of time. Concluding, the model is not sensitive to the duration of the simulation.

In the rest of this chapter the analysis as described will be compared to data found in previous literature and additional expert interviews.

8.4.1 Bio-waste Generation & Separation

Without any policies the model currently shows a separation rate of 30%. This is in line with the bio-waste separation behaviour of households and SMEs all over Europe (European Compost Network, 2016). With all policies implemented the model currently shows a separation rate of 70%. This can be seen as an ultimately reachable amount. When looking at bio-waste there can be three types of waste subcategorized: avoidable waste, possibly avoidable waste and truly unavoidable waste (Exodus Market Research, 2008). In any case there will be waste that is truly unavoidable due to its difficulty to be recognized (used teabags) or separated (bio-waste that is inseparable from different types of waste will always end up in the regular bin).

8.4.2

Figure 8 & Figure 9 show the decision making in bio-waste separation behaviour. The steps of local recognition, willingness to walk, container experience and difficulty of disposal have been constructed through a literature study and recognized by researchers in the bio-waste domain at the HvA, TU Delft and Municipality of Amsterdam as important factors for successful waste separation.

8.4.3 Biodegradable Waste Knowledge Growth & Happiness with the network

The decisions made on knowledge & happiness with the symbiotic network are not based on real data. Rather they are parameters affected by the values, beliefs and norms of the individual together with the learning and forgetting over time. Consequently, it is difficult to compare these parameters with real-world values or by literary review. Through validation of the final effects of the parameters, a weakened validation of the knowledge and network development can be established, however when given more time for this study it would be wise to ask for a more thorough expert opinion of the internal details of the model.

8.4.4 Policy and Scenario Effects

The effects of the policies are validated on previous research to increase recycling rates of organic and other types of waste. The results shown through the feedback and newsletter are researched in various information prompting studies, where an ultimate 20% of bio-waste recycling occurs (Hopper & Nielsen, 1991). Our results show this 20% growth when prompting both general and waste specific information, and the system can absorb the increased bio-waste recognition flows. A simple implementation of only a newsletter has a lesser effect on the behaviour of people in this study.

The results shown in the group policy implementation are limited. We see that in combination with the on-demand policy the group policy can have a great improvement in percentage sorted bio-waste, but adding more combined policy possibilities reduces the added value. However, a type D agent which has an interest in the community and the biospheric values as well as the ambition and drive to become a leader can greatly influence the effect of certain policies.

According to research of Hopper & Nielsen (1991) it can even double the percentage sorted bio-waste. In our research a doubling does not occur in the simulations, however significant percentage growths are measured.

The results from the on-demand policy seem to easily take away on out of four pain points in separating bio-waste correctly, the ability to throw away bio-waste. The real time trashcan filling status is proven to increase the waste collection efficiency and reduce organic waste up to 33%, though it can triple the distance travelled by collection cars (Chowdhury & Chowdhury, 2007; Gutierrez, Jensen, Henius & Riaz, 2015).

The results from the Container Interaction policy are validated through an interview with the AEB and Municipality of Amsterdam, where it is recognized that making the waste interaction easier can reduce hurdles in waste disposal and therefore be a quick solution. Also, it validates the importance of more socially oriented policies to improve the bio-waste separation rate more long-term.

8.4.5 Further Validation Possibilities

It is important to note that validations are a never-ending process. One can continue to enrich the knowledge around a topic and research. However, with the limitations that are set when writing this study, decisions had to be made to create as much outcome for the time on hand. Increasing the number of case studies is a way of increasing the predictive validity of the model. Increasing the types of models is a way of testing the representation of reality. Thirdly, an increased level of experts performing face validity can support or falsify the model assumptions. Finally, time will tell. Monitoring the developments within NDSM, or future case studies, and linking these to the model can better support the prediction of real-world events.

First, increasing the number of case studies to different symbiotic bio-waste sortation networks can be done within the context of Amsterdam, and beyond. Testing the model within and outside of its original focus area can create new insights into the collaboration patterns of these symbiotic bio-waste sortation networks in different environments.

Secondly, creating different types of agent-based or other simulation models, based on different literature studies, can result in outcomes that are either similar or different from the model in this study. These different models can further test the assumptions made in this model and help to see limitations in the findings and room for improvements.

Thirdly, the model has currently be face validated based on the interviews, questionnaires and workshops. However, the programming of the model has mainly been reviewed by people either skilled in industrial symbiosis or agent-based modelling. Face validating the model through experts with a reputation in both fields, can increase the validity of the model even more.

Finally, comparing the model outcomes with historic data, now and in the future, can give a clearer image of the capabilities of this model and its error margins.

8.5 Limitations of the Model

As described earlier in the scope of this research, simplifications have been made to limit the complexity of the model and the research as such. These simplifications of reality were needed to cope with complexity, but also bring limitations with them in this study. Major limitations will be discussed here.

The model as conceptualized based on the Value-Belief-Norm theory is not capable of predicting intense activism (Stern, 1999). Lately, (student) demonstrations are hosted to generate awareness on sustainability and circularity throughout the Netherlands and Europe. These demonstrations are a form of intense activism and are difficult to predict due to its chaotic character. Also, the approach used to create a quantitative conceptualization of the VBN theory simplified the four values of people (altruistic, biospheric, egoistic and hedonic) to a yes or no question in a 16-profile setup. Naturally, human values are far more complicated than this. The 16-profile approach showed valid results, but can be much improved by creating individual measurements per human value. Also the happiness with the symbiotic network and the collaboration between firms is a complex study field, in further research it is proposed to enrich these calculations through event sequence analysis, multiple streams analysis or other forms for intractable collaboration analysis (Spekkink, 2013, Hernandez et al., 2018).

Secondly, the research in this study focusses on SMEs and does not make differences between the ages, educational level, income, gender and employment levels of employees. Even though Stern (1993) predicts that females show a higher level of consequence, this distinction is assumed to equal out over the agents and is not taken into account.

Thirdly, simplifications have been made when modelling the waste at SMEs and the social happiness with the network. Differences can occur in comparison to general household waste. Hanc et al. (2011) have distinguished different compositions of bio-waste throughout the seasons, also SMEs receive expected (self-generated) and unexpected (client-generated) waste. No distinction has been made between the different types of waste inputs in the model. In 2006 the European Commission described five types of industrial waste; Waste comparable with the waste generated by common households (food and kitchen waste from canteens), waste from industrial sectors comparable to the working of a common household (restaurants, garden maintenance), pre-consumer waste (processed food), animal by-products and waste from the treatment industry. By excluding big corporates in this research, the effects of large quantities of non-comparable waste are reduced, nevertheless SMEs have an opportunity in using this better prediction of bio-waste in a way to increase separation rates beyond the current values. Additional research is needed to distinguish better separation policies for non-comparable waste quantities.

Fourthly, when researching the different policies and combining them, no considerations have been programmed for spill-over effects in the model. When implementing an on-demand policy, the chips in the container can improve the feedback loop, because it offers a more precise representation of the bio-waste and its content (Chowdhury & Chowdhury, 2007). This could ease the implementation of a feedback policy in the system. However, when researching combined policies, the policies will be researched in their limited state.

Lastly, for separated bio-waste to be recognized as recycled waste it needs to be composted or the digestate needs to be re-used. This step of the waste management process is out of scope since the processing technique is not yet selected. Depending on the processing technique different types of organic waste should be sorted (see Appendix A – Bio-waste) and further research within Re-StOre plans on researching this decision.

9 Discussion

In previous chapters a model is constructed, simulated and analysed to the best of our capabilities, however reflection on the process, the model use and the outcome is needed to address the usability of this study. The model aims to predict bio-waste separation rates in the NDSM case of the Re-StOre project Amsterdam. As such, it made assumptions and has limitations in achieving this goal. In Chapter 8.4 & 8.5 the model is validated and the limitations have been taken under further inspection. The model, however, is not the ultimate outcome of this study. In the literature study, scoping and result analysis, assumptions have been made to create a focus and consistency in the study. These decisions are also in need of reflection.

This chapter answers the remaining questions about implementation possibilities in the current situation, different scale implementations, water management and the external effects together with social cohesion. By discussing these questions, the results of this study are set in a new daylight. Hopefully sparking the broader discussion of bio-waste separation possibilities.

This chapter aims to partially answer question 5:
What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?

9.1 Social theory decision

In Chapter 4.1 the decision was made to use the altruistically oriented Value-Belief-Norm theory (VBN) instead of the cost-benefit oriented Theory of Planned Behaviour (TPB), which has a wider scientific usage (Barr, 2007; Ashton & Bain, 2012). In Chapter 4.5 the VBN theory was adapted to include 16 value profiles.

Kaiser, Hübner & Bogner (2005) researched the abilities of the TPB versus the VBN theory in the prediction of conservation behaviour based on respectively, the behavioural intention and the personal norms. In their research the TPB predicted a variation of 76% of the behavioural intention, while in the VBN theory the personal norms only predicted a 64% variation of the behavioural intention.

However, this study exclusively incorporated students as agents. Since a more cost-benefit type of behaviour can be expected in student behaviour this test is regarded limitedly interpretable (Aguilar-Luzón, García-Martínez, Calvo-Salguero & Salinas, 2012; Kaiser, Hübner & Bogner, 2005). Additionally, the TPB & VBN theory have been represented in many forms, separately and joined, and they keep on developing (Oreg & Katz-Gerro, 2006; Park & Ha, 2014; Poškus, 2015; Stern, 1999). Research is therefore quickly outdated or investigates only a small section of the theory. Resulting in difficulty for comparison research to analysing the full model in the past years (Aguilar-Luzón et al., 2012). The further analysis of the results can elaborate on the usability of our VBN approach in symbiotic networks for bio-waste separation.

9.1.1 Bio-waste Recognition & Local storage

It is likely that there is little to no self-interest in the recognition and local storage of bio-waste in the Dutch context. Unlike in Switzerland where the general waste stream is taxed and the sorted waste is free, SMEs in the Netherlands create little value from their waste streams (sorted and non-sorted). This difference is important in determining the self-interest for participants. Self-interest is an important aspect of the decision-making through the TPB

(Abrahamse, Steg, Gifford, & Vlek, 2009; Wiidegren, 1998), whereas the VBN theory incorporates it only as a part of human values (hedonic). A model based on TPB might have a lower percentage bio-waste being separated locally, whereas the VBN theory would show a clearer distinction between hedonic and not hedonic agents. This study added the possibility that people can be pursuing both self-interest and world-interest, and is expected to have therefore the highest percentage locally stored bio-waste. The waste levels as predicted by the VBN model are validated with European data (European Compost Network, 2016).

9.1.2 Willingness to walk

The willingness to walk is found to be dependent on the distance and time to reach the central container. In this study people with biospheric values are likely to walk further than people with different values. In the TPB walking to the container is recognized as a high cost of time and energy with no obvious benefit and would likely be avoided. Social factors are included in the TPB, the social status of being recognised as an environmentally-friendly neighbour could therefore induce a percentage of people willing to walk. This prosocial behaviour is also included in the personal norms of the VBN theory (Harland, Staats & Wilke, 2007).

9.1.3 Container interaction, Container disposal & Container storage

The container interaction is based on safety, hygiene and social atmosphere. Low values would lead in the TPB to high costs, and are recognized as negative factors for people with all types of value combinations. The container disposal is dependent on its fullness and other abilities to dispose. Vice versa, high values affect the agents in the network based on TPB, VBN and the new approach equally. In both theories people have an expectation of their waste separation capabilities (through perceived control & awareness of consequence). Therefore, no difference is expected in these decisions.

9.1.4 Percentage sorted bio-waste

The perceived behavioural control of agents might be unrealistic, since the environmental effect of the percentage sorted bio-waste is dependent on many fickle, remote and unfamiliar elements. Therefore, the TPB would have trouble estimating the effects of the behaviour on the agent benefits (Ajzen, 1991).

9.1.5 Policy & scenario effects

In previous research on environmental campaigns, it's deemed validated that pro-environmental leaders in the creation of awareness (Rootes, 2013). The output improvement through a biospheric attitude and vice versa, corresponds with the idea that environmentally motivated regions result in the success stories for industrial symbiosis (Dennis et al., 2017).

To the participant there are low and unknown benefits of bio-waste separation, increasing the benefit of the behaviour and therewith its likelihood could be explored further. Monetary policies could be far more effective if the agents make rational choices, than in the current model. Additionally, group dynamics could play a bigger role through social expectance and support (Klöckner, 2013). The costs as measured in this model are likely to be similar if people make a rational choice or base their decision on normative values.

9.1.6 Conclusion value & limitations

The new VBN approach on a symbiotic bio-waste sortation network, has found significantly different results than when a different social theory would have been used. In conclusion, it is likely that with the VBN a percentage of sorted bio-waste is predicted, that is in line with historic data. Using the TPB, many steps show similar behaviour (e.g. a party leaving the network would also reduce agent interest in a TPB approach). However, the model would predict a lower separation rate on average, with a higher effect from benefit-increasing policies.

In this study it is found that it is more realistic to focus on the values, beliefs and norms, rather than the intrinsic cost-benefit analysis of the participants, when researching the environmental impact in a symbiotic network. This is because the study shows that the implementation of policies can be completely cancelled out if the values of the agents do not align the policy goals.

9.2 Implementation in the NDSM Standard

To be able to achieve change on a large-scale, a powerful movement is necessary of all involved parties in the socio-technical environment. Examples to create such a movement are through connection with civil society or in the support of broader bio-waste initiatives (Fischer et al., 2012). This study has focussed on the sortation of bio-waste and all involved parties. However, on a practical level it is important to link the NDSM research to parties in the rest of the bio-waste processing line. On a societal level, it is important to link the research to national or international collaborations to support awareness and higher societal impact. To reach both of these goals this research has stepped beyond the boundaries of the model focus, to include possibilities at the AEB, one of the current bio-waste processors in Amsterdam, and in international initiatives.

9.2.1 National impact

The model in this study predicts a rough 30% sortation rate for bio-waste in the NDSM case, a total 100 tonne of bio-waste. To give a fully accurate insight into what the environmental effects are for these quantities a thorough understanding is necessary of the further processing. While this falls out of the scope of this research, a quick estimation is done here to give a better understanding of the consequences of these bio-waste percentages.

One of many options that can be researched for processing is sending the bio-waste of NDSM to a central biogas digestor. The 100 tonne bio-waste of the wharf could result in 100.000 Nm^3 biogas, or 200.000 kWh in half a year (Netherlands Enterprise Agency, 2019). With an average annual electricity usage of 3000 kWh in Dutch households, this could provide ±130 houses in their demand (Milieu Centraal, 2019). At the moment, a household pays on average a rough €700 for their electricity per year, resulting in a total revenue of €91.000 for the waste processor (Milieu Centraal, 2019). Alternatively, the bio-waste can be composted and sold with associated revenues. When implementing combined policies, the total quantity of bio-waste (with a 60% separation rate), as well as the number of households provided with energy would double.

This result assumes that the waste processor is technologically capable of processing all the waste. In a validation session with AEB this assumption has shown to be untrue. The bio-waste can be sorted, but because AEB has no other option than to burn the waste for city heating, it can practically be regarded as unsortable. This is no final limitation in itself, as it is possible for the AEB to invest in greener processing mechanisms or waste processing contracts can be adapted to greener alternatives. However, investment periods take a minimum of two years and big publicly supported funding.

9.2.2 International impact

On national and international levels initiatives are proposed to promote self-sustainable symbiotic networks and create a larger environmental and societal benefit. Fisher et al. (2012)

promotes the Millennium Alliance for Humanity & the Biosphere that has scholars working across disciplines to work together as citizens and earth, as a way to promote large-scale movements. Van Renssen (2012) suggests the inclusion of Climate-KIC as promotor on EU level. Additionally, this research has introduced the URBACT initiative, which aims to boost interaction between initiatives in the European Union. For the scope of the Re-StOre NDSM project, a collaboration with the City of Warsaw could be beneficial due to their joined interest in separate waste collection and the circular economy. Furthermore, the CEMEX-TEX Award for global recognition of high impact societal development project could offer an opportunity to the Re-StOre NDSM wharf project. Recognition of these collaborations are mentioned to improve the effects of implementations in the current situation, with the ambition to promote international awareness.

9.3 Different Implementations

Depending on the size of the bio-waste quantities, different processing methods can be chosen. This decision will have a secondary effect on the behaviour of SMEs in sortation through the visibility of the processing method.

Examples of processing methods are combustion, gasification, pyrolysis, integrated thermal plants, aerobic mechanical–biological treatments, anaerobic mechanical–biological treatments (Rada, Istrate, & Ragazzi, 2009). Two important environmentally friendly possibilities are aerobic and anaerobic digestion. Anaerobic bio-waste digestion asks for bigger investment costs and a more constant input flow of bio-waste, while aerobic digestion (composting) can be done almost immediately but has a longer rate-of-return (Lim, Lee & Wu, 2016). Other possibilities are mushroom or worm composting, techniques that can be implemented at a scale as small as one household. Composting methods such as the latter, can be hosted more locally and are therefore in general more visible than the anaerobic digestors, creating a feedback loop.

9.4 Water

For AEB one of the main benefits of separating waste at the source is the reduction of water in the regular waste stream. In general, organic waste is very wet due to the high percentages of water in fruits and vegetables (Rada, Istrate, & Ragazzi, 2009). When the residual waste is incinerated in a waste-to-energy process to create for example city heating, it is better if the residual stream is dry. Less water in the waste stream results in an increased lower heating value, meaning that less energy is lost due to water evaporation and higher burning efficiencies.

Furthermore, if the residual waste contains fewer wet ingredients, waste post-sortation of alternative recyclable materials can be more effective or even possible (Schüch, Morscheck, Lemke & Nelles, 2016). As an example, dry paper can simply be removed and sent to a paper recycling site, while wet paper will end up incinerated or landfilled. Removing the wet organic waste stream from the residual waste prevents this problem and therewith creates positive ecological footprints in different recycling fields.

9.5 External Effects & Social Cohesion

In the literature there is uncertainty about the optimum level of social cohesion and embeddedness on the external effects of a symbiotic network (Doménech & Davies, 2011a; Uzzi, 1996). However, once a so called optimum is found, people suspect that it would lead to environmental behaviour improvement on a wider scale. Although often associated with industrial symbiosis, a singular focus on physical resource exchange it is neither necessary nor sufficient (Lombardi & Laybourn, 2012). As an example, Barr (2007) states that participation in the ecological friendly separation behaviour of bio-waste will lead to more willing uptake of other ecologically friendly actions.

Contradicting, an increased knowledge and/or interest in plastic sortation does not necessarily improve the ecological behaviour of bio-waste separation. For example, Abbott, Nandeibam & O'Shea (2011) found that their results on recyclable collection is not applicable to compostable waste, as the bio-waste has specific hygienic and structural compositions that are not comparable to other waste streams.

As described in Chapter 3, this research focusses on place-oriented symbiotic networks as they aim for environmental, economic and societal value through geographical proximity and community involvement (Boons et al., 2015). This type of symbiotic network has a lesser focus on the type of waste stream in the network than the others (Boons et al., 2015). Implying that collaboration on different fields would also be plausible. This is also supported by the fact that in the Dutch context Industrial Symbiosis often only one of the policy implementations is in innovative areas and a demand for further collaboration is desired (Boons et al., 2015).

Finally, external effects through improving social cohesion in symbiotic bio-waste sortation networks is likely but not proven. While bio-waste separation behaviour is expected to spill-over to all sorts of pro-environmental behaviour, it does not have an indisputable causal effect (Thomas & Sharp, 2013). Further research is therefore necessary to ensure the links between the type of symbiotic network, its social cohesion and embeddedness and additional environmental benefits.

9.6 Conclusion

This research has touched many of the topics as described in Chapter 2.3. Figure 45 shows an adaptation on the earlier version, including different findings from the analysis and discussion of this study.

In the centre the topic of value creation is illustrated, the orange boxes represent the outcomes of the model analysis and the discussion. As shown in the Analysis Chapter, there is the possibility for the percentage sorted bio-waste to increase from non-existence to 30% - 70%. Furthermore, this discussion has described the possibilities of a reduction of the water level to create more environmental and economic value. It was found that implementing more technical policies, such as an on-demand waste collection scheme or the improvement of container interaction, can reduce the quantity of bio-waste to end up non-sorted. This would be described as a quick improvement. The introduction of more social policy, such as a feedback policy, can create a more long-lasting improvement. Additionally, in the literature much emphasis has been put on the embeddedness of the symbiotic network. A key finding of this research is the dependency of the symbiotic network on the type of agents involved in the network.

The top of the diagram shows the social cohesion and secondary pro-environmental value creations. In the analysis it was found that a social happiness in the model can create value through a second loop beyond the direct effect of social cohesion on value creation. This is in line with what is described in the literature.

When looking at the bottom of the diagram, anchoring shows that there is currently no physical infrastructure available for AEB to process the sorted bio-waste. Even though the symbiotic bio-waste sortation network could create value, it shall not reach a self-sustainable stage if there is no use to separating the bio-waste. Meaning that the possibilities for international influence are limited if the network will not reach this self-sustainable stage. Finally, one can find the topic of trust in the figure. This topic is included in this research as connection between embeddedness and the self-sustainable state. While it does not play a prominent role in this research, and new findings remain out of the scope of this research, it is important to display trust as part of a symbiotic bio-waste network that aims for a self-sustainable stage of many-sided value creations.

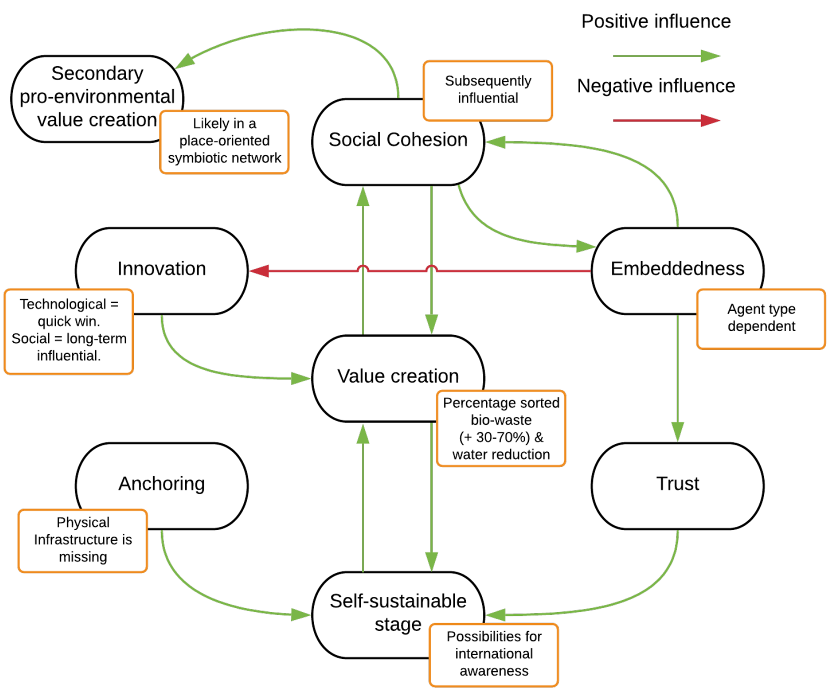

Figure 45 - Adaptation of Figure 2 to include the findings of this study on each topic.

10 Conclusion

To reduce human health issues and a loss of the planet's resources, this research sought a quantitative approach to address the topic of bio-waste separation in Amsterdam. The previous chapters discussed the state of the art literature on this topic, the case study Re-StOre NDSM wharf and the conceptualization, experimentation and validation of the agent-based bio-waste separation model. Now, the results of this research and the general conclusions are discussed by answering all sub-questions from Chapter 2.6, and therewith giving a mutually excluded and exhausted answer to the main research question. Additionally, the social and scientific relevance of this study is repeated, followed by a proposition of further research possibilities.

10.1 Sub-Questions

1. **How can the theory of Industrial Symbiosis be connected to social theories for the conceptualization of a symbiotic network?**

For the creation of a quantitative approach to a symbiotic bio-waste sortation network a connection was needed between the research of industrial symbiosis and social theories. A few of these theories are the Norm Activation theory and the theory of Planned Behaviour. This research aimed to include the environmental outlook of industrial symbiosis in the decision for a suitable social theory. In the Theory of Planned Behaviour the focus is on costs and benefits, and a rationality in agents is assumed. This assumption has often been proven to be unlikely in environmental behaviour. In this research environmental behaviour is not rationally predicted, and is often caused by a social atmosphere and inner desire for well doing.

One theory that focusses on altruistic behaviour rather than cost-benefit analyses is the Value-Belief-Norm (VBN) theory. This theory has been iterated over the past decades, developing from the Norm Activation theory, the New Environmental Paradigm and the Value theory. The theory includes biospheric and altruistic values as well as egoistic and hedonic ones, and combines this with an environmental world-view (beliefs). Finally the social interaction is connected with an awareness of consequence and an ascription of responsibility (norms) resulting in the behaviour of agents. This theory will be connected to the research of symbiotic bio-waste sortation networks because of their mutual interest in user-driven and self-organising behaviour.

2. **How can values, beliefs and norms be collected in a quantitative approach to research the effect on a symbiotic bio-waste sortation network?**

Participant behaviour includes the general bio-waste sortation decision-making steps and how this affects the percentage sorted bio-waste. An approach is suggested to translate the qualitative and randomized behaviour of agents towards a quantitative agent-based setup. Therefore, it describes how our values, beliefs and norms affect the decision making process.

Through literature reviews and expert validations there are four steps in the general bio-waste separation decision making process recognized: the recognition of bio-waste, the willingness to walk the distance for disposal, the disposal experience and the difficulty of disposal. In each of these steps a decision can be made to not correctly separate the waste, but rather to dispose this waste in the regular bin. If the bio-waste is correctly separated it will get collected through a logistics collections scheme of the municipality or a private party. Municipal disposing and processing methods did not fit the scope of this research.

To connect the social VBN theory for behavioural decision-making to this generic step-wise plan, a quantitative method was necessary. In the research about VBN the values are often used as a simplified way of describing the intrinsic motivation a person is likely to act upon. However, in this research a new approach is taken based on the idea that people have complex intrinsic values which are not mutually exclusive. To mediate between computational complexity and added prediction value, an approach is chosen where the four values are interconnected in a 16-profile setup. With this setup, real-world agents can be represented in a simplified manner.

Thirdly, the beliefs and norms are included in this model. These values remain stable over time, however human behaviour can evolve. To be able to represent this in the behaviour conceptualization a knowledge value is created, together with a feeling about the symbiotic network. These values are able to change over time, based on the intrinsic values, beliefs and norms of an agent. Together all these parameters determine the decisions that are made at each of the four steps in the waste separation flow.

Finally, several policies are found to be influential on this behaviour and on the dynamics in bio-waste separation behaviour: the creation of a feedback loop, the distribution of a newsletter, a group behaviour policy, an on-demand waste collection scheme and improvements for human interaction with a central container.

3. **How can a symbiotic bio-waste sortation network be modelled?**

In Chapter 6 the modelling of the behaviour is described. This incorporates all the knowledge as found in the previous sub-question, based on literature reviews, expert interviews and workshops. It incorporates how the model has digitalized the behaviour and the randomness of decision-making. To be able to model a real-world case study, one is in need of assumptions to restrain the model from overcomplexity. These assumptions can be found in Chapter 6.2. The agent-based model, as programmed in Netlogo, is ultimately the answer to this sub-question.

4. **What is the effect of sortation policies on the sortation outcome of participants in the NDSM wharf?**

In Chapter 7 & 8 the results of the model and the effects of the policies have been described and analysed. In the symbiotic bio-waste separation model behaviour came to light differentiating types of actors. Type A & Type C agents have biospheric values and shall therefore sort more bio-waste with lesser incentive from policies than type B agents. Large numbers of people with hedonic values (Type B) can cause policy implementations benefits to cancel out. The inclusion of type D or type E agents can improve the usefulness of a specific policy. Running the model over a longer time period resulted in little difference in model output.

Individual policies are found to have little effect on the percentage sorted bio-waste, when implemented independently, enforcing the idea that bio-waste separation is a network of incentives. There is no significant evidence that the feedback, newsletter or grouping policy will improve the sortation rate. Though, the on-demand waste collection scheme or the improvement of containers for human interaction can significantly improve the bio-waste separation rate of the Re-StOre NDSM case up to 10%.

Combining several policies in the NDSM case, the option of implementing all policies is recognised as the most sortation rate improving (up to ~70%). By combining the on-demand policy with the feedback policy a percentage sorted bio-waste of 54% can be expected in the NDSM case, optimizing the output with the least number of policies. However, large numbers of Type B agents decrease the effect in all simulations, and can even lower the policy impact on the percentage sorted bio-waste to less than in the standard setup.

5. **What lessons can be learned from this research to increase the environmental impact of Re-StOre and other bio-waste networks in the future?**

This research found that the implementation of bio-waste source separation policies can improve the percentage sorted bio-waste, depending on their internal values, beliefs and norms. The standard model predicts an energy supply for 130 houses, ranging up to 260 houses based on the policy implementations. However, there are currently no administrational, logistical and technological facilities contracted that can process the sorted bio-waste into compost, biogas or other valuable outputs.

Opportunely, bio-waste sortation can also improve the environmental impact of bio-waste processing via a secondary route. By extracting bio-waste, which holds a lot of water, from the general waste stream earlier, the post-sortation processes of other recyclables can be improved, and the energy needed for the incarnation of the general waste stream is reduced.

10.2 Main Research Question

Combining the results of the previous sub-questions, this study used an agent-based modelling approach of the NDSM wharf case study to ultimately answer the main research question:

What is the influence of different groups of human behaviour and policy interference in the development of a symbiotic network around bio-waste separation for environmental benefit?

This research has shown that agents with different values, beliefs and norms have a significantly different influence on the percentage sorted bio-waste, with and without policies implemented. In the NDSM case the inclusion of agent types with biospheric values increases the separation with around 8%. The inclusion of people with biospheric and egoistic values of power and ambition can even increase the percentage sorted bio-waste with 15%. Additionally, policy interferences can introduce separation rate from 10% up to 70%. Both positive and negative differences are seen when the different groups of agent types are combined with policy implementations, resulting in rate growths up to 30% and drops up to 20%.

Once the technological and capacity limitations of the region are solved, environmental benefit can be found three-fold. First, by creating quantities of bio-waste for composting or anaerobic digestion (biogas). Secondly, by improving the usability of the general waste stream through a reduction of water. Thirdly, by creating a self-sustainable stage for international awareness.

10.3 Social & Scientific Relevance

The research had a clear practical and scientific goal. Respectively, to support the successful development of the NDSM wharf as symbiotic network and to find a quantitative approach to researching industrial symbiosis.

10.3.1 Scientific Relevance

Biodegradable waste can enter a sustainable energy loop, where valuable resources remain usable. However, due to bad sortation and processing it often ends up in landfills or burned (Haas, Krausmann, Wiedenhofer & Heinz, 2015; Tozlu, Özahi, & Abuşoğlu, 2016; Khalid, Arshad, Anjum, Mahmood & Dawson, 2011; Wiedinmyer, Yokelson, & Gullett, 2014; Al-Yaqout, Koushki

& Hamoda, 2002). Industrial symbiosis has proven to be a research field where innovative and transitional regions of SMEs come together to create economic, environmental and societal value (Weijnen, ten Heuvelhof, Herder & Kuit, 2004). To be able to structure industrial symbiosis introduction in areas of bio-waste separation for further research, a qualitative framework has previously been proposed. Quantitative approaches have remained underdeveloped. This study aimed at filling this knowledge gap in our current literature.

To do so, the human behaviour in symbiotic bio-waste sortation networks should be predicted. For this study several social theories were examined and the Value-Belief-Norm theory has shown to incorporate the altruistic instincts of pro-environmental behaviour. This theory can incorporate scientific values to increase the quantizability of human behaviour, even though it should be noted that individual human behaviour first and foremost remains unpredictable and only be aggregating behaviour can we find consistent patterns. To be able to analyse these patterns and answer the knowledge gap the VBN theory for individual SME behaviour has been adapted.

In this research this new approach to behaviour is used in combination with the decision-making steps that have been recognized in bio-waste separation management literature and through expert interviews. The different components of the VBN theory are connected to each decision-making step, offering a solid approach to predicting human decision making in this context.

As a result, the study is able to incorporate altruistically-based behaviour in a social environment and therewith give a more realistic view of the behavioural choices that people make when behaving pro-environmentally within the domain of bio-waste separation. This gives a quantitative approach for symbiotic bio-waste sortation networks, and therefore helps to close the knowledge gap. Hereby, the use of agent-based modelling in this study has proven extremely helpful due to its bottom-up approach. It reflects the complexity of predicting individual SME behaviour, and offers a good way to test top-down policy approaches. The model has shown that agents with a hedonic value profile, can cancel out the effects of policy implementation effects. The VBN theory is therefore shown to be extremely useful in the symbiotic network design.

10.3.2 Social Relevance

Through the EU Landfill Directive (2014) a strong signal is sent out for a more environmentally friendly collection and processing of our current waste streams. Specifically, bio-waste and industrial symbiosis have been discussed. In light of this global ambition, small innovative regions have started to cooperate towards the closing of the energy loops (Centre for Applied Research Technology, 2019). One of these regions is the NDSM wharf in Amsterdam, this region is used as a case study. This research aimed at offering new insights into the NDSM case, as well as create a generalized image for similar regions to NDSM.

Five different policies have been implemented with a focus on the NDSM wharf case study of the Re-StOre project in Amsterdam. This resulted in a number of socially relevant outcomes that can ease the transition of this area towards a more environmentally friendly industrial region. These model results are validated through experts and historic data to be able to sketch a generalizable idea of networks with similar characteristics.

This study proposes that policy implementation is dependent on the values, beliefs and norms that are in a network. In combination with fitting policies to these network types societal benefit can be realised through recovering valuable organic resources and improve the processing of general waste streams. When searching to improve a small network of bio-waste sorters, the most influential policies are the creation of an on-demand waste scheme and an improvement of the container for human interaction. These fairly technological changes can reduce hurdles to correctly separate waste. The improvement of the system on the societal and technological level together makes for a strong and robust network result.

10.4 Further Research

During the course of this study, many interesting directions have come to light that could not be further researched within the limited time available. This includes research in the field of industrial symbiosis, the case study, the validation and its implications.

Industrial symbiosis is aimed at creating both environmental as well as societal and economic value. In this research only environmental value has been measured and tested. This study found that bio-waste can be used as a valuable resource. Therefore, social cohesion can be expected in the network and both societal and economic value are predicted, though not proven. It would be beneficial for the development of symbiotic bio-waste sortation networks to be able to predict these types of benefits better on forehand. This could lead to a higher social happiness and knowledge level from the start, simultaneously improving the environmental impact too.

To continue this train of thought, de Young et al. (1995) stated that specific research on individual's behaviour and the focus situation is always an improvement to this type of recycling research. Several assumptions and limitations arise within the case study. However, the usage of industrial symbiosis for bio-waste separation and processing is encouraged throughout the European Union (2014). This research aims to improve bio-waste separation behaviour on a wider scale than the NDSM wharf, and therefore supports model expansion and adaptations. Increased practical applicability could lead to new insights for the research domain, enhancing the positive pro-environmental impact.

Also, to increase the usability of this study, it is important to continually improve the validity of this study. For one, this can be done through applying the research on more case studies to simultaneously improve the scientific and societal relevance of the new approach. Furthermore, it is important to highlight the applicability of the findings in a broader context. An important aspect here is the creation of agent type profiles, by testing non-binary levels for each of the four values, higher levels of detail could be measured.

Finally, this research has shown limitations within the expanding field of bio-waste sortation, such as the limited capabilities of the current waste processor of Amsterdam. Several processing technologies are available and affect the total environmental, societal and economic value of the network (Rada, Istrate, & Ragazzi, 2009). It is important to get a good idea of the full network implementation to recognize the different types of added value of the new bio-waste separation behaviour. It would be very beneficial for the setup of future symbiotic bio-waste sortation networks to have a clear understanding, not only of the first-degree benefits, but also of the second-degree implications of their behaviour change. A first step towards this goal is to research the logistics and processing techniques, once the waste is sorted.

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Appendix A – Bio-waste

This study describes the possibilities around bio-waste separation. Hereby, it is important to note that there are differences between recyclables, organic materials and bio-waste. The figure below shows that vegetables, meat and sewage sludge are all possible biodegradable wastes.

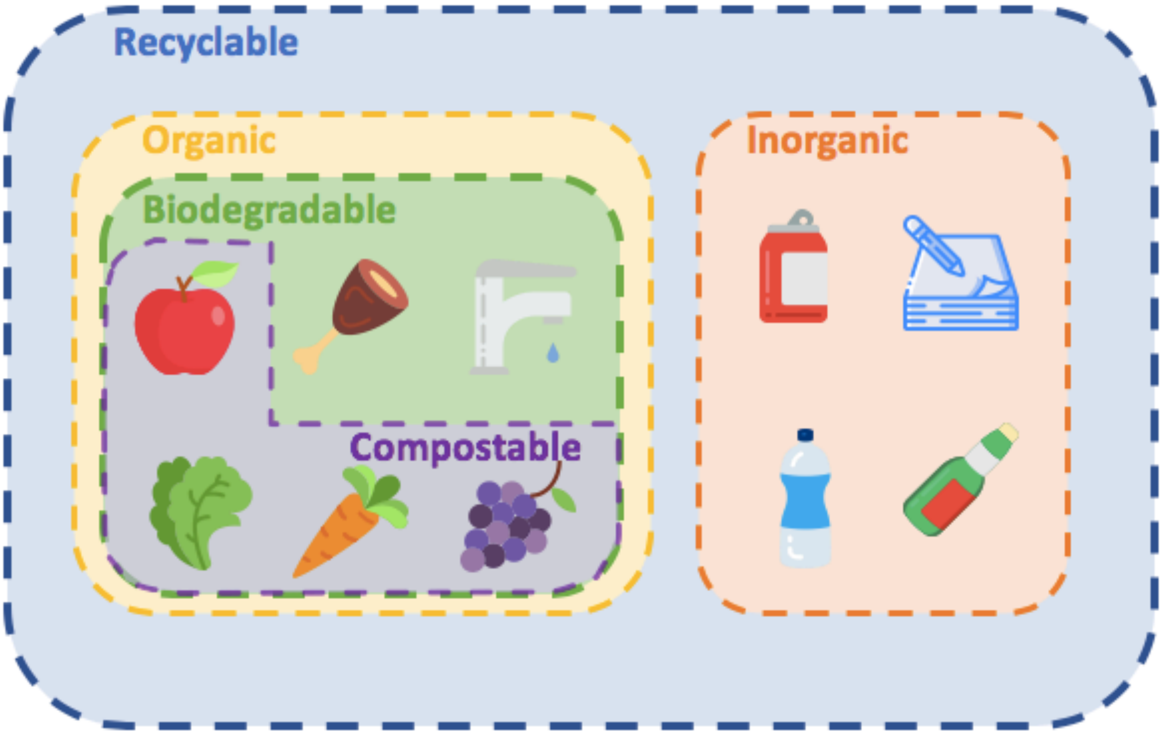

Figure 46 - Literature review on waste sorts (Icons made by Smashicons from www.flaticon.com)

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Appendix B – Delimitations Simulation Modelling

This appendix describes how the decision for agent-based modelling as a simulation tool has come about. Table 6 shows this on the different levels of simulation modelling.

Table 6 - ABM assessment

Theory	**Re-StOre**
Why simulation modelling? • Affordability • Flexibility (Bonabeau, 2002) • Over a wide range of scenarios • Making data more relevant and useful (Holland, 1995) • Creating a generalizable model • Robustness & Resilience testing (Capano & Woo, 2017). Why not simulation modelling? • Time-costly • Model assumptions can have a big and faulty impact on the results • Four steps removed from reality Why Agent-based modelling? • Complex behaviour (Macal & North, 2005). • Individual agents make decisions based on their own properties and states (Siebers, Macal, Garnett, Buxton & Pidd, 2010). • Emergent behaviour (Bonabeau, 2002). • Decentralized data (Jennings, Sycara & Wooldridge, 1998). • Agents have a limited world view & capabilities • No central control (Jennings, Sycara & Wooldridge, 1998). • Asynchronous computation & change during the simulation (Davis, Nikolić & Dijkema, 2009). • types of problems for which equations either cannot be solved or are impossible to formulate (Axtell 2000). Why not Agent-based modelling? • System Dynamics for dealing with relations between system elements and feedback in the system. • Discrete Event Simulation is based on the time of certain events and with knowledge of the duration of every event it simulates the operation. Why Netlogo? • See demarcation document in Appendix C – Delimitations Simulation method Why not Netlogo • See demarcation document in Appendix C – Delimitations Simulation method .	Why simulation modelling? • Limited funding for research on Re-StOre • Supporting informed decision making • Various inputs, external factors and policies to take into account • Relevant for broader scientific research • Offers possibilities for policy testing Why not simulation modelling? • Finite window of opportunity Why Agent-based modelling? • Many agents • Dynamic network links • No top-down approach / bottom-up • Independent actors with different values and goals • Includes both technical & social sciences Why not Agent-based modelling? • Impossible to write complex equations for SD, and there are no time certain events. Why Netlogo? • In line with current research group at TU Delft and Re-StOre project.

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Appendix C – Delimitations Simulation method

This appendix shows the considerations taken into account when chosing for Netlogo as the preferred simulation method. In comparison with MESA (Python 3), REPAST Py, SWARM, ASCAPE, MASON, Mathematica, MATLAB (SimEvents toolbox) & Excel, Netlogo showed a great capability in the desired factors of simulating with an easy to understand interface. Together with the large community that is associated with Netlogo, and the current research on the topic of Industrial Symbiosis in Netlogo this method was chosen. The Genius method (General Environment for Negotiation with Intelligent multi-purpose Usage Simulation) was not taken into account due to its bilateral and not multi-agent focus.

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	Dedicated Agent-based Prototyping Environments:		Large-Scale (Scalable) Agent Development Environments:				General Computational Mathematics Systems		Spreadsheets
Topic	**Netlogo**	**MESA (Python 3)**	**REPAST Py**	**SWARM**	**ASCAPE**	**MASON**	**Mathematica**	**MATLAB (SimEvents toolbox)**	**Excel**
Programming language for user	Easy	Python 3	More complicated			Not learned			Easy
Simulations involving agents located on a rectilinear grid	Good	Good	Good		Good				No
simulations that have no spatial aspects			Bad		Bad				No
models that require a geographical information system to simulate an actual terrain.			Bad		Bad				No
fluency in the underlying programming language	Not needed	Not needed	Not needed		Not needed				Not needed
Have a complex interface	No	No	Yes		Yes		No	No	No
comparing multiple model runs	In R	Yes (Python imaging)	Baby shoes		Baby shoes				Yes
loading or calibrating models from data	No	No	Baby shoes		Baby shoes				
automatically generating large numbers of cases from experimental designs	In R	Yes	Baby shoes		Baby shoes				
collecting and statistically analyzing the results of large numbers of experiments	In R	Yes	Baby shoes		Baby shoes				
Price	Free	Free	Free	Free		Free		Expensive	
Global views of time	Yes	Yes	Yes	Yes					
Local views of time	Yes	Yes	Yes	Yes					
Time step simulation	Yes	Yes	Yes	Yes					
Discrete event simulation	Yes	Yes	Yes	No		Better	Faster	Faster	
Integration with GIS		No	Possible & Open	Possible - Kenge library					
Agent diversity	High	High	High						Bad
Agent behaviors	High	High	High						Bad
Scalability	No	Yes	Yes						Bad
Easy of modelling	High	Python					C++	C++	High
Mathemetical power		High	Medium				High	High	Medium
Sequential or Simultanious modeling	Sequential	Both							
Status	Large community	Work in progress	W.I.P. REPAST 3 &					Large community	Large comm
Date of development	1990	2015	Repast 2: 2003					1984	1985

Figure 47 - Simulation methods assessment

Appendix D – Social Theory Analysis

The first chapters will discuss some more generally used social theories, the Social Impact Theory & The Social Comparison Theory. The second part discusses the most used theories in the environmental psychological domain, namely the Theory of Planned Behaviour, The Norm Activation Theory and the Value-Belief-Norm theory (Sopha, Christian, Bjørnstad & Matthies, 2011) and their development. Lastly, the applications to this research are discussed.

D.1 Social Impact Theory

The Social Impact Theory is designed to measure the effect of other persons on an individual (Latané, 1981). According to the theory, when other people are the source of impact and the individual is the target, impact should be a multiplicative function of the strength, immediacy, and number of other people (Latané, 1981). This has later been enriched with the concept of spatial distance towards the dynamic social impact theory (Latané, 1996). To measure the aforementioned strength the theory looks at persuasiveness and supportiveness, but these two properties are complex functions of many components (Macas & Lhotska, 2008). Therefore, the usage of the theory is limited by the complexity of the computational process.

D.2 Social Comparison Theory & Social Approval

The Social Comparison Theory is a useful tool in measuring the projective perception of the individual to the social world. It makes use of the term "self-anchoring" for people's view towards themselves in the social world and the collection of data to position others (Suls & Wheeler, 2013). In this framework social approval is sought for instrumental utility (Jellison & Gentry, 1978). The framework assumes that people desire to self-evaluate and have the necessity to base this evaluation on comparison with others (Festinger, 1954). Gergen (1973) states that these assumptions cannot be taken as certain, but rather they adapt over time and context. As an example, he refers to Riesman (1953), who has cogently argued that social approval has far more reward value in contemporary society than it did a century ago.

D.3 Theory of Planned Behaviour

The Theory of Planned Behaviour is an extension of the theory of Reasoned Action, and includes people's incomplete volitional control (Ajzen, 1991). Figure 48 shows the basic outline of this approach. The attitude towards the behaviour, the subjective norms and the perceived behavioural control are interlinked and creating an intention. According to the TPB, people perform a behaviour with positive environmental outcomes if they hold a positive attitude to them, if other people expect them to act in that way and support them in doing so, and if they perceive themselves as being able to implement their intentions (Klöckner, 2013). This theory is based in the rational-choice theory, where individuals are expected to make fully-informed decisions, weighing the costs and the benefits, to optimize self-interest (Abrahamse, Steg, Gifford, & Vlek, 2009; Wiidegren, 1998). With this origin, the TPB had its limitations from the start. Ajzen (1991) states that "perceived behavioural control may not be

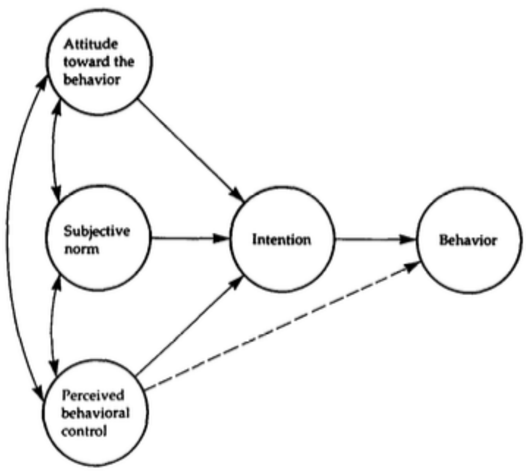

Figure 48 - The Theory of Planned Behaviour (Ajzen, 1991, p. 182)

particularly realistic when a person has relatively little information about the behaviour, when requirements or available resources have changed, or when new and unfamiliar elements have entered into the situation" (p. 184-185). But it also brings a lot of benefits. The theory explains 19 - 38% of the variance of behaviour on average (Sutton, 1998). Over the past 30 years hundreds of empirical papers have supported the usability of the theory (Ajzen & Driver, 1992; Albarracín, Kumkale & Johnson, 2004; Armitage & Conner, 2001; Beck & Ajzen, 1991; Hagger et al., 2016), while at the same time the use of correlations as proof for validity is questioned and therewith the validity of TPB's existence (Sniehotta, 2009; Sniehotta, Presseau & Araújo-Soares, 2014; Weinstein, 2007). Furthermore, the underrepresentation of morality in the model has been criticized (Klöckner & Blöbaum, 2010).

D.4 Norm Activation Theory

A theory which not only focuses strongly on moral drivers, but is created upon the idea of altruistic behaviour is the Norm Activation Theory. According to this theory, people construct self-expectations regarding prosocial behaviour and this is called norm activation. These behavioural self-expectations are termed 'personal norms' and are experienced as feelings of moral obligation (Harland, Staats & Wilke, 2007). The exact factors that influence the personal norms have been known to change over the years. Including and excluding varying influences from "awareness of need", "situational responsibility", "efficacy", "ability", "awareness of consequences" and "denial of responsibility (Harland, Staats & Wilke, 2007). In the generalized model Schwartz & Howard (1981) describe people to feel morally obliged to help when they are aware of the (adverse environmental) consequences and perceive their own ability to control the outcome, or ascription of responsibility. Recycling behaviour is consistent with Schwartz' Norm Activation Theory (Hopper & Nielsen, 1991).

D.5 New Environmental Paradigm

The Norm Activation Theory has its roots in the New Environmental Paradigm. The NEP scale was developed by Dunlap and Van Liere (1978), and is now the most widely used measure of environmental attitudes (Dunlap & Jones, 2002). The scale has an orientation toward the natural environment that Dunlap & Van Liere (1978) argued constituted a "new ecological paradigm". The scale is universal in the way that it focusses on multiple environmental issues and multiple expressions of concern. Hence, the scale can be used to find a simplified measurement within Schwartz' norm activation theory (Wiidegren, 1998). The New Environmental Paradigm itself problematically evolved in many different directions, reducing the comparability and usefulness of the theory (Hawcroft & Milfont, 2010). Dunlap (2008) also adapted his theory himself, from a socio-political domain to the ecological domain, and is now often referred to as the New Ecological Paradigm.

D.6 Value Theory

The Value theory can stimulate the understanding of the whole integrated system of value priorities and their relation to people's background, attitude, and behaviour variables (Schwartz, 1992). Schwartz (1992) defined values as "desirable transsituational goals varying in importance, which serve as a guiding principle in the life of a person or other social entity" (p. 21). According to Steg, De Groot, Dreijerink, Abrahamse & Siero (2011) values appeared to be more predictive of environmentally relevant beliefs, preferences, and behaviour than other general beliefs, such as environmental concerns and worldviews. In research by De Groot & Steg (2007) they conclude that examining environmentally relevant behaviour can be done by making a distinction between altruistic, biospheric and egoïstic value orientations. This has later been extended to include hedonic values (Steg, Perlaviciute, Van der Werff & Lurvink, 2014).

D.7 Value Belief Norm Theory

The Value-Belief-Norm theory offers the possibility to include normative factors in explaining sustainable attitudes and behaviour (Stern et al., 1999; Stern, 2000). This theory links to Schwartz extended Value theory (de Groot & Steg, 2007), Dunlap & Van Liere (1978) their New Ecological Paradigm and the Norm Activation Theory (Stern, 2000). Figure 49 shows how these different theories are interconnected to create personal norms that influence behaviour. Evidence has shown that, depending on the type of behaviour (i.e., private-sphere behaviour, policy support action, or environmental citizenship), the VBN model explains 19% to 35% of its variance (Stern et al., 1999). This is comparable with the explained variance of the Theory of Planned Behaviour.

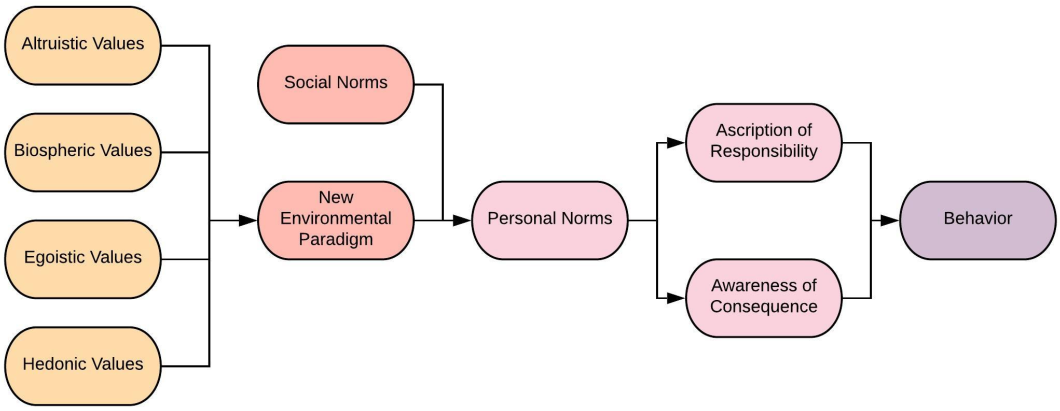

Figure 49 - Illustration of the Value-Belief-Norm theory.

D.8 From individual to corporate theory

In light of this research and the research area of Industrial Symbiosis, a distinction between individual and corporate decision-making is necessary. Corporations are a gathering of individuals, and often they are capable of narrating the corporate values. Nevertheless, the decision-making process of the business is not necessarily equivalent to that of the individual.

The dominant theory to address firm behaviour is the economic model, where companies behave to obtain a perfect profit maximization (Gibbard & Varian, 1978). Guagnano (2001) suggests that the market and market-like behaviour, the context where self-interest is expected to dominate, is in fact often motivated by altruism. Constanza (2000) argues that a broader set of goals should be included in valuation of systems, such as ecological sustainability and social fairness, along with the traditional economic goal of efficiency. To enrich the dominant firm behaviour theory with the idea of corporate generosity is beneficial within the scope of this research.

The paper of Dowling & Pfeffer (1975) offers an insight into the connection between individual and corporate generosity. They claim that corporate generosity is constructed through three perspectives: A cost-benefit analysis is made that offers the base of the decision (1), variations in this decision arise through the altruistic behaviour of individual administrators (2) and by the desire for legitimacy over context and time (3). For example, an industrial symbiotic network can be identified as moderately beneficial for a company. Because of the altruistic desire of its employees in charge and the global corporate sustainability focus it might decide to become a beneficiary to the project.

In this research the Value Belief Norm theory (Stern et al., 1999) will be used because it explains successfully the altruistic behaviour of the administrator. Additionally it incorporates legitimacy over context and time through its inclusion of the social value. To limit the complexity of the model, the cost-benefit analysis of the participation in the symbiotic network are assumed to be incorporated in the awareness of consequence and ascription of responsibility. The altruistic behaviour reported by the agents in name of their corporate body will be connected to the modelling of the symbiotic network and the policy scenarios.

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Appendix E – Questionnaire

By using below questionnaire the New Environmental Paradigm value, the Awareness of Consequence value and the Ascription of Responsibility value of the participants has been measured. The questionnaire consists of three times 6 – 7 statements that can be answered with on a 1 – 7 scale, 1 being totally disagreeing and 7 being totally agreeing. The online version is available on request.

New Environmental Paradigm
Humans have the right to modify the natural environment to suit their needs.
When humans interfere with nature it often produces disastrous consequences.
Humans are meant to rule over the rest of nature.
The balance of nature is very delicate and easily upset.
Plants and animals exist primarily do be used by humans.
Humans must live in harmony with nature in order to survive.

Awareness of Consequence
Environmental protection will provide a better world for me and my children.
Protecting the environment will threaten jobs in my sector.
Environmental protection will help people have a better quality of life.
The effects of pollution on public health are worse than we realize.
Over the next several decades, thousands of species will become extinct.
Claims that current levels of pollution are changing earth's climate are exaggerated.

Ascription of Responsibility
I feel jointly responsible for the exhaustion of energy sources
I feel joint responsibility for the contribution of bio-waste production to global warming
I feel joint responsibility for the contribution of bio-waste production to local ecological damage
I feel joint responsibility for the negative consequences of bio-waste production

Corporate Generosity
My company encourages the circular economy
My company puts much value on the circular economy
My company is actively committed on the circular economy

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Appendix F – Interviews

To get an overview of the current situation in the case area below questions have been asked to participants of the Re-StOre project, de AEB, Avalex, Indaver and the Municipality of Amsterdam. The answers to these questions are available upon request.

Interview questions:
How did you get in contact with this project?
How are you experiencing the bio-waste separation in the NDSM wharf?

How do you see the role of your company within the NDSM network?
Do you see the possibility of your behaviour changing as a result to this project?
If yes, in what way? If no, why not?

Do you see biodegradable waste as a problem or an opportunity?
What value do you see in biodegradable waste?
What are the possible methods for bio-waste separation?
Which methods are currently available in your region?

How do you experience the disposal of biodegradable waste at the wharf?
How often do you separate your waste?
What are hick-ups that you see in the bio-waste separation process at the wharf?
Do you have any problems like smell, hygiene or a bad social atmosphere at the wharf?

What possibilities do you see for the NDSM network to become more sustainable within the topic of circular economy? How do you see this adaptation in terms of time and money?
What initiatives have you seen in the past that have proven successful or unsuccessful?
How do you experience the communication and knowledge on biodegradable waste in the wharf?

How do you see the future of the NDSM circular economy project?

Appendix G – Policy Discussions

In a various of sessions with TU Delft members, locals in Amsterdam and the participants of the NDSM wharf brainstorm sessions have been held to come up with new policies to improve the system's separated bio-waste output. The first results are described below.

Brainstorm results (April 5th, April 7th and April 12th)

Hold workshops to increase knowledge on bio-waste separation
Flyers with importance of circular economy
Facilitate bio-waste disposal process
Give examples on the feedback of mushroom growth
Feedback from what your effort yields
Investigation into current separation behaviours
Exert influence on biospheric values
Increase support: (If x has no interest)
CO2 subsidy in SMEs
Feedback of financial values
Get free compost soil because you are participating correctly.
Insight into what your bio-waste can do. If it serves as fish food, you could get a fish back, or a printing company gets back green waste as blue ink.
Giving guidance by feedback
Give insights into the radiance of the efforts of people.
Garbage is thrown next to it, which makes a central container point dirty / unattractive.
Small businesses might be better off handing in waste at the Hilton.
Example companies. Are there leaders who give presentations.
Glass / Paper / Bio / Plastic together / uniformity
Saving system. "Green miles". Night in Hilton, coffee at Hema.
Participate = exposure at the green festival
Participating = becoming a winner / "green entrepreneur NDSM"
Give someone an example. Appoint ambassadors
Make a competition of it. You get one cup per 10 plastic cups
Put a company there that is physically involved with bio-waste "take it to Henk"
Companies can also pay to do it circularly
Participate in Rotterzwam
In coordination with the EU objectives
Making non-sorted waste more expensive
Create a solid "green story".
CO2 efforts or bio-waste quantities are shared in a measurer.
Create clarity on what can and cannot be separated.
Increase user friendliness
More separation locations
Green separation
Waste processing out in the open for people to see
Child-friendly containers
Colours on waste containers (local & central)
Social cohesion
Fines
Affordability
Beautiful locations
Celebrate successes
Make it mandatory
Make it a habit for people
Use the local sports club
Decrease the distance to the bin
Collective composting

Appendix H – Experimental Design

In this appendix the standard setup of the model is illustrated. Together with the other values the model will be tested for in policy and scenario analysis. The experiments conducted for this study are based on an initial setting as described through previous research within the Re-Organise group and a more inclusive model of all actors in the NDSM wharf.

The standard model setup as described in Table 7– initial values is used to research the implementation of bio-waste separation in the model. In a second run the policies will be implemented one by one, without any overlaps to reduce the computational complexity of the model. A third run will iterate over the different types of agents together with the standard model. A fourth run will iterate over the different types of agents together with the policies separately tested.

This setup with independent policies and without agent type changes is relatively easy to compute due to the independence of the policies. The 7 runs and the leaving scenario are tested which leads to 8 unique combinations of parameter values to describe the full model. This low number can therefore be repeated 250 times to aim to ensure that all possible trajectories are included.

The setup without policies and with agent type changes has 32 different parameter combinations and therefore a relatively similar computational cost. The simulation has been repeated 100 times. Resulting in 3200 model runs.

The setup with independent policies and agent type variations hols 224 parameter interactions, multiplying this by 30 iterations holds for 6720 model runs.

More complex are the interactions of policies. To run all policies and the leaving scenario together with all possibilities per policy the total parameter interaction already holds 1250 different runs. By running this model 15 times more than 30000 model runs are generated. Therefore the use of this model has been limited to the final interaction results in Chapter 7.4.8.

Table 7 - Standard model setup

Variable	Variable name	Initial value	Other values	
n_bw	Number of Birdwatchers	6	15	50
n_p	Number of Pleasurers	6	15	50
n_np	Number of Boss of National Park	5	15	50
n_nh	Number of Boss of Neighborhood	1	15	50
n_ns	Number of Non-Selfish	2	15	50

startchyg	Start container hygiene	200	100	
num_readers	Readers newsletter in percentage	100	60	
Startschedule	Waste collection schedule in ticks	15		
num_links	Number of Links	2	1	5
policies	Policies	"off"	"all"	"1, 2, 3, 4, 5"
newsletter	Newsletter policy	"off"	"on"	
feedback	Feedback policy	"off"	"on"	
HumanEngmt	Container Interaction policy	"off"	"on"	
ondemand	On-demand policy	"off"	"on"	
group	Group policy	"off"	"on"	
leaving	Leaving scenario	"off"	"on"	
duration	Duration in ticks Sensitivity	385	3850	

Table 8 - Standard model output

Output	Output name
sorted_bio	Sorted quantity of bio-waste
non_sorted_bio	Non-sorted quantity of bio-waste
mean [bioknow] of turtles	Average knowledge on bio-waste separation
mean [symbhappiness] of turtles	Average happiness with the symbiotic interaction

Appendix I – ODD+D Protocol

The ODD+D Protocol gives a different guidance of the description of an agent-based model than used in this research. For easy reference the guiding questions of the ODD+D protocol are partially answered here, and partially it refers to chapters, tables and appendices in this research. The bold marked questions are found to be leading in this research.

Guiding questions
I.i.a What is the purpose of the study?
to get a clearer image of the context and the possibilities of scenario testing and policy interventions in the NDSM symbiotic bio-waste sortation network.

I.i.b For whom is the model designed?
Researchers and parties that are interested in the NDSM wharf symbiotic network research, beyond what the study can answer.

I.ii.a What kinds of entities are in the model?
There are five types of entities in the model, based on the description in Chapter 4.2.

I.ii.b By what attributes (i.e. state variables and parameters) are these entities characterised?
[*;; static*
values
a *; altruistic*
b *; biospheric*
eg *; egoistic*
h *; hedonic*
NEP *; New Environmental Paradigm*
AwoC *; Awareness of Consequence*
AscoR *; Ascription of Responsibility*

;; dynamic
herkenningbio *;; recognition of biowaste*
willwalk *;; willingness to walk*
cexp *;; container experience*
cdisp *;; container disposal*
l_storage *;; kg of biowaste in local bin*
last_time_success *;; subjective view on disposal experience*
bioknow *;; knowledge about bio-waste separation*
contdist *;; willing distance to walk to nearest container*
positive *;; positive feeling about the symbiotic network (yes/no)*
symbhappiness *;; overall happiness about the symbiotic network (numerical)*
]

I.ii.c What are the exogenous factors/drivers of the model?
Container storage is 1500 kg
Container is max 800m away
Duration of the simulation modelling is 5 * 7 * 25 *;; 5 times to the waste bio-waste-bin a day, for 25 weeks*
Startschedule is every 15 ticks
Start container hygiene is 200 (and reduces every tick)

A Type D agent makes 2 links per round.

I.ii.d If applicable, how is space included in the model?
There is a symbolic representation of the network collaboration shown.

I.iii.a What entity does what, and in what order?
Type A, B & C produce waste. Type A, B & C decide if they can sort their waste. Type D & E influence the behaviour of the other agents. Type A, B & C dispose of their waste. Waste is collected in a municipal scheme.

II.i.a Which general concepts, theories or hypotheses are underlying the model's design at the system level or at the level(s) of the sub-model(s) (apart from the decision model)? What is the link to complexity and the purpose of the model?
The continually adapting network of participants, technologies and interests in the organic waste debate can be considered a complex system, incorporating both social and technical aspects on all parts of the waste management process (Dijkema & Basson, 2009).

II.i.b On what assumptions is/are the agents' decision model(s) based?, II.i.d If the model/submodel (e.g. the decision model) is based on empirical data, where do the data come from? II.i.e At which level of aggregation were the data available?
See Appendix L – Modelling assumptions for these details.

I.i.c Why is/are certain decision model(s) chosen?
See Appendix B – Delimitations Simulation Modelling and Appendix C – Delimitations Simulation method.

II.ii.a What are the subjects and objects of the decision-making? On which level of aggregation is decision-making modelled? Are multiple levels of decision making included?
Decision-making is done by the agents of type A, B and C to decide if they sort their bio-waste or not. This is the only level of decision making. Apart from that the Type D & E agents influence the decisions of the earlier mentioned agents.

II.ii.b What is the basic rationality behind agent decision-making in the model?
This is based on the VBN theory, as described in Chapter 4.4.

Do agents pursue an explicit objective or have other success criteria?
The behaviour of the agents is dependent on their own values, beliefs and norms. If their knowledge grows it is likely that they will sort more bio-waste, however without a feedback loop in the model this is not communicated with the agent, resulting in no explicit objective of the agents.

II.ii.c How do agents make their decisions?
Chapter 6.1.1 and 6.1.2 describe the different general bio-waste behaviour steps, and how the VBN theory and the approach as designed in this study influence the decisions of the waste generating agents.

II.ii.d Do the agents adapt their behaviour to changing endogenous and exogenous state variables? And if yes, how?

There are no state variables changing over time influencing the decisions of the agents, however if the Leaving scenario is tested agents will reduce their learning and happiness in the network.

II.ii.e Do social norms or cultural values play a role in the decision-making process?
Social norms are included through the communication of the Type D agents.

II.ii.f Do spatial aspects play a role in the decision process?
No

II.ii.g Do temporal aspects play a role in the decision process?
Yes, every step the different waste separation steps are recalculated.

II.ii.h To which extent and how is uncertainty included in the agents' decision rules?
The inclusion of randomness can be read in Chapter 6.1.4.

II.iii.a Is individual learning included in the decision process? How do individuals change their decision rules over time as consequence of their experience?
Through bio-waste separation knowledge the agents learn over time, however this is only based on their output behaviour if the feedback is communicated in the model (policy 1).

II.iii.b Is collective learning implemented in the model?
No

II.iv.a What endogenous and exogenous state variables are individuals assumed to sense and consider in their decisions? Is the sensing process erroneous?

```
[ l_storage_max
 l_hygiene
 c_storage
 c_storage_max
 c_hygiene
 distcmax ; maximum distance to a container in Amsterdam
 totsymbhappiness ; number of turtles positive about symbiotic network
 cdist
]
```

II.iv.b What state variables of which other individuals can an individual perceive? Is the sensing process erroneous?
None

II.iv.c What is the spatial scale of sensing?
Non existing

II.iv.d Are the mechanisms by which agents obtain information modelled explicitly, or are individuals simply assumed to know these variables?
Individuals are assumed to know if the distance to their nearest container is within their preferred distance, if they consider the container clean enough to interact with and if they should empty their own local bin.

II.iv.e Are the costs for cognition and the costs for gathering information explicitly included in the model?
No

II.v.a Which data do the agents use to predict future conditions?
To future conditions are predicted.

II.v.b What internal models are agents assumed to use to estimate future conditions or consequences of their decisions?
The consequences of their decisions are not necessarily communicated back to the agent.

II.v.c Might agents be erroneous in the prediction process, and how is it implemented?
The waste container distance, experience and disposal are predicted and behaviour will happen based on these predictions, however this can be adapted by policy interventions.

II.vi.a Are interactions among agents and entities assumed as direct or indirect?
Type D has direct interactions with the waste generating agents.

II.vi.b On what do the interactions depend?
Interactions depend on the "Group" policy and on the number of Type D agents and the number of links.

II.vi.c If the interactions involve communication, how are such communications represented?
Communication between Type D agents and other agents are represented through links

II.vii.a Do the individuals form or belong to aggregations that affect and are affected by the individuals? Are these aggregations imposed by the modeller or do they emerge during the simulation?
No

II.viii.a Are the agents heterogeneous? If yes, which state variables and/or processes differ between the agents?
Yes, the values, beliefs and norms of each agent differs, together with his knowledge and walking distance.

II.viii.b Are the agents heterogeneous in their decision-making? If yes, which decision models or decision objects differ between the agents?
Yes, based on the values, beliefs and norms of each agent the decisions differ in outcome. However agents with type A, B and C behave similarly following the general waste behaviour as described earlier. Type D and type E agents behave completely different as they influence communication and other policy implementations.

II.ix.a What processes (including initialisation) are modelled by assuming they are random or partly random?
As described in Chapter 6.1.4, there is a lot of random variables in this research. This is logically as human behaviour is quite unpredictable.

II.x.a What data are collected from the ABM for testing, understanding and analysing it, and how and when are they collected?

Sorted bio-waste, Non-sorted bio-waste, Knowledge levels and symbiotic happiness levels, together with the central container levels are collected at each tick.

II.x.b What key results, outputs or characteristics of the model are emerging from the individuals? (Emergence)
See Chapter 8.

III.i.a How has the model been implemented?
This model has been implemented in Netlogo. For further discussions on why this method was chosen and how it is implemented see Chapters 3.4, 3.5 & Appendix K – Netlogo code.

III.i.b Is the model accessible, and if so where?
This model will be made accessible via GitHub: https://github.com/Sabine-1/MSc_Thesis.

III.ii.a What is the initial state of the model world, i.e. at time t = 0 of a simulation run?
There are two tables describing the initial states : Table 3 – Initial values and Table 7 - Standard model setup.

III.ii.b Is the initialisation always the same, or is it allowed to vary among simulations?
In the initialisation the number of agents, the number of links, the start schedule, the policies and scenarios can be altered. Additionally, the values, beliefs and norms of the agents are always different.

III.ii.c Are the initial values chosen arbitrarily or based on data?
The initial values are based on the questionnaire from Appendix E – Questionnaire. Additionally the container distances and bio-waste knowledge are randomized and different (partially based on the questionnaire values). Agents are always represented as coloured dots in a circle.

III.iii.a Does the model use input from external sources such as data files or other models to represent processes that change over time?
No other models or data files are imported in the model, however data from previous data is implemented through normal random distributions.

III.iv.a What, in detail, are the submodels that represent the processes listed in 'Process overview and scheduling'?

RecognitionBio
hygiene_check
WillingnessToWalk
SubjExperienceCont
DisposalCap
positivefeeling
loseinterest
setsocialnorms
ReadNews
socialbehaviour
techbehaviour
municipalsortation
Discharge-Waste-Local
discharge-waste-container

For more details see the Appendix K – Netlogo code.

III.iv.b What are the model parameters, their dimensions and reference values?
Table 7 gives an overview of the parameters, their dimensions and references.

III.iv.c How were the submodels designed or chosen, and how were they parameterised and then tested?
See Chapter 6.

Appendix J – Verification analysis

This appendix shows the results of the four verification tests.

The objective of verification is for the model to be free of errors and it ensures the correctness of the conceptualization to computational model translation (van Dam, Nikolic, & Lukszo, 2013). It is important to ensure that the values and relations in this model offer a good representation with reality, to be able to make sound conclusions and recommendations. According to Van Dam, Nikolic & Lukszo (2013) there are four tests available to check various aspects of a model's correctness: recording and tracking of agent behaviour, single-agent testing, minimal model testing and multi-agent testing.

The first test looks at the intentioned and reported behaviour of agents. This is tested by looking at the intrinsic decisions of agents. As the name suggests, the second tests the model with only one agent in normal and extreme conditions. In the minimal model of this research one agent of each type is included and tested in normal and extreme conditions. Finally, the model is run with the general setup as suggested in the NDSM case study. In addition a timeline sanity analysis is conducted throughout the creation and analysis phases of this study.

J. 1 Recording and tracking of agent behaviour

To setup

Previous values are cleared. All variables and plots in the model are given a starting value. Agents and globals are created and the environment is designed.

1. Interface input:
    a. Number of each type of agent
    b. The start hygiene of containers is set
    c. The schedule of waste collection is determined
    d. The start value for links is set
    e. Policies can be set.
2. Setup output
    a. Outputs are equal to the input, and simulation stops when 0.
    b. Startchyg = 200
    c. Startschedule = 15
    d. Num_links = 2
    e. Policies = off

    Verified

3. Setup globals
    a. num-nodes = n_bw + n_p + n_np + n_nh + n_ns
    b. duration 5 * 7 * 25
    c. non_sorted_bio 0
    d. sorted_bio 0
    e. l_storage_max 200
    f. c_storage 0
    g. c_storage_max 1500
    h. schedule startschedule
    i. mcapacity True
    j. mtechnology True

k. distcmax 800
l. totsymbhappiness 0.1
m. newsimpact 0.01 * n_ns
4. Globals output
   a. Num_nodes = 20
   b. Duration = 875
   c. Schedule = 15
   d. Newsimpact = 0.02
   e. Other globals are equal to given input

   Verified

5. Setup agents
   a. Give types values
   b. Set AwoC, AscroR, NEP, bioknow, contdist
   It should be noted that the bioknow is supposed to be designed based on the NEP value. However a direct step is made from values to knowledge.
6. Agent output
   a. Values a , b , e & h are [1 or 0]
   b. AwoC (0.69), AscroR (0,47), NEP (0,72), bioknow(0,52), contdist (547)
   Verified

To Recognise Bio-waste
The recognition and successful sortation of bio-waste is dependent on: Time and reachability of the local bin, bio-recycling knowledge and environmental attitude of the actor.

1. Input
   a. Bioknow < 0.75
   b. B = 0
   c. Random variables are run over 15 simulations through the behaviour space
2. Output
   a. Herkenning = True or False
   Verified

To Willingness to Walk
The willingness to walk to the container is dependent on: the distance to the container, the time it takes to get there (time * distance could make for a random value, see below) & biospheric values of the actor.

1. Input
   a. Contdist = 547
   b. Random * cdistmax = 600 (randomized)
2. Output
   a. willwalk = True
   Verified

To SubjExperienceCont
The subjective experience of bio-waste containers is dependent on: the safety, the hygiene & the social atmosphere of the container. Random variables are used therefore the threshold and actual values have been checked for a correct output at both levels (see Figure 50).

1. Input
    a. Cexp = True or False
    b. C_hygiene = (randomized)
    c. Startchyg = 200
2. Output
    a. cexp = True or False

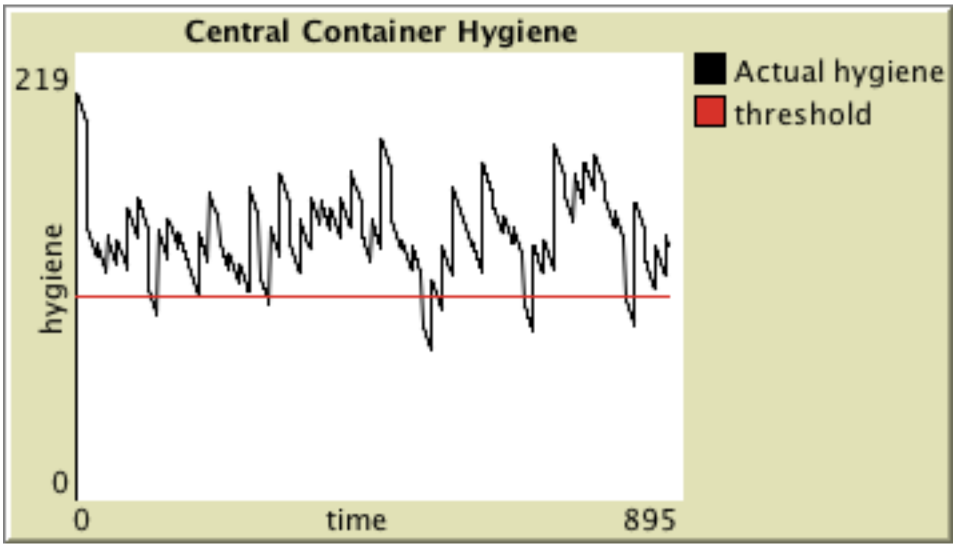


Figure 50 - Central Container Hygiene

Verified

To DisposalCap

The disposal capability in the bio-waste containers is dependent on: the capacity of the container and the ease of container interaction. Random variables are used therefore the threshold and actual values have been checked for a correct output at both levels (see Figure 51).

1. Input
    a. C_storage_max = 1500
    b. C_storage = (randomized)
2. Output
    a. cdisp = True or False

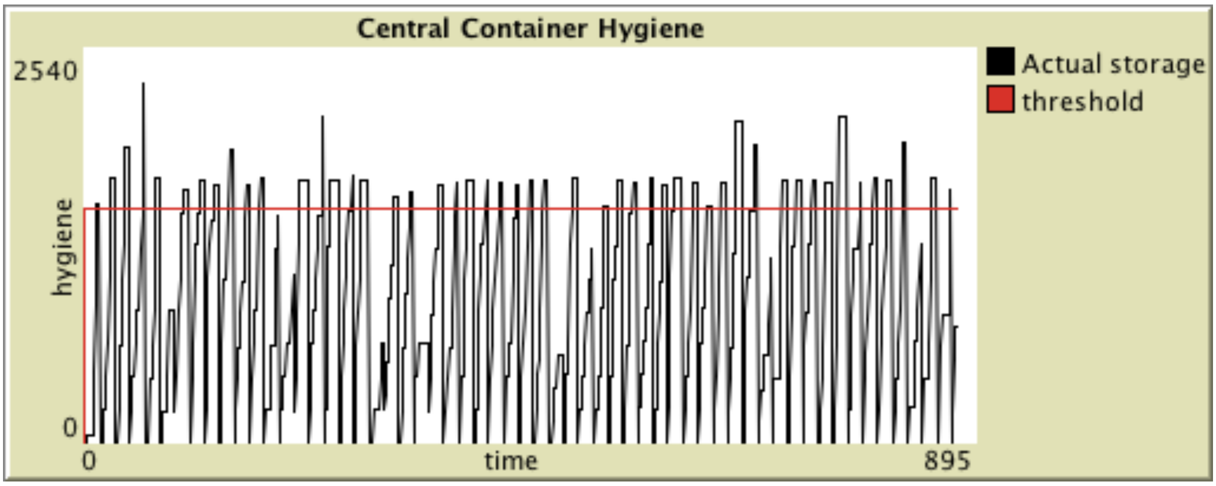


Figure 51 - Central Container Disposal

Verified

To Discharge-Waste-Local
Local waste is separated in the local bin if agents are positive about the network or if the agent recognises the waste.

1. Input
   a. herkenningbio = true or false
   b. positive = true or false
   c. l_storage = 0
2. Output
   a. L_storage = [0 or 19,29] (randomized)

Verified

To Discharge-Waste-Container
Individuals want to separate their local waste to a central bin when the bin is full or smelly. If they are willing to walk the distance, are okay with the experience and if there is a disposal possibility and the container storage rises by the amount in the bin. Random variables are used therefore the threshold and actual values have been checked for a correct output at both levels.

1. Input
   a. willwalk = true or false
   b. cexp = true or false
   c. cdisp = true or false
   d. l_storage = (randomized)
   e. l_storage_max = 200
   f. l_hygiene = true or false
2. Output
   a. C_storage = [0 or 19 or 200] (randomized)
   b. L_hygiene = true
   c. L_storage = 0
   d. Cexp = true or false

Verified

To municipalsortation

To measure the sorted and non-sorted bio-waste in the area the central containers are emptied and that results to the final quantity of sorted bio-waste.

1. Input
    a. Mcapacity = True or False
    b. Mtechnology = True or False
    c. C_storage = (randomized)
2. Output
    a. C_storage = 0
    b. C_hygiene = [130] (randomized)

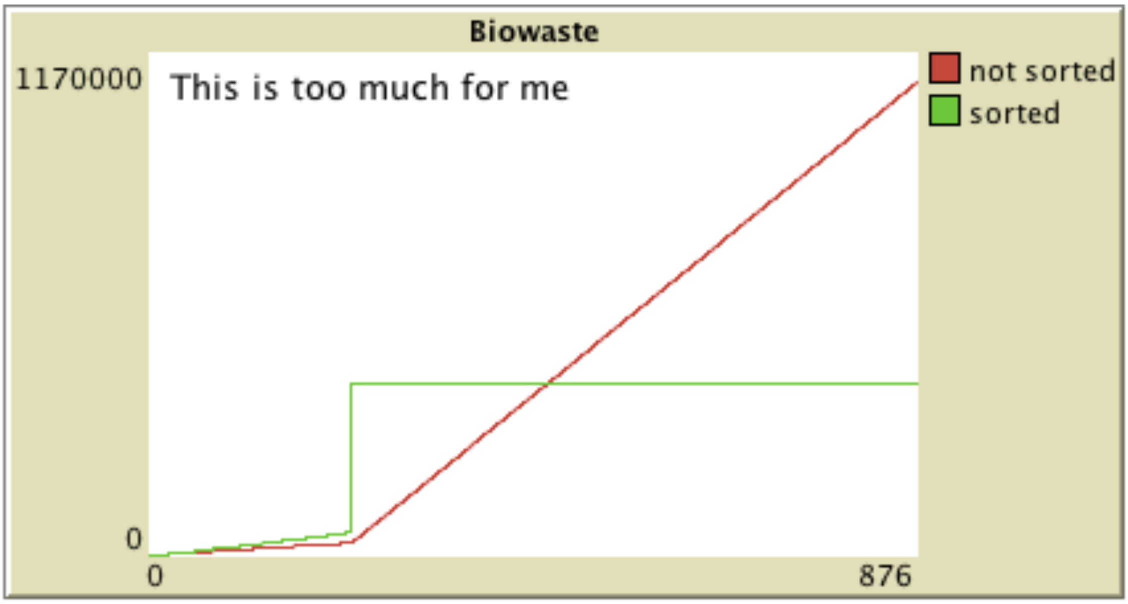


Figure 52 – Sortation levels when sorted bio becomes 5x non-sorted bio.

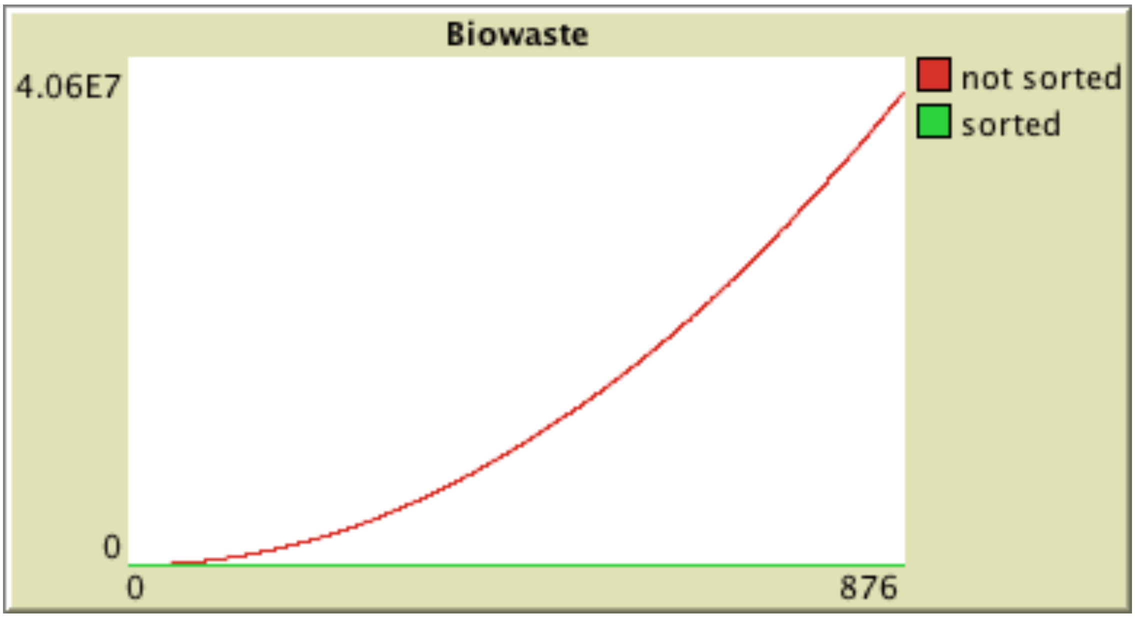


Figure 53 – Sortation levels when Mcapacity or Mtechnology = False

Verified

To lose-interest

1. Input
    a. Bioknow = 0.35
2. Output
    a. Bioknow = 0.30

Verified

To Newsletter

3. Input
    a. Bioknow = 0.50
4. Output
    a. Bioknow = 0.52

Verified

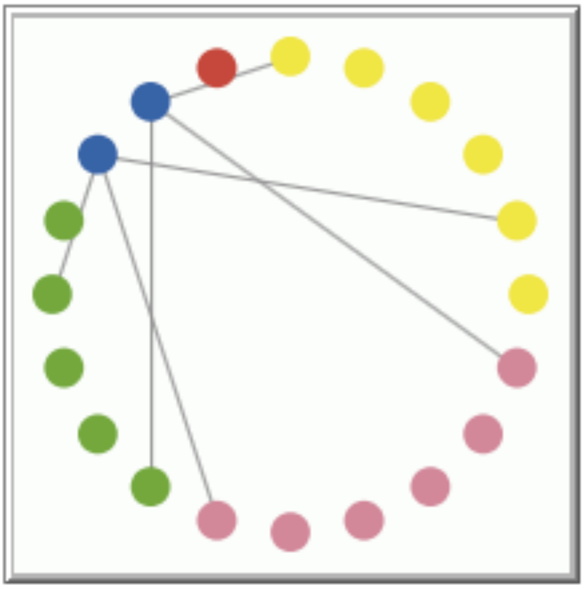
To positivefeeling

1. Input
    a. Positive = True or False
    b. Feedback = True or False
    c. Contdist = 547.5
    d. Bioknow = 0.42
    e. Percentage sorted bio = 0.39
    f. AwoC = 0.85
    g. AscoR = 0.40
2. Output
    a. Contdist = 582.9
    b. Bioknow = 0.43
    c. Positive = True

Verified

to Set Social Norms

1. Input
    a. Num_links = 2
    b. Pleasurers = 6
    c. Natparks = 5
    d. Birdwatchers = 6
2. Output
    a. Links report willwalk = true, cdisp = true & cexp = true



Verified

To Socialbehaviour

1. Input
    a. symbhappiness = 0.350
    b. contdist = 600
2. Output
    a. symbhappiness = 0.351
    b. contdist = 600.5

Verified

To techbehaviour

Random variables are used therefore the threshold and actual values have been checked for a correct output at both levels.

1. Input
    a. HumanEngmt = True
    b. Cdisp = True or False
    c. Cexp = True or False
2. Output
    a. Cdisp = True or False
    b. Cexp = True or False

Verified

Conclusion: All internal processes of the agent behaviour are a logical consequence of the inputs. Therefore the calculations and the model are verified by the means of this test.

J. 2 Single Agent Model verification

The single agent model verification offers a good overview of the model when run with minimum boundaries. In light of this research different outputs are anticipated based on the different agent breeds. This verification has been run with 5 different setups. For setup 1, 2 and

3 a single agent is similar to creating a minimal model, and will therefore be limited to these runs.

Table 9 – Single Agent Model Setup

Run 1	**Run 2**	**Run 3**	**Run 4**	**Run 5**
n_bw = 1	n_p = 1	n_np = 1	n_nh = 1	n_ns = 1
n_p, n_np, n_nh & n_ns = 0	n_bw, n_np, n_nh & n_ns = 0	n_bw, n_p, n_nh & n_ns = 0	n_bw, n_p, n_np & n_ns = 0	n_bw, n_p, n_np & n_nh = 0
startchyg = 200	startchyg = 200	startchyg = 200	startchyg = 200	startchyg = 200
startschedule = 15	startschedule = 15	startschedule = 15	startschedule = 15	startschedule = 15
num_links = 2	num_links = 2	num_links = 2	num_links = 2	num_links = 2
policies = off	policies = off	policies = off	policies = off	policies = off
duration = 875	duration = 875	duration = 875	duration = 875	duration = 875

The amount of sorted bio-waste and non-sorted bio-waste has been measured over all runs. The prediction of these values is dependent on the type of actor. In run 4 and run 5 it is expected that there is no waste generated. In run 1, 2 and 3 high sortation percentages are expected due to the low interaction of agents with the system. As an example of this the container storage will be modelled to show the interaction with the system.

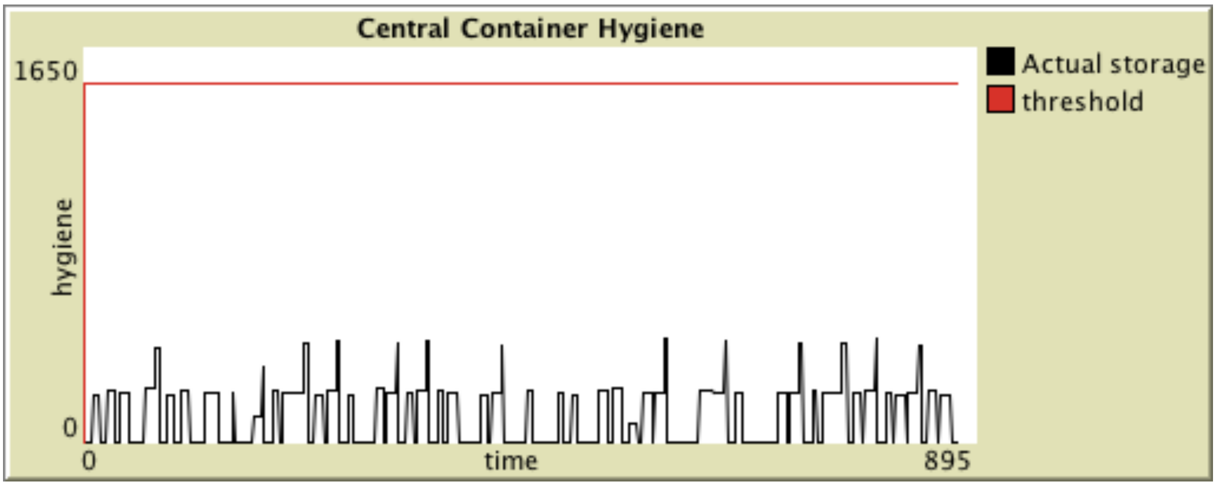


Figure 54 - Single Agent Model system dynamics run 1

Figure 54 shows that the central container will never reach values that reach the threshold to which the container becomes dirty and unattractive. This supports the prediction that general sortation values will be higher than in the regular model.

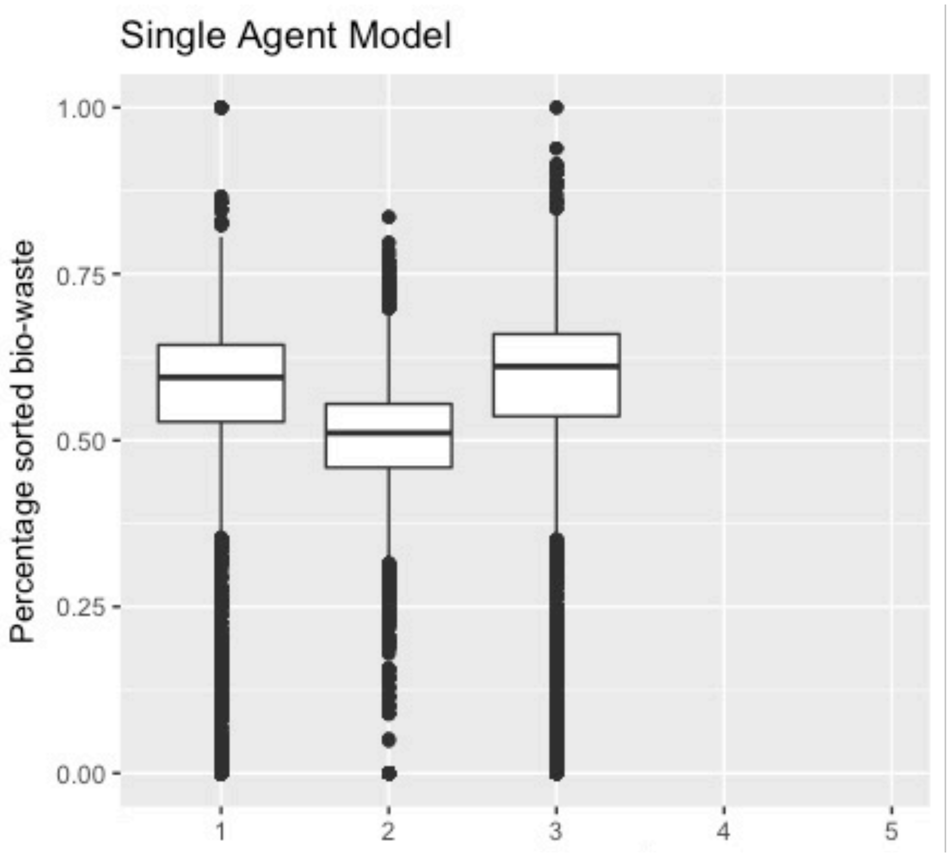


Figure 55 – Single Agent Model Output per run

Figure 55 shows the percentage sorted bio-waste in the model over the 5 different runs. As predicted the second two models do not produce any waste, and the first to show values over the whole spectrum, focussing on relatively high percentages.
Table 10 shows the model run over the different runs with the outcome summarizing the first 3 runs.

Table 10 - Extreme value input & output single agent model

Extreme values	Outcome (Summarized over the first 3 runs)
startchyg = 1	The model runs successfully. Separated waste decreases to 23%. No errors show.
startchyg = 1000	The model runs successfully. Separated waste remains the same. No errors show.
startschedule = 1	The model runs successfully. Separated waste increases to 40%. No errors show.
startschedule = 400	The model runs successfully. Waste is collected and separated waste decreases to 16%. No errors show
num_links = 0	The model runs successfully. No errors show.
num_links = 100	The model runs successfully if the single agent is not run 4. Otherwise the setup shows an error and the model is interrupted.
duration = 10	The model runs, but does not collect any sorted bio-waste. Waste remains in containers not counted as sorted percentages. No errors show.
duration = 10000	The model runs successfully. Waste is sorted in a predictable manner. No errors show.

Conclusion

The model shows behaviour of agents within the system in accordance with the predictions made and in extreme situations. Therefore, it is verified by the means of the single agent model test.

J. 3 Minimal Agent Model verification

The single agent model verification offers a good overview of the model when run with minimum boundaries. In light of this research different outputs are anticipated based on the different agent breeds. This verification has been run with 5 different setups. For setup 4 & 5 a single agent is not similar to creating a minimal model, and will therefore be verified here.

Table 11 - Minimal model setup

Run 1	Run 2	Run 3 (extreme)	Run 4 (extreme)
n_nh = 1	n_ns = 1	n_nh = 1	n_ns = 1
n_ns = 0	n_nh = 0	n_ns = 0	n_nh = 0
n_bw, n_p & n_np = 1	n_bw, n_p & n_np = 1	n_bw, n_p & n_np = 1	n_bw, n_p & n_np = 1
startchyg = 200	startchyg = 200	startchyg = 1000	startchyg = 1000
startschedule = 15	startschedule = 15	startschedule = 400	startschedule = 400
num_links = 2	num_links = 2	num_links = 100	num_links = 100
duration = 875	duration = 875	duration = 10000	duration = 10000

The amount of sorted bio-waste and non-sorted bio-waste has been measured over all runs. The prediction of these values is dependent on the type of actor. The model should run without errors and with a higher percentage sorted bio-waste than in the standard model.

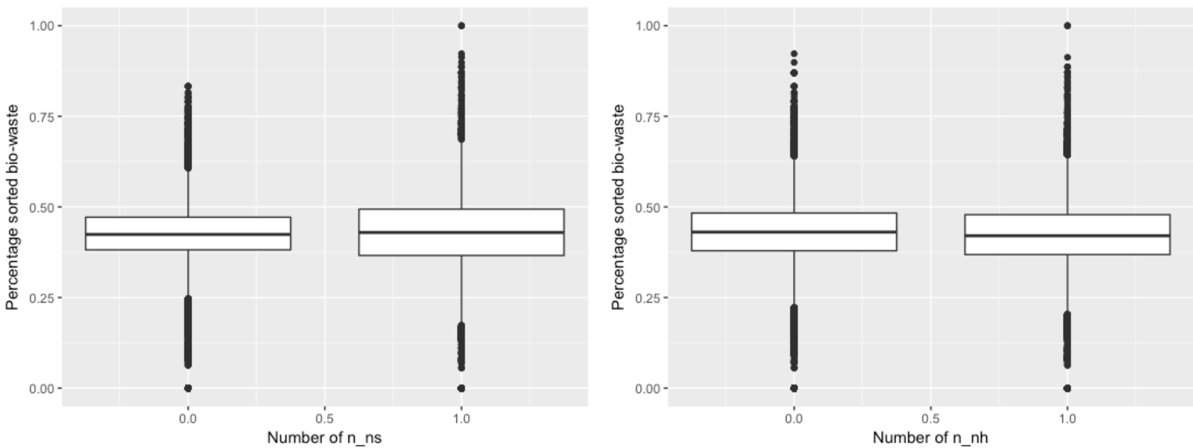


Figure 56 - Minimal model output

Figure 56 shows runs 1 and 2, it can be noted that the types of actors have little to no effect to the amount of bio-sorted and that the model runs correctly as expected.

Conclusion
The model can be run with normal and extreme values without errors, however the results of the model might not always be representative of reality. Chapter 6.2 shows more details on this topic. The model is additionally verified by the means of the extreme values test.

J. 4 Multi-Agent verification

For the multi-agent versification the standard model is used. This model has been run throughout the Analyse Chapter of this research. In addition an extreme value test will be done. In this verification the input variables will be adapted one by one through the setup given in Table 12. When adapting one value the other values will remain equal to start values given in Table 7.

Table 12 - Extreme value input & output

Extreme values	Outcome
n_bw = 1000	The model shows the 1000 new agents correctly. Model runs as predicted. No errors show. Separated waste is extremely low (±4%) due to the over-exposure of the system.
n_p = 1000	The model shows the 1000 new agents correctly. Model runs as predicted. No errors show. Separated waste is extremely low (±2%) due to the over-exposure of the system.
n_np = 1000	The model shows the 1000 new agents correctly. Model runs as predicted. No errors show. Separated waste is extremely low (±3%) due to the over-exposure of the system.
n_nh = 1000	The model shows the 1000 new agents correctly. Model runs as predicted. No errors show. Separated waste is normal. Separated waste increases to 72% with only "Group" policy.
n_ns = 1000	The model shows the 1000 new agents correctly. Model runs as predicted. No errors show. Separated waste is normal when policies are off. Separated waste increases to 70% with only "Newsletter" policy.
n_bw, n_p, n_np, n_nh & n_ns = 0	The setup shows "No turtles to run simulation" and is interrupted. Go-procedure does not create any waste. No errors show.
startchyg = 1	The model runs successfully. Separated waste decreases to 23%. No errors show.
startchyg = 1000	The model runs successfully. Separated waste remains the same. No errors show.
startschedule = 1	The model runs successfully. Separated waste increases to 40%. No errors show.
startschedule = 400	The model runs successfully. Waste is barely collected and separated waste decreases to 1%. No errors show.
num_links = 0	The model runs successfully. No errors show.
num_links = 100	The model setup shows that more links need to be created than agents in the model and is interrupted. When running without adaptation an error shows.
duration = 10	The model runs, but does not collect any sorted bio-waste. Waste remains in containers not counted as sorted percentages. No errors show.

duration = 10000	The model runs successfully. Waste is sorted in a predictable manner. No errors show.

In the first three runs over-exposure of the model is detected. An example of this is given in Figure 57.

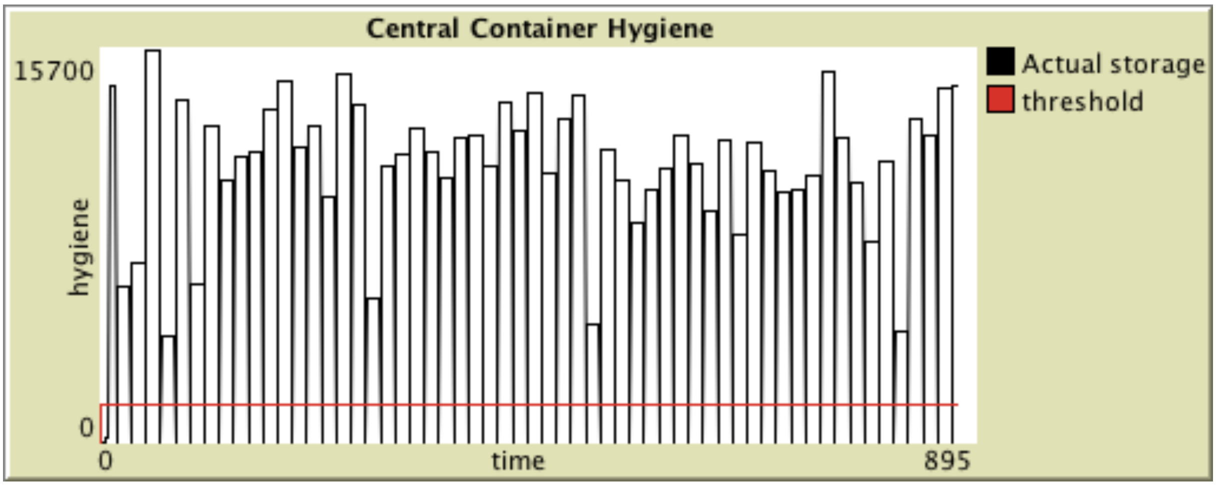


Figure 57 - Overexposure container hygiene

Conclusion
The model can be run with extreme values without errors, however the results of the model might not always be representative of reality. Chapter 6.2 shows more details on this topic. The model is verified by the means of the extreme values test.

J. 5 Timeline sanity verification

Implementation errors over time have been checked in the full model. By applying this testing method throughout the creation and verification phases of this study corrections have been implemented on a constant basis. Examples of the sanity check are:

- Updating the model output before updating the ticks
- Preventing unnatural locks
- Deadlock is prevented through interrupting the model.
- Updating the limitations of agents knowledge capabilities
- Updating the agents to have different roles

Conclusion: This test is never-ending. While many corrections have been implemented, improvements can be made.

J. 6 Total verification conclusion

The model has been tested over the four verification methods described by Van Dam, Nikolic & Lukszo (2013): Recording and tracking of agent behaviour, single-agent testing, minimal model testing and multi-agent testing. The model has been verified over all four methods and in addition a timeline sanity check is constantly improving the model. The model can therefore be regarded verified, whereby it should be noted that verification is a never-ending process. Furthermore, the connection between knowledge about bio-waste separation and the VBN theory could be revised further.

Appendix K – Netlogo code

Interface

```
breed [birdwatchers birdwatcher]
breed [pleasurers pleasure]
breed [natparks natpark]
breed [neighbosses neighboss]
breed [nonselfs nonself]
```

turtles-own

```
[ ;; static
 values
 a ; altruistic
 b ; biospheric
 eg ; egoistic
 h ; hedonic
 NEP ; New Environmental Paradigm
 AwoC ; Awareness of Consequence
 AscoR ; Ascription of Responsibility


 ;; dynamic
 herkenningbio ;; recognition of biowaste
 willwalk ;; willingness to walk
 cexp ;; container experience
 cdisp ;; container disposal
 l_storage ;; kg of biowaste in local bin
 last_time_success ;; subjective view on disposal experience
 bioknow ;; knowledge about bio-waste separation
 contdist ;; willing distance to walk to nearest container
 positive ;; positive feeling about the symbiotic network (yes/no)
 symbhappiness ;; overall happiness about the symbiotic network (numerical)
]
```

globals

```
[ day
 yesterday
 num-nodes
 duration
 non_sorted_bio
 sorted_bio
 l_storage_max
 l_hygiene
 c_storage
 c_storage_max
 c_hygiene
 schedule
 mcapacity
 mtechnology
 distcmax ; maximum distance to a container in Amsterdam
```

```
 totsymbhappiness ; number of turtles positive about symbiotic network
 cdist
 newsimpact
]
```

Setup Procedures

```
to setup-globals
 set num-nodes n_bw + n_p + n_np + n_nh + n_ns
 set duration 5 * 7 * 25 ;; 5 times to the waste bio-waste-bin a day, for 25 weeks
 set non_sorted_bio 0
 set sorted_bio 0
 set l_storage_max 200 ;; 200 kilogram of bio-waste
 set c_storage 0
 set c_storage_max 1500
 set c_hygiene startchyg
 set schedule startschedule
 set mcapacity True
 set mtechnology True
 set distcmax 800
 set totsymbhappiness 0.1
 set newsimpact 0.005 * n_ns ;; 2 non_selfish = 2% growth


 ;; policies
 ;if policies = "off" [
  ; set newsletter False set feedback False set humanengmt False set ondemand False set
group False]
 if policies = 1 [
  set newsletter False set feedback True set humanengmt False set ondemand False set group
False]
 if policies = 2 [
  set newsletter False set feedback False set humanengmt False set ondemand False set group
True]
 if policies = 3 [
  set newsletter False set feedback False set humanengmt False set ondemand True set group
False]
 if policies = 4 [
  set newsletter True set feedback False set humanengmt False set ondemand False set group
False]
 if policies = 5 [
  set newsletter False set feedback False set humanengmt True set ondemand False set group
False]
 if policies = "all" [
  set newsletter True set feedback True set humanengmt True set ondemand True set group
True]
 ; if pps != "off"[
 ;  set schedule round (150 / num_people) set startschedule round (150 / num_people)]
 ;if pps = "off"[
  ;set startschedule 15 set schedule startschedule]
```

```
end

to make-turtles
 ;; arrange them in a circle in order by who number

 create-birdwatchers n_bw [
  set a 0
  set b 1
  set eg 0
  set h 1
  set color yellow]
 create-pleasurers n_p[
  set a 0
  set b 0
  set eg 0
  set h 1
  set color pink]
 create-natparks n_np [
  set a 0
  set b 1
  set eg 1
  set h 0
  set color green]
 create-neighbosses n_nh [
  set a 0
  set b 1
  set eg 1
  set h 1
  set color blue]
 create-nonselfs n_ns[
  set a 1
  set b 1
  set eg 1
  set h 0
  set color red]

  ;; people scenarios
 if pps = 1 [
  ask birdwatchers [die] create-birdwatchers num_people [set b 1 set color yellow] ]
 if pps = 2 [
  ask pleasurers [die] create-pleasurers num_people [set b 0 set color pink] ]
 if pps = 3 [
  ask natparks [die] create-natparks num_people [set b 1 set color green] ]
 if pps = 4 [
  ask neighbosses [die] create-neighbosses num_people [set b 1 set color blue] ]
 if pps = 5 [
  ask nonselfs [die] create-nonselfs num_people [set b 1 set color red] ]


 ask turtles[ set size 2.5]
```

```
 layout-circle (sort turtles) max-pxcor - 2

;;; Create personal norms based on the questionnaire
 ask turtles[
  set AwoC random-normal 0.7 0.104
  set AscoR random-normal 0.5 0.215]

;;; Setup humans beliefs and their local waste bins.
 ask turtles [
  set contdist round(0.3 * distcmax + 0.7 * (random distcmax + 1))
  ifelse b = 1 [
   set NEP (random-normal 0.8 0.15)
   set bioknow (2 + (random 8)) / 10
   set contdist min (list (contdist + 0.25 * contdist) distcmax)]
   [
   set NEP (random-normal 0.6 0.15)
   set bioknow random 10 / 10]
  set l_storage 0
  set l_hygiene True
  set cexp True
  set cdisp True
  set mynonsort 1
  set mysort 1
  set symbhappiness 0.1
  set positive False
 ]
end

to setup
 clear-all
 reset-ticks
 set-default-shape turtles "circle"
 setup-globals
 make-turtles
  ;;error prevention
 if count turtles <= 0 [print "No turtles to run simulation" stop]
 if num_links > num-nodes [print "I cannot talk to that many people" stop]
  ;;
 set cdist (mean [contdist] of turtles)
 ask patches[
  set pcolor 69.9]
end
```

Main Procedure

```
to go
 if ticks = duration [ stop]
 if sum [contdist] of turtles != 0 [set cdist (mean [contdist] of turtles)]
 set totsymbhappiness sum [symbhappiness] of turtles

 ;; individual behaviour
```

```
ask pleasurers[
 RecognitionBio
 hygiene_check
 WillingnessToWalk
 SubjExperienceCont
 DisposalCap ]

ask birdwatchers [
 RecognitionBio
 hygiene_check
 WillingnessToWalk
 SubjExperienceCont
 DisposalCap
 positivefeeling ] ;; check how the project is coming along

ask natparks [
 RecognitionBio
 hygiene_check
 WillingnessToWalk
 SubjExperienceCont
 DisposalCap
 positivefeeling ];; check how the project is coming along


;; effects of time
set c_hygiene c_hygiene - 1
ask turtles [loseinterest]

set day floor (ticks / 4)
if yesterday != day [
 ask neighbosses [setsocialnorms]
 ask n-of (0.01 * num_readers * (count turtles)) turtles [ReadNews]]
set yesterday day

socialbehaviour
techbehaviour

;; municipal behaviour
if ondemand = False [
 if ticks - schedule = 0 [
  municipalsortation
  set schedule schedule + startschedule ]]

if ondemand = True [
 if ticks - schedule = 0 [set c_hygiene random-normal (startchyg - (startchyg / 3)) (startchyg /
10) set schedule schedule + startschedule]
 if ceiling c_storage >= c_storage_max [
  municipalsortation]]
```

```
;; scenario death
if leaving = True [
 if ticks = (round (0.5 * duration)) [
  ask one-of neighbosses [set color white die]
  ask turtles [
  set herkenningbio False set willwalk False set cexp False (set bioknow min (list 0.5 (bioknow))) set newsimpact (0.75 * newsimpact)]]]

if count turtles < n_ns + n_nh + n_p + n_bw + n_np [
 ask turtles [
 set contdist round(0.3 * distcmax + 0.7 * (random distcmax + 1))
 set symbhappiness 0 ]]

;; discharge
ask pleasurers[
 Discharge-Waste-Local
 discharge-waste-container]
ask birdwatchers[
 Discharge-Waste-Local
 discharge-waste-container]
ask natparks[
 Discharge-Waste-Local
 discharge-waste-container]


clear-links
tick
```

end

Setup own behaviour

to RecognitionBio

; The recognition and successful sortation of bio-waste is dependent on:
; time and reachability of the local bin
; Bio-recycling knowledge
; Environmental attitude of the actor.

```
ifelse b = 1 [
  ifelse random 100 < 75[
  set herkenningbio True] [set herkenningbio False]]
 [ ifelse random 100 < 60 [ ;; random function to represent the time and reachability of the local bin
  set herkenningbio True][
   set herkenningbio False ] ]
if bioknow > 0.70 [ set herkenningbio True] ;; AANNAME you need to hear something 7 times before it sticks
```

end

to WillingnesstoWalk

```
;The willingness to walk to the container is dependent on:
; the distance to the container
; the time it takes to get there (time * distance could make the random value, see below )
; biospheric values of the actor.
  ;; A random container is placed at every step, to include the time variable and the
randomness of people's
 ifelse ((random 100) / 100) * distcmax < contdist [ ;; is the nearest container in my walkable
range?
  set willwalk True] ;; if yes, walking distance is ok
 [set willwalk False]

 if willwalk = False [ if (bioknow > 0.5) or (symbhappiness > 0.5) [ if random 100 < 80 [set
willwalk True]]]
end

to SubjExperienceCont
 ;The subjective experience of bio-waste containers is dependent on:
 ; the safety
 ; the hygiene
 ; the social atmosphere of the container.
 ifelse cexp = True [ ;; Question how the experience was last time.
  ifelse random 100 > 20 [ ;; If positive, it will most likely be positive again/
   ifelse c_hygiene > 0.5 * startchyg [ set cexp True ]
   [ifelse random 10 < 5 [ ;;if container hygiene is clean, more chance on bad experience
    set cexp True]
    [set cexp False]]]
  [set cexp False] ]

 [ ifelse random 100 > 20 [ifelse c_hygiene > 0.5 * startchyg
   [ set cexp True ][
   ifelse random 10 > 4 [
    set cexp True][set cexp False ]]] [set cexp False]]
end

to DisposalCap
 ;The disposal capability in the bio-waste containers is dependent on:
 ;the capacity of the container
 ;and the ease of container interaction.
 ifelse c_storage < c_storage_max[ ;; container capacity
  ifelse random 100 < 98 [ ;; container too difficult to interact with 2% of the time
   set cdisp True][set cdisp False]] [set cdisp False]


end
```

Bio-waste behaviour

```
to hygiene_check
 ;; roughly every other month the bin is too smelly and should be emptied earlier than normal
```

```
 if random (num-nodes * 100) >= ((num-nodes * 100) - (0.5 * num-nodes)) [ ;; e.g. random
1900 <= 1891
  set l_hygiene False]
end
```

to Discharge-Waste-Local

```
 ;Local waste is separated in the local bin if agents are positive about the network or if the
agent recognises the waste.
 ifelse herkenningbio = True or positive = True [ ;; you will either recognize the waste, or you
will put in more efforts because of your positive attitude
    set l_storage l_storage + random-normal 21.9 2.8 ; based on research Re-Organise
 ] [set non_sorted_bio (non_sorted_bio + random-normal 21.9 2.8)] ;; unrecognized without a
positive symbiotic network means unsorted + 1

end
```

to Discharge-Waste-Container

```
 ;Individuals want to separate their local waste to a central bin when the bin is full or smelly.
 ;If they are willing to walk the distance, are okay with the experience and if there is a
disposal possibility and the container storage rises by the amount in the bin.

 if l_storage >= l_storage_max or l_hygiene = False [
    ifelse (willwalk = True) and (cexp = True) and (cdisp = True) [
     set c_storage (c_storage + l_storage)
     set mysort (mysort + l_storage)
     set l_storage 0
     set l_hygiene True
     set cexp True]

  [ set non_sorted_bio (non_sorted_bio + l_storage)
   set mynonsort (mynonsort + l_storage)
   set l_storage 0
   set l_hygiene True
   set cexp False

     ] ]

end
```

Municipal behaviour

to municipalsortation

```
 ;To measure the sorted and non-sorted bio-waste in the area the central containers are
emptied and that results to the final quantity of sorted bio-waste.
 if sorted_bio > 5 * non_sorted_bio [set mcapacity False set mtechnology False print "This is
too much for me" ask turtles [die]]

 ifelse mcapacity = True and mtechnology = True [
  set sorted_bio (sorted_bio + c_storage)
  set c_storage 0] [
```

```
  set non_sorted_bio (non_sorted_bio + c_storage)]

 set c_hygiene random-normal (startchyg - (startchyg / 3)) (startchyg / 10)
end
```

Effects over time

```
to loseinterest
 ;; roughly every other month people lose some interest
 if random (num-nodes * 100) >= ((num-nodes * 100) - (0.5 * num-nodes)) [
   if symbhappiness < 0.5 or positive = False [
   set bioknow max (list 0 (bioknow - (0.3 * random-float bioknow))) stop]
   if symbhappiness > 0.5 or positive = True [
   set bioknow max (list 0 (bioknow - (0.1 * random-float bioknow))) stop]]
  ;; AANNAME
end

to ReadNews
 ;; impact of newsletter policy
 if Newsletter = True [
   set bioknow min (list 1 (bioknow + newsimpact))

 set bioknow (bioknow - (0.5 * newsimpact / (875))) ]
end

to positivefeeling
 ;; creation of positivity
 ifelse non_sorted_bio != 0 [
  ifelse feedback = True [ ;; if the turtle knows about the results of the model
   ifelse sorted_bio / (sorted_bio + non_sorted_bio) > (0.8 - ((AwoC + AscoR) / 2))[ ;; interest
linked to your awareness and responsibility
   set positive True ]
   [set positive False]]
  [set positive False]] ;; get a positive attitude
 [set positive False]

 if positive = True [
  set contdist min (list(contdist + (0.1 * random contdist)) (distcmax))
  set bioknow min (list 1 (bioknow + (0.5 * newsimpact))) ]

end

to setsocialnorms
 ;; the creation of links by the Type D agent.
 if num_links = 0 [stop]
 if pleasurers != 0 [create-links-with n-of round (0.1 * num_links * count pleasurers)
pleasurers]
 if birdwatchers != 0 [create-links-with n-of round (0.1 * num_links * count birdwatchers)
birdwatchers]
 if natparks != 0 [create-links-with n-of round (0.1 * num_links * count natparks) natparks ]
```

if group = False and in-link-neighbors != 0 [ask one-of in-link-neighbors [set herkenningbio True set willwalk True set cexp True]]
if group = True and in-link-neighbors != 0[ask in-link-neighbors [set herkenningbio True set willwalk True set cexp True set symbhappiness min (list 1 (symbhappiness + random-normal 0.002 0.001))]]

end

to socialbehaviour
;; update numerical symbiotic happiness with yes/no positivity.
ask turtles[
ifelse positive = true [set symbhappiness min (list 1 (symbhappiness + random-normal 0.001 0.005))]
[set symbhappiness min (list 1 (symbhappiness + random-normal 0.0004 0.004))]]

end

to techbehaviour
;; impact of the Human Engagement policy on the container display and experience
ask turtles [
if HumanEngmt = True [if random 100 < 80 [ifelse random 100 < 50 [set cdisp True] [set cexp True]]]]
end

Appendix L – Modelling assumptions

A summarization of the assumptions made in the Netlogo NDSM model.

L.1 Environment

- A central waste bin can be maximum 1000 meter away from a participant.
- It is assumed that the central container is emptied and cleaned weekly.
- In NDSM the geographical proximity and its effect on the behaviour is assumed non-existent.

L.2 Waste Quantities

- Every waste-producing agent has a local waste bin.
- Local waste bins can hold up to 200 kg of bio-waste.
- Central waste bins can hold up to 1.5 tonne of bio-waste (Das & Bhattacharyya, 2015).
- In the standard setting the municipality is able to deal with an 83% separation rate.
- The model does not include any growth in bio-waste, when run longer than half a year, it is likely that waste quantities will grow (EU Landfill Directive, 2014; AEB, 2019).

L.3 Actors

- All participants in the model are physically able to separate waste.
- People represent one out of the five Value-Belief-Norm profiles obtained from the NDSM case study.
- The values of the actors will not be influenced by their waste separation behaviour, also because they play a certain "role" in this system. However, their AwoC, AscroR, and NEP will.
- The start value of Awareness of Consequence is 70%, with a standard deviation of 10,4% based on the NDSM questionnaire.
- The start value of Ascription of Responsibility is 60%, with a standard deviation of 21,5% based on the NDSM questionnaire.
- Without biospheric values the start value of NEP is 60%, with a standard deviation of 15,1% based on the NDSM questionnaire and the knowledge about bio-sorting is a random variable between 0 and 90%. The walkable container distance is somewhere between 50 and 100% of the maximum distance.
- When having biospheric values the start value of NEP is 80%, with a standard deviation of 15,1% based on the NDSM questionnaire. The knowledge about bio-sorting is a random variable between 20 and 90 % and the walkable container distance is somewhere between 62 and 100% of the maximum distance.

L.4 Bio-waste separation knowledge

- Participants with biospheric values recognize waste 90% of the time, participants without these values recognize waste 70% of the time.
- If the knowledge about bio-waste separation exceeds 75% participants will recognize what to sort.
- You can either recognize the waste, or you will put in more efforts because of your positive attitude of the symbiotic network.
- Roughly every other month people lose 0 - 20% interest in waste separation.

L.5 Bio-waste separation in central container

- Time and distance together result in the nearest container being a random variation of the maximum distance.
- 1% of the time the container is too difficult to interact with.
- Container experience is path-dependent.
- Roughly every other month the bin is too smelly and should be emptied earlier than normal.

L.6 Other behaviour patterns

- Symbiotic happiness is growing over time with 0.5 or 1% depending on the type of agent.
- Participants of Type D communicates with a chosen number of one of the participant groups to ensure the successfulness of the separation initiative.

L.7 Policy & scenario assumptions

A summarization of the assumptions made when implementing different policies.

- The news impact from one type E participant will induce a 1% growth in knowledge.
- Participants with a Type B value profile are not responding to the symbiotic network's (lack of) positive feeling, but are responding to overall symbiotic happiness.
- Participants of Type D communicates with a chosen number of all participants to ensure the successfulness of the separation initiative.
- The number of newsletter readers is 100% in the original model, but can be less depending on the receiver.
- In case of the leaving scenario symbiotic happiness, knowledge and container distance willingness fall back to starting values.

Appendix M – Additional results and analysis

Additional parts of the model have been used for experimentation and further analysed. This appendix shows a more detailed view on the model behaviour.

M.1 Standard NDSM model

While running the standard NDSM model without policies, the container fills over time. Figure 58 shows how the central container is filled with bio-waste over time. The orange shows scattered values of the container. It represents how every tick the value of the container changes. A density plot is layered on top of the container behaviour to show the more often measured values. This is concentrated at the bottom representing an empty container storage, and at the top in need of emptying.

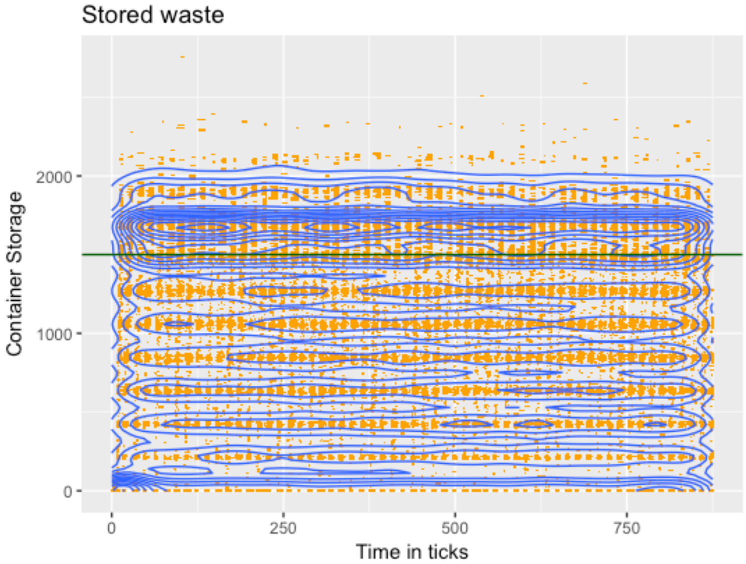


Figure 58 - container storage over time

In Figure 58 the time is displayed on the x-axis in ticks, where 875 is equal to half a year of simulations. The y-axis shows the percentage. The dark green line represents the quantity a container can hold while staying fully clean.

M.2 Leaving Scenario

Figure 59 takes this to a more specific level, showing all individual implementation of the policies. The dark grey top on each graph shows the relevant policy, hereby refers “off” to no policy, number 1 refers to the feedback policy, 2 refers to the group policy, 3 refers to the on-demand policy, 4 refers to the newsletter policy and 5 refers to the container interaction policy. The boxes in the feedback policy (1) overlap partly and therefore it cannot be certain that these median values differ at all.

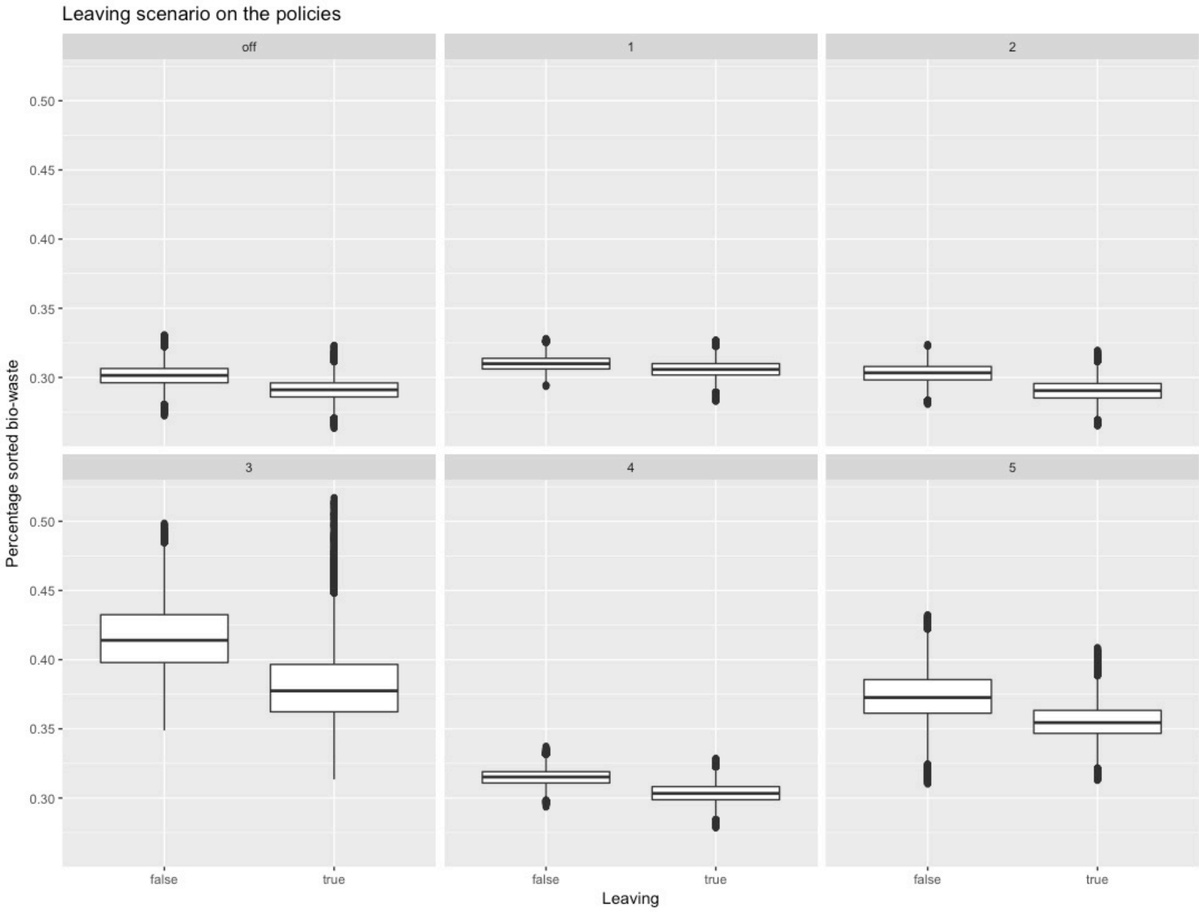


Figure 59 - Leaving scenario individual policies

Below the table gives a more quantitative image of the values as described above.

Table 13 - Impact of the different policies and the effect of the leaving scenario on them.

	Diference sorted bio-waste	Leaving Scenario
No policies	0%	-2%
feedback	0%	0%
group	0%	-1%
on-demand	11%	-4%
newsletter	1%	-2%
human engagement	7%	-3%

M.3 Additional Policy Adaptations

Several different variables can influence, or be influenced by different parts of a policy implementation. The results of these experiments are displayed here.

M.3.1 Feedback policy

Since knowledge about bio-waste separation is not as easily learned throughout the profiles, a differentiation has been made between type A and type B agents, respectively including and excluding an interest in our biosphere. This difference is shown in Figure 60.

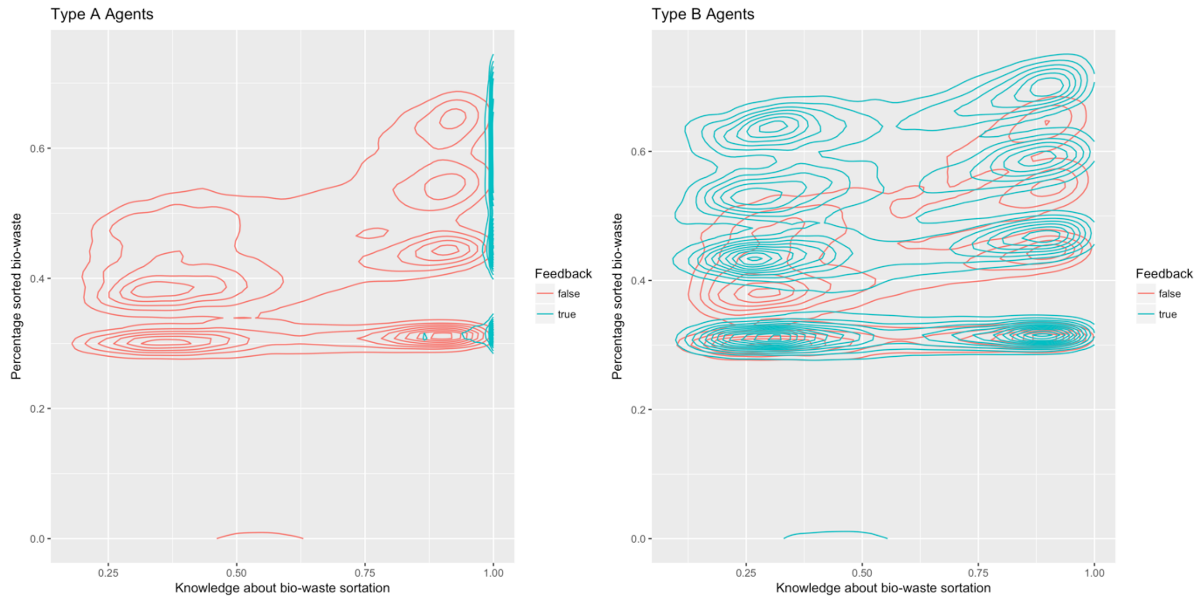


Figure 60 - Impact of bio-waste separation knowledge on the percentage sorted bio-waste for Type A agents (including biospheric values) and Type B agents in the model (excluding biospheric values).

Looking at the knowledge levels of type B agents in Figure 60 a clear distinction has been shown between simulations where the feedback policy has been implemented or not. When feedback is given to the agents in the model, the knowledge level of Type A agents about bio-waste separation almost immediately grows to the maximum amount and remains at that point throughout simulations. While the feedback loop has a more complex influence on Type B agents. The connection between knowledge and percentage sorted waste seems to have a reinforcing effect for the Type B agents. In both plots there is a starting value shown, at this point in time the percentage sorted bio-waste is 0. For type A agents this value is approximately 60%. Type B agents have a knowledge level more towards the 40%.

M.3.2 Group policy

In Figure 61 the effect of changing the number of links on the percentage sorted bio-waste in the implementation of the group policy with and without the other policies is shown.

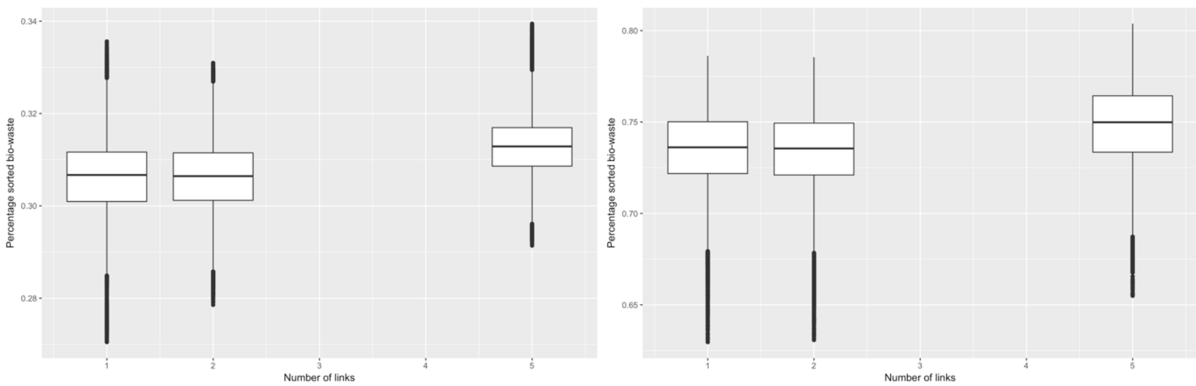


Figure 61 – Impact of number of links in the model on the percentage sorted bio-waste by implementing the group (left) vs all policies (right).

Figure 61 shows the different values of number of links on the percentage sorted bio-waste when only the group policy is implemented, while on the right the simulation effects of implementing all policies is displayed. When implementing solely the group policy, the outliers and the interquartile range reduce slightly when the number links is increased by one, however these changes can be seen as arbitrary. Looking at the impact with all policies implementing there is no difference showing at all. When the number of links is increased more significantly to 5 links per type D agent the median value of percentage sorted bio-waste increased from 30,6% to 31,3% (±0.7%), if all policies are implemented this median increase ranges from 73,5% to 74,8% (±1,3%).

Similarly, Figure 62 will display the effect of the number of type D agents on the simulations.

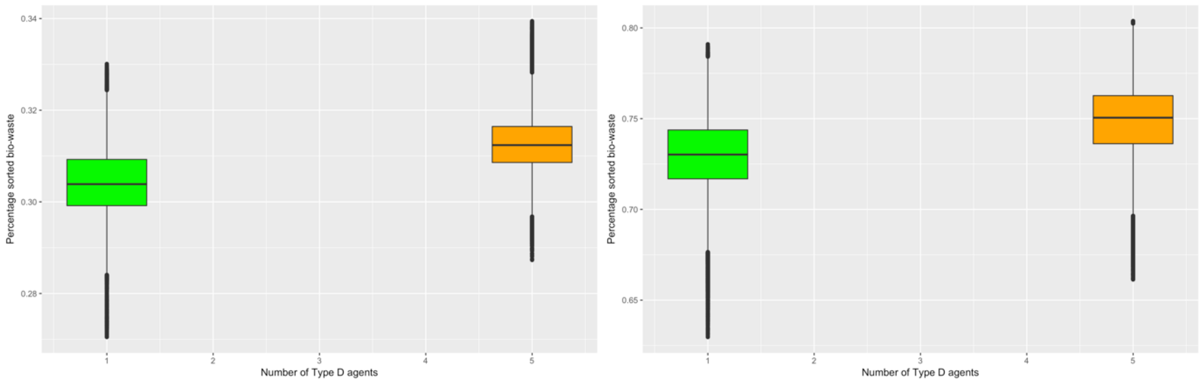


Figure 62 - Impact of a different number of agents on the group policy.

The green box represents the simulations where the group policy was implemented with only one Type D agent, the orange box represents simulations where five Type D agents have participated. There is a slight difference in the two boxplots. A higher number of type D agents increases the percentage bio-waste as can be seen as the median value rises from 30,4% to 31,2% (±0.8%) and from 72,9% to 74,9% (±2%) sorted bio-waste.

M.3.3 Newsletter policy

To understand the effects of the policy better Figure 63 & Figure 64 will discuss respectively, the effect of the number of readers and the effect of the number of theory spreaders (type E agents).

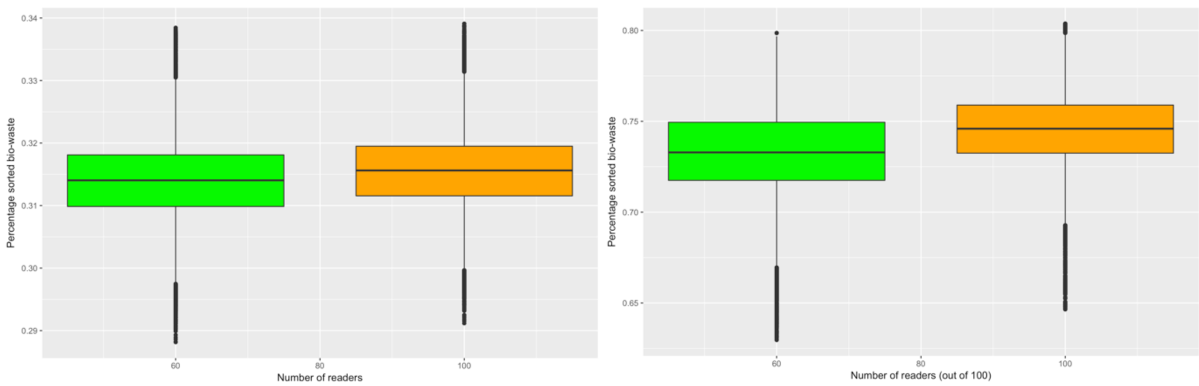


Figure 63 – The effect of the number of readers (out of 100) on the percentage sorted bio-waste.

In Figure 63 is shows that when the number of readers increases from 60% to 100% of the recipients, in case of only the Newsletter policy the percentage sorted bio-waste increases from 31.4% to 31.6% (±0.2%), while if all other policies are implemented too that increase is higher at a 1.3% from 73.2 to 74.5% of sorted bio-waste. This implies that other policies are an important factor in determining the effect of the number of readers.

To understand more about the effects of other policies on the internal factors of the newsletter policy, Figure 64 demonstrates the difference between 2 or 5 type E agents in the model to distribute the newsletter information.

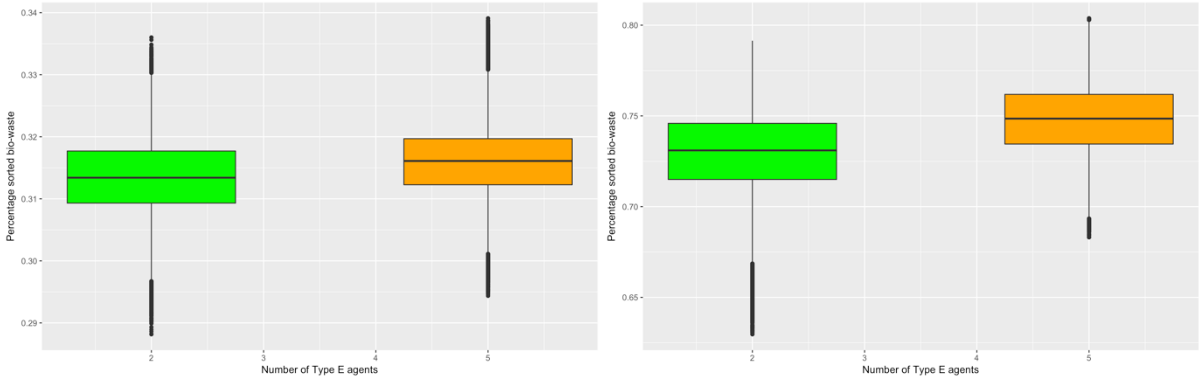


Figure 64 – The effect of the number of type E agents on the percentage sorted bio-waste.

Figure 64 shows that in an implementation of only the newsletter a small growth of separation percentages from 31.3 to 31.6% (±0.3%) and from 73% to 74.8% (±1.8%) sorted bio-waste. The orange boxplot shows the simulations with a group of 5 type E agents, in the green boxplots this group is 2 type E agents.

M.3.3 Combined policies

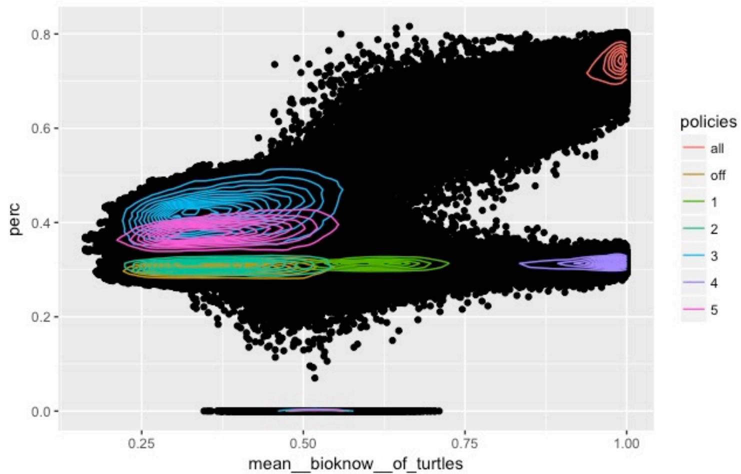


Figure 65 - Percentage sorted bio-waste as an effect of the knowledge about bio-waste separation excluding any policy interactions.

Figure 65 shows that knowledge values are present on every level of the spectrum. Different policies have different influences on the x-value knowledge. For example, the newsletter policy (4) has a big influence on the average knowledge, whereas the feedback policy (1) includes more values under the 0.75 standardized bio-waste separation knowledge. No interactions between different policies, except for the "all" policy, have been included in this figure.

On the 0 percent sorted axis a small line of values is shown, representing the starting values of the different agents, ranging from 0.35 to 0.7 standardized bio-waste separation knowledge. Over time the knowledge of agents seems to result in a wider range of values than they have started with, due to a disinterest to new bio-separation knowledge coming available or at the other end of the spectrum learning behaviour.