Extended Producer Responsibility to Reduce Plastic Waste Pollution

An agent-based analysis for Indonesia

by

Mira Groot

November 2021

Universiteit Leiden
TU Delft
ABEL

This page is intentionally left blank.

EXTENDED PRODUCER RESPONSIBILITY TO REDUCE PLASTIC WASTE POLLUTION: AN AGENT-BASED ANALYSIS FOR INDONESIA

Master thesis submitted to Leiden University and Delft University of Technology in partial fulfillment of the requirements for the degree of

Master of Science in Industrial Ecology

by

Mira Groot

Student numbers Leiden S1396919 & Delft 4374754

To be defended in public on November 15th 2021

Graduation Committee

First supervisor:	Dr. ir. Jaco Quist (TU Delft)
Second supervisor:	Prof.dr. Martijn Warnier (TU Delft)
External supervisor:	Eline Leising (Rebel Group)
External supervisor:	Michiel Kort (Rebel Group)

Universiteit Leiden TU Delft REBEL

Page 1: Photo by Naja Bertolt Jensen on Unsplash
Page 15: Photo by Fiqri Aziz Octavian on Unsplash
Page 39: Freepik Water photo created by jcomp
Page 92: own picture
Page 110: own picture

Pre-face

I believe everyone has some form of responsibility in the transition towards a more sustainable and circular society. Not only consumers, not only producers, and not only governments. They will and cannot do it on their own; we need to do it together. Even though I found out that this is much harder than I thought, I tried to contribute to a world with less pollution by writing this thesis.

With this research project, I am not only finishing my thesis, but I am also closing a beautiful period of student life, which I have enjoyed to the fullest. Before thanking my friends for being part of this, I would like to say a few words to other people who have supported me during these final thesis months.

Firstly, of course, all the interviewees that have participated. I had many great and enthusiastic conversations, and it made me happy to see so many people passionate about improving waste management. Secondly, all colleagues at Rebel. You inspired me with great ideas, could direct me to other interesting people to talk to, and just made me have a good time at the office in Rotterdam!

Then, to my graduation committee.

Jaco, I appreciate that you showed your interest in me and my thesis from the start of our collaboration. The passion for Indonesia came from both sides, and you helped me find possibilities to make it happen. Your critical comments during our meetings made this thesis of a more extensive piece; thank you.

Martijn, your warm words and genuine care for students will always stay with me. You never hesitated to offer help and were always able to motivate me, and I value that greatly. Your confidence in my work made me want to live up to this, even when I was not so convinced myself. Thank you for believing.

Michiel and Eline, I am very thankful for the possibility of writing my thesis in collaboration with you. Michiel, your knowledge on the academic ánd consultancy side has taught me so much about being transparent, correct, and outspoken at the same time. Eline, it was a real pleasure to work together. Thanks for all your valuable contacts, and I appreciate that you were thinking along so much with me during the whole process.

This thesis work could not have been possible without people close to me. I've met many friends during the past years, for which I am very grateful. However, writing a thesis during a pandemic is something I would not recommend to people, and I am very thankful to the group that helped me work through Summer. Many friends supported me by proofreading and helping me with modeling, but also cooking, drinking coffees, and distracting me when I should not think about my thesis. Specifically, I would like to express my appreciation to Anna, with whom I have worked so well during our master's. She is one of the funniest and smartest persons I have met and could help me content-wise and emotionally through this challenging period. Thanks.

I want to thank my family for their support throughout my student years. You gave me the feeling of freedom and support at the same time, for which I am very grateful. Especially your help during the last year of many ups and downs, you have always made sure that I would be more confident in decisions, no matter which one. Thank you.

Lastly, Tim. I've expressed my appreciation for you in many different ways. But being able to call you during highs and lows made me feel like I could conquer this fcking thesis. Your motivational speeches, your vicarious pride, and everything in between – thank you for being there next to me.

This page is intentionally left blank.

Summary

Research background

Plastic debris in the environment consists primarily of plastic consumer waste. One of its leading causes is the lack of waste collection systems in developing countries. Actions need to be taken to overcome this issue, and **Extended Producer Responsibility** (EPR) seems to be an effective solution for encountering plastic waste. Indonesia is the second-largest plastic polluter and is, therefore, a location of interest for implementing EPR systems.

EPR is a policy approach in which **producers become responsible** for the whole life cycle of their product. In Europe, this is a standard tool that makes producers (mostly financially) accountable for the end-of-life stage of their product. EPR can also stimulate design-for-environment: optimizing products to become more reusable or recyclable. EPR consists of many instruments that can be implemented in different ways. Still, **little research has been done** on which instruments can be effectively applied in developing countries like Indonesia. There are no EPR instruments currently used, little waste management infrastructure exists, and most recycling activities are realized through informal waste collectors. These types of local factors are of great importance when implementing waste management policies like EPR.

Two gaps were found in previous literature. First, the **effects** of individual and combinations of EPR instruments on developing waste management systems have not been researched before. Secondly, simulation studies have not analyzed EPR instruments in combination with **contextual factors** of the country of interest. Therefore, this thesis tries to answer the following research question.

"What are the effects of 3 selected Extended Producer Responsibility instruments on the key actors in the plastic waste system of average cities in Indonesia?"

Research approach

A design-science research approach is combined with an agent-based model to answer this question, consisting of three parts.

First, the **Knowledge base** was established by desk research. Literature was consulted to find the state of the art of the most critical aspects of the study: plastic waste in Indonesia and EPR. Secondly, the **Environment** is created by integrating semi-structured interviews with literature to find important factors that make the implementation of EPR interventions in the context of Indonesia more realistic. The third part of the design science research is to **design the artifact**. A conceptual model was made of the plastic waste system in Indonesia. This model was put into the programming language NetLogo, which can capture agent behavior in complex adaptive systems.

Findings

The plastic system is described as a complex adaptive socio-technical system, and an actor analysis is done to visualize the relations between the different stakeholders involved. Furthermore, more emphasis is laid on the behavior of specific actors in the system. Based on interviews, the lack of awareness of the effects of (im)proper waste management was found to be an essential factor of waste pollution. The involvement of households to separate their waste was often mentioned as a solution to stimulate less pollution. Furthermore, four aspects that need to be considered when implementing EPR-related policies have been formulated: **little existing waste management infrastructure**, involvement of the **informal sector**, involvement of **hard**

to recycle plastics, and **compliance**. Considering these four factors and the (plastic) product's life-cycle, three EPR instruments have been chosen to implement in the analysis.

1. **Mandatory take-back requirements**
2. **Advanced disposal fees**
3. **Awareness-raising campaigns**

These findings contributed to the conceptualization of the agent-based model. When the base case was established, the three interventions were integrated into the model individually and combined. The effects on the **collection and recycling rate** and the amount **collected by waste pickers** were analyzed.

Model results

When the model was run without any interventions, it became visible that the plastic leakage would increase over time if no measures were taken due to the **rising plastic production** and consumption. Implementing take-back requirements resulted in extra waste collection vehicles that collect recyclables and residues separately. An increase in waste collection and recycling is visible, but it also **harmed** the informal waste pickers. They seemed to be able to collect fewer recyclables when the take-back requirements were implemented, which can cause significant socio-economic effects. The effects on the recycling and collection rate (and to a lesser extend on the waste picker's collection) were highest in areas where households have a high density.

Implementing advanced disposal fees (ADF) focuses on the upstream phase of a product as it stimulates to redesign products that their end-of-use phase can be recycled better. This results in **more recyclables** in household waste.

The awareness-raising campaigns contribute to the product's use phase and stimulate **awareness amongst communities** about the causes and effects of plastic pollution. Implementing these campaigns makes people more willing to separate the recyclables from residual waste. This is important to retrieve more recyclable materials from the waste, which otherwise gets polluted with other (mainly organic) waste streams. The campaigns can best be located in areas based on a low separation percentage of households to achieve the highest results. Repeating campaigns can result in a higher separation percentage, but **collecting their waste separately** is more effective. Municipal collectors that collect and dump the waste in landfills are discouraging households from separating their waste.

Combining campaigns with take-back requirements does not result in higher collection rates than take-back requirements individually. However, it does increase the recycling rate due to the **higher quality of the separated waste streams**. This indicates that sorting at the household level is more effective in saving recyclables than only sorting different waste streams after it is collected. Combining these interventions also changes the location strategy of the extra collection vehicles – they should be placed **where the households separate their waste**.

Combining all three interventions results in a slightly lower collection rate than implementing take-back requirements alone. Furthermore, the combination increases the amount collected by the informal waste workers. This could be because the ADF results in more recyclables available, and the campaigns result in higher quality materials that waste pickers can collect. Combining the take-back requirements with other interventions thus reduces the adverse effect of the take-back requirements on the informal sector. Lastly, when **implementing the interventions in a specific**

order, the highest results are achieved. First, the awareness-raising campaigns should start, then take-back requirements, and finally, the advanced disposal fees.

Discussion

This research found some insights for implementing EPR systems. First, the three interventions complement each other in the **life-cycle phase**. This is visible in the results, as the combination affects multiple life cycle stages and result in different effects than interventions individually. Secondly, the order of implementing interventions can influence the outcome of the results. For example, this thesis found that the communication instrument, awareness-raising campaigns, should be implemented before take-back requirements. Also, advanced disposal fees should be implemented after the take-back requirements. Both can **improve the recycling rate**, and to a lesser degree, the collection rate.

The take-back requirements can significantly improve the collection and recycling rate and seem to be the **most effective instrument**. However, they also collect in areas where waste pickers work, which causes adverse socio-economic effects for them. This **trade-off** should be realized and possibly avoided to limit interference with many people's livelihoods. Implementing multiple interventions like the ADF and awareness campaigns can reduce this effect.

EPR is a very new concept in Indonesia. Many citizens are not aware of the plastic problem and that the cause of pollution lies in a lack of waste management facilities. Producers, but also consumers, and governmental organizations need to make this a **priority** to be able to reduce environmental pollution. Even, or maybe primarily, in places with little formal infrastructure, EPR interventions can provide a step towards a better responsibility division for waste management.

Modeling comes with limitations like observer bias, and many assumptions need to be made that can influence the results. For example, the model's innovation adoption level is based on a well-known distribution (Rogers, 1995). Adapting this distribution, however, results in changes in the outcomes of the model. **Verification** of the model and **validation** of the results have been conducted to optimize the results, but these limitations should be considered.

Conclusions

The results of this study increase the **knowledge** on the effects of EPR in developing countries. Furthermore, it can create more social awareness in local and national organizations to tackle environmental and human health issues. Most optimally, they can be used as policy recommendations to improve plastic waste collection and recycling without harming essential stakeholders.

Answering **the research question**, the effects of the three EPR instruments are the following. Take-back requirements increase collection and recycling rates and reduce the collection of informal waste pickers. Advanced disposal fees increase recyclables in household waste, and awareness-raising campaigns increase the behavior of households to start source sorting. **Combining the interventions** results in different strategies for locating the collection vehicles. Furthermore, the order of implementation can affect the effectiveness of the results and location strategies.

This thesis fills two scientific gaps. First, it analyses single and combined EPR instruments. Secondly, it simulates EPR instruments that can integrate multiple perspectives and enables the evaluation of policy interventions and their trade-offs.

Table of Contents

Glossary

Term	Definition
ABM	Agent-based modeling
Actor	See stakeholder
ADF	Advanced disposal fees
Arc	Awareness-raising campaigns
BPMN	Business Process Modelling Notation
CAS	Complex Adaptive System
DRS	Deposit-refund system
EPR	Extended Producer Responsibility
HDPE	High-density polyethylene
HH	Household
IE	Industrial Ecology
IPRO	Indonesian Packaging Recovery Organization
IS	Information Systems
KPI	Key Performance Indicator
LDPE	Low-density polyethylene
MSW	Municipal Solid Waste
NGO	Non-governmental Organization
OECD	Organisation for Economic Co-operation and Development
PET	Polyethylene terephthalate
PP	Polypropylene
PRO	Producer Responsibility Organization
Tbr	Take-back requirements
TPST	Temporary waste storage sites before it is transported to landfills
TPS3R	Private collection vehicle that collects waste separately
Scavenger	See WP
Stakeholder	Someone who is involved in the issue
UCTS	Upstream combined tax/subsidy
UML	Unified Modeling Language
WP	Waste picker, an informal waste worker that collects waste

List of figures

List of tables

PART I – KNOWLEDGE BASE

1. Introduction

It has been widely acknowledged that plastic waste is causing environmental damages to oceans, freshwater, wildlife, and humankind due to leakages of plastics (Chen, 2019). Plastic packaging of consumer goods contributes significantly to plastic leakage into the environment, as well as visual depredation and air pollution (WWF, 2020).

1.1 EPR to tackle plastic pollution

Multiple policy approaches have been formulated to stimulate better disposal and decrease the environmental damages due to plastic leakages. One of these approaches is Extended Producer Responsibility (EPR), which transfers (part of) the financial or physical responsibility of the end-of-life product disposal from municipalities and users, to producers of those products (OECD, 2001). EPR instruments are in line with the polluter-pays principle and aim to internalize environmental costs earlier in the product's life cycle (Nahman, 2010; OECD, 2016). The EPR principle is based on the idea that producers are the most suitable stakeholders who can implement changes to minimize the environmental impact of all life cycle stages of their products. (Leal Filho et al., 2019). Studies on plastic waste pollution emphasize the necessity of producers taking more responsibility for the final stage of their products: the end-of-life phase (Li, Tse, & Fok, 2016; Tristiana, Koeswahyono, & Fadli, 2018). Plastics' largest market is packaging, and this is a waste stream for which EPR can provide a solution (Geyer, Jambeck, & Law, 2017).

EPR schemes have been proven to be successful in OECD countries. It has namely been proven that the financial burden of waste management has shifted towards producers and recycling rates in most of these countries (OECD, 2016; Romenska, 2016). However, the main contributor to global waste leakage is found to be the lack of proper waste management systems in developing countries (UNEP, 2016). In many developing countries, little to no waste management systems are in place, causing plastic contamination in ecosystems (Li et al., 2016). The absence of collection schemes makes it difficult to accumulate all waste (Jambeck et al., 2015; The Pew Charitable Trusts & Systemiq, 2020). Furthermore, most inhabitants do not see or prioritize this issue as a problem that needs to be addressed (Quartey, Tosefa, Danquah, & Obrsalova, 2015). In combination with an increase in population and plastic waste generation in developing countries, this is a very concerning issue that needs to be addressed and resolved (Fostinone, 2016; The Pew Charitable Trusts & Systemiq, 2020). Implementing EPR instruments can make society more aware of this issue and stimulate behavior change of consumers, producers, and governmental organizations to improve the collection of plastic waste (Arry Rahmawan Destyanto, Kirana, & Ardi, 2019).

Indonesia is a country that faces high amounts of plastic pollution. In most European countries, plastic packaging is a waste stream that gets processed via Extended Producer Responsibility principles. In developing countries, EPR is now being explored as well. However, due to the lack of waste management budget and infrastructure, the implementation is a challenge. Furthermore, besides formal waste management, many people in Indonesia are informally contributing to the collection of recyclable materials like plastic. The integration of a formal EPR system could therefore have significant effects on the livelihood of these informal workers (Aleluia & Ferrão, 2016; Chaerul, Fahruroji, & Fujiwara, 2014; Sembiring & Nitivattananon, 2010).

1.2 Literature gap and research questions

Previous research has shown that Extended Producer Responsibility can be beneficial for the reduction of plastic waste in Indonesia. Even though they acknowledge challenges ahead, they

agree that a system approach is needed and local context needs to be considered when implementing an EPR system. However, previous studies do not simulate the effects of EPR interventions that should be implemented in Indonesia. Simulations have been done on other waste management policies, but not on EPR specifically, which is a new and upcoming direction. This literature gap is more elaborately discussed in section 2.5. Based on this gap, this research will answer the following research question, with its accompanying sub questions.

"*What are the effects of 3 selected EPR instruments on the key actors in the plastic waste system of average cities in Indonesia*?"

1. What does the current plastic waste system in Indonesia look like, and what factors need to be taken into account when implementing EPR policies?
2. What EPR instruments are applicable for the Indonesian plastic waste system?
3. How can the plastic waste system of a medium-sized Indonesian city be conceptualized in an agent-based model?
4. Based on the model, what effect do EPR interventions have on the Indonesian plastic waste system?

1.3 Research objectives

Since Indonesia is a large polluter regarding plastic waste, it is a location of interest for implementing EPR-related policy interventions (Jambeck et al., 2015). Research shows that the implementation of EPR instruments in developing countries would be beneficial for reducing plastic pollution but also comes across multiple challenges (Nahman, 2010; OECD, 2016; Ebo Tawiah Quartey et al., 2015; Tristiana et al., 2018). Therefore, this research will focus on the implementation of EPR instruments in Indonesia to reduce plastic pollution, taking into account the context of the Indonesian environment. Indonesia will be used as a reference country due to its prominent role in this sector and the availability of data and connections for interviews.

1.4 Relevance

This thesis has been conducted to fulfill the master program Industrial Ecology. Simultaneously, a graduation internship at Rebel Group was done to combine academic research with practical knowledge. The relevance for society and the field of industrial ecology is explained. For organizations like Rebel Group, this research could deliver insight into how EPR instruments can be used in developing countries. This helps companies give better advice to local and governmental agencies, hence helping them create better policies.

1.4.1 Societal relevance

In most countries, policies are formulated by the national or municipal government to tackle the plastic waste problem. However, the execution of these policies could be improved by implementing specific instruments. Even though plastic waste is a significant problem in these countries, it also brings informal employment opportunities. People with little to no income collect or buy waste and sell it to middlemen, who sell it to recycling or waste disposal facilities. Therefore, many civilians' livelihood depends on this informal sector, which makes the integration of the formal EPR schemes run into other, more social-economic issues. On the one hand, the formal waste collection system cannot capture all waste without the informal sector. On the other, the informal sector does not have proper working conditions due to a lack of protective clothing and health insurance. The challenge is to find a way to combine the complexity of the informal sector with the formal legislation on plastic waste without harming either of the parties involved. Therefore, this research aims to contribute with insights into how plastic pollution can be reduced

while taking into account the country's local context. The complexity lies in the many stakeholders involved, and their visions and context should be considered when solving this problem.

1.4.2 Industrial Ecology

The field of Industrial Ecology (IE) explores sustainability in economic and environmental systems. It is acknowledged that these two systems have more overlap than what was thought before. Higher economic output is resulting in increased environmental harm, too (Ehrenfeld & Gertler, 1997). This can be seen in the plastic system in Indonesia as well. The increasing economic growth results in more purchasing power, which requires more (plastic) packaging. Packaging turns into waste right after the use phase, and the lack of proper waste management systems leads to environmental plastic pollution. Erkman (1997) explains IE as a way of viewing industrial systems as an ecosystem, where material, energy, and information flows are distributed and connected in a specific way. This ecosystem approach is applicable for the plastic system since stakeholders interact with each other through products and knowledge. Chiu & Yong (2004) see Industrial Ecology as a framework that connects industrial and natural systems as well. They emphasize that this approach should be used in Asian developing countries, where economic growth, economic size, and resource allocation are demanding challenges. Lastly, Davis, Nikolic, & Dijkema (2010) add the social dimension while describing IE, which is present in the current plastic crisis. They describe the IE approach as a connection between "the economy, social concerns, and the environment" (p. 708).

1.5 Geographical scope

This research focuses on Indonesia, which is the second-highest plastic polluter in the world (Jambeck et al., 2015) and has a large informal waste sector (World Bank Group, 2018). With the choice for a specific country, more specific behavior on a lower-level scale can be analyzed, which can be used to formulate more specific recommendations and insights. The focus will be on plastics that come from domestic municipal solid waste only. Imported- and industrial waste are not within the scope of this study.

1.6 Structure of this research

The first three chapters of this thesis outline the knowledge base of the research. In the following chapter, literature is consulted to discuss the core concepts needed to address this issue. The third chapter focuses on the research approach. The fourth and fifth chapters comprise part of the system analysis where the Indonesian context and EPR interventions are elaborated upon. Part III consists of chapters six, seven, and eight. It consists of the development and implementation of the model and analyzes its results. Finally, part IV comprises the discussion of the results and conclusion of the research.

2. Theoretical background

This chapter focuses on reviewing existing literature on EPR approaches for plastics in developing countries. Firstly, the plastic system in Indonesia will be explained as a socio-technical system. Secondly, Extended Producer Responsibility will be elaborated on in more depth through a semi-systemic literature review on the state-of-the-art literature on EPR policies regarding plastics. This topic is analyzed more extensively because this can provide insights into the most suitable measures for encountering plastic pollution. Lastly, research on (agent-based) modeling is analyzed to provide more context on this specific method.

2.1 Plastic waste in Indonesia

Plastic is a relatively new packaging material compared with metal, glass, and paper. Halfway through the 20th century, plastic was used for soap and shampoo packaging, and around 1980, food and beverages were packed in plastics (Berger & Welt, 2005). Plastic could be used as packaging to extend the shelf life of fresh products. Furthermore, plastic was convenient for marketing since it was easily changed into visually-attractive packaging (Jones & Tadajewski, 2016). Plastic is thus a practical packaging material. However, the environmental footprint of plastic for packaging is higher than glass or paper (Gentil, Gallo, & Christensen, 2011). More problems are associated with plastic waste since it is more challenging to recycle single-layered and multi-layered plastics (Kedzierski, Frère, Le, & Bruzaud, 2020), which are used massively in Indonesia. It is therefore of great importance to acknowledge the need for better plastic disposal. Especially in Indonesia, where many people earn daily incomes, which allows them only to buy products for one time use. These are usually packed in hard-to-recycle sachets that end up in the environment and cause environmental pollution.

Roughly, the life cycle of plastic packaging consists of five phases which are visualized in Figure 2.1 (based on The Pew Charitable Trusts & Systemiq, 2020; World Economic Forum, 2020).

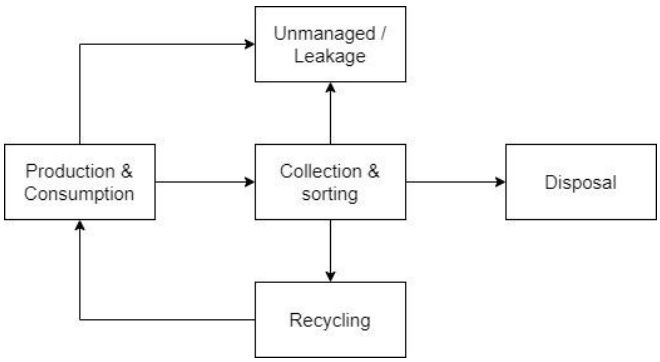


Figure 2.1 – Life cycle plastic packaging

Production & Consumption

Plastic can be used in different forms, but plastic packaging is one of the most used plastic types (Hopewell, Dvorak, & Kosior, 2009; Satapathy, 2017). Not only do packages take up to 40% of the plastic products, but 60% of the plastic waste is from plastic packaging (Brouwer, Thoden van Velzen, Ragaert, & ten Klooster, 2020).

Collecting & Sorting

In Indonesia, only 39% of the plastics are collected (World Economic Forum, 2020). The recovery rate varies per type of plastic, where High-Density Polyethylene (HDPE) and Polyethylene

Terephthalate (PET) have the highest collection rates due to their relatively high recyclability possibilities (Wongthatsanekorn, 2009). Sorting plastics from municipal solid waste is rarely done in Indonesia. This is mainly because of the low share of source separation (segregating waste at the household level) and little segregation facilities (Ministry of Environment and Forestry, 2020).

Recycling

After the collection of plastics, they can either be recycled or disposed of. Part of the collected plastics also stays unmanaged, for example, by leakage or mismanaged waste (World Economic Forum, 2020). In Indonesia, only 10% of plastic waste gets recycled (Geyer et al., 2017). Almost all recycling is done by the informal sector (Raharjo, Matsumoto, Ihsan, Rachman, & Gustin, 2017). On the other hand, European countries have an average recycling rate of plastic packaging of 42% (Eurostat, 2019). High-value plastics like HDPE and PET are easier to recycle than low-value, single-use plastics. This also determines their economic value, and therefore the chance of recycling by the informal sector (World Bank Group, 2018).

Disposal

In Indonesia, collected waste that is not recycled is mainly disposed of via landfilling (Ratna, Takashi, & Takaoka, 2018; World Economic Forum, 2020). Municipalities that collect household waste bring it straight to unsanitary landfills (dumpsites) because there are no proper sorting facilities and budget. Due to the durability of harmful materials like plastics, unsanitary landfilling results in plastic debris in the soil (Barnes, Galgani, Thompson, & Barlaz, 2009). In addition, incineration with energy recovery does not occur in most developing countries like Indonesia due to a lack of technology and budget (Nkwachukwu, Chima, Ikenna, & Albert, 2013).

Unmanaged/ Leakage

For a large part, (plastic) waste ends up in the environment. This causes large amounts of plastic waste to end up in the environment and contaminates soil, air, and waterways due to open burning or illegal dumping. These practices are imaginable since there is often no waste collection available. By improving the collection rate of plastic waste in developing countries, the overall environmental impacts thus can be significantly reduced (OECD, 2018). Also, when waste has been collected, leakage occurs when it is not managed and disposed of properly (World Economic Forum, 2020).

2.1.1 The informal sector

In Indonesia, many people working in the waste management sector are based on unmanaged business. People are picking waste from streets, communal bins or dumps, to resell and recover its materials. This is often without any official documentation and under unsafe conditions, without protection clothes or health insurance. Since this type of employment is better than not having a livelihood, this is still an ongoing business in many developing countries (OECD, 2016; Quartey et al., 2015).

The informal sector has been greatly undervalued in terms of its contribution to plastic recycling. However, it is important to acknowledge that in most developing countries, informal waste workers are covering the largest share of the recycling chain (Alhanaqtah, 2018). In Indonesia, the informal sector works more effectively than the formal waste system, and provides environmental benefits for the government by picking waste of streets. Furthermore, there is a

financial benefit because the saved costs of waste collection for municipalities can be more than the income of that waste picker (Alhanaqtah, 2018).

On the other hand, the informal waste management sector interferes with the waste management system since they illegally detach high-value elements from waste products and sell that on other markets (OECD, 2016). Therefore, city authorities and informal waste workers should cooperate to benefit from each other's strengths and avoid economic and environmental damages (Audi, 2019; Chen, 2019; OECD, 2016). Recently, there are some cooperatives established for waste pickers to be able to negotiate with municipalities. This results in semi-formal waste workers when there are some agreements made (Alhanaqtah, 2018). Also, semi-formal waste banks (where individuals can hand in recyclables for a small amount of money) and TPST / TPS3R facilities (where waste gets sorted and sometimes processed) are organizations that are involved with waste collection (Darus et al., 2020). The Alliance of Indian Waste pickers indicates that EPR can strengthening the informal sector via adding value to hard to recycle plastics. This results in increased waste collection and provides scavengers with a more steady income (Anantakrishnan, 2021).

2.1.2 Household behavior

Besides the informal sector, researchers also emphasize the importance of the attitude of households towards waste and waste management. Their behavior and interactions with each other can be essential for organizing waste management systems (Oberlin, 2011; Oosterveer & Spaargaren, 2010). When analyzing waste management policies in literature, little attention is given to the social dynamics of actors involved, even though this is an important aspect of policies' effectiveness (Aprilia, Tezuka, & Spaargaren, 2012). Aprillia et al. (2012) analyzed the attitude of households towards separation at home in Indonesia. When conducting the surveys, most Indonesian households did not separate waste but were willing to do so under some conditions as information sharing or financial support. Besides the interview, they calculated the willingness to pay for certain waste disposal scenarios, but with the assumption of source separation at all households. However, they mention that source sorting takes time to achieve and can be done by voluntary or mandatory measures (Aprilia et al., 2012).

In other developing countries like India and East Africa, it was researched that the current source separation practices are mainly done due to economic incentives, without the knowledge of the environmental benefits (Nandy et al., 2015; Oberlin, 2011). Also, with the provision of separation facilities, source separation at all households does not come naturally (Tong et al., 2018). Households consider factors such as time and cost-utility, and social influence before starting waste separation (Meng, Wen, & Qian, 2016).

Source separation at the household level is thus behavior that can be changed, which is a research field on its own. Literature describes three factors where policy interventions should focus on when influencing behavior change: motivation, capability, and opportunity. These are based on a systematic literature review of behavioral intervention frameworks (Michie, Stralen, & West, 2011). These three factors seem to generate certain behavior. Motivation is based on habits, emotions, and analytical decision-making. Capability is to have the physical and psychological capacity to behave in a certain way. Opportunity focuses on the activities that lay outside the individual that stimulate affect the activity.

2.1.3 A complex adaptive socio-technical system

Three aspects are considered for the Indonesian waste management system.

Socio-technical system

The plastic waste system of Indonesia can be seen as a socio-technical system. A socio-technical system can be described as a network of social and technical artifacts that interact with each other and their environment (Geels, 2004). It emphasizes the interconnectedness of the social components like individuals, organizations, companies, and institutions and technical components like machines, products, and factories. In the plastic waste system, plastic gets produced from oil into a product, which then is sold on a certain market and after usage gets burned, thrown into the environment, or disposed of properly. There are technical aspects involved in, for example, the production of plastic products and their disposal. Social components are involved as many people and organizations are involved in the whole process: the product comes on the market, gets used, and disposed of in a certain way. This disposal is influenced by the type of product and the availability of collection facilities, which vary in different areas. Multiple researchers describe STSs as the interaction – and the interdependency of technical and social elements with actors and each other (Borrás & Edler, 2014; Rohracher, 2001; Vernay, Mulder, Kamp, & De Bruijn, 2013). The interactions between the plastic products, their users, and the environment and between users themselves can result in different system behaviors and can therefore be seen as a socio-technical system.

Complexity

Borrás & Edler (2014) also emphasize that elements in a socio-technical systems (STSs) are always interconnected with each other. They mention the interactions are complex, in a sense that they create specific dynamic behavior, which can also be seen in the plastic waste system. Based on van Dam, Nikolic, & Lukszo (2013), the complexity of an STS comes in when over time, the model can change its form. These dynamics result in outcomes that cannot be predicted and can vary, even when the elements of the system are the same. The presence of the informal sector is an example of this complexity. The informal waste workers are individuals who try to make a livelihood based on the availability of waste and the demand for recyclables by middlemen. Individual behavior of waste pickers is therefore dependent on different factors in their environment. On the other hand, their individual actions also influence the environment and each other because other waste pickers have less to recover in an area when a waste picker is active in that same area. Due to these interactions and interdependencies between different stakeholders, emergent behavior occurs (van Dam et al., 2013). This makes the implementation of waste management solutions in Indonesia a complex process (Nahman, 2010).

Adaptivity

Van Dam et al. (2013) explain adaptivity as a system's characteristic when its components can adjust over time. The plastic waste collection system in developing countries is such because multiple stakeholders are involved, who are dependent on each other and the system as a whole. The interaction between these stakeholders is constantly arising and emerging and can vary under different circumstances.

When describing a system as a complex adaptive socio-technical system, it can provide a particular lens to look at the system. It acknowledges the difficulty of understanding and visualizing the system. It also provides suggestions to use specific methods for analyzing these systems, which will be explained in more detail in sections 2.4 and 3.3.

2.2 Extended Producer Responsibility

The definition of Extended Producer Responsibility is not straightforward in literature. EPR can be seen as a specific policy tool, as well as a general policy approach. Some definitions are somewhat overlapping, but they all focus on making the producer of a product responsible for that product's entire life-cycle chain. After the definition of EPR in this thesis, examples of EPR instruments are explained based on three policy instrument types. Thirdly, decisions when implementing EPR are reflected upon.

2.2.1 Definition of EPR

In general, implementing EPR instruments incentivizes including environmental externalities into the product's price (Destyanto et al., 2019; OECD, 2001). More concrete, the implementation of Extended Producer Responsibility has two main goals Quartey et al., 2015; Van Rossem, Tojo, & LindHqVist, 2006).

1) It should relieve some burden on public organizations that are responsible for collection and disposal of the waste streams;
2) It should be an incentive for producers to design their product in a way that is easily reusable or recyclable to improve the product's reusability (*design for environment*).

The first goal refers to 'downstream' activities, which occur after the use phase of a product's life cycle, whereas the second goal focuses on 'upstream' activities, which focus on the phases before the consumer uses the product.

The words "Extended Producer Responsibility" can refer to different concepts.

1. EPR as a policy principle, where it is used as guidance for policymakers (Lindhqvist, 2000)
2. EPR instruments, which entail specific policy instruments that "act to implement the basic principles of EPR" (OECD, 2001; p.40)
3. EPR schemes, which emphasizes more the practical use of a combination of specific policy instruments that relate to shifting responsibility to the producer (Lifset, Atasu, & Tojo, 2013)

In this thesis, EPR will be seen as a policy principle to improve environmental waste pollution. Different policy instruments will be evaluated based on their implementability in the context of the plastic waste system in Indonesia. In the model, multiple EPR instruments can be combined as EPR schemes to analyze the effects of the combined instruments.

2.2.2 Three types of instruments

The goals of EPR can be achieved by different kinds of regulatory, financial, or informational tools (Nahman, 2010; Nkwachukwu, Chidi, & Charles, 2010). An overview of most-used instruments is provided in Table 2.1 (based on Gupt & Sahay (2015); Leal Filho et al. (2019); Nahman (2010); OECD, (2016)). The reason to implement one of these instruments depends on the type of material and waste stream and the origin and value of the product (Dubois, Graaf, & Thieren, 2016; Nahman, 2010; Pires, Martinho, Ribeiro, Mota, & Teixeira, 2015). When looking at developing countries, the type of mechanism to use is also based on current infrastructure and the scale of the system (Nkwachukwu et al., 2013). These regulatory, financial, and communication instruments can promote more sustainable supply chains of products.

Table 2.1 - Examples of most used EPR instruments, adjusted from Nahman (2010)

Type	Examples
Regulatory instruments	• Take-back requirements • Recycled product standards • Prohibition of certain hazardous materials • Disposal bans • Emission limits
Financial instruments	• (Advanced) Disposal fees (ADF) • Deposit-refund systems (DRS) • Product taxes • Upstream combination tax/subsidy (UCTS) • Virgin material taxes
Information instruments	• Environmental report requirements • Environment labeling requirements • Awareness-raising campaigns

2.2.3 EPR implementation decisions

In this subsection, some considerations for EPR implementations are elaborated on.

Mandatory and Voluntary

A distinction can be made between mandatory and voluntary EPR programs. Mandatory EPR programs are in place because of governmental targets or requirements, whereas voluntary EPR systems are created when market forces draw producers to a form of self-management (OECD, 2016). Mandatory programs are usually established for products that are not directly profitable to collect. For example, when the waste stream contains hazardous materials or has low recyclability, and is therefore not financially beneficial (Dubois et al., 2016; Quoden & Grant, 2019). Mandatory systems are also more effective in discouraging free-rider behavior, as all producers need to comply with rules (OECD, 2016).

Voluntary systems can occur due to different reasons. The recycling or reusing of waste streams that still have a high (economic) value is usually done because it is financially beneficial. It, therefore, does not always need governmental interference and can be considered a voluntary EPR system when organizations set arrangements with each other (Dubois et al., 2016; Quoden & Grant, 2019). Voluntary EPR can also occur when mandatory policies are likely to occur in the coming months or years. In this way, organizations can benefit from competitive advantages when starting earlier (Chen, 2019). These voluntary programs usually also include agreements with cooperating parties. The naming of 'voluntary' programs sometimes also lies in the fact that it is not set in stone *how* specific goals are achieved, but only what those goals are and when they need to be realized. (Nahman, 2010).

Individual and collective responsibility

To meet the EPR obligations, the responsibility can be established individually or collectively. For individual responsibilities, every individual producer needs to make sure the waste of their

product is taken care of. When collective responsibility is arranged, producers of a particular sector need to ensure their waste is managed correctly (OECD, 2016).

Collective responsibility can be managed via a Producer Responsibility Organization (PRO). A PRO can be set up for being responsible for managing and executing the responsibilities of the producers in this sector. They collect and distribute financial means and take responsibility for the compliance of the participating parties. Even though obligations *can* be achieved individually, a collective organization can benefit from shared administrational and financial hassles. The exact relation between the PRO and involved governmental organizations depends on the country and type of waste stream (OECD, 2016).

The establishment of PROs can also have adverse effects. Free-rider behavior can occur, and there is a lack of competition, as the goals need to be achieved collectively. This also means that there are fewer incentives to innovate the product in an environmental-friendly way, which decreases the *design for environment* goal of EPR (Kaffine & O'Reilly, 2015). However, this effect is also dependent on the exact structure of the EPR instrument. The fee that producers have to pay to the PRO can, for example, be based on market share, product weight, or material content. Therefore, individual responsibility is theoretically considered more desirable to achieve a more competitive market and would require less interference for fair competition (Pouikli, 2020). In practice, most EPR systems are set up collectively, as it is difficult, sometimes impossible, to manage to collect your specific end-of-life products as a producer. Furthermore, the advantages of the economics of scale and lower investments in monitoring with collective responsibility are especially important for EPR on plastic packaging (Kaffine & O'Reilly, 2015). A way to still incorporate the incentive for companies to eco-design their packaging is by tariff differentiation. The differentiation can be based on material volume, weight, or quality (De Jong & Wolsink, 1997). This can, for example, result in higher fees for hard to recycle materials than for easy recyclable materials into new products (Afvalfonds Verpakkingen, 2021).

There are also examples of multiple PROs, which still create competition, but then between PROs (Cahill, Grimes, & Wilson, 2010; Rubio, Pereira Ramos, Rodrigues Leitao, & Barbosa-povoa, 2019). These PROs then focus on the same waste stream materials. This could be an initial design of an EPR system, which has been done in the UK, or this can emerge after pro-PRO-competition legislation is established, like in Germany (OECD, 2011). On the other hand, having multiple PROs makes it harder to make agreements on targets or quality. Furthermore, competition stimulates innovation, but this innovation can also solely result in economic benefits rather than social or environmental benefits. This can be seen in Germany, where the competition between PROs is so high that PROs give discounts on plastic volumes of large brand owners. This results in a higher kilogram price for smaller companies.

2.3 EPR for plastic packaging globally

The currently available literature on EPR for plastic packaging will be semi-systemically analyzed. The method for the semi-systemic literature review is explained in chapter 3.

2.3.1 EPR in developed countries

Since 2016, around 400 EPR systems have been in place worldwide. 17% of these systems are established for packaging, of which 48% and 42% are located in North America and Europe, respectively (OECD, 2016). Plastic packaging like PET, HDPE, and LDPE are mainly targeted with EPR for packaging (Leal Filho et al., 2019; Pires et al., 2015).

In many developed countries, mandatory take-back requirements and advanced disposal fees are implemented (Appendix A). The Netherlands was one of the first countries to implement an EPR

scheme to support the plastic recycling policies (OECD, 2001). Since 2012 a PRO was established, Afvalfonds Verpakkingen, who is collectively responsible for the packaging supply chain (Afvalfonds Verpakkingen, n.d.). They contribute financially to municipalities, which are legally responsible for collecting municipal solid waste in the Netherlands. Furthermore, they pay the waste industry to sort and valorize the waste and invest in activities to promote recycling. They are a non-profit organization, and their earnings come from fees from organizations that bring the packaging to the market. This Dutch system can be classified as product take-back requirements: the producers are required to be responsible for the take-back of their products at the end of their lives.

Researchers have discussed how EPR can affect plastic collection and recycling in Europe (Leal Filho et al., 2019; Pires et al., 2015). These articles mainly focus on how the implementation of EPR can be extended to live up to EU- or global regulations regarding plastic reduction. Leal Filho et al. (2019) mention that EPR can contribute to specific waste targets, but they conclude with three important recommendations when designing an EPR framework. Firstly, it should be taken into account to include concrete measures, rather than only high-level guidelines. Secondly, multiple instruments result in a system approach, which is needed to achieve the higher goal of reducing plastic waste. Thirdly, they emphasize the necessity for a fair EPR scheme to reduce free-riding behavior through transparency on fees and targets. Pires et al. (2015) provided a financial model to promote sustainable packaging. They mention that local context is of great importance to contribute to more sustainable production.

2.3.2 EPR in developing countries

Besides developed economies, research has been done that assesses EPR instruments in developing countries. Some suggestions that have been found are similar to developed countries. For example, Tristiana et al. (2018) recommended focusing on regulatory, financial, and informative policy instruments EPR implementation to reduce plastics in Indonesia. The combination of all three makes the impact more significant. They highlight that the government is responsible for setting out guidelines for organizations and the community should be actively and passively concerned and involved with reducing plastic waste.

Some developing countries have specific legislation related to EPR on (plastic) packaging, like Indonesia, Thailand, and India (Johannes, Kojima, Iwasaki, & Edita, 2021). There are also many emerging markets where the EPR concept is put on the political agenda but is not formalized regulations yet, like Brazil, Chile, Vietnam, the Philippines, Malaysia, and Nigeria (Johannes et al., 2021; Kaffine & O'Reilly, 2015). In Taiwan and South Africa, a deposit refund system is implemented. In Taiwan, this was initiated publicly by the Waste Disposal Act, but in South Africa, the system has been set up by retailers and producers themselves to prevent harmful legislation.

2.3.3 Comparisons

Researchers confirmed that multi-instrument policies seem to be more efficient than single EPR instrument policies for both developing and developed countries (Kaffine & O'Reilly, 2015). Other researchers emphasize that the context of the implementation needs to be taken into account for effective performance (Aleluia & Ferrão, 2016; Dubois et al., 2016; Fostinone, 2016; OECD, 2016; Quartey, Tosefa, Danquah, & Obrsalova, 2015).

When looking at contrasts, Hotta, Hayashi, Bengtsson & Mori (2009) highlight that in developed countries where EPR policies have been implemented, there almost always already was a form of waste collection in place by the government, where consumers pay municipal solid waste taxes. Introducing an EPR system shifted the financial burnings from the municipalities and taxpayers

to the producers. They then are responsible for paying the municipalities or another external organization in the form of a PRO to collect their end-of-life product. However, in most developing countries, there is a large part collected by the informal sector. This is perceived as a barrier to implementing EPR for plastic packaging since contact and transparency are unavailable (Nahman, 2010). This means a change in responsibility is harder to implement. Therefore, they emphasize that governmental support is necessary for a proper EPR implementation (Hotta et al., 2009). Tristiana et al. (2018) acknowledge this and mention that Indonesia specifically lacks funding, awareness, and commitment of stakeholders that prevent the implementation of EPR. They do mention multiple EPR instruments but do not recommend specific ones over others that might be suitable for Indonesia. Therefore, it is needed to investigate what interventions can be most valuable to reduce plastic pollution in Indonesia.

Gupt & Sahay (2015) also compare EPR in developed and developing economies. One finding was that developing countries with a large informal sector, like China and India, have difficulty making the EPR regulations work efficiently. This is because the informal sector collects more efficiently, and the formal sector, therefore, cannot reach its recycling targets. The retailers and households favor the informal sector more because they come more frequently than the formal sector (Gupt & Sahay, 2015). This gives friction because the producers cannot live up to the recycling targets, as the informal sector already takes end-of-life products.

2.3.4 Low and high-value plastics

Kaffine & O'Reilly (2015) initiated another financial reason why EPR in developing countries might not work. In developing countries, most packaging materials are mainly low-value waste streams that are more difficult to recycle. Therefore, it is challenging to include low-value waste streams in industry-led EPR systems since the financial potential is very low or even negative.

There are a few examples where voluntary EPR schemes are used. For example, the PRO PETCO manages the EPR fees for PET importers in South Africa (Quoden & Grant, 2019). It uses the fees to assist collectors and recyclers financially. In Mexico, ECOCE is a voluntary initiative of producers and local organizations and stimulates better collection, sorting, and recycling of PET waste, and focuses on awareness creation. Voluntary systems thus result mainly in high-value plastics collection because only plastics with a high economic value can provide revenue with recycling (OECD, 2016).

However, plastic pollution is mainly due to low-value plastics that are difficult to recycle; thus, more than a voluntary system is needed to encounter the plastic waste problem. EPR systems are also designed to finance the waste system as a whole (Ana Pires et al., 2015; The Pew Charitable Trusts & Systemiq, 2020), but to establish this, all stakeholders need to be involved. Especially the brand owners need to pay for their plastic products, which needs to be established in a mandatory EPR system. Governmental support and compliance are needed for this, which is difficult in Indonesia (Hotta et al., 2009). It is also hard to establish a mandatory system when there is no proper collection system in place yet. South Africa showed that implementing a voluntary system prior to a mandatory system can be beneficial. It can give motivate innovation in an early stage. They started voluntary, but the high-value waste streams give the incentive to cooperate. When this works, the system can expand to lower-value waste streams, as it can built on existing networks and infrastructure (Nahman, 2010).

2.3.5 Improvements

Leal Filho et al. (2019) also analyzed the role of EPR on plastic products in developing countries. They come up with some improvements that can be made to enhance EPR. One of them is to

increase waste separation and collection to improve the quality of the waste streams so they can be recycled more easily (Leal Filho et al., 2019). They also mention that governmental organizations need to take the lead in this and take into account the necessities of other stakeholders involved. Finally, they emphasize that EPR instruments need to be put in line with other policy instruments to achieve the most optimal results. Using complementary policies that stimulate consumer behavior is confirmed by other research (Gupt & Sahay, 2015).

2.4 Agent-based modeling

Agent-based modeling is a bottom-up approach that can analyze how individual behavior impacts the system level (van Dam et al., 2013). It can conceptualize the current plastic collection system in a developing country to answer the third sub question. An ABM is an effective way to capture complex adaptive systems (CAS) (van Dam et al., 2013). The plastic waste collection system in developing countries is such, as explained in section 2.1.3. The interaction and interdependencies between the different stakeholders result in emergent behavior (van Dam et al., 2013). Therefore, it is needed to gather insights into how individual behavior can be stimulated into the desired system behavior. This (emergent) behavior analysis can be captured in an agent-based model (ABM) (van Dam et al., 2013).

Previous research analyzed the informal sector via an ABM (García-Díaz & Moreno-Monroy, 2012; Gibson, 2012). These studies focused on generally working in the informal sector rather than waste workers. Gibson (2012) modeled whether workers become formal or informal, based on the exhaustion of a specific trade market, and analyzed policy effects that specifically would promote the inclusion of informal workers. García-Díaz & Moreno-Monroy (2012) modeled the informal sector due to urban migration and social influence and concluded that the share of social influence could determine the behavior a lot. These ABM articles thus focused on working when informal workers want/can change their occupation. However, it is questionable whether informal waste workers can change their occupations.

Kerdlap et al. (2020) used ABM for analyzing plastic collection, sorting, and recycling possibilities. However, they used the model's output, together with material outputs and transportation data, for environmental impact analysis, rather than simulating policy interventions or looking at recycling rates. The research of (Meng, Wen, & Qian, 2018) focused on the recycling behavior of households in China. They implemented policy scenarios with a fee on collected waste and a fee on non-recyclable waste. This impacts the willingness to separate waste at a household level, but not specifically on the waste collection itself. There also was little difference between formal and informal collectors made.

Destyanto et al. (2019) researched the effects of EPR on plastic waste management policies in Indonesia. They used System Dynamics modeling, a top-down approach rather than bottom-up (Ding, Gong, Li, & Wu, 2018). They made valid conclusions on the need for specific governmental regulations. Even though they acknowledged that the informal sector is a prevalent topic in Indonesia, the behavior of the informal sector was not included in their model.

These studies show that bottom-up research can have great value. Waste management systems require this type of analysis due to their complexity and to be able to simulate policy interventions.

2.5 Summary chapter 2

This chapter focused on the available literature on three topics. First, it analyzed plastic waste in Indonesia. The plastic waste system in Indonesia can be described as a **complex adaptive socio-technical system**, as there are many stakeholders involved that behave in a certain way. Social components like producers, households that produce waste, different collectors, and recyclers interact with technical artifacts like plastics and recycling facilities. The **dynamic behavior** between these types of artifacts with each other and their environment can cause emergent behavior. In previous literature, the behavior of the informal sector and households are deemed to be important in the waste management context of Indonesia.

Secondly, Extended Producer Responsibility was defined based on literature, and most common practices in different countries were evaluated. In Europe, some things have been working well when implementing EPR on packaging materials. 1) **concrete instruments** should be implemented, not only guidelines; 2) **multiple instruments** should be implemented for a system approach that can achieve better results; 3) **local context** should be taken into account; 4) **targets** should be set and lived up to, including **penalties** when not achieving those targets.

In developing countries, there are a few issues that complicate the implementation of EPR. First, the **informal sector** usually does a large part of the recycling already, making it challenging to implement formal instruments. Secondly, the financials of waste collections and disposal are not good as the plastics that linger around are **harder to recycle**. Thirdly, there is a lack of **awareness** of stakeholders about the environmental effects of waste pollution. Fourthly, there is little **commitment** and **compliance** of stakeholders.

Three things should therefore be taken into account when implementing EPR in developing countries. 1) improve the **source separation** and waste **collection** system; 1) implement a **combination** of regulatory, financial, and communicative instruments; 2) take the **local context** into account.

Then, the third topic of the theoretical background was explained. A specific research method is required in a complex adaptive plastic system, where interventions need to be analyzed. **Agent-based modeling** (ABM) is a method that 1) captures complex adaptive systems, 2) can model the behavior of specific stakeholders, and 3) can simulate and analyze policy interventions.

This bottom-up approach has been used before in the waste management sector of developed and developing countries (García-Díaz & Moreno-Monroy, 2012; Gibson, 2012; Kerdlap et al., 2020; Meng et al., 2018). However, these studies did not analyze **EPR-related policy interventions**. Analyzing single and combinations of EPR instruments for Indonesia is thus one research gap. The second is that **simulating EPR instruments** enables integrating multiple perspectives, which can consider a country's local context.

3. Research approach

This chapter provides an overview of the research approach of this thesis. The overarching research approach used in this thesis is based on the design science research of Hevner & Chatterjee (2010). This framework consists of three aspects: the environment, the knowledge base, and the design of an artifact. The knowledge base is created in the introduction and theoretical background, laying the foundation for the research. Chapters four and five consist of the environment, where people, organizations, and technical systems are defined. The design of the artifact is done via agent-based modeling. In the first section of this chapter, an overview of the thesis outline is presented. Then, the methodologies of design science research and agent-based modeling are explained.

3.1 Thesis outline

The diagram below provides an overview of the structure of the proposed thesis research. The thesis broadly consists of four parts, which are visualized in yellow in Figure 3.1. The sections supplement each other, indicated with the arrows. Even though all parts need iteration, the Design Science Research phase requires more emphasis in this regard.

The first part of the thesis focuses on the Knowledge Base, setting the base of the research. In the second part, the Environment is described. This is done by analyzing contextual factors of the Indonesian waste system to answer the first sub question. Furthermore, different EPR interventions are evaluated to answer sub question two. The output of these analyses is used for the Design Science Research. The system will be conceptualized into an agent-based model to answer sub question 3. The model will simulate the plastic waste system and run experiments with different EPR interventions. The running of experiments and analyzing its results will be done to answer sub question 4. The fourth part of the thesis discusses the results, concludes the research, and makes recommendations based on the outcomes.

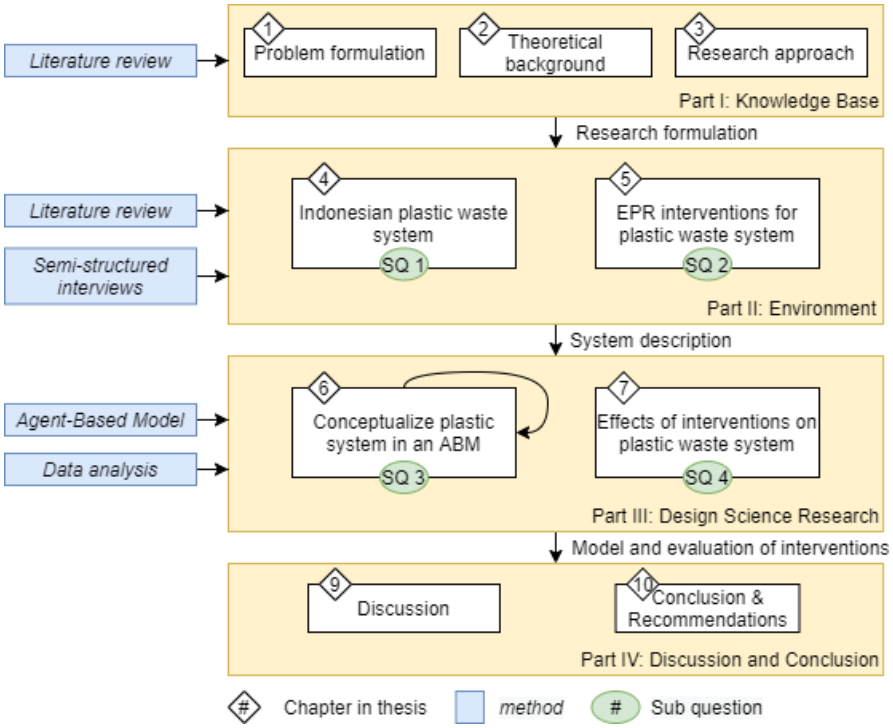


Figure 3.1 - Thesis research outline

3.2 Design Science Research

Hevner & Chatterjee (2010) combine the use of research with design science to innovate artifacts through scientific research and practical relevance. This approach is applicable for this thesis since the model (the artifact) should be substantiated by scientific literature for a scientific background and practical relevance to contribute to the plastic waste problem.

Hevner (2007) provided a framework using three cycles: the Relevance, the Rigor, and the Design Cycle (Figure 3.2). These illustrate the three aspects of proper design science research in the field of Information Systems (IS). IS are seen as the discipline of combining information technology with organizational issues (A. Hevner & Chatterjee, 2010), which is relatable to the socio-technical system of this thesis.

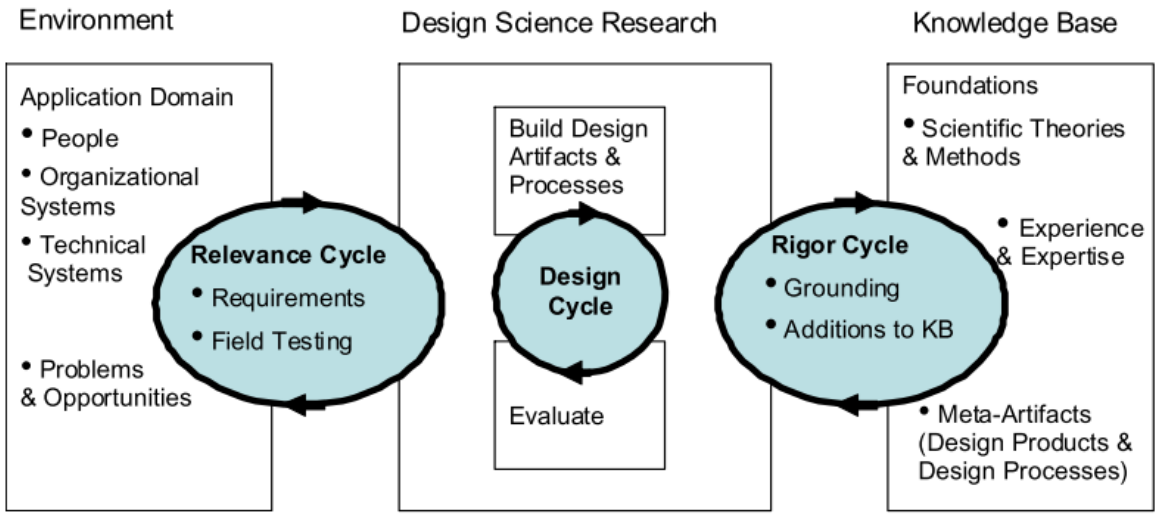


Figure 3.2 - Design science research cycles (Hevner, 2007)

In the Relevance Cycle, the contextual environment of the research is laid out. The problem is determined, the system is analyzed, and the contextual factors are made clear. It ensures the research not only fills a scientific gap but also provides recommendations that improve the environment (Hevner, 2007). The Relevance Cycle can mainly be found in chapters 4 and 5, where the system analysis occurs (see 3.3.1 for more explanation on the system analysis). It provides the context of Indonesia to the agent-based model.

In the Rigor Cycle, the scientific knowledge base is established. This cycle focuses on the scientific aspects of the design artifact to lay the theoretical base and ensure the artifact's innovation. It emphasizes the scientific focus by laying out the knowledge gap and provides insights into the study's scientific contribution (Hevner, 2007). This is mainly expressed in the theoretical background of chapter 2, where it gives theoretical input to the model. In the discussion chapter, the academic contribution is explained, which is also part of the rigor cycle.

The Design cycle is an iterative process of building an artifact while keeping in mind the Rigor and Relevance cycle (Hevner, 2007). This artifact is the agent-based model (ABM) that is created for analyzing EPR interventions in Indonesia. The model is based on both the scientific literature review and the interviews with people from the (Indonesian) plastic system. The input of previous chapters is used in the design of the ABM in chapter 6.

The three Design Science Research Cycles of Hevner can have some overlap and can occur in different orders, which stimulates an iterative design and benefits the credibility of the artifact (Hevner & Chatterjee, 2010). The three Cycles in the context of this thesis research are visualized in Figure 3.3.

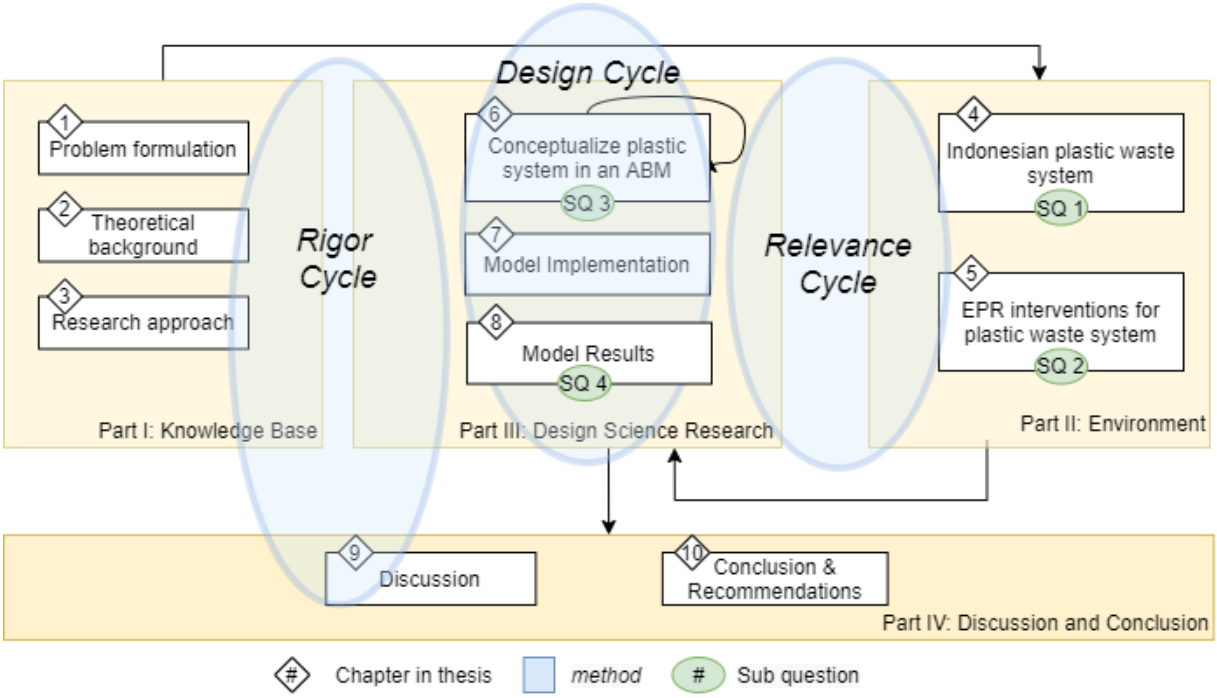


Figure 3.3 - Three Design Research Cycles of this research

3.3 Agent-based modeling

For designing the artifact, an agent-based model is made. This is a way of modeling complex socio-technical systems (van Dam et al., 2013). The ten steps proposed by van Dam et al. (2013) are used as a guideline for building the agent-based model (ABM). The ten steps are as follows:

Step 1: Problem formulation and actor identification
Step 2: System identification and decomposition
Step 3: Concept formalization
Step 4: Model formalization
Step 5: Software implementation
Step 6: Model verification
Step 7: Experimentation
Step 8: Data analysis
Step 9: Model validation
Step 10: Model use

Step 1 and step 2 will be done based on the system analysis of Enserink et al. (2010). They explain well how complex systems can be analyzed, and their approach is explained in more detail in section 3.3.1. These parts give a conceptual overview of the system in chapters 1-4. For step 3, the concepts will be translated into agents, networks, and the environment in chapter 6. This is supported by flow diagrams, a UML diagram (Dijkman, Hofstetter, & Koehler, 2011), and a BPMN-based flow diagram that visualizes the agent's behavior. Steps 4 to 6 are presented in chapter 7. For step 4, a model narrative is made, and the agents, their networks, and environment are

translated into computer-acceptable terms to model them. In step 5, the system is put into the programming language Netlogo (Wilensky, 1999). This tool can provide insides in the complex structure of adaptive systems (Nikolic, 2004), which is the case for the waste sector in developing countries. The model verification of step 6 has the goal to check whether the model in Netlogo does what it should do according to the conceptualization. The experimentation and data analysis of steps 7 and 8 will be done in chapter 8. Here, the experimental designs will be explained, as well as the results of the model runs. The *experiments* consist of the policy interventions, which are chosen and elaborated on in chapter 5. The data analysis will be done in the programming language Python (Van Rossum & Drake Jr, 1995). The model validation of step 9 will focus on the model's results and put them into perspective. This will be validated based on other literature in chapter 8. The goal of step 10 is to critically assess the results and make sure the results are interpreted with the limitations of modelling in mind. This will be elaborated on in the discussion section of chapter 9.

3.3.1 System analysis

The system analysis explained by (Enserink et al., 2010) will be used as a baseline in this thesis. The system analysis assesses a system, which is done in the first two modeling steps. The system analysis in this thesis consists of four parts.

1) problem formulation
2) actor identification
3) criteria identification
4) means analysis

The problem formulation has been done in chapter 1, where the societal problem and literature gap are extendedly explained. Then, based on literature and stakeholder interviews, an actor analysis is conducted, and criteria for the system are defined in chapter 4. Enserink et al. (2010) explain the actor analysis separately and not as part of the system analysis. This thesis combines them to provide an overview of the Indonesian plastic waste system to answer the first research question. The actor analysis is of value for this thesis, as it can be beneficial to capture all stakeholders involved when analyzing projects that require long-term investments (Bryson, 2004). The next step in the system analysis is analyzing the 'means' of the system, which are the interventions. Again, based on literature and stakeholder interviews, different policy interventions will be analyzed in chapter 5. In chapter 6, a decision strategy is made to determine which interventions will be included in the model. This strategy is elaborated upon in section 3.3.2. This can answer the second research question. As these steps of the system analysis can already answer the research questions, the last system analysis step of Enserink et al. (2010), the making of a system diagram, is not used.

Literature review

The literature review has been done semi-systemically to evaluate how Extended Producer Responsibility (EPR) has been analyzed by different researchers. The semi-systematic review is developed to provide an understanding of a complex topic and identify knowledge gaps. (Snyder, 2019). It focuses on relevant ways how EPR has been used before. Below the steps are described that were taken for the semi-systemic literature review.

Since EPR is a broad concept, a semi-systemic approach is used rather than a systemic literature review. The latter elaborates more extendedly on a specific topic (Wong, Greenhalgh, Westhorp, Buckingham, & Pawson, 2013). Since EPR is a very broad topic, a systemic literature review would take too much time. With the semi-systemic review, the EPR concept can still be analyzed. A more

general overview will be outlined rather than listing all relevant articles (as in a systemic literature review) (Snyder, 2019).

The literature review had three focus points. First, the context of plastic waste systems in Indonesia. Secondly, Extended Producer Responsibility (EPR) is explained extensively since this concept differs throughout literature. Thirdly, the use of agent-based modeling is elaborated upon.

Both Scopus and Google Scholar have been used to find relevant articles. In a first stage, search words comprise "EPR" OR "Extended Producer Responsibility" AND "Plastic*". Only articles in English and published in 2010 or later were included to filter the newer information. The article should focus on either 1) what type of EPR policies would be relevant for plastics or 2) what factors need to be considered when implementing them. The abstract was read first to evaluate the relevance before the full article was read. Furthermore, the so-called 'snowballing effect' was applied, where relevant references of found articles regarding EPR instruments will also be consulted for further assessment. Not only scientific literature but also grey literature has been analyzed because some non-scientific projects that involve the investigation of applying EPR instruments also provide relevant insights into effective strategies.

Interviews

Unfortunately, a field study was not possible during the pandemic. Nonetheless, online interviews were conducted with public and private parties who focus on plastic waste in Indonesia to provide a multi-perspective view on the problem. Based on the actor analysis, different types of organizations were asked for an interview. Eight semi-structured interviews were held with public, private, and communal organizations. Most interviews were conducted with Indonesian organizations, like the Indonesian national government, a private waste collector, a waste bank, and Indonesia's Packaging Recovery Organization. One interview was conducted with the Producer Responsibility Organization of the Netherlands to get insights into the Dutch and European EPR systems for packaging. This was used as inspiration and reference for a system in Indonesia. The interviews focused on the plastic waste system, which stakeholders are involved, how they interact with their environment, and what factors influence their behavior. Furthermore, in the interviews, EPR was discussed with stakeholders who were familiar with the concept. The interview guide with the protocols and data usage can be found in Appendix B. The interviews were organized via contacts of Rebel Group and personal contacts of the author.

3.3.2 Method for determining interventions

A list was made of the most used interventions that are associated with Extended Producer Responsibility. Three factors contributed to the decision of the interventions that were analyzed. The specific motivation for each intervention can be found in section 5.3.

Firstly, the instruments were divided into regulatory, financial, and communication tools, based on previous research (Gupt & Sahay, 2015; W. Leal Filho et al., 2019; A. Nahman, 2010; O. Nkwachukwu et al., 2013; OECD, 2016). Secondly, the instruments were evaluated based on their effects on the life cycle phases of a product. This was done to consider a possible consequence of EPR, burden-shifting to other product life cycle stages. The evaluation was based on literature and the author's interpretation of intervention explanations. Lastly, the factors that were deemed important when implementing EPR policies in Indonesia, established in section 4.4, were also considered when deciding on the interventions.

PART II – ENVIRONMENT

4. The Indonesian plastic waste system

When implementing policy measures, it is important to take into account the local context of that country. As has been explained in chapter 2, this can result in more systemic and long-lasting results. The second and third step of the system analysis are presented in this chapter. The current situation is explained by the actor analysis and is based on Enserink, Hermans, Kwakkel, Thissen, & Koppenjan (2010). This will also result in factors that should be considered when implementing policies in Indonesia. They are realized based on literature research and stakeholder interviews. They support the identification of interventions in chapter 5, which is the last step of the system analysis. The last subsection of this chapter defines criteria (or Key Performance indicators) that can measure the impact of the agent-based model.

4.1 The current plastic system in Indonesia

Since Indonesia has many islands, the waste management practices vary greatly between the areas, even between different cities on the same island. The level of rural and urban land determines how the waste system is set up, if at all. World Economic Forum (2020), together with the Global Plastic Action Partnership and the Indonesia National Plastic Action Partnership, provided an overview of the waste practices in Indonesia and divided the country into four 'archetypes': mega, medium, rural and remote. The end of life of (plastic) products differentiates a lot between these archetypes. For this thesis, the *medium* archetype is chosen to focus on because of two reasons.

1) In medium and mega cities, there is already (limited) waste collection infrastructure present;
2) Possible EPR interventions will initially have the focus on Java and Bali island, where most areas have a medium or rural archetype.

A schematic overview of the plastic system in Indonesia has been made in Figure 4.1. The arrows indicate plastic in different life-cycle phases. After production, the consumers 'produce' the plastic waste, which gets collected by either formal or informal workers. A large part does not get collected but gets burned in backyards or thrown away in rivers. This mainly happens in rural areas, where there is little to no collection infrastructure, and also still in cities (World Economic Forum, 2020). Waste pickers go to houses to collect recyclable waste. They then bring their waste to middlemen, who further sort, clean, and shred the plastics in their turn. Finally, they sell the shredded plastics to recycling facilities. Usually, multiple middlemen (also called aggregators/big bosses/small bosses) buy and sell the recyclables before they reach the recyclers (Bank Sampah, personal communication, 2021).

Formal plastic collection is available mainly in medium to large cities. Waste collected by the municipality gets mixed with other waste streams. Some waste pickers retrieve recyclables from this waste at transfer stations, but almost everything gets directly disposed of into unsanitary landfills (World Economic Forum, 2020). Private waste collectors bring the waste first to a sorting and processing center (TPS3R), but this is only a tiny amount of all waste (Adupi & IPF, personal communication, 2021). This TPS3R separates organic waste from recyclables and residues. The organic waste gets composted, the recyclables get further decomposed and sold to middlemen, and the residues are brought to landfills. Since most harmful material like plastic gets separated from the residues, these are 'sanitary' landfills rather than unsanitary. Even though there are hundreds of the TPS3R facilities placed in Indonesia, the majority of them are not in use right now due to a lack of knowledge and commitment of stakeholders (IPF & McKinsey.org, personal communication, 2021).

Currently, 39% of waste gets collected, of which 10% gets recycled, not more than 1% gets managed via TPS3R, and 28% goes straight to landfills. The other 61% does not get collected at all (World Economic Forum, 2020). The recycled 10% is almost entirely done by the informal sector, who collect it on streets, in front of houses, or at landfills.

However, municipal collectors usually don't treat the waste before transporting it to a landfill (The Pew Charitable Trusts & Systemiq, 2020). This results in enormous dumpsites, where hazardous materials can still harm the environment. First, sorting out harmful materials, organics and recyclables can reduce much of the adverse effects (IPF & McKinsey.org, personal communication, 2021).

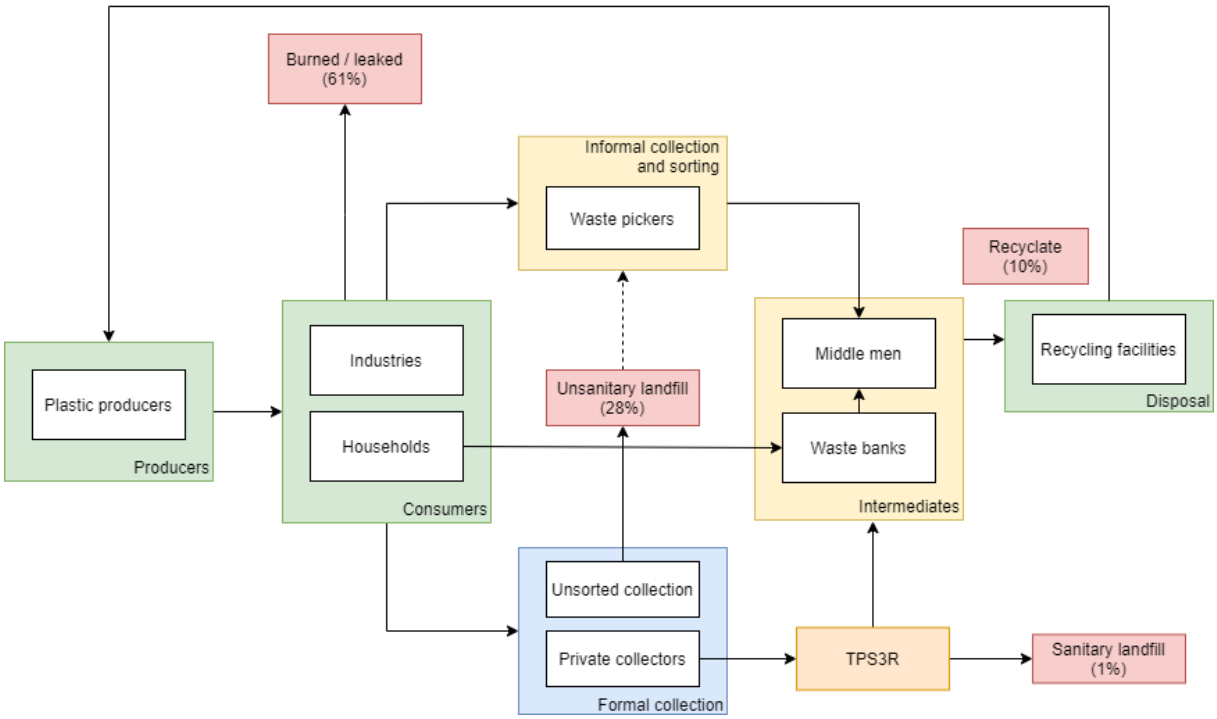


Figure 4.1 – Simplified Indonesian plastic system

4.1.1 Actors

An actor analysis has been made to have an overview of all stakeholders (or actors) involved. All stakeholders involved in Indonesian waste management are listed in Appendix C. Based on the stakeholder list, a formal chart can be made. A formal chart of the actors can give context to relations within the system and provides insights into the dependencies between actors (Enserink et al., 2010). In Appendix C, the full formal chart is visualized. A simplified version is presented in Figure 4.2. The most important actors are visualized here, and their relations are captured in arrows and the accompanying text.

The actor with the highest level of the national government is the national Ministry of Environment and Forestry (MoEF). They are responsible for national regulations and policies regarding waste management in Indonesia (MoEF, personal communication, 2021). These have to be followed by citizens, producers, and lower-level governmental organizations. However, some regulations of regional governments aren't fully aligned with the higher-level rules, which causes bureaucratic inconsistencies (McKinsey.org, personal communication, 2021).

Furthermore, MoEF provides regional governments with funding for waste management to invest in infrastructure, machinery, and vehicles. In the interview with the director of food packaging of the MoEF, they pointed out the responsibility of the lower-level governmental organizations: "The implementation of solid waste management is the responsibility of the local government. In this (waste management) context, a central government assists the local government to improve their capacity, ability, and infrastructure. " (MoEF, personal communication, 2021). He meant that the division of responsibility should be maintained, but also collaboration is needed. The local government he referred to was at desa-level (subdistricts).

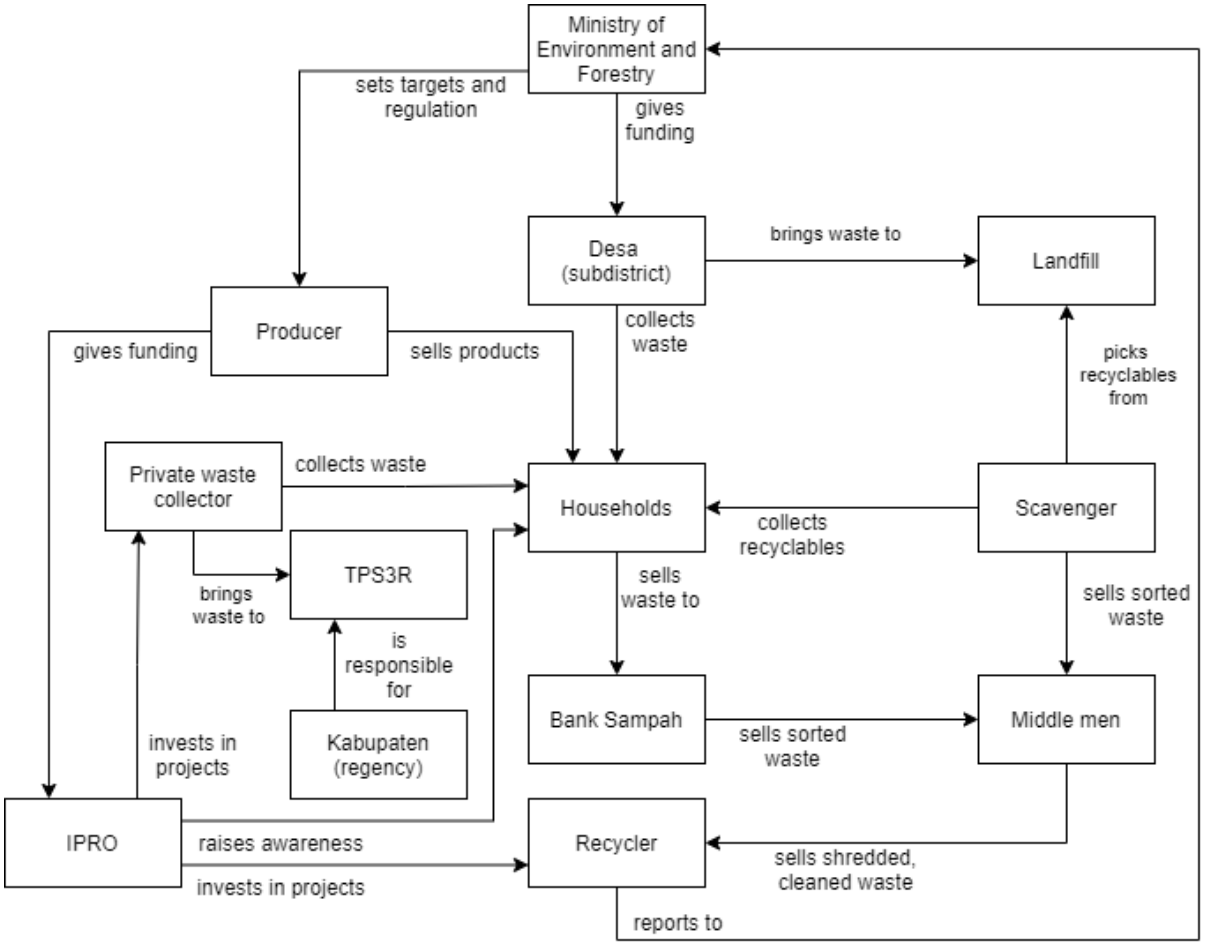


Figure 4.2 - Simplified actor map

The *kabupaten* is a regency in Indonesia, of which there are 416 right now. Almost every regency has a TPS3R, which is a waste separating facility. From here, the organic fracture can be composted, recyclables can be sold, and the residues are brought to landfills. However, after the construction of the TPS3R facilities, there was no one to manage the facility and the waste streams. That is why they closed most of them before they were actually in use (IPF & McKinsey.org, personal communication, 2021).

Desa is a subdistrict, who is responsible for the implementation of waste management. In some subdistricts, there is municipal collection of waste, which picks it up at households. They usually pay a fee for the collection. However, this is not offered in every subdistrict, which leads to households burning their waste on streets and dumping it in rivers. Practically all municipal waste

collection is going straight to landfill because the government doesn't "have a proper system to collect and segregate the waste," and they "don't have a network to sell the segregated waste to. That is why they just collect and dump into to the landfill." (Adupi, personal communication, 2021).

Households buy products with plastic packaging and, depending on the subdistrict, community, and personal motivation, separate recyclables from the rest of the waste or not. The household separation behavior is explained in more detail in section 4.3. If they do separate, they either bring it to a *bank sampah* (waste bank) or let a waste picker pick them up. Waste pickers and waste banks bring recyclables to middlemen, who resell, clean, and shred them into small pieces. Only high-quality, well-separated parts can be sold to recyclers (Adupi, personal communication, 2021).

IPRO, the Indonesian Packaging Recovery Organization, was formally established in February 2021. They focus on 1) stimulating small collecting and recycling initiatives currently in place, 2) investing in TPS3Rs management, and 3) awareness-raising regarding source segregation. They, therefore, invest in projects that collect household waste or recycle plastics (IPRO, personal communication, 2021).

The TPS3R is a facility that sorts solid waste into wet waste, recyclables, and residues. The wet waste is composted, the recyclables are brought to middlemen, and the residues are brought to landfills after harmful materials are extracted. The facility's operational costs can be covered when a small waste management fee is asked to the households (McKinsey.org & IPRO, personal communication, 2021). TPS3Rs are an example of conflicting responsibilities. They were built by the Ministry of Public Works, which is responsible for the infrastructure. The MoEF needs to get the systems running, but the funding is the responsibility of the Minister of Desas, which results in a "lack of accountability" (McKinsey.org, personal communication, 2021).

4.1.2 Governance

In Indonesia, there is a national law on Solid waste management (Act No18/2008). It indicates that the national government is responsible for formulating national waste management policy and should facilitate cooperation among regions and local governments. It is also responsible for coordination and monitoring of the performance of local governments.

The provincial government has similar responsibilities, but then for lower-level organizations. They are responsible for formulating district policies that should be in line with the national guidelines. They furthermore need to facilitate cooperation between regions within one province. They are also responsible for the coordination of the performance of districts and municipalities.

The act indicates the district/municipal government is more responsible for the operational tasks. They need to carry out waste management at the district level in a way that is in line with provincial and national policies. Furthermore, they need to monitor the waste management performance and waste processing sites. They are also responsible for the locations of temporary collection sites and final waste processing sites.

The Act implies that mainly the lower-level governmental organizations are responsible for the implementation of waste management practices. In practice, however, there is some discussion on which parts of waste management are managed nationally, regionally, or locally. The complexity lies in the different districts and regencies' different preferences, infrastructure, and

capabilities (McKinsey.org, personal communication, 2021). Furthermore, organizations that try to support local governments with better waste collection and separation systems seem to encounter inconsistent national and regional regulations. Although formally, the national one should support the lower-level laws, and the other way around, this isn't always the case (McKinsey.org, personal communication, 2021).

For example, there is an excellent amount of TPS3R facilities installed all over Indonesia, but their use is less than 10% (IPF & McKinsey.org, personal communication, 2021). Formally, the TPS3Rs are under the responsibility of *kabupatens* (regencies). Still, in practice, they are managed (if at all) by more local *desas* (subdistricts), as the local communities usually manage the area's waste management.

Furthermore, there has been a regulation since 2019: Ministerial Regulation (MoEF) No. P.75/2019 on Roadmap to Waste Reduction by Producers. Rather than suggest concrete measures for producers to live up to, the regulation focuses on reducing plastic production and stimulates the recycling of plastic packaging. They have set ambitious targets for 2025 and 2030 regarding collection and recycling, but no strict rules for non-compliance are installed.

IPRO advocates for a shared vision on waste management between lower- and higher-level governmental organizations, but with a clear division in responsibilities. The MoEF itself mentioned their main task is to formulate the regulations, which they have done, and it is now to the local governments to improve their waste management capacities (MoEF, personal communication, 2021). However, almost all other interviewees mentioned that of all stakeholders, the MoEF has the most significant responsibility to improve the waste management system actively, besides making regulations. Instead of dumping all different waste streams on landfills, they should focus more on improving the waste management system and invest in better disposal and recycling infrastructure.

Almost all stakeholders agree that the national government needs to set proper regulations and that there are good regulations to divide responsibility regarding waste management. However, the national Ministry of Environment and Forestry (MoEF) is not so much enforcing their policies, and therefore "acting more like an operator, rather than a regulator," according to private waste collector Waste 4 Change (W4C, personal communication, 2021). Other stakeholders agree that enforcement of the national regulations would be beneficial for all waste management practices.

4.1.3 Level of power and interest of stakeholders

When looking at the system, it is beneficial to analyze the different stakeholders based on their level of 'power' on the issue of interest, in this case, plastic waste management. This namely indicates to what extent the stakeholder can influence the situation. On the other hand, the interest of stakeholders in the problem can tell to what extent the stakeholder *wants* to control the situation. In Figure 4.3 below, a power-interest grid is shown with the most critical stakeholders present. It is made based on the interviews and the formal power the different actors have.

The figure shows that the ministry has the most power since they can legally enforce the others to live up to the regulations. In practice, however, they do not actively make producers take back their end-of-life products or make households segregate their waste. And even though they have sanction articles in their regulations, it is not common for them to use them (IPF, Adupi, McKinsey.org, W4C, personal communication, 2021).

Private waste collectors are also in a power position since they try to make a business case out of the waste collection and processing phase. They ask for a small collection fee to make it a sustainable business and also to pick up low-value waste, besides recyclables (W4C, personal communication, 2021). These private collectors can therefore impact the waste collection system when they scale up or expand their services.

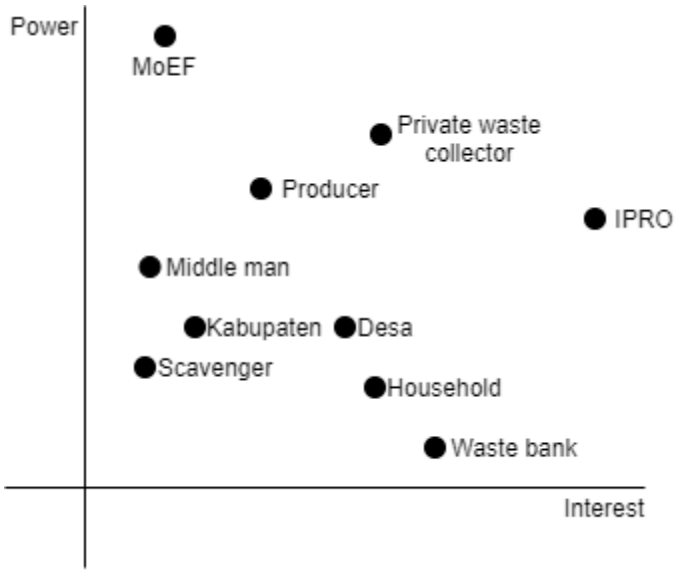


Figure 4.3 - Power-interest grid

Furthermore, IPRO has a very high interest in the waste management issue since this is the core of why they are established. And since they are learning a lot from similar initiatives in other Asian and European countries, they have an extensive knowledge base to rely on. Producers have a bit more power since they are funding IPRO to exist and to be able to invest in projects.

Then there are middlemen, scavengers, and kabupatens, who don't have much interest in the issue. The main goal of the first two is to make a living out of waste streams rather than solving the waste management problem. The level of kabupatens is just too high to implement things, and they have too little financial and knowledge means to contribute. Desas are connected more to the community, which confronts them with the waste management problem more directly. But since their financial and knowledge means are still relatively low, they still cannot contribute very much.

Households have a higher interest, but it is not at the maximum interest level since not all citizens know the waste management problem. Moreover, their power is rather low since they are dependent on waste collection and disposal services. Waste banks have an even higher interest since they also have an educational aspect besides their recyclable intake possibilities. Also, their power is meager since waste banks operate locally and therefore have few recyclable volumes to present to middlemen (McKinsey.org, Bank Sampah, personal communication, 2021).

4.2 Informal sector waste collection

The recycling rate in Indonesia is around 10%, which is captured almost entirely by the informal sector. In this sense, the meaning of 'informal' is that people pick waste and sell it again and make

their livelihood out of these earnings without having an official employer for it. They could pick up recyclables from streets, households, bins, transfer stations, or dumpsites. Research has been done on these practices, and there is a lot of social commitment involved (Sasaki & Araki, 2014).

According to Sasaki & Araki (2013), the informal sector in waste management has eight different types of workers. Small bosses, big bosses, big middlemen, small middlemen, live-in and live-out waste pickers, daily workers, and independent waste pickers. All waste workers have their own dependencies with other people involved. For example, waste pickers rely on middlemen and are therefore relying on them for a steady income. "Scavengers are in-depth to the bigger junk shops. They provide a place to live, and then they need to give them some recyclable materials" (W4C personal communication, 2021). These dependencies lock the scavengers, or waste-pickers, in the informal waste working sector, and it is difficult to get out of them.

On the other hand, there are many competitors in the PET market, which creates a better position for the waste pickers. According to IPRO, "there are a lot of junk shops that want PET waste" (personal communication, 2021). This indicates there is enough demand for recycled materials. However, the job of collecting waste still has a negative connotation and is therefore not very attractive to do (ADUPI, W4C, personal communication, 2021).

Waste pickers use a large bag or small handcarts to collect the waste (Chaerul, Tanaka, & Shekdar, 2007; IPI, personal communication, 2021). They sell the collected recyclables to the nearest aggregator without treating them. This aggregator also determines the price they pay for it, which is around 2500 IDR (± €0.15) per kg, with minor variations for the type of plastic (Chaerul et al., 2014).

Gibson (2012) and García-Díaz & Moreno-Monroy (2012) analyzed the behavior of the informal sector as a market based on economic and social incentives. In this thesis, however, informal waste workers are more seen as essential stakeholders in the system than emerging agents. This is based on the interviews that acknowledge that most informal waste workers do not actively choose to work or not work in this sector.

4.3 Household separation behavior

It has been mentioned in almost every interview that the first step for better (plastic) waste management is source separation to enable segregated collection. At the household level, waste needs to be separated to be able to recover more recyclables. Contamination of too much organic waste causes plastics or other recyclables to deteriorate quicker, resulting in less or no recyclability. However, households don't seem to separate their waste much, as they either don't know about its benefits or get demotivated when they see municipal collectors mix everything together (Aprilia, Tezuka, & Spaargaren, 2012; IPF&ADUPI, personal communication, 2021).

Literature too emphasizes the necessity of household separation to improve the recycling rate. However, they also emphasize this behavior change is something difficult to change. To improve household behavior, three main factors are considered to be of most importance: motivation, capability, and opportunity (Michie et al., 2011). Private collectors *Waste 4 Change* confirmed this in their interview. One of their four pillars ('Campaigning') is to promote awareness amongst Indonesian households and acknowledge the necessity of behavior change: "Behavior change can only be achieved if you have 1) motivation, 2) capability, and 3) opportunity." (W4C, personal communication, 2021).

4.3.1 Motivation

The motivation for households to separate waste is answering the question of whether households *want* to separate their waste. This involves awareness about plastic waste pollution because they want less waste pollution on the street or in the environment. This depends on their own experience and that of others. Especially in Indonesia, the influence of people's community is largely due to the large social cohesion, so the experiences of waste separation are shared amongst each other (Aprilia et al., 2012).

Their initial motivation is based on the diffusion of innovation theory of Rogers (1995). He states people can be categorized into five groups when it comes to accepting new innovations. The Innovators, which is 2,5% of the society, are most open to changes and are front-runners when it comes to new ideas and opportunities. The next 13.5% are called Early adopters, who too are willing to change their behavior quite soon but are less active looking for new innovations. Then there is 34% Early majority, who are willing to adapt but somewhat slower in the adaptation process. The next 34% are the Late majority who have a higher degree of skepticism towards innovations. The last 16% are Laggards who are usually conservative and averse to change. These five categories (Figure 4.4) lay the basis of the attitude of Indonesian households towards implementing source segregation.

Figure 4.4 - Diffusion of Innovation theory, based on Rogers (1995) from (Castro, Cox, & Fukumoto, 2017)

4.3.2 Capability

Even when people are willing to change, they require to have resources to live up to their desired behavior. This can consist of time to do the separation, money to buy different bins, but also the knowledge of how to separate waste. In this thesis, the capability aspect is based on the financial means to make the source separation possible. 72% of Indonesian households in urban areas are associated 'non-poor' by the World Bank. This percentage of households is assumed to be able to purchase separate waste bins and have the space for this in their homes (World Bank Group, 2016). It is known that 'capability' could include more than just this financial means, but for the purpose of this research, it is simplified to this percentage. This percentage is reflected upon in the sensitivity analysis (see section 8.3.1).

4.3.3 Opportunity

When households have the motivation and capability, they will separate their waste. However, since the waste collection in Indonesia is not evident, this does not mean the separated waste gets collected separately. Therefore, the opportunity is defined as the occurrence of waste collectors at the households.

Motivation and Capability thus determine whether the households separate their waste. Opportunity decides whether the segregated waste gets collected in separately or mixed. In section 6 these three factors are conceptualized for the model input and their interdependencies are visualized by a flow diagram.

4.4 Four factors to take into account

The EPR system that is in use in most countries in Europe cannot directly be implemented in Indonesia. As mentioned in chapter 2, the most important factor that has been discussed in literature for implementing policies is improving source separation and collection, implementing a system approach, and keeping the local context in mind.

The need for separation and collection improvements is formulated as little existing waste management infrastructure. The system approach should be taken into account by involving low-value or multi-layered plastics (Sulami et al., 2018; IPF, personal communication, 2021). Assessing literature in combination with the interviews, the local context mainly comes down to three things. 1) inclusion of the large informal sector, 2) compliance is needed to make people comply with regulations, 3) the lack of waste management infrastructure and its needed funding to establish this (Chaerul et al., 2014; Raharjo et al., 2017; Sulami et al., 2018; IPF&W4C&Adupi&McKinsey.org, personal communication, 2021). Since the third point is similar to the first element, it is combined into four factors.

- Little existing waste management infrastructure
- Involvement of hard to recycle plastics
- Involvement of the informal sector
- Compliance

4.5 Key Performance Indicators – measuring effects

The goal of the model is to achieve insights into the effects of different EPR measures on the Indonesian waste system. Key Performance Indicators (KPIs) are output variables of the model where the model's 'performance' is evaluated. The KPIs are specific variables that should reflect the most essential objectives of the system. In this research, 5 KPIs are formulated. The first four focus on the end-of-life phase of the materials, and the fifth focuses on the informal sector.

Collection rate of the total waste
Municipal collectors usually do waste collection in Indonesian cities. This is the first step towards reducing environmental pollution, as households don't have to get rid of their waste themselves by burning or dumping it illegally. The ambition of the Indonesian government is to achieve a target of 70% waste collection by 2025 (Ministry of Environment and Forestry, 2020).

Collection rate of recyclables
Until now, only 39% of all used plastics get collected in Indonesia (World Economic Forum, 2020). This low number is usually due to the lack of collection infrastructure. The many islands and different waste management strategies throughout the country do not help this proper waste management system deficit. In medium-sized cities, this is a bit more (45%) due to the better collection infrastructure and availability of the informal sector. This number should increase to reduce the environmental pollution due to plastic debris.

Recycling rate
Most of the collected recyclables are still not separated from other waste, as municipal collectors don't separate waste before transporting it to landfills. Of the 45% collected plastics in medium-sized cities, around 1/4th (12%) gets recycled, almost all of which is done by the informal sector (World Economic Forum, 2020). If this percentage can be increased, less waste goes into landfills, where plastic leakage harms the environment.

Leaked recyclables
Most of the uncollected waste is burned by households (78%). The rest is either dumped in rivers or on land, which causes the large plastic volumes to end up in water bodies through rainwater runoff. This percentage should thus decrease to reduce environmental pollution through plastic debris.

WP recycled
Estimations of informal waste workers in an average Indonesian city go up to thousands of people (Sembiring & Nitivattananon, 2010). When the governmental ambitions of 70% waste collection (Ministry of Environment and Forestry, 2020) are lived up to, the livelihood of many waste pickers might be in danger. To evaluate this, the amount of kg that is collected by waste pickers is the last KPI of this study. It is assumed that when this decreases, the income of their household decreases which can cause social and financial distress.

4.6 Summary chapter 4

The most important stakeholders of the Indonesian plastic waste system and their relationships are discussed. In Indonesia, many waste management policies are in use, but they appear to not all be consistent with each other. Due to the lack of communication between parties and different visions on waste management responsibilities, **inconsistencies** and (unnecessary) complicated processes occur. As a result of the lack of transparent governance and a financial structure, many households do **not have the opportunity** to let their waste get collected.

Furthermore, many stakeholders want to improve the waste management sector but do not always have the **resources**. The informal collectors take care of almost all recycling activities but do not get proper training, health conditions, and **social acceptance**. Due to the negative association that people still have with waste workers, it is not a favored job. This results in less interaction with other stakeholders that affect the collection and recycling rate. **Household behavior** is an aspect of waste management that is of great importance, according to literature and interviews. Therefore, **source separation** should be a priority for municipal solid waste management to achieve higher collection and recycling rates.

There are four factors of importance when implementing EPR policies in Indonesia. 1) **Little existing waste management infrastructure**; 2) Involvement of **hard to recycle plastics**; 3) Involvement of the **informal sector**, and 4) **Compliance**. In the agent-based model, five KPIs are included. Collection rate of the total waste, the collection rate of the recyclables, the recycling rate, the leaked waste percentage, and the amount recycled by waste pickers.

5. EPR for plastic waste management

Chapter five is the next phase of the system analysis, which is based on Enserink, Hermans, Kwakkel, Thissen, & Koppenjan (2010). Chapter 4 focused on the actor analysis and determined KPIs. This chapter will identify means, or interventions, to influence this system to improve the plastic waste condition in Indonesia. These interventions will be based on Extended Producer Responsibility (EPR). In chapter 2, it was briefly shown that literature has multiple definitions of EPR. However, a clear problem definition and a proper explanation of how EPR seems to tackle this problem are needed to effectively implement the policy (Hotta et al., 2009). Therefore, this chapter goes into more detail about what EPR measures can be applied in Indonesia.

5.1 Plastic life cycle

When looking at plastic waste management, there are multiple life cycle stages of plastic products. The material is produced, manufactured, used, collected, disposed and possibly recycled. EPR is a way to stimulate producers to improve the environmental effect of their products throughout the entire value chain (OECD & Ministry of the Environment, 2014). This means when implementing policies, there should be a focus on the product's complete life cycle to prevent environmental harm from being shifted towards a different part of the value chain (OECD, 2016) as a critical element of using EPR systems. Furthermore, they emphasize that EPR instruments can affect different parts of this product value chain, stimulating different behavior (OECD, 2016). The life cycle stages of a product are also referred to as *upstream* and *downstream* interventions. Upstream inventions focus on the phases before the product reaches the retailer or consumer, whereas downstream interventions refer to policies that affect stages of the product post-consumption. Figure 5.1 shows the phases of a product life cycle (based on Mckerlie, Knight, & Thorpe, 2006 and OECD, 2016) and contain upstream and downstream stages as well as the consumption phase.

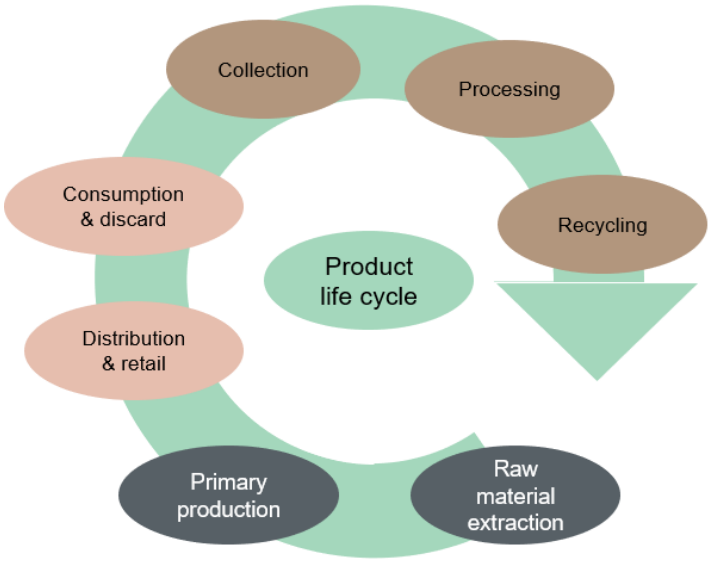


Figure 5.1 - Product life-cycle (based on McKerlie et al., 2006 and OECD, 2016)

Instruments that target the upstream phase of a product were recommended by private parties in the system and NGOs since it stimulates producers to redesign (IPF & Adupi, McKinsey.org, personal communication, 2021). However, upstream interventions are not implemented in

European EPR systems due to higher-level legislation regarding free market (Besluit regeling voor uitgebreide producentenverantwoordelijkheid, 2020; EIMPACK & European Investment Bank, 2011). Nevertheless, since the Indonesian national government does have ministerial regulations regarding upstream interventions like plastic bags bans (Ministry of Environment and Forestry, 2020), it is assumed that upstream interventions are possible in the Indonesian context. The EPR interventions in Indonesia should take into account three things:

1) the life cycle stages of a product
2) the type of instruments
3) the factors for waste management in Indonesia

In the next section, the interventions will be combined with the life cycle stages. Afterward, the factors of chapter 4.4 will be integrated to determine the interventions that will be used for the rest of the analysis.

5.2 Combining EPR with the product life-cycle

In section 2.2, EPR interventions were divided into regulatory, financial, and information instruments (A. Nahman, 2010). The different EPR instruments are evaluated based on their effect on the product's life cycle. Table 5.1 represents the integration of the life cycle stages with the EPR instruments. This analysis is based on papers on current EPR-systems worldwide (OECD, 2016) and the author's interpretation of the explanation of the instruments (Gupt & Sahay, 2015).

As mentioned in the previous section, the upstream, downstream, and consumption phases should be addressed. Of all the instruments, take-back programs are currently primarily used, especially for (plastic) packaging materials. It is sometimes combined with either advanced disposal fees or with deposit-refund systems. UCTS, minimum product standards, and (virgin) material taxes are policy instruments that are rarely implemented (OECD, 2016).

Take-back requirements mainly affect the downstream phase of the product's life cycle since producers are mandated to collect and process their products. However, it also has some effect on the upstream stage. Due to the incentive to provide lesser primary material production – because the program's costs are based on the amount of input, there also occurs some effect here. Take-back requirements are used in most European countries. For (plastic) packaging, there is usually a collective Producer Responsibility Organization (PRO) set up, who needs to achieve certain requirements that are agreed upon. In the Netherlands, this consists of recycling targets (Afvalfonds Verpakkingen, personal communication, 2021). Packaging organizations pay a fee based on the weight of the materials. For hard to recycle materials, higher fees are collected than for materials that are easy to recycle into new products, which is called tariff differentiation. A PRO manages the fees and supports the collection and sorting organizations, which in turn provide input for recyclers (Afvalfonds Verpakkingen, personal communication, 2021). It is recommended to organize this via a separate organization in Indonesia, as the financial flows are directly targeted for waste management rather than other governmental projects (IPF, personal communication, 2021).

Advanced Disposal Fees (ADF) are a tax paid by the producers that introduce a product to the market. It is based on the recyclability of the end-of-life product and thus viewed similar to a virgin material tax (Fishbein, 1994; OECD, 2016). The collection and organization of the fees should best be done through an external organization that contacts the disposal facilities for financial support (IPF, personal communication, 2021).

In deposit-refund systems, a tax is paid by the consumer when purchasing the product with packaging, which gets refunded when the consumer hands in the packaging again at a collection point. Some pilots have been conducted with deposit systems for PET bottles in Indonesia, but they have not been working correctly (IPF & ADUPI, personal communication, 2021). Hotta et al. (2009) also indicate that DRS can cause competition, which will make the operation less desirable and more costly. Furthermore, the competition can cause negative effects on waste pickers' income (UNESCAP, 2019).

Upstream combination tax/subsidy (UCTS) is also a way to incentivize producers to contribute financially to waste management. It is used to stimulate more sustainable design and less virgin material.

Virgin material taxes can be raised on 1) products that are potentially dangerous or difficult to recycle, 2) virgin materials, to stimulate recycled materials. A virgin plastic tax can be implemented to give the recycled plastics market a better competeable option (Sekhri, 2018).

It can be seen that the communication instruments focus mainly on the consumption phase. Especially the information provision, or awareness creation, is a crucial step in reducing plastic waste (Destyanto, Kirana, & Ardi, 2019; Leal Filho et al., 2019; Tristiana et al., 2018; Bank sampah, IPRO, MoEF, personal communication 2021). With this instrument, Indonesian citizens are being told about the consequences of waste dumping on the environment and eventually on the economy. It is emphasized that source separation of waste streams at the household level can contribute a lot to the better disposal of the waste.

Table 5.1 - Combining EPR instruments with the product's life cycle phases

Type	Phase:	Upstream		Consumption		Downstream		
	Examples	Raw material extraction	Primary production	Distribution & retail	Consumption discard	Collection	Processing	Recycling
Regulatory instruments	Take-back requirements		(x)			x	x	x
	Recycled content standards	x	x					x
	Prohibition of certain hazardous materials	x	x					
	Disposal bans	x	x					
	Emission limits	x	x					
Financial instruments	(Advanced) Disposal fees (ADF)	x	x					
	Deposit-refund schemes (DRS)			x		x		
	Product taxes	x	x					
	Upstream combination tax/subsidy (UCTS)		x					x
	Virgin material taxes	x						(x)
Communication instruments	Environmental report requirements			x				
	Environment labelling requirements			x				
	Awareness-raising campaigns			x	x			

5.3 Defining the instruments

The three chosen instruments for further analysis are based on the product life-cycle, instrument type, and Indonesian contextual factors for waste management. Integrating these three components, the following EPR interventions will be used in the model.

Take-back requirements mainly focus on the downstream phase of a product. This is important for a developing country like Indonesia, with a meager collection rate. Without proper collection, no recycling is possible. It, therefore, accommodates the little waste management infrastructure and can also take into account hard to recycle plastics if it is not thrown in the environment but put in (municipal) bins.

The Advanced Disposal Fees have the goal of eco-modulation. Based on the content of a product, the fees can become higher or lower. This stimulates the design of products that consist of higher

quality materials, which are better recyclable. This means there is the involvement of hard to recycle plastics. Furthermore, it is applicable for the waste management infrastructure in Indonesia, as waste pickers can capture the recyclable material.

Awareness-raising campaigns are the third intervention. It focuses on the consumption phase that the other two instruments have not targeted. It is a communication instrument, which deemed of great importance based on interviews and literature research. The campaigns can raise awareness of the benefits of proper waste management and the downsides of polluting the environment. This can even stimulate a better waste management infrastructure and benefit informal waste workers, as they might have to work with less polluted materials.

5.4 Summary chapter 5

The list of EPR instruments was categorized into **regulatory**, **financial**, and **communication** instruments. One intervention of each category was chosen to adhere to literature that recommended using a **systems approach** when implementing EPR (Tristiana et al., 2018). Furthermore, the instruments were evaluated based on their effect on the **product's life cycle**. To prevent environmental burden shifting from one life cycle phase to another, instruments were chosen in each life cycle stage. Lastly, the Indonesian context factors of chapter 4 were taken into account as well. The three EPR instruments are **take-back requirements**, **advanced disposal fees**, and **awareness-raising campaigns**.

The next part goes into the design science research by conceptualizing and analyzing the agent-based model.

PART III – DESIGN SCIENCE RESEARCH

6. Model conceptualization

In the last part, step 2 of the agent-based model has been conducted: the system analysis. Then, in Part III, steps 3 to 8 will be covered, where chapter 6 focuses on the model conceptualization and formalization of the model, and chapter 7 on the results. The goal of the model is to provide insights into the effects of EPR interventions on the Indonesian plastic waste system.

As the name suggests, the agent-based model consists of multiple ***agents*** that interact. Every agent has its own *state* and behaves in a way that is determined by *rules*. The state of each agent consists of values of its properties, and the **network** of agents interact with each other based on their rules. The **environment** is the part of the system where the agents interact and can get influenced by (van Dam et al., 2013).

6.1 Individual behavior – agents

Based on the agent's state and rules, he behaves in a certain way. Since the decision of households to separate waste or not seems to be an essential factor in literature, and from interviews, the behavior of households is analyzed in more detail. Then, the behavior of the three types of waste collectors is conceptualized.

6.1.1 Households

Three main factors that were highlighted in section 4.3 are motivation, capability, and opportunity of households for segregated waste collection. Their initial motivation is determined by the Theory of Innovation diffusion (Rogers, 1995), and the capability is based on whether households are wealthy enough for (space for) separate waste bins (World Bank Group, 2016). These two factors determine the initial decision for households to separate their waste (see Figure 6.1). During the day, the motivation can decrease based on the household's personal experiences with the waste collection (Figure 6.2). They stay satisfied if their separation efforts result in a separate waste collection by waste pickers or TPS3R collectors. However, municipalities collect waste mixed and dump it together at the landfills (IPF & ADUPI, personal communication, 2021). It also happens that there is no waste collection, and households have to burn their waste. Both situations make the households feel like they separate for nothing, which lowers their willingness to separate. At the end of each day, the household updates their motivation and, based on this, starts, stops, or continues their waste separation. This motivation check is visualized in Figure 6.3. Households with an innovation-level of 'Late majority' or 'Laggard' are averse to innovations, so their motivation even decreases when the motivation of neighbors to separate is low. Larger versions of these figures can be found in Appendix D .

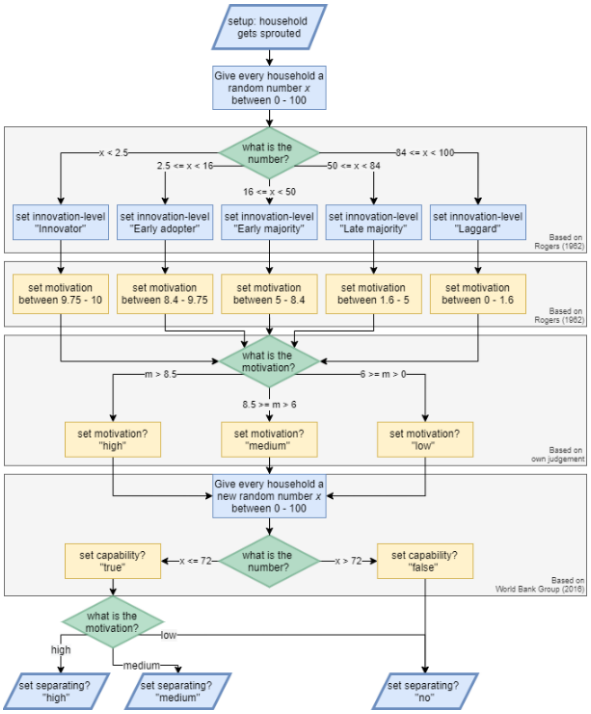


Figure 6.1 – Motivation setup of households

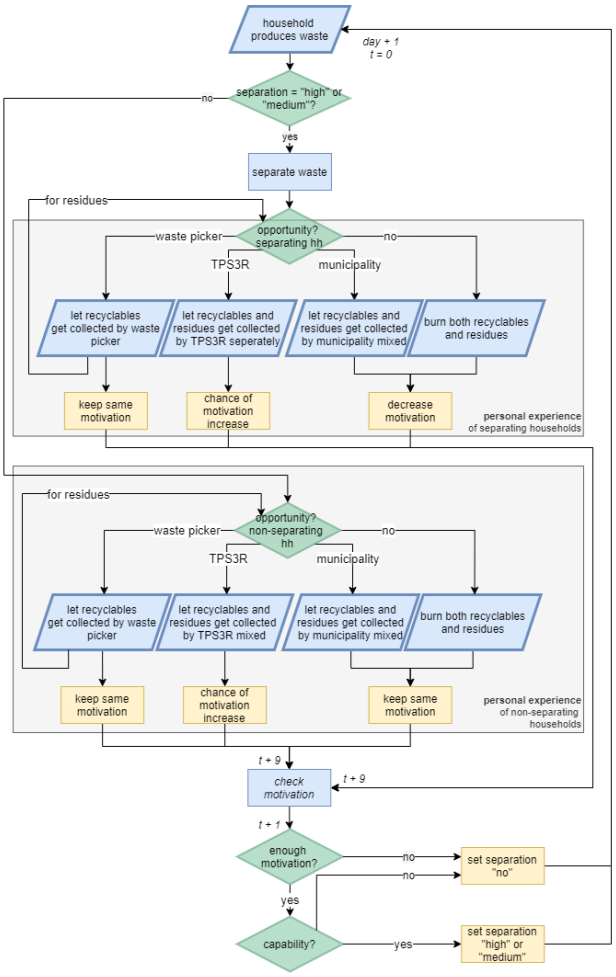


Figure 6.2 – Motivation influence personal experience

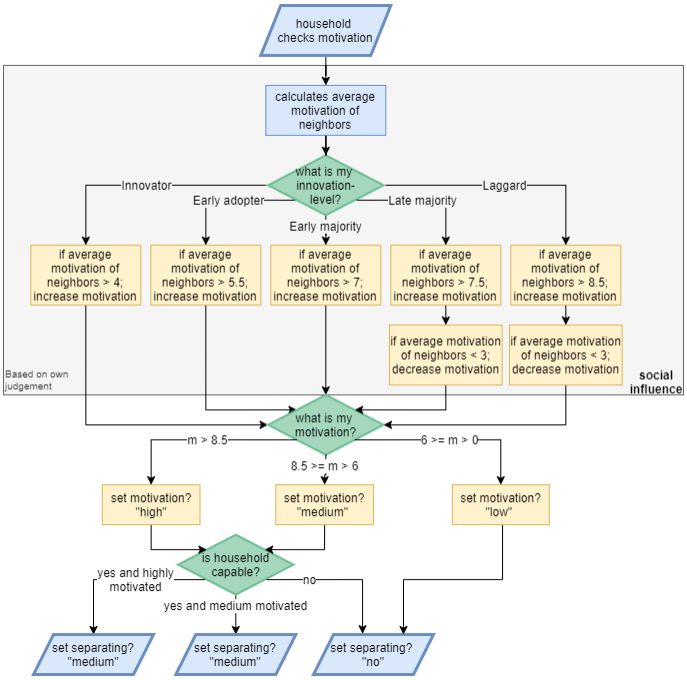


Figure 6.3 – Household updates motivation at the end of the day

6.1.2 Collectors

In the model, three types of waste collectors are included. Figure 6.4 visualizes the behavior flows of the waste pickers, municipal and TPS3R collectors. The three types of collectors get placed randomly in the system. They start collecting waste when the day begins. There are two conditions in which the collector brings their collected materials to the recycler or landfill: when the working day is done or when their (truck) capacity is full. Otherwise, they keep going to households that still have waste. TPS3R collectors give priority to households that separate waste, as that is what they want to achieve. If these households are collected, and there is still capacity left, they go to other households. They sort this in their sorting facilities of the mixed waste that they collect and can recycle up to 25% of the recyclables. The rest is already contaminated and not fit for recycling (Alberts et al., 2020). Since they can sort out harmful materials, the TPS3R collectors bring the residues to so-called 'sanitary' landfills.

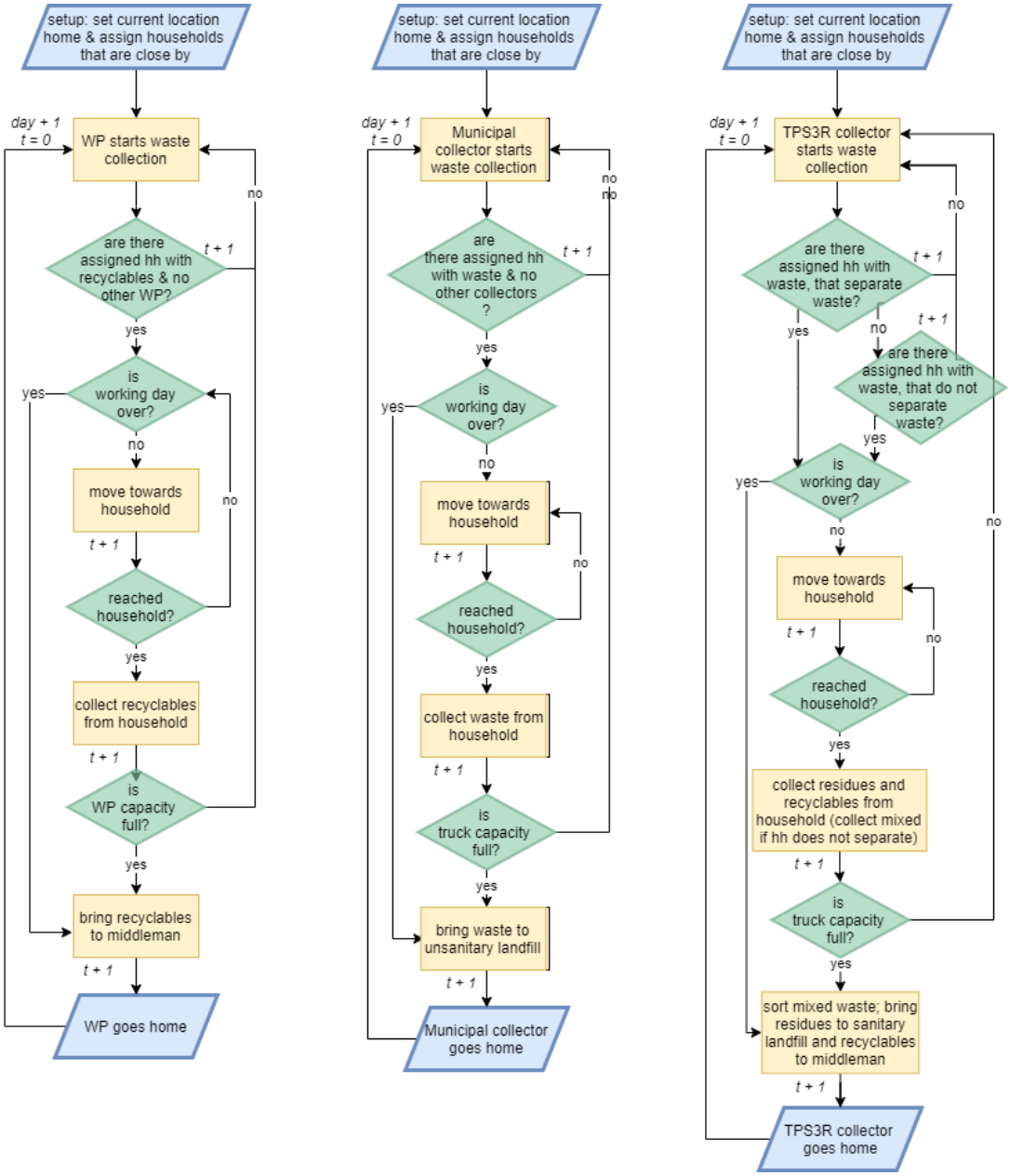


Figure 6.4 – Collectors' behavior

6.2 Integrating agents – network

In the previous section, the agents' behavior is visualized independently. However, they also influence each other. In this section, the agents that are included in the model are shown, and their properties are represented in a Unified Modeling Language (UML) diagram in Figure 6.5. The UML diagrams consist of classes with their accompanying attributes (properties of the classes) and refer to the relation between the classes. The environment is a class, too, to give a more comprehensive overview of the model properties.

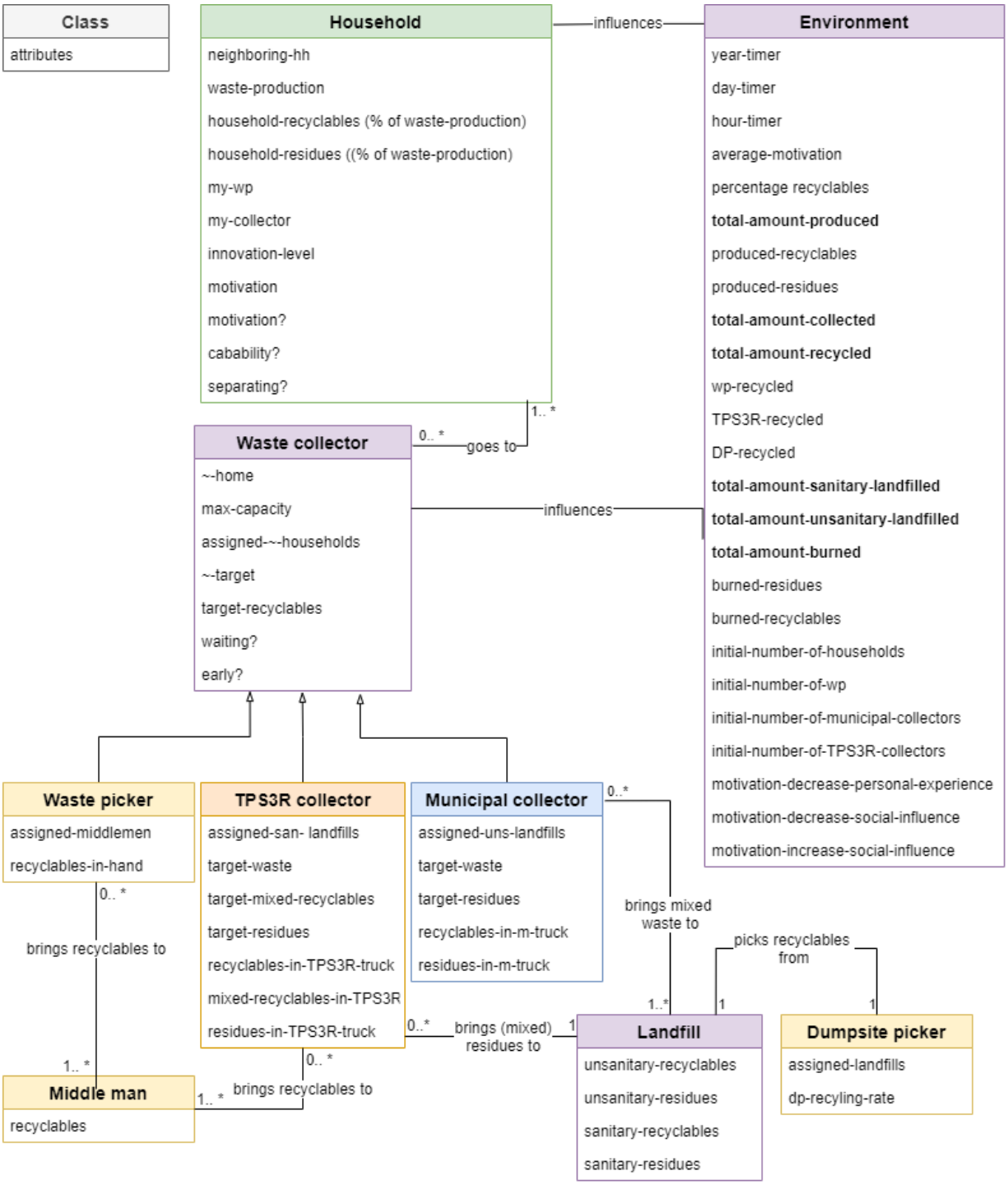


Figure 6.5 - UML diagram of the agents in the model

6.3 System behavior – environment

As explained in chapter 4.1, the model represents a part of a medium-sized city in Indonesia. The behavior of agents with each other and the environment can be visualized in a BPMN-inspired conceptual model. This Business Process Modelling Notation (BPMN) is a language used to visually present processes that occur in a system (Wohed, Aalst, & Dumas, 2006). In this way, the interactions between the different agents can be shown. Figure 6.6 shows five 'swimming lanes' for each type of agent and one for the environment. The lanes contain the processes (rectangles) and choices (diamonds) of the agents. The parallelograms are the end and start points of the system; the dashed lines show the interactions between different actors. Interaction occurs between actors of the same type, too, such as between households that check each other's motivation or between collectors that check whether another collector already occupies the house.

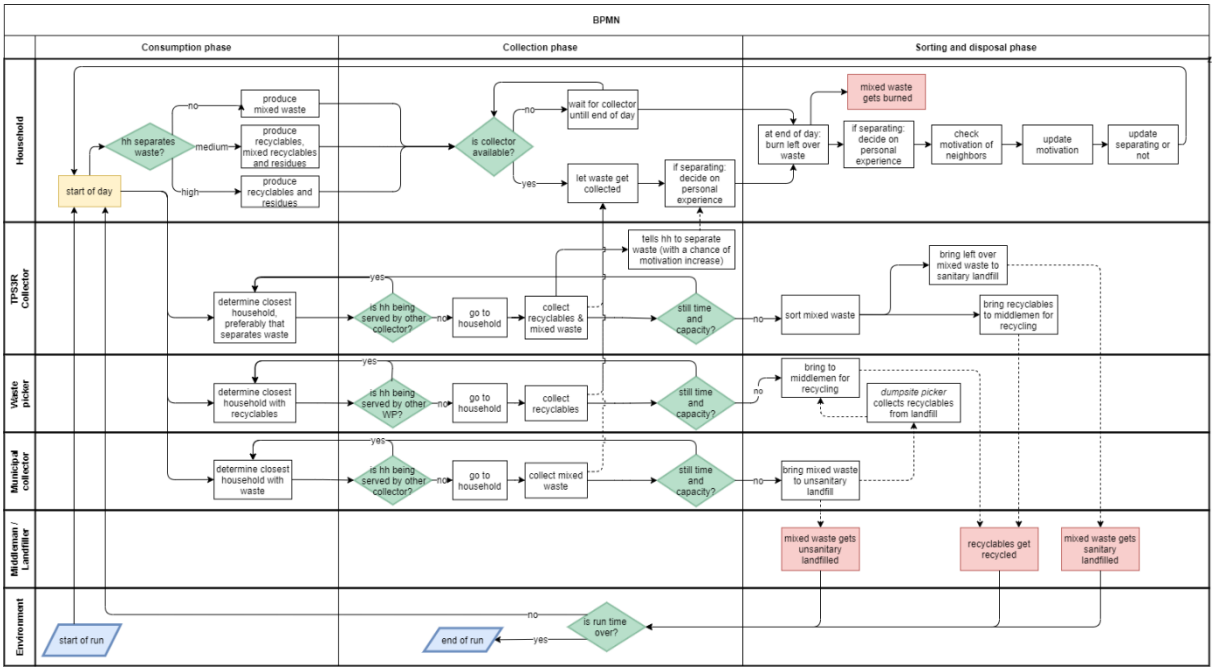


Figure 6.6 - BPMN-inspired flow diagram, a larger version can be found in Appendix D

The model consists of five types of agents: households, waste pickers, municipal collectors, TPS3R collectors, and middlemen/landfiller. The latter is put into one lane to represent the next stage of waste management and, for the purpose of the model, does not have specific behavior. The environment is the system around the agents but within the scope of the model. Agents can affect each other, and the environment, as well as the environment, can impact the behavior of the agents (van Dam et al., 2013). The environment determines the time and randomly assigns the agents' location and the innovation levels and capability of the households. Lastly, the environment determines the chance of households accepting the request of TPS3R collectors to increase their motivation for waste separation. This chance is based on their innovation level.

Every 'step' of the model is an hour, and during the day, the collectors go to different households to pick up waste and recyclables. The distance to middlemen or landfills is not important since it is assumed that the collectors will reach the next stage anyway (McKinsey.org & Adupi, personal communication, 2021). The runtime is limited to a few months because the dataset became too large when it ran longer. Other options to limit the model size were considered, like changing the model resolution, but the days can be different from each other, this should be kept in the model.

The waste produced by households is divided into recyclables and residues. Because modeling plastics alone would be too unrealistic, and it is the largest share of collected recyclables (Sasaki & Araki, 2014).

The government is not modeled as an agent but is technically located in the environment of the model. It puts some constraints on the agents, like making legislation and rules for households and collectors, which is a characteristic of the environment in an agent-based model.

6.4 Summary chapter 6

In this chapter, the model is conceptualized. First, the behavior of the individual agents is explained based on **flow diagrams**. Households and three types of waste collectors (waste pickers, municipal collectors, and TPS3R collectors) are the main actors in the model. The agent where the collectors bring the waste towards is the fifth agent, but they do not actively interact with the other agents. Secondly, the **network** of the agents is discussed, where the interactions of the agents are explained based on a UML diagram. Lastly, the **environment** is also involved. An overview was made of all involved actors and their interactions with each other and the environment in a BPMN-inspired model.

7. Model Implementation

In the previous chapter, the conceptual model is described and explained. In this chapter, the system will be formalized based on steps 3 to 6 of the agent-based modeling approach (van Dam et al., 2013). First, the model narrative will be explained. Subsequently, the agents' behavior conceptualized in the previous chapter will be formalized into computer-acceptable language, which is called the parameterization of steps 4 and 5 of the modeling steps. Lastly, the model will be verified in section 7.37.2.

7.1 Model narrative

The model narrative describes the processes and interactions that happen in the system. The model starts with the setup. The different agents are set on a specific location and receive their properties. When the model starts running, the day begins with households putting their waste on the streets. Based on their properties, they segregate this in separated bins or have it all mixed together. Next, the three types of collectors go to the households in their neighborhoods, and at the end of the day (or when they have reached their personal capacity), they bring their yield of the day to the next step: the middlemen, or the transfer station to landfills. In the following sections, the agent behavior is explained in more detail.

7.1.1 Set up

The setting up of the model starts with placing all five agents randomly in the system, which can look like Figure 7.1. House-icons indicate households, and green houses indicate houses that separate their waste. Since the study mainly focuses on a medium-sized city (see section 4.1), the number of waste pickers and collectors is calibrated with the base case's recycling and collection rate. Appendix G explains the model calibration in more detail. At this moment, households determine their innovation level based on a random number and Rogers' 5 categories (Rogers, 1995). They also identify their neighboring households, whereas waste pickers, municipal collectors, and TPS3R collectors identify households in their neighborhood where they can collect waste from.

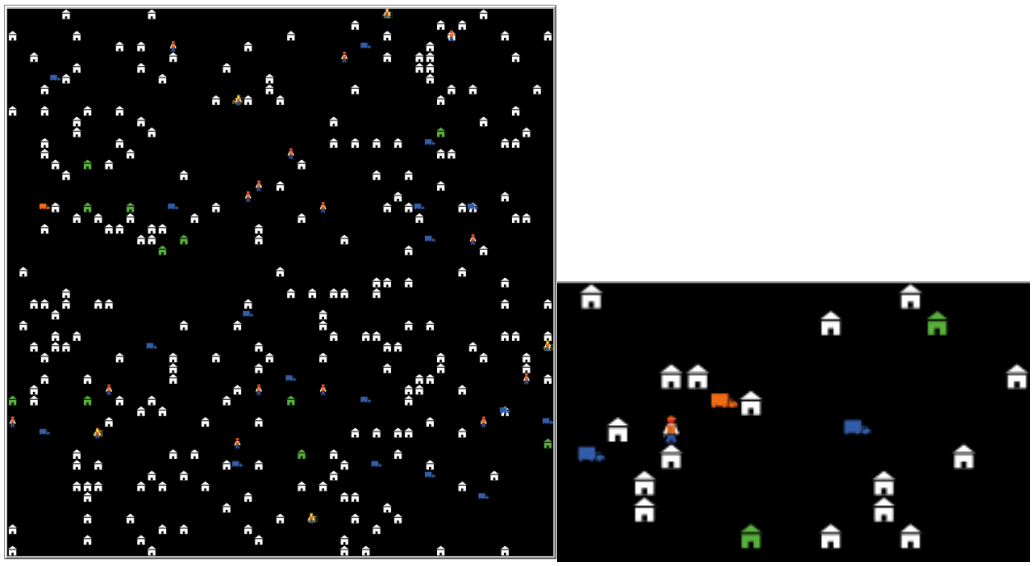


Figure 7.1 - Example of the initial set up in NetLogo – right a zoomed-in screenshot

7.1.2 Waste production

Indonesian households produce around 2.8 kg of waste per day (United Nations Environment Programme, 2017; World Bank Group, 2018). One house-icon in the model represents a street of houses. Once a collector is there, it can pick up recyclables or residues from that street in one hour (one step in the model, a tick). This means that every day, a house-icon produces $2.8\ kg * 10\ households = 28\ kg$ waste. The waste consists of 'wet waste' (organic waste, 50%) and dry waste (United Nations Environment Programme, 2017). This contains recyclables (40%) and non-recyclables (10%). Since the model focuses on household waste and doesn't include industrial waste, the percentage of organic waste is higher and the recyclables lower (IPF & WB, personal communication, 2021). In the model, this has been divided into 20% recyclables and 80% residues, similar to other studies on municipal solid waste in Indonesia (Aprilia et al., 2012; Sudibyo, Budiman, Pradana, & Wiratni, 2017). This is modeled that at the end of every day (after 12 ticks), a household-icon produces around 28 kg (with a randomizer for some diversity), of which 20% are recyclables and 80% are residues. Since the Indonesian population increases significantly, urbanization is happening, and their economy grows steadily, their municipal solid waste production increases by around 8% annually (Sudibyo et al., 2017).

7.1.3 Waste separation

Even though almost 70% of households' waste is from organic material ('wet waste'), most households do not separate their waste into wet and dry waste, let alone segregate their recyclables (Aprilia et al., 2012; Ratna et al., 2018). It is known that households are unwilling to separate their waste, as a large part of this is mixed again when the municipality collects it (Waste Bank, personal communication, 2021; Aprilia et al., 2012). Neighbors influence the motivation to start sorting (Aprilia et al., 2012; Sweep Smart, personal communication, 2021). In the model, this is incorporated as 'motivation' which increases when households in their surroundings are separating waste. The model starts with around 5% of the households that separate their waste and is based on their innovation level. Innovators are thus more likely to separate their waste than the Late majority or Laggards.

7.1.4 Waste collection

A study that analyzed the plastic flow in Jakarta found that waste pickers collected 34% of all collected plastics. The municipality collected 65%, and less than 1% was collected via waste banks, where waste separation is required, just like at TPS3R sites (Ratna et al., 2018). However, since the model studies a medium-sized city in Indonesia, the numbers for the base case calibration are adjusted accordingly (World Economic Forum, 2020).

Waste picker collection

As explained in section 4.2, waste pickers collect recyclables in multiple places. In the model, only informal waste pickers at households and dumpsite pickers are included for simplicity purposes. The door-to-door collection is the most common since there is the most variety of valuable materials (Damanhuri & Padmi, 2012). However, Sasaki & Araki (2014) found that still around 5% of the waste transported to a large landfill close to Jakarta is being collected for recycling. Therefore, the dumpsite collectors are included at the landfills and collect recyclables there with this 5% collection rate. Two options make a door-to-door waste picker bring their collected recyclables to the middleman. Either after a certain amount of working hours (hours-of-work) or after they have reached their capacity. The average capacity of waste pickers is around 7 kg (Aprilia et al., 2012). There are a few examples of using wheel carts for collection to increase their capacity. This is included in the model to have a chance on such a wheel cart. It is assumed that all

collected recyclables via waste pickers end up at a recycling facility (World Economic Forum, 2020).

Municipal collection

Municipal collectors go to households that are within their neighborhood. Municipal collectors mix the waste in their collection trucks without further processing it. In reality, this is brought to transfer stations before it goes to landfills. However, for the sake of simplicity, the waste is labeled as 'unsanitary landfilled' when municipal collectors have moved it to the landfiller at the end of the day. During their collection round, they decide on the household to go to based on their distance from where they are at that time. The landfill is not separately modeled, but the municipal collectors go to the middlemen. This is to prevent many different agents, and the time it takes to bring the waste is not of importance for the goal of this model.

TPS3R collection

TPS3R collectors are scarce right now. Namely, source separation is required, and investments in facilities and knowledge about waste management (Adupi & IPF & McKinsey.org, personal communication, 2021). The base case has one TPS3R collector that goes to separating households in its neighborhood. However, when these households are collected, they go to other households if they have capacity and time. It is modeled that they leave a note requesting to separate their waste, which results in a chance for the households to increase their motivation level. If this motivation level reaches a certain threshold, and they have the capability to separate their waste, they start separating.

7.1.5 Waste disposal

In chapter 4, it is shown that middlemen play a role in the recycling industry since they set a certain standard to accommodate the informal workers. However, as there is no direct influence of the EPR interventions on the middlemen, and to simplify the model, they are not modeled elaborately. As middlemen, recycling facilities, temporary waste facilities, and landfills are the next stage in the waste supply chain; it would make the visualization of the model more complex to insert more different types of agents. Therefore, they are modeled as one type of agent to which the three types of collectors bring their collected items.

7.1.6 Intervention 1: implementing mandatory take-back requirements

In the model, the take-back requirements are modeled so that after the model has been running for a while, ten more TPS3R collectors come available. When these requirements are implemented in real life, the Indonesian PRO receives more fees from producers. As a result, they become responsible for more waste collection, and they can invest these revenues in projects that improve the collection capacity (IPRO, personal communication, 2021). These projects result in more collectors that stimulate separate waste collection. Furthermore, TPS3R collectors also treat the mixed materials to filter out some recyclables and make sure the harmful materials do not end up in landfills.

The location strategy of the placed TPS3R vehicles can be based on

1) **household density** – where the initial TPS3R location is placed where households are closest to each other;
2) **motivation density** – where the initial TPS3R location is placed where households are highly motivated;

3) **separation density** – where the initial TPS3R location is placed where households are already separating waste.

7.1.7 Intervention 2: advanced disposal fee

This policy intervention aims to reduce the number of hard-to-recycle plastics. The disposal fee is usually based on the product's weight or of certain materials that the product is made of. This creates an incentive to use better recyclable materials in products. This is modeled as a steady increase of a higher percentage of recyclable waste that households produce. In the base case, this is 20%, based on literature for municipal solid waste. The target of the intervention that gradually increases over time varies between 25, 30, and 35% recyclables. This intervention thus affects the content of the waste production of households.

7.1.8 Intervention 3: creating awareness for source separation

As mentioned before, source separation is a crucial step to increase the recycling rate (Bank sampah, Adupi, MoEF, IPRO, personal communication, 2021). Implementing awareness-raising campaigns is a way to stimulate this. The intervention is modeled as a new agent type coming into the model: awareness-raising campaigns (arcs). They can be held in different time periods to see the longevity of the campaign effects:

1) **One week** – for one week, every day, the campaigns are trying to convince the surrounding households to increase their motivation. The chance this works is higher for innovators than for laggards;
2) **One month** – for one month, the campaigns support the surrounding households to increase their motivation;
3) **Monthly** – every month, there is are days in which the campaigns try to convince their surrounding households to increase their motivation.

Furthermore, the campaign strategy can be based on similar location strategies as intervention one:

1) **Household density** – where the location of the arc is placed where households are closest to each other;
2) **Motivation density** - where the initial TPS3R location is placed where households are <u>not</u> motivated;
3) **Separation density** – where the initial TPS3R location is placed where households are <u>not</u> separating their waste.

7.2 Implementation and parameterization

In the previous sections, the conceptual model is described and explained. In the next step, the implementation of the model, the conceptual system is put in the model environment NetLogo 6.1.1. NetLogo enables agent-based models to be implemented with a relatively easy syntax. However, this also comes with the limitation that it is challenging to create more complex models and therefore requires (as any model) many assumptions. A list of all model assumptions can be found in Appendix E .

The interface of the model is shown in Figure 7.2. In the middle, the output of the model is visually displayed. On the left side, input parameters can be set and varied, and on the right side, the output of certain parameters is shown in numbers and graphs.

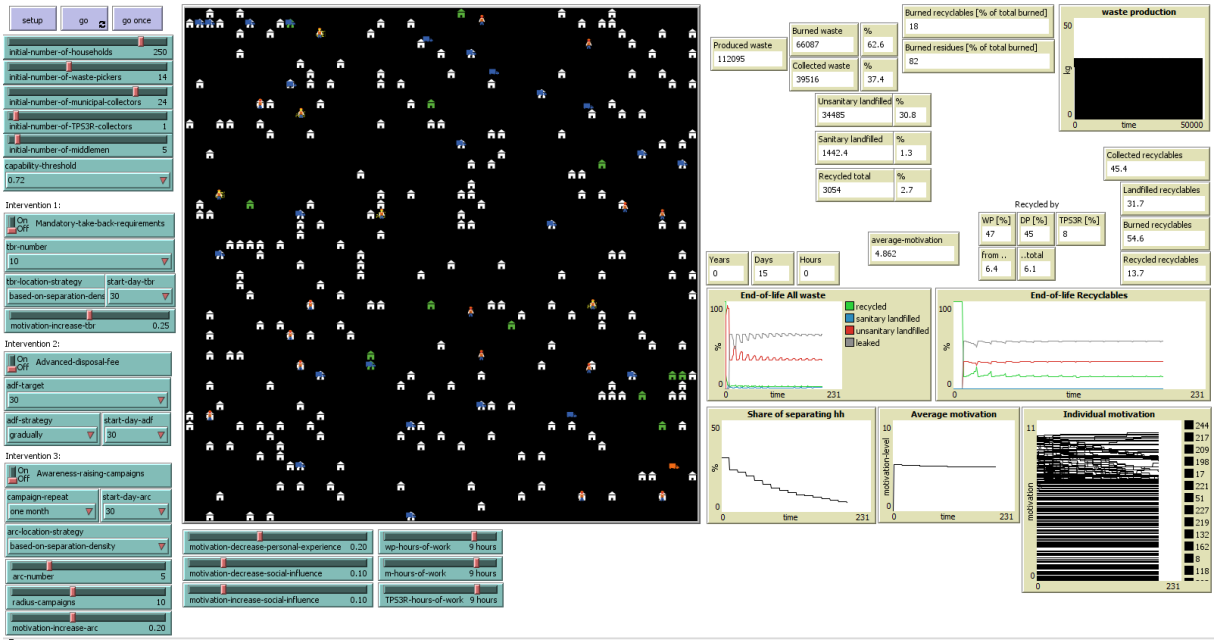


Figure 7.2 - model visualization in NetLogo

The parameterization step determines model values for the parameters of the conceptual model. The parameters are divided into five categories (see table Table 7.1 below). A complete overview of all parameters and model values can be found in Appendix F .

Table 7.1 - Categories of model parameters

Category	Description
Model	The global values of the initial settings of the model
Agent properties	The characteristics of agents
Motivation values	The variables that influence the motivation of households
Simplifying the model	Variables and decisions which make the model easier to interpret
Settings for interventions	The strategy variables for implementing the interventions

7.3 Model verification

The goal of model verification is to analyze whether the model works as it is expected to work. Therefore, during and after the designing of the model, verification steps were taken. Most of the model has been verified by recording and agent behavior tracking (van Dam et al., 2013).

Three types of verification have been done on the model. First, based on **code walk-through,** the code was analyzed in-depth, and possible adjustments were based on the order of happening procedures. Second, the **recording and tracking** of **agent** behavior improved the model when individual agent behavior was checked into more detail. Thirdly, **multi-agent testing** was used to analyze the different graphs that indicated agent values or behavior. The verification steps are visible in Appendix H .

The model was assumed to be correctly implemented based on the verification and implementation of the adjustments accordingly.

7.4 Summary chapter 7

This chapter elaborated on the model **narrative**. First, it described how the agents in the model behave and what assumptions have been made. Furthermore, it was explained how the three interventions were modeled, and their individual strategies were elaborated upon. Then, it was shown how the **model environment** Netlogo looked like and which parameters were used. Lastly, three ways of model **verification** were mentioned: code walk-through, agent recording and tracking, and multi-agent testing.

8. Model Results

This research analyzes the effects of specific EPR interventions on the plastic waste system in Indonesia. The Indonesian waste system has been (conceptually) modeled in the previous chapters, and the interventions have been chosen. In this chapter, the interventions and the model are combined, and the results are presented. The performance of the system is evaluated based on the KPIs defined in section 4.5.

8.1 Experimental Design

The experimental design consists of scenarios that can be used to evaluate the interventions. First, the three interventions will be individually assessed. Based on their strategies that were explained in section 7.1, there are 15 different scenarios. Then, different interventions will be combined with each other. There would be too many scenarios if all strategies of all interventions were combined, and it would be hard to get understandable conclusions out of those. Therefore, based on the individual assessment, some strategies will be selected to continue with (see Table 8.1). All scenarios will be evaluated based on the five Key Performance Indicators.

- **Collected waste**
- **Collected recyclables**
- **Recycled recyclables**
- **Leaked recyclables**
- **Collected by waste pickers**

Table 8.1 - Run experiments and their characteristics

Experiment	Variable	Strategy options	Replications
Base case	Run time	6 months 4 years	100 1
Intervention 1	Run time	6 months	20
	tbr-location-strategy	Based on household density Based on motivation density Based on separation density	
Intervention 2	Run time	6 months	20
	ADF-target	25 % 30 % 35 %	
Intervention 3	Run time	6 months	20
	Arc-location-strategy	Based on household density Based on motivation density Based on separation density	
	Campaign-repeat	One week One month Montly	

8.2 Results

This section presents the outcomes of the base case and the interventions. Per experiment, the line plots provide an understandable overview of the effects of interventions, whether boxplots show more precision of the results on the KPIs. For some experiments, only the impact on certain KPIs is presented. The results on all KPIs can be found in Appendix I .

8.2.1 Base case

In Appendix I , the model results for the base case can be found. It is visible that in the first few weeks, the model is calibrating, which results in a large shift in collection percentages. Only after a while, the collection becomes more consistent, and the results can be more reliable. The outputs stay relatively constant over the months. This means the outcomes do not change much when having the same initial values. Due to the model's size, multiple runs cannot be done for longer than one year. However, due to the small standard deviation, a single run can be done to evaluate the outcomes over a longer time period. This single run shows that over a time span of 4 years, in which the Indonesian government wants to achieve a waste collection target of 70%, continuing the current waste collection practices result in a waste collection decrease (Figure 8.1). This effect, caused by the waste production increase, thus emphasizes the necessity of interventions to achieve the collection targets, which will be discussed below.

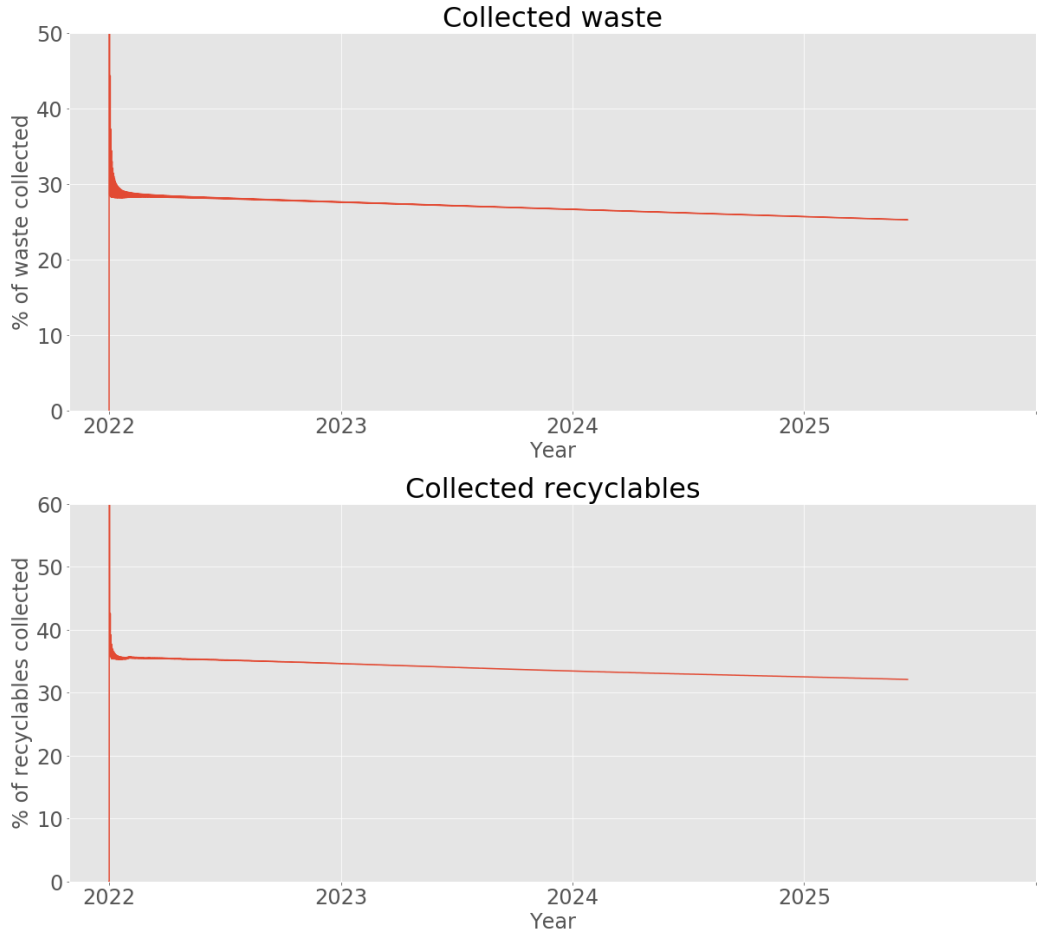


Figure 8.1 - Base case: waste and recyclables collection over four years time

8.2.2 Interventions

For the results of the interventions, it is visible that in the first weeks of the run, the results on the KPIs need to become consistent. That is why the interventions are implemented only after 30 days in the model, when the base case is more steady. Besides the one below, more graphs from the results of the interventions on all five KPIs can be found in Appendix I .

Intervention 1

Intervention 1 shows the increased TPS3R collection in the system. As can be seen in the graphs below, the waste collection and recycle ratio increases due to the intervention (Figure 8.2). The different location strategies seem to have a small influence on the outcome. The strategy to place the initial TPS3R vehicle on a location where the households are closest to each other shows the highest recycling and collection rate, and result in the lowest leakage (Figure 8.3). However, it also shows that waste pickers collect less waste per day. Graphs on other KPIs can be found in Appendix I .

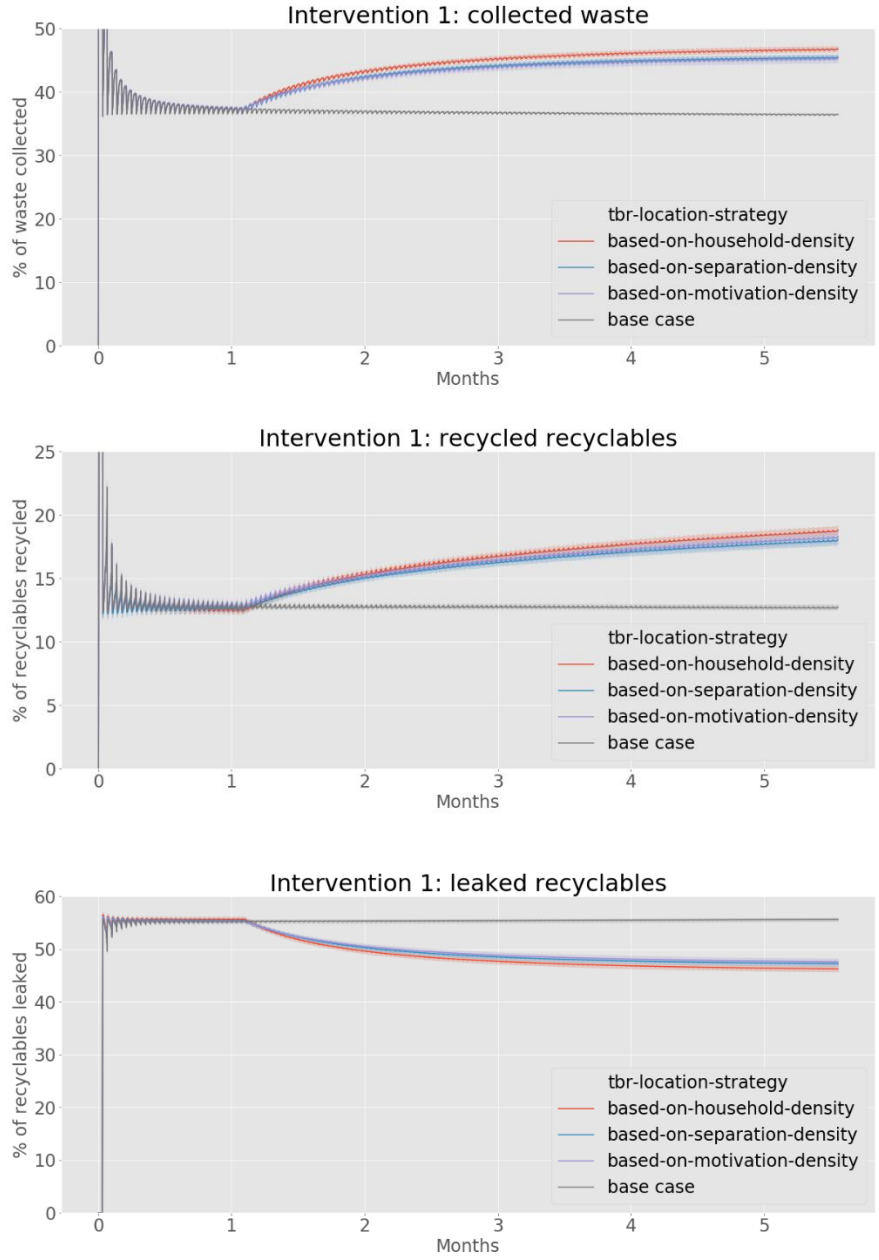


Figure 8.2 – Line plots of intervention 1

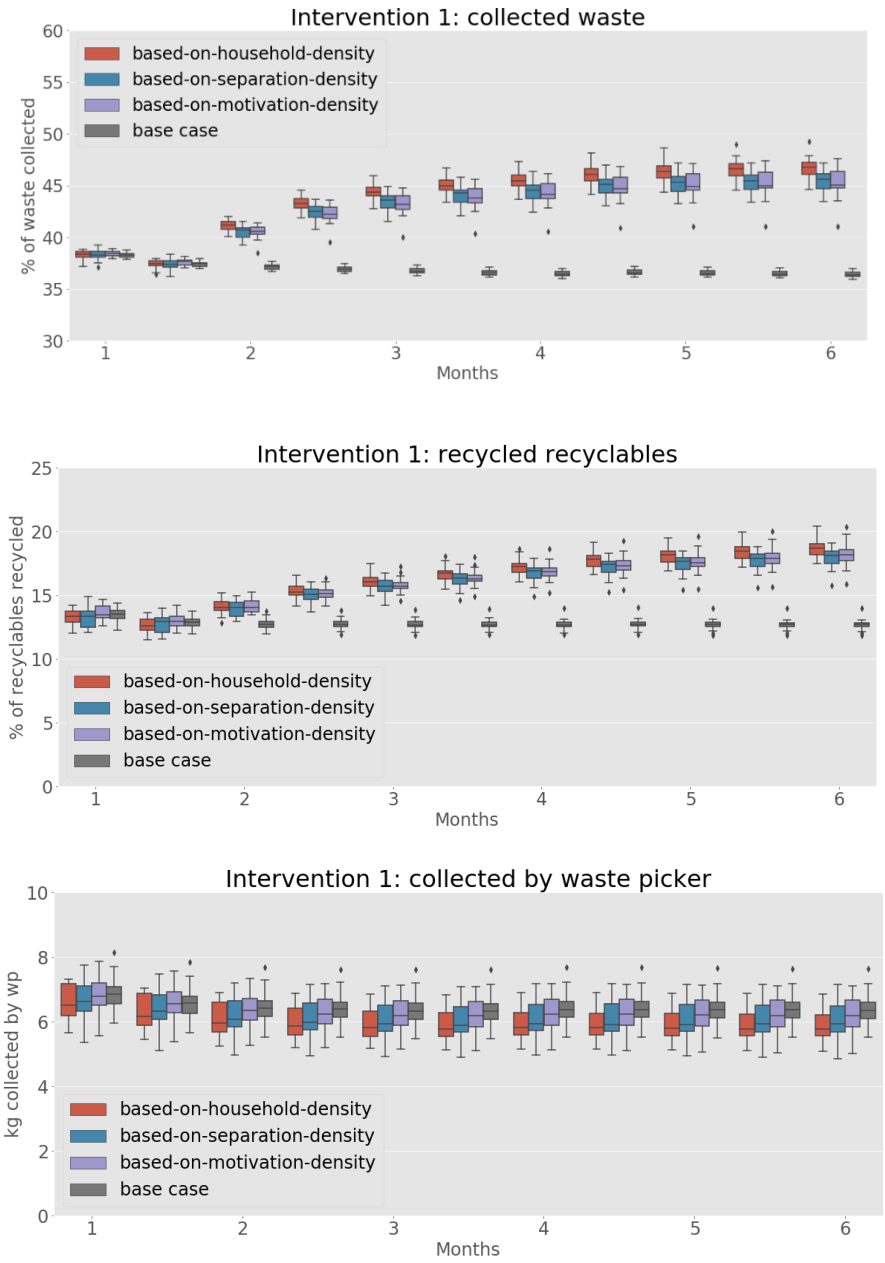


Figure 8.3 - Boxplots of intervention 1

Intervention 2

The second intervention steadily increased the number of recyclables compared to residuals in households waste due to the advanced-disposal fee. This has little to no impact on the collection rate of the total waste and recyclables (Appendix I) but does affect the recycling rate. This is since this intervention stimulates producers to make products of which the materials become better recyclable. The amount of recyclables in the municipal solid waste thus increases, but the collection capacity does not. Moreover, as the collected recyclables almost do not change, the absolute number of recyclables has increased.

The leaked recyclables are limited affected by the ADF intervention, and when there is a closer look, the target of 30 and 35 results in a higher leakage percentage than the 25% target or base case (Figure 8.4). This is because the intervention increases the recyclable percentage, which leads to a higher percentage of leaked recyclables with no other intervention that increases the recycling rate. Interestingly, the 30% target seems to result in a slightly higher leaked recyclable rate than the 35% target. The difference is minor, but more than the difference between the 25% target and the others. The amount of kg recyclables collected by the waste picker shows a slight increase compared to the base case (Figure 8.5).

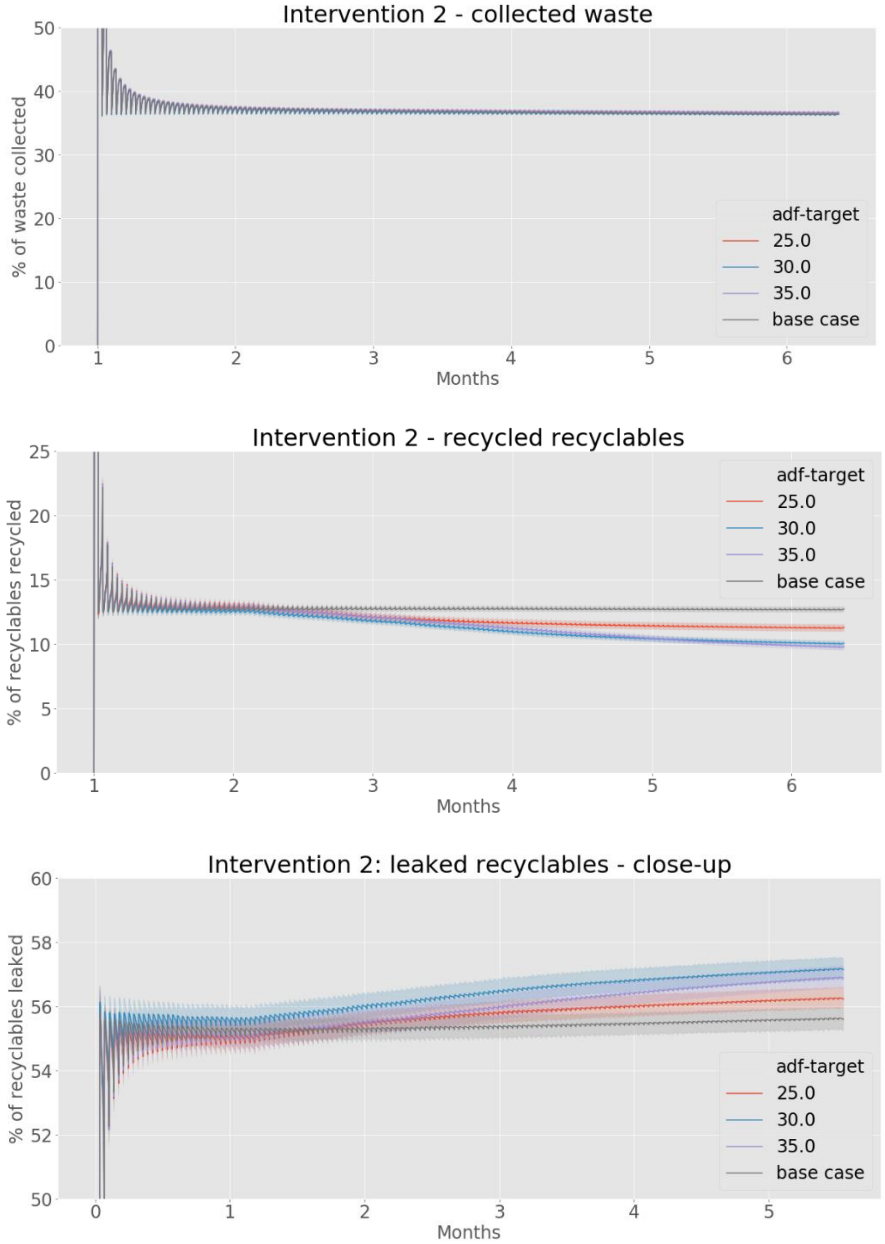


Figure 8.4 - Line plots of intervention 2

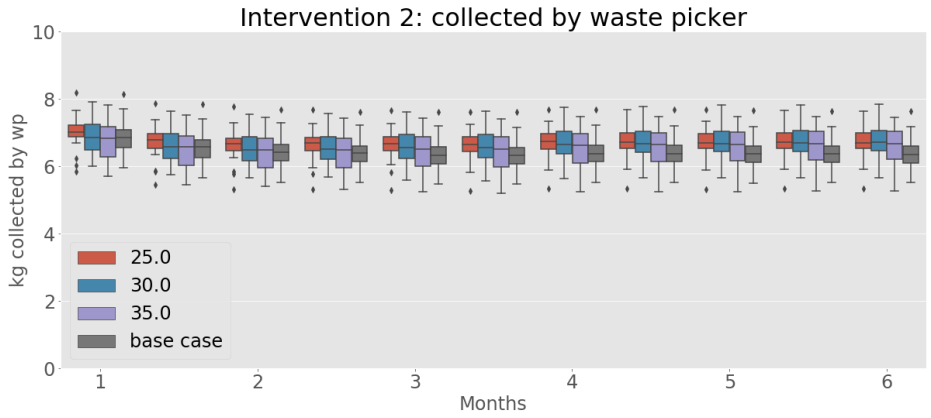


Figure 8.5 - Boxplot of intervention 2

Intervention 3

After one month in the model, the awareness-raising campaigns start. Besides a slight potential increase in the recycling rate, the campaigns do not seem to affect the KPIs (see Appendix I). However, the awareness-raising campaigns do affect the separating percentage of households (Figure 8.6). When looking at the repetitions of the campaigns, the three timing-related strategies have some different outcomes. All three campaigns make sure the separating percentage in the first week increases for the households. When implementing the campaign that lasts one week, the numbers fall back but stay higher than the base case. The same effect occurs for the campaign that lasts a month but with a slightly higher percentage at the end. After a while, this decrease comes from households' negative personal experiences since their waste separation efforts are being penalized by not getting collected separately. The steep drop of the two strategies is because the household's property `motivation` is for most households at its maximum during the campaign time. When the campaign stops, the motivation slowly decreases. When it reaches the separating threshold, they stop separating their waste. Since the slope of decreasing motivation is the same for an average household, they reach the threshold for separating their waste at the same time. As shown in purple, when the campaign takes place every month (actively for the first five days of every month), the households stay motivated to separate their waste.

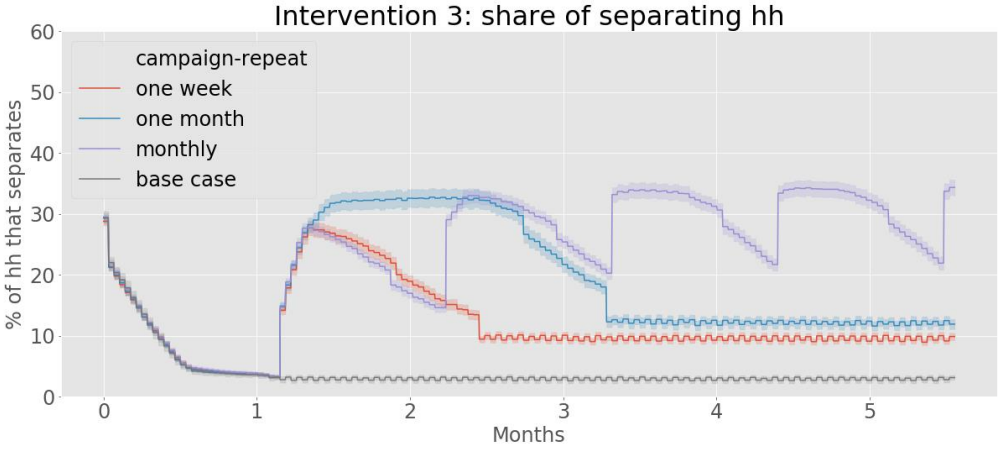


Figure 8.6 - Line plot of intervention 3 based on campaign repetition

When looking at the different campaign repetitions (Figure 8.7), the location-strategy of the awareness-raising campaigns does not seem to make an enormous difference.

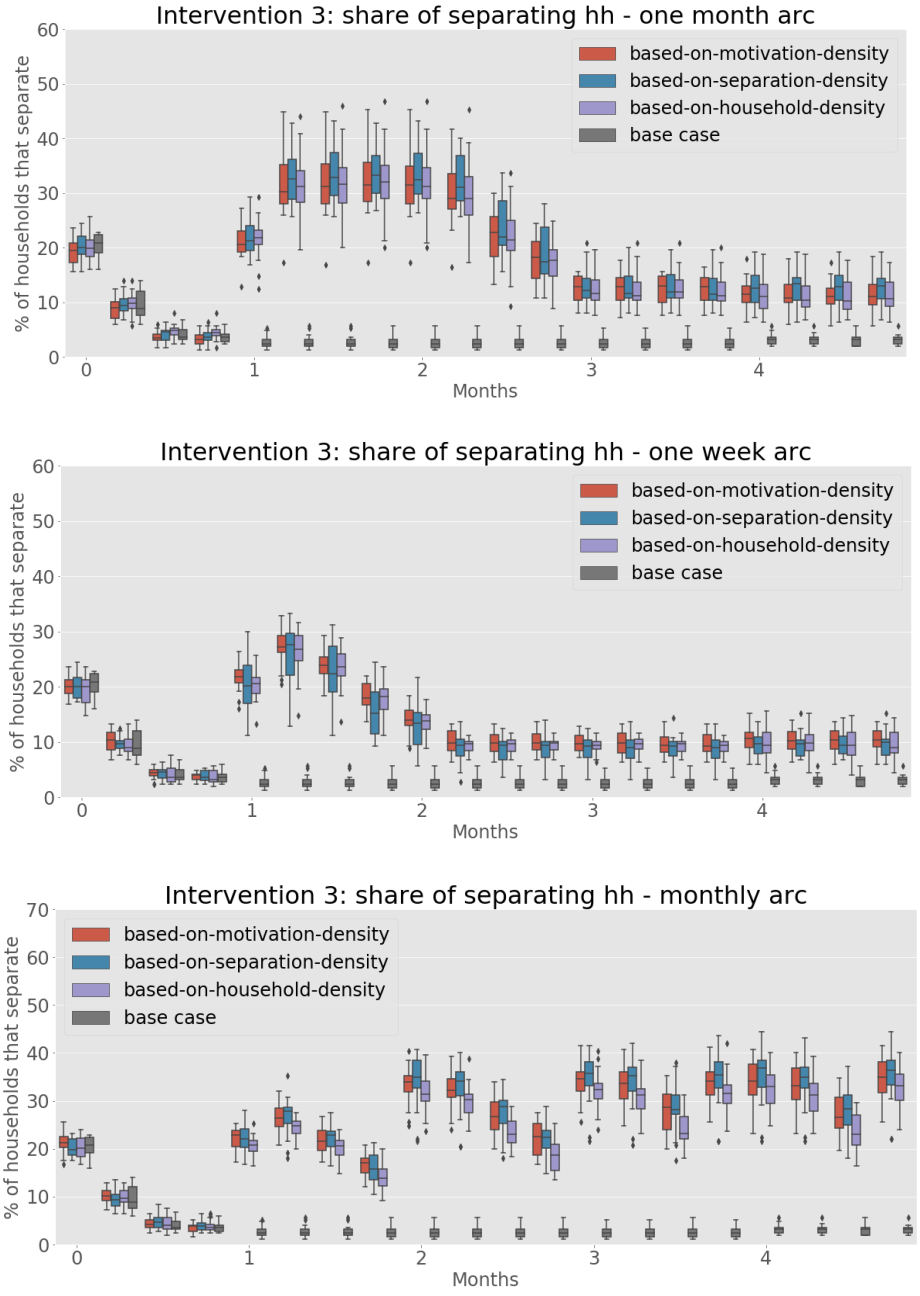


Figure 8.7 - Boxplots intervention 3

Since the separation of waste at the household level does not directly affect the collection and recycling rate, interventions should be combined to achieve less plastic pollution.

8.2.3 Combining interventions

Since EPR and waste management challenges require a 'system approach', the interventions are also combined to see what these outcomes can do (Table 8.2).

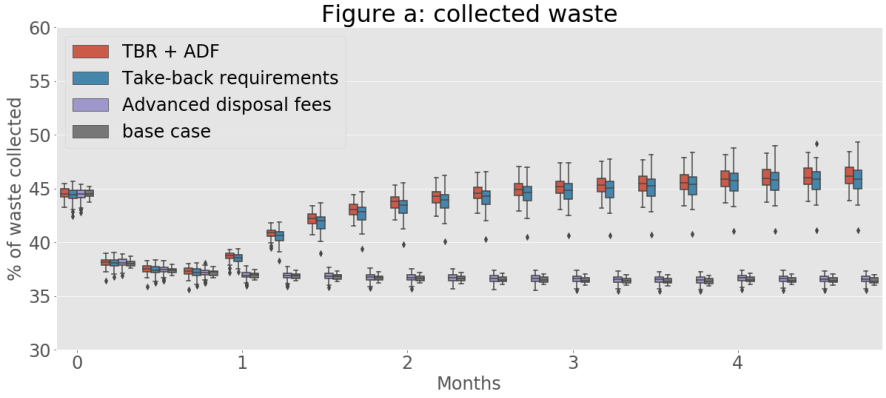
For intervention 1, the location strategy will be based on household and separation density since these two seemed to have the highest effect. However, there was no clear answer to what target for the percentage of recyclables would be best, so all three options will be included in the combinations. For intervention 3, the location strategy will be based on separation density, and all three repetition strategies will be included. In the figures, the base case, the individual interventions, and the combination of interventions are plotted.

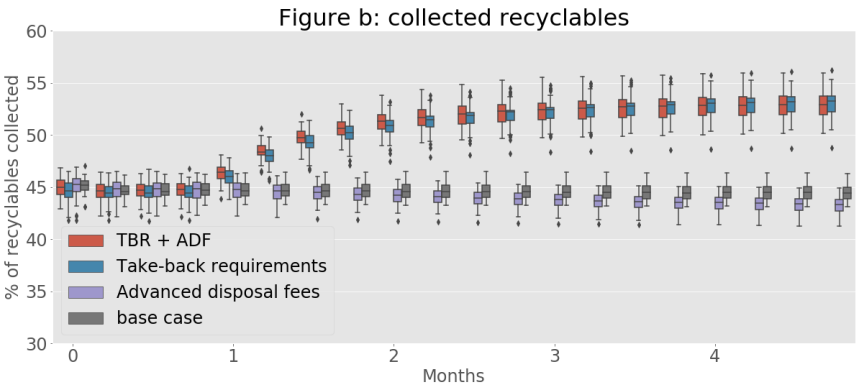
Table 8.2 - Experiments for combining the interventions

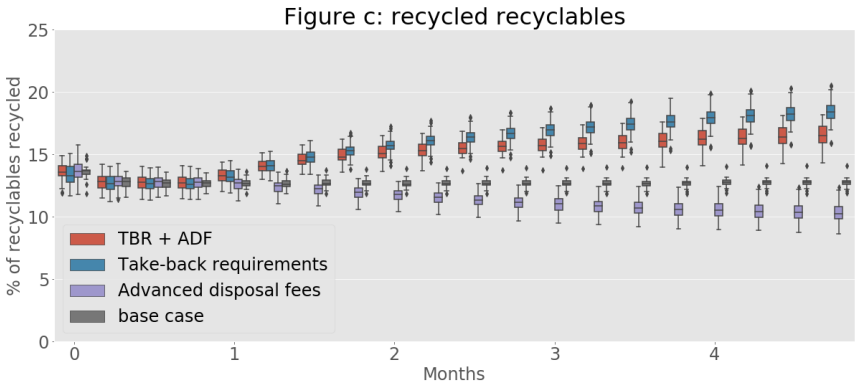
Experiment	Variable	Strategy options	Replications
1&2	1: location-strategy	based on household density	20
	2: target	25, 30, 35	
1&3	1: location-strategy	based on household density, based on separation density	20
	3: location-strategy	based on separation density	
	3: repetition-strategy	one week, one month, monthly	
2&3	2: target	25, 30, 35	20
	3: location-strategy	based on separation density	
	3: repetition-strategy	one week, one month, monthly	

Take-back requirements & ADF

Combining the mandatory take-back requirements and advanced disposal fees results in an increase in the KPIs total waste and recyclable collection and a decrease in leaked recyclables. There is a limited effect on the different ADF targets (see Appendix I). The following boxplots are found when the individual interventions are compared with the combined interventions (Figure 8.8). It shows that the increased waste collection of the take-back requirements is supported by the advanced disposal fee intervention (Figure 8.8a). However, the recycling rate gets somewhat downgraded due to the ADF (Figure 8.8c), just like the leaked recyclables (Figure 8.8d). Figure d does indicate that the decreasing effect of ADF on the leaked recyclables percentage is diminished when ADF is combined with TBR. The number of recyclables collected by waste pickers seems to be evened out when combining interventions 1 and 2 (Figure 8.8e).







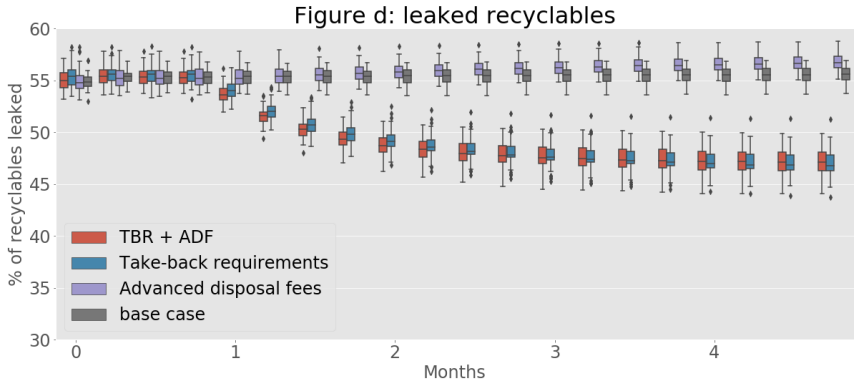


Figure 8.8 - Boxplots of combined interventions 1+2, compared with individual interventions

The timing of the interventions does not significantly impact the collection rate. It does have some effect on the recycling rate. Earlier take-back requirements can result in a higher recycling rate in the short term. When ADF is first implemented, the recycling rate first decreases before it goes up. The lines seem to converge towards each other, but the model runs until six months, so the effects afterward should be investigated further (Figure 8.9).

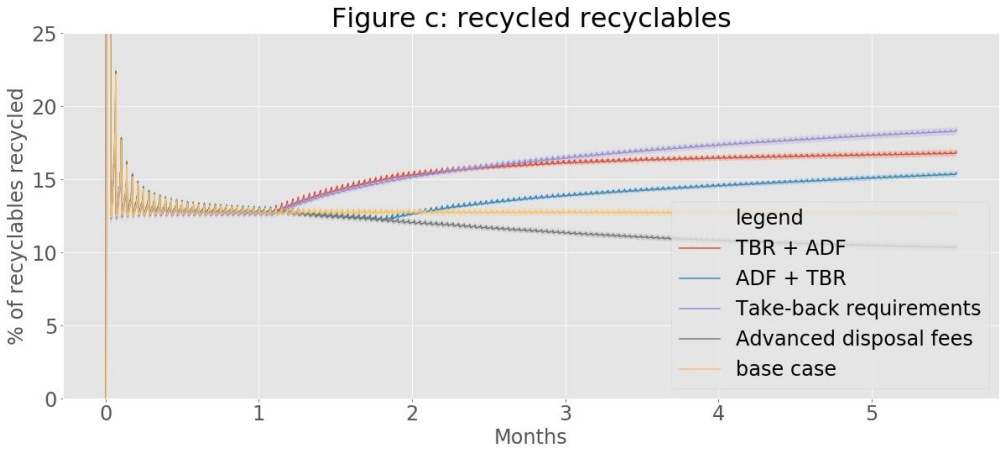
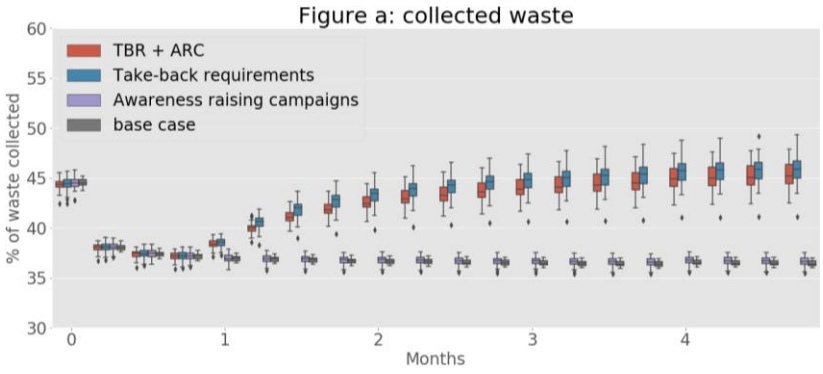


Figure 8.9 - Intervention 1+2, with different starting days

Take-back requirements & Awareness campaigns

The interventions start at the same time, after one month. In Appendix I3, it is visible that the KPIs do not seem to be affected much by the campaign repetition (Figure I.17 in Appendix I). When looking at the combined interventions, they even seem to be less effective on the waste and recyclable collection than the take-back requirements individually (Figure 8.10 a & b). However, when looking at the recycling rate (Figure 8.10c), the combined interventions significantly increase this KPI. Interestingly, compared with the take-back requirements alone, the combined interventions show a slight decrease in the collection rate but an increase in the recycling rate.



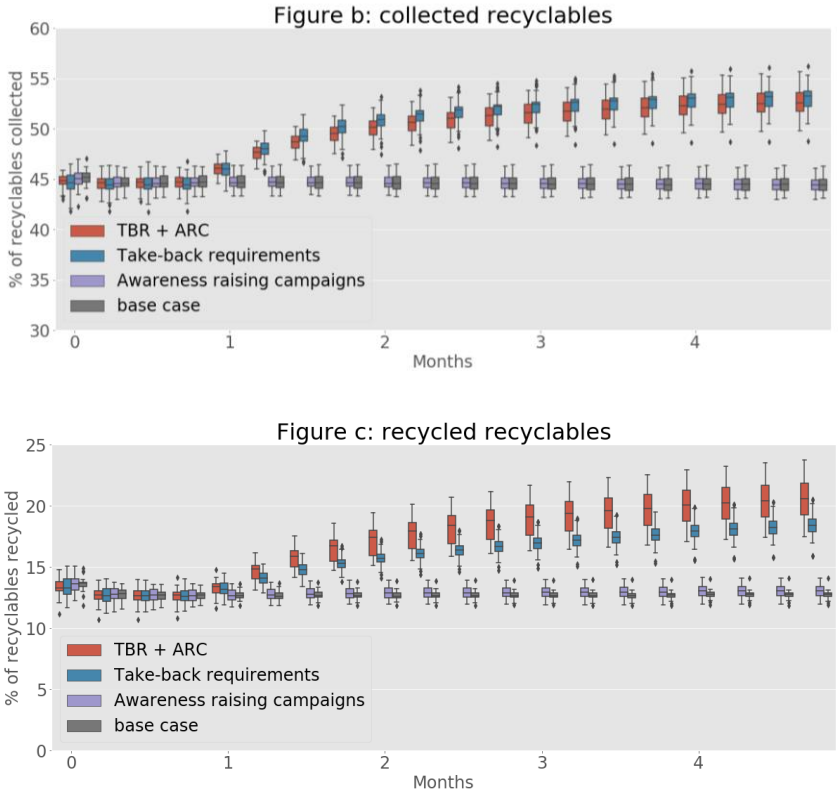
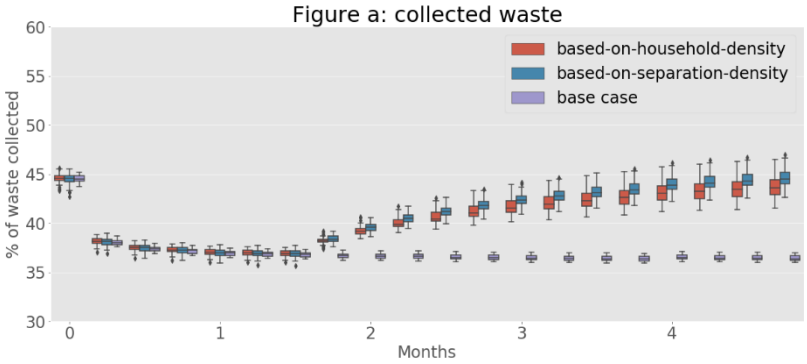


Figure 8.10 - Boxplots of intervention 1 and 3, compared with individual interventions

Since it would be expected that the combined interventions would have more effect on the waste collection, too, the model is run with the settings that the extra TPS3R collectors only start after the campaigns have been going on for a few weeks. Nevertheless, this also shows a similar effect on the collection and recycling rate (Appendix I).

There is another effect visible on the location of the collection vehicles. When implementing take-back requirements individually, the preferred location strategy of the collectors would be based on household density (Figure 8.3). However, when combining the intervention with the awareness-raising campaigns, the TPS3R collection locations can be better placed in areas with the highest separation density (see Figure 8.10).



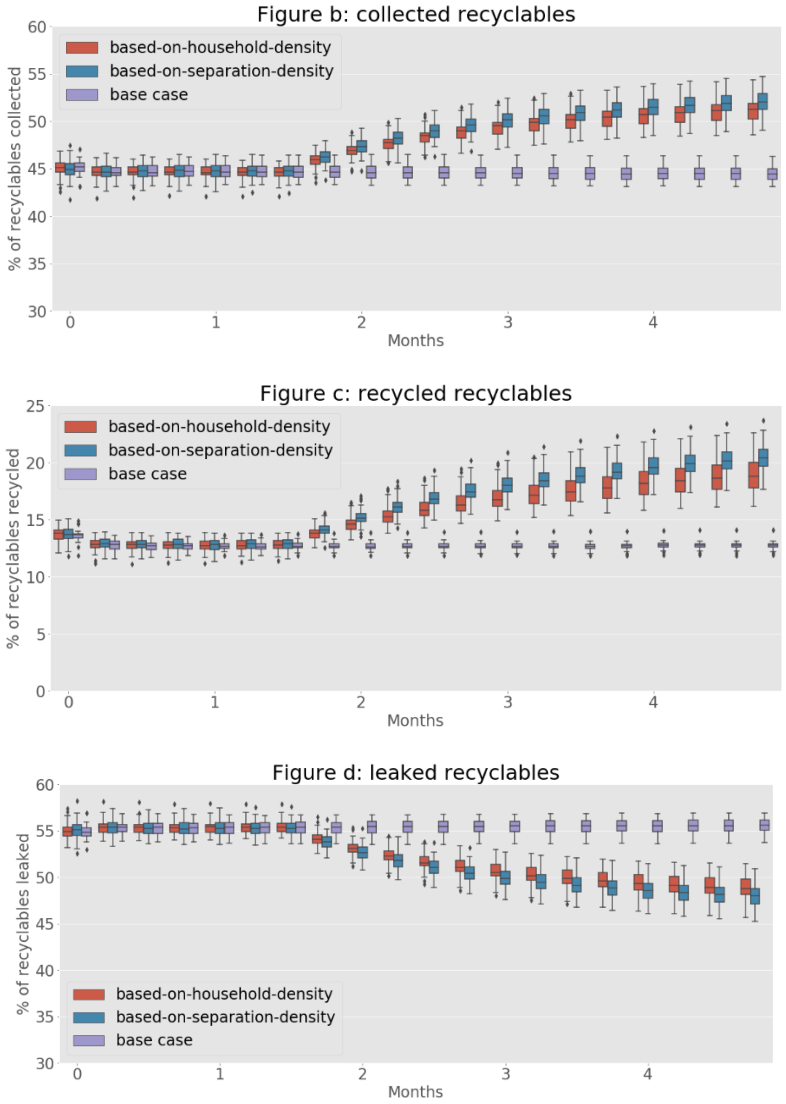


Figure 8.11 - Boxplots of intervention 1+3, based on tbr-location-strategy

The repetition strategy of the campaigns barely shows any differences in outcome (Figure 8.12). When separating households thus get their waste collected, they stay motivated to separate their waste.

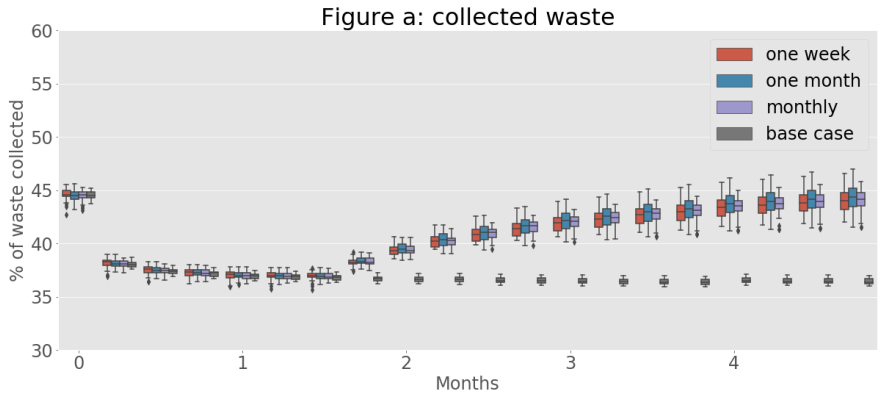


Figure 8.12 - Boxplot of intervention 1+3, based on campaign-repeat

ADF & Awareness campaigns

These two interventions individually did not have a considerable influence on the KPIs. The ADF negatively influenced the recycling rate (Figure 8.4), and the ARCs only slightly increased the collection and recycling rate (Figure I.13 in Appendix I). Combining these two interventions shows that waste pickers' collected materials are higher than the individual interventions (Figure 8.13).

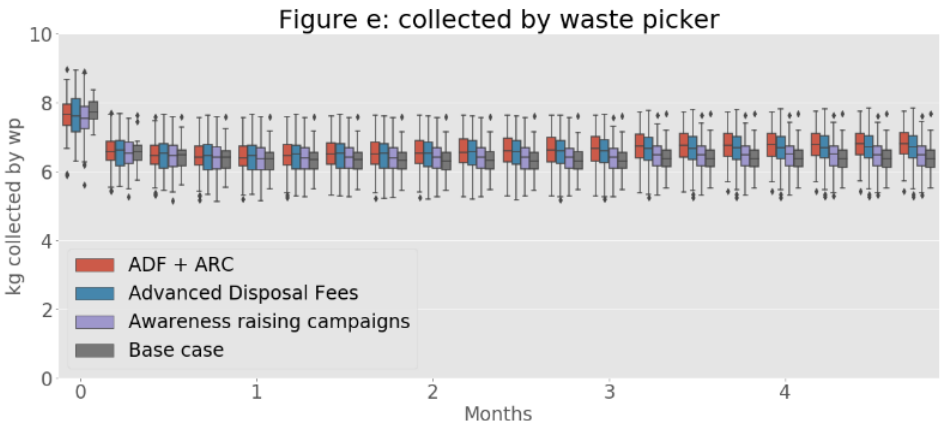


Figure 8.13 - Boxplot of intervention 2+3, compared with individual interventions

Take-back requirements & ADF & Awareness campaigns

The following experiment has been run (Table 8.3). When combining the three interventions, both household density and separation density have been included. In the earlier analyses, it was found that both strategies could result in higher collection rates. The three interventions that were run together are compared with the individual interventions.

Table 8.3 - Experiments of combining all three interventions

Experiment	Variable	Strategy options	Motivation	Replications
1&2&3	1: start day	30, 50	All together and in order based on previous analyses	20
	1: location-strategy	based on household density based on separation density		20
	2: start day	30, 70	All together and in order based on previous analyses	20
	2: target	30	Highest collection rate	20
	3: start day	30	All together and in order based on previous analyses	20

	3: location-strategy	based on household density based on separation density		20
	3: repetition-strategy	one month		20
Compared with:				
1	tbr-location-strategy	Based on household density	Highest collection rate	20
2	target	30	Highest collection rate	20
3	arc-location strategy	Based on household density	Highest collection rate	20
	repetition strategy	One month	No clear preference between strategies	

When combining the three interventions altogether, there are a few results visible. The two collection rates are lower with the combined interventions than when the take-back requirements are implemented by themselves (Figure 8.14a and b). The combined interventions seem to achieve a higher recycling rate. However, the difference with the take-back requirements individually becomes smaller over time and seems to shift after a few months (Figure 8.14c). In Figure 8.14e, it is visible that the take-back requirements individually affect the collected materials of the waste pickers. When combining the interventions, this loss is not visible anymore.

Figure a: collected waste

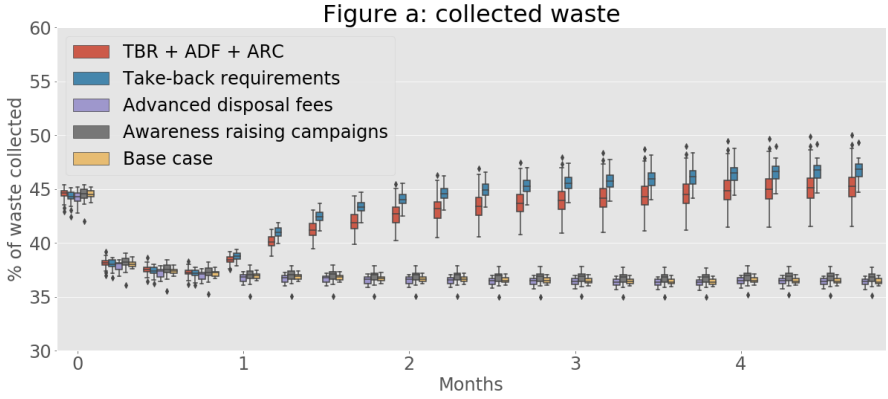
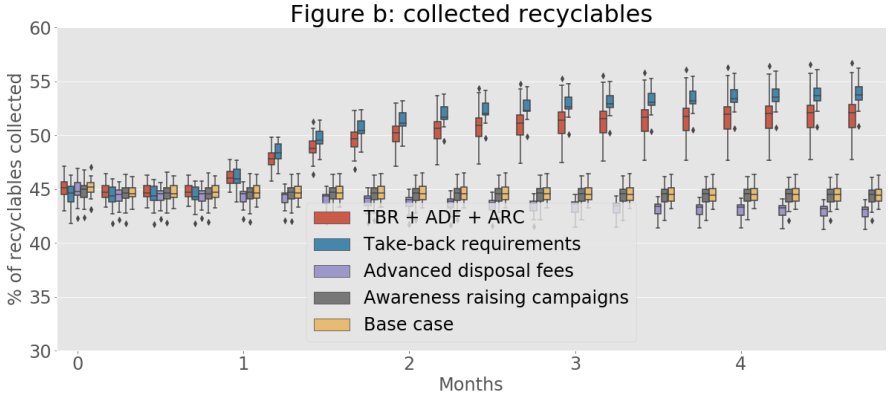


Figure b: collected recyclables



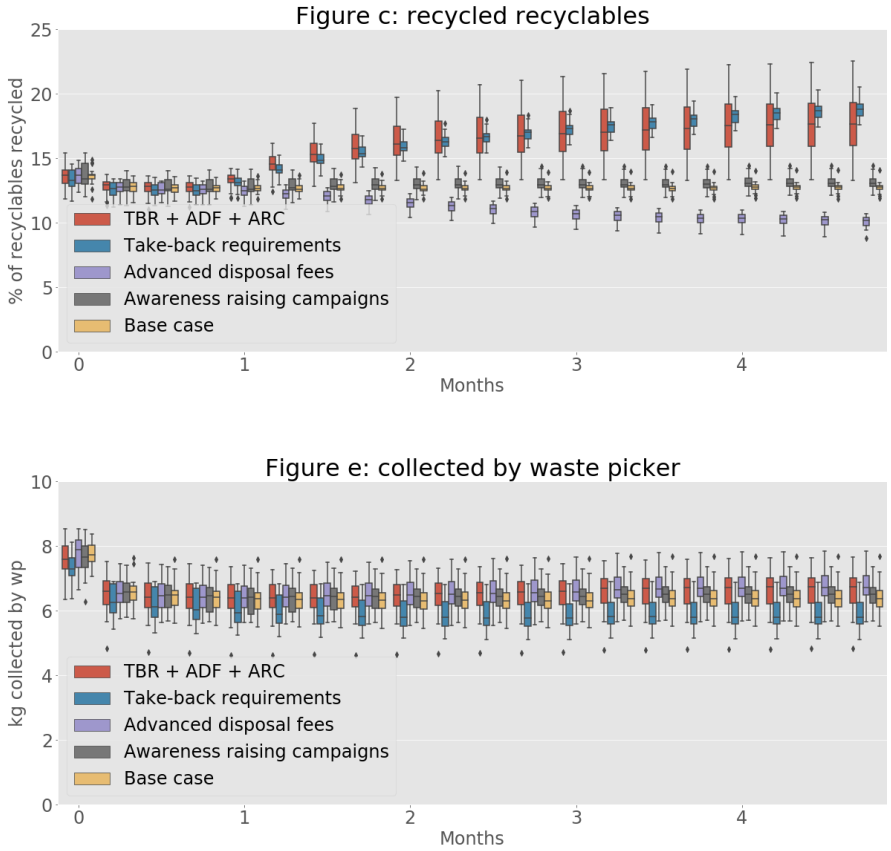
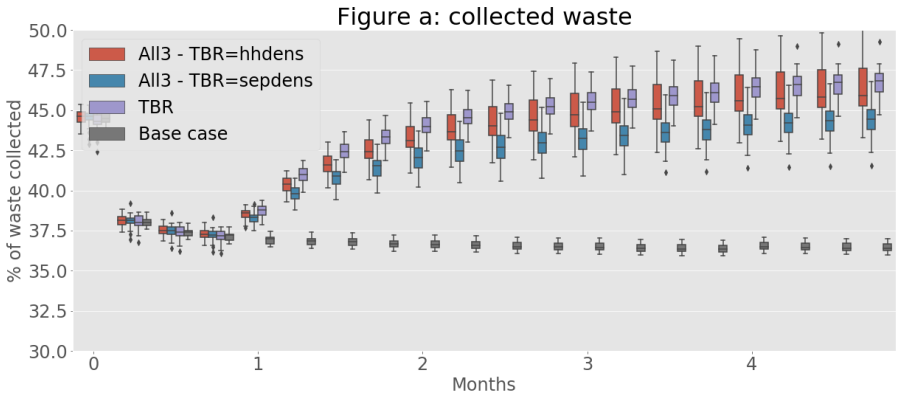


Figure 8.14 - Boxplots of combining all three interventions, compared with individual interventions

A closer look is taken at the combined interventions, compared with the take-back requirements individually. The take-back requirements individually seemed to result in the best collection and recycling rate when the collection locations were placed in locations based on the household density (Figure 8.3). This conclusion can also be made for the combined interventions (where the interventions start at the same time), as can be seen in Figure 8.15a, b, and c below.



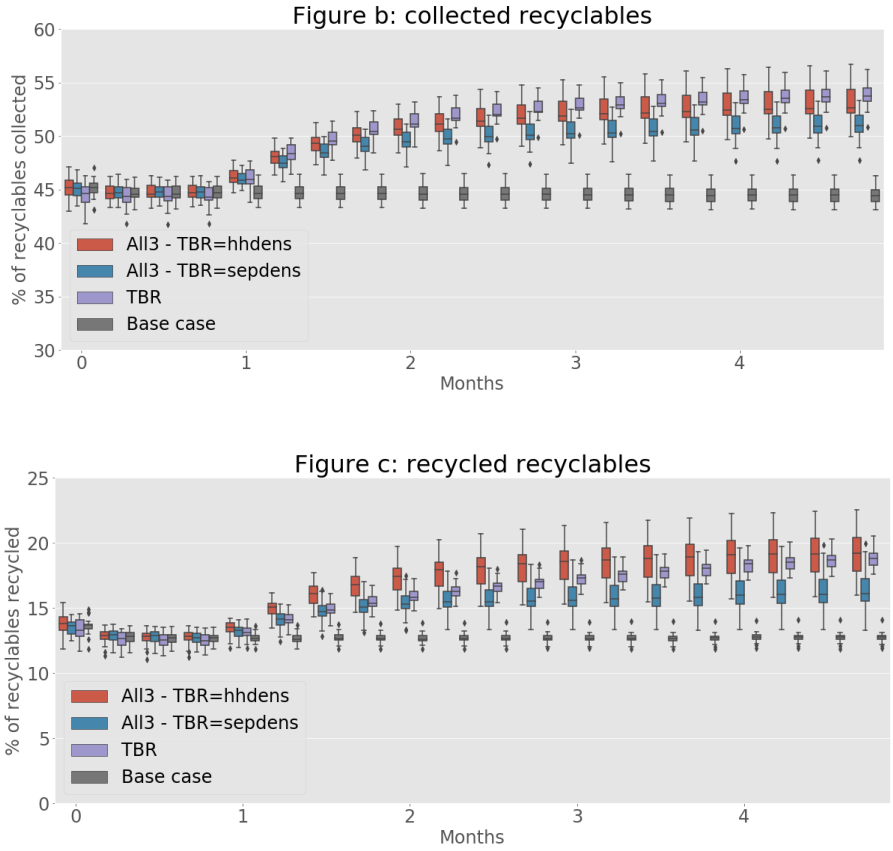


Figure 8.15 - Boxplots of all interventions combined, based on tbr-location-strategy

Before, the interventions all started on the 30th day in the model. When the interventions are implemented based on when their combinations resulted in better outcomes, there is a preferred order of implementation. First, awareness-raising campaigns start, then take-back requirements are installed, and lastly, the advanced disposal fee gets implemented. When using this order, the best location strategy of the take-back requirements shifts from household density to separation density (see Figure 8.17 and Figure 8.17).

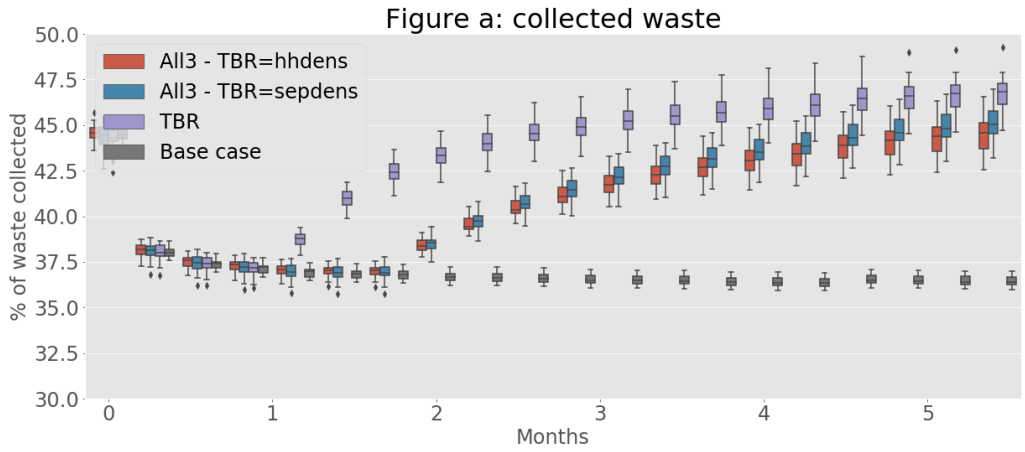


Figure 8.16 - Boxplot of interventions when implementing them in different time orders - compared with the individual take-back requirements

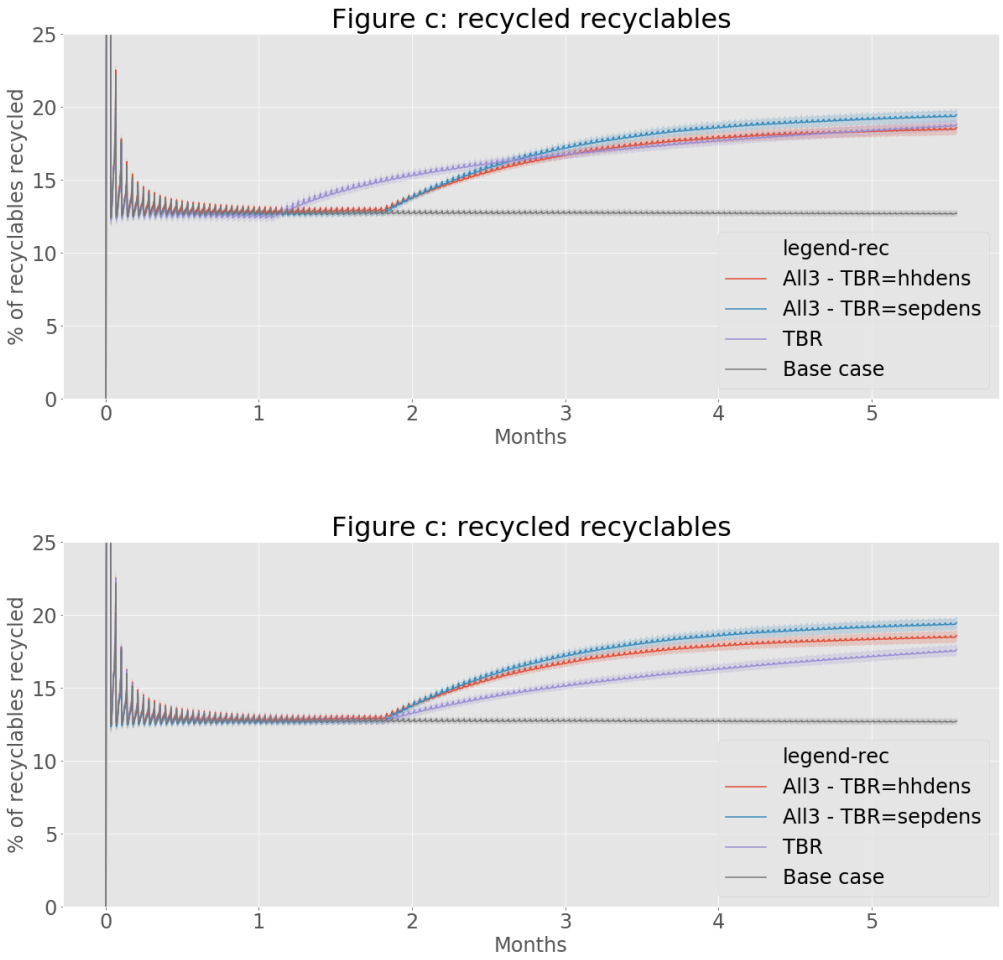


Figure 8.17 – Line plots of interventions when implementing them in different time orders - compared with the individual take-back requirements that start on day 30 (above), and day 50 (below)

8.3 Validation of model

The validation of a model is a crucial step when there is a desire to use the model's results in a broader context. The goal of model validations is to determine whether the model represents the thing that it models (van Dam et al., 2013). It thus needs to be checked if the model actually models the waste collection system of Indonesia accurately enough to interpret the results in a valuable way.

The goal of the model should be taken into account when conducting the validation. In this thesis, the purpose is not to indicate how much the interventions can increase the collection- or recycling rate. Instead, the goal is to gain insights into the agent behavior and the collection and recycling rate when specific EPR interventions are implemented. Therefore, the model validation focuses on 1) the agents' behavior, 2) the relative outcomes of the collection and recycling rate, and 3) the modeled effects of the EPR interventions.

First, a sensitivity analysis has been done to analyze the sensitiveness of certain behavior parameters. Then, a literature validation was conducted by comparing the model outcomes with other research. Thirdly, an expert interview validated the effects of the EPR interventions.

8.3.1 Sensitivity analysis

A sensitivity analysis was conducted to evaluate the effects of the chosen parameters. The values of the parameters were varied, and the effects of these changes are analyzed to see whether the model is sensitive to parameter changes. The sensitivity analysis is discussed in greater detail in Appendix J .

In the model, the distribution of Rogers (1995) is used as a basis for the adoption of innovations, like waste separation at the household level. However, based on Mollaoglu & Syal (2015), a different innovation distribution was applied, with more innovators and early adopters to analyze the model's sensitivity. The results of the sensitivity analysis show that the model is susceptible to the innovation level distribution. The distribution of Mollaoglu & Syal results in more than a duplication of household separation percentage in the base case (see Figure 8.18).

A change in capability threshold did not result in much change in separation percentage. From the three motivation-increase and -decrease parameters, the `motivation-decrease-personal-experience` was quite sensitive to changes. The `motivation-decrease-social-influence` and the `motivation-increase-social-influence` were relatively stable.

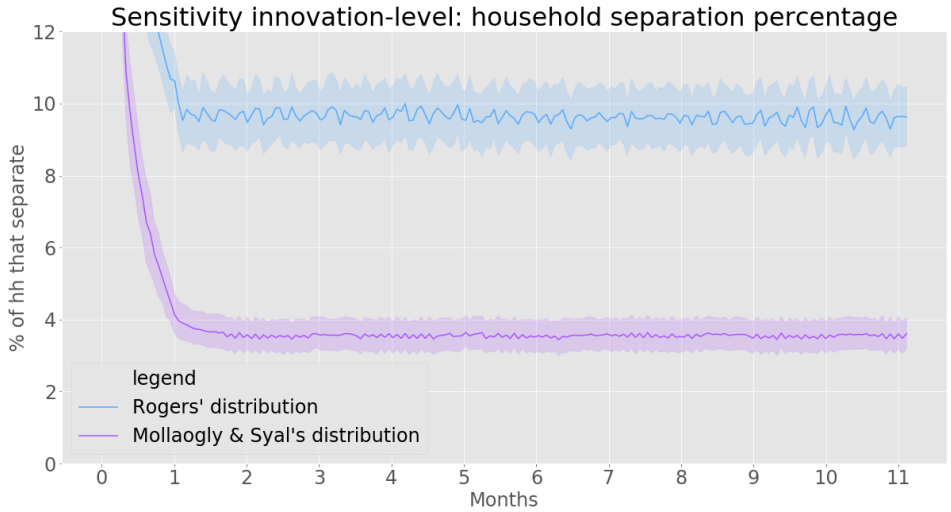


Figure 8.18 - Result of sensitivity analysis based on the innovation-level distribution

8.3.2 Validating the relative collection and recycling rate

The collection and recycling rate are two values that are usually available in the literature that analyze (plastic) municipal solid waste management. These two variables are therefore obtainable to validate. No articles were found that analyzed municipal solid waste management in medium-sized Indonesian cities, which is the modeled scope. However, two articles focus on municipal solid waste management in two megacities in Indonesia. They will be compared with the source on which the model's base case numbers are based (World Economic Forum, 2020).

Ratna et al. (2018) analyze plastic flows in Jakarta, Indonesia's capital city. They found a plastic recycling rate of 24% of the plastics produced through a Material Flow Analysis. World Economic Forum (2020) showed that the average recycling rate in mega archetypes (like Jakarta) is around 20%. Therefore, the 20 and 24% that were found in the studies can be comparable. For comparison, based on the WEF research, medium-sized cities have a recycling percentage of 12%, which is used to calibrate the model (see Appendix G).

Sembiring & Nitivattananon (2010) studies solid waste management in Bandung, another megacity in Indonesia. They analyzed the residential waste collection of the city and how much the informal sector contributes to this. They measured a waste collection of 76%. World Economic Forum (2020) shows a collection rate of plastics, not solid waste in general. It can be assumed that the collection of plastics is higher than the collection of all waste due to the informal sector activities (Sembiring & Nitivattananon, 2010). World Economic Forum (2020) finds that in mega archetypes, the collection rate of plastics is 74%, which is thus comparable with the article. World Economic Forum (2020) indicates that plastic collection in medium archetypes is limited to 44%. In the agent-based model, the average waste collection of plastics is around 45%.

Even though the scope of the articles is different, when having the WEF research as an intermediate source, the results of the collection and recycling rate are similar to the model.

Ratna et al. (2018) do, however, see quite some leakage at the informal collection (3.5%) and at the recyclers (10.2%), which has not been taken into account in the agent-based model. This will be elaborated on in the discussion section of this thesis.

8.3.3 Expert validation

After the model and experiments had been done, the results were reflected upon with one of the previous interviewees. Waste 4 Change is an organization that tries to tackle (plastic) waste pollution via local communities and creating cooperations. They are knowledgeable about the plastic system and can therefore provide insights into the possible effects of the EPR instruments. The interview started by giving a short recap of the research goal since the interviewee was interviewed before. Then, the three EPR interventions were discussed in more detail, indicated in the slides (Appendix J). First, some open questions were asked to get the first thoughts on the interventions of the interviewee. Then, we went into more detail on each of the interventions. Only after the first round, the conclusions of the interviewer were discussed to prevent bias in the interviewee's answers.

The interviewee mentioned that the first two interventions are very likely to be implemented hand-in-hand. As more collection costs money, and the disposal fees could fund this. This can be done via a waste credit system, where producers receive 'waste credits' when they give funding to collectors or recyclers for processing their waste.

Regarding the effects of the first intervention, the interviewee suggested that take-back requirements could start two more interactions. Firstly, it can stimulate producers/brand owners to work together with the most efficient player in the recycling sector – the informal collectors. This would also stimulate informal collectors to work via a union that can make better arrangements with the producers. Furthermore, they would need to pay the informal collectors more than the middlemen do or provide better working conditions. This could thus lead to positive effects for the waste pickers financially and physically. It could also influence them socially, as waste pickers "will be seen as the backbone of the recycling sector rather than second-

class citizens" (W4C, personal communication, 2021b). It will probably not directly result in the emergence of more waste pickers due to the bad working circumstances they have to do the job in. It requires a process to transform their working conditions.

Secondly, take-back requirements can increase the number of recyclers because there is a 'supply' available of waste streams. Right now, the recyclers need to put much effort into sourcing input materials, whereas this would become easier if companies start collecting themselves. This can also lead to the recycling of multi-layered plastics. The technology to recycle these is available, but the material supply is so tiny that it is not profitable to do so (yet).

The interviewee reflected on the Advanced disposal fee to increase the quantity of the recyclables in the waste streams and their quality, which is the same effect as the modeler implemented. Furthermore, the interviewee mentioned it could stimulate "bring your own packaging" concepts and buying in bulk. Moreover, he warned that data monitoring might be challenging and that brand owners might go abroad to prevent paying for the fees.

The interviewee was very optimistic about the awareness campaigns since he confirmed this is very important to achieve less waste pollution. He emphasized the importance of independent campaigners to prevent greenwashing of certain brands. A third party can keep in mind the overall goal of the awareness campaigns like less consumption and better disposal. Furthermore, the campaigns do stimulate not only waste separation but also less consumption and less littering.

8.4 Summary chapter 8

In the table below, the results per experiment are presented. The first intervention is the implementation of take-back requirements, intervention two is the advanced disposal fees, and three is the awareness-raising campaigns.

Experiments	Outcome
Individual	
Base case	When nothing happens, there are lower collection and recycling rates in the long run due to higher plastic consumption.
1	Placing the collection vehicles in areas where the household density is the highest result in the highest collection and recycling rates. There are fewer leaked plastics, but unfortunately, waste pickers can retrieve fewer recyclables.
2	The recycling rate decreases due to the higher amount of recyclables in the municipal solid waste. However, the absolute value of collected recyclables increases.
3	No influence on KPIs, but there is on separation behavior. Results are best when the campaigns are placed in areas where there is little separation behavior. Trivially, the longer or more frequently the campaigns occur, the higher the separation percentage is.
Combinations	
1+2	The collection and recycling rates increase but are lower than the take-back requirements alone. Waste pickers collect similar or slightly more recyclables than in the base case. Even though long-term effects are not visible, starting with take-back requirements before advanced disposal fees result in higher recycling rates than the other way around.

1+3	The collection rates rise similarly as the take-back requirements would do individually. The recycling rate increases much more during the combination of interventions. Implementing awareness-raising campaigns before the take-back requirements results in higher collection and recycling rates. Additionally, placing the collection vehicles in places with the highest separation density results in higher collection and recycling rates than in places with high household density. The duration of the campaigns is of little importance to the effect on the KPIs.
2+3	A slight decrease in the recycling rate (see intervention 2 individually). A slight increase in the amount collected by waste pickers.
1+2+3	The collection and recycling rates increase but are lower than the take-back requirements individually. The number of recyclables collected by waste pickers was higher than in the base case. Placing the collection vehicles of the take-back requirements in areas with the highest household density results in the highest collection and recycling rates. However, the location strategy can better focus on a high separation density when the awareness-raising campaigns are implemented before the take-back requirements.

The next part reflects upon the study and discusses the results.

PART IV – DISCUSSION AND CONCLUSION

9. Discussion

This chapter explores the results in more detail. First, the method and results are reflected upon. Secondly, results will be put into perspective by discussing the interpretation and implications of these results. Thirdly, the academic contribution of this thesis is described. Finally, the limitations of this study are discussed.

9.1 Reflection on methods

In this section, the used methods and their implications will be discussed.

9.1.1 Agent-based modeling

In the knowledge base part, especially chapter 2, the agent-based modeling (ABM) approach has been motivated. There were three aspects of this research that stimulated using an ABM. 1) It can model complex adaptive systems, 2) it can model the behavior of different agents, and 3) it can implement and simulate policy interventions (section 2.5). As this research aims to analyze the effects of interventions on the Indonesian plastic waste system, the first and third reasons are directly covered. Furthermore, based on the literature review, agent behavior was found to be of importance in this research. It namely indicates that the dynamic behavior of the different stakeholders, especially the informal waste collectors, with the rest of the waste system components could lead to emergent behavior (section 2.1.3). However, the agent behavior was different than initially thought.

Based on the interviews, the waste pickers do not have many behavioral thresholds and interactions with other stakeholders that influence the collection and recycling rate. Therefore, the focus of the model became more focused on the household separation behavior. This can also be the result of biased interviews due to the background and networks of the interviewees. The interviewees working for the government, private parties, NGOs, or waste banks do not directly interact with waste pickers, whereas they are all part of a household themselves. They all see households as people that can and should change their behavior for a better environment. Furthermore, waste pickers usually do not actively choose this occupation and might therefore be seen as less responsible for the waste management problem.

Although the second reason to choose for ABM, the ability to model the behavior of different agents, was still valid, it is based on other reasons than initially decided upon. The behavior of households got a larger share in the model than the informal waste pickers.

9.1.2 Choosing interventions

The three interventions of the analysis were based on three factors initiated by the author. These factors were the product's life cycle, the type of instrument, and the Indonesian contextual factors (see section 5.3). The decision was relatively subjectively made and not directly validated with stakeholders because most interviewees were not familiar with all EPR instruments. Therefore, they could not make a deliberate consideration. Consequently, the three instruments were selected based on the three factors.

Only a few EPR instruments have an effect on the downstream phase of a product's life cycle (see Table 5.1 in section 5.2). Besides the take-back requirements, only the recycled content standards, deposit-refund system, and the upstream combination of tax and subsidy. However, they all have direct effects on the other stages too. It would be interesting to see the effects of instruments that affect multiple life cycle phases, but it can be more difficult to determine where these effects originate from.

The consumption phase is mainly targeted by communication instruments since this involves the consumers the most. All three instruments of Table 5.1 focus on the awareness of consumers and would thus have similar effects. Although, the environmental reports and labeling would require more from companies themselves. This involves compliance which is hard to establish in Indonesia.

Many instruments affect the upstream phase of a product's life cycle. However, since the take-back requirements are a regulatory instrument, the instruments that affect the upstream phase are limited to three financial instruments: advanced disposal fees, product taxes, or virgin material taxes. All three can result in similar effects: less production of harmful or hard to recycle materials. This can also depend on the height of the tax or fee. When the fee is relatively low, the effects on the material content of a product will be minor. The investments in changing production are then higher than the costs of paying the fee. Hence, defining the exact fee should be carefully determined, and other research has been conducted to calculate this (Pires, Martinho, Ribeiro, Mota, & Teixeira, 2015).

9.1.3 Behavior change factors

The three components of the household behavior consist of motivation, capability, and opportunity. Michie et al. (2011) describe that these three elements generate particular behavior, which also affects motivation, capability, and opportunity again. The same effect is visible in the waste management system. If the behavior of separating recyclables from wet waste and residues results in separated waste collection, the motivation to continue this behavior increases. In this research, the focus was thus mainly on motivation and opportunity. The capability threshold was static and reflected upon in the sensitivity analysis (section 8.3.1).

Furthermore, Michie et al. (2011) explain that certain types of policies affect one or more of the three behavior elements. Interventions that focus on external forces, like restrictions and coercion, mainly affect motivation and opportunity; interventions emphasizing personal agency, like education, incentivization, and training, influence capability and motivation. When looking at the three interventions of this research, take-back requirements are "enablements", according to Michie et al., which can influence all three behavioral factors. In this research, the take-back requirements mainly focused on the opportunity as the number of collection vehicles increased. The advanced disposal fees (ADF) are a form of "coercion", which affects motivation, according to Michie et al.. In this research, the ADF influenced the production of packaging, but not per se the agent's behavior. Lastly, awareness-raising campaigns are a form of "education" that can influence capability and motivation (Michie et al., 2011). In this thesis, the campaigns only contributed to motivation and not to capability.

Concluding, there are many effects that interventions can have on behavior. The behavior change factors of Michie et al. (2011) can be valuable to get insights into behavior based on intervention types. However, in reality, these do not always overlap, and thus the effects always need to be carefully investigated.

9.2 Reflection on results

A main outcome of the simulation of the interventions is that multiple interventions can cover a broader effect than individual interventions. Implementing the take-back requirements alone can achieve a high collection rate, but also has a high chance of damaging the possibilities for informal waste pickers. Implementing this intervention together with advanced disposal fees or

awareness-raising campaigns can diminish the negative effect for waste pickers. As will be explained extensively in section 9.6, modeling comes with many assumptions. Integrating the complex interventions in the relatively simplistic agent-based model can, thus, have different interpretations in reality. Therefore, it is needed to properly reflect on the use of the interventions in reality and the model. This section describes the goal of the intervention, how it is modeled and what the implications of the results thus are.

9.2.1 Intervention 1 – take-back requirements

Take-back requirements are meant to stimulate the downstream phase of a product to be adequately taken care of. With collective responsibility, a third party collects fees from individual producers, which they can use to collect and dispose of waste streams. This intervention is modeled as implementing more TPS3R collection vehicles in the system. They pick up waste, preferably separated waste, and bring it to their sorting facility. They go through the mixed waste and sort out the recyclables that are not contaminated. The recyclables are brought to middlemen, and residual waste is brought to a landfill.

In reality, take-back requirements are more complex than solely more collection vehicles. Vehicles and sorting facilities need to be installed, and many people are involved in establishing and operating these aspects. Ten vehicles are included in the model that work for 9 hours with a certain vehicle capacity, but this can also be different based on local working conditions. It is modeled that they only go to households, but they could also include waste from industries. Furthermore, making sure every producer pays the fee takes a lot of time and effort. The party responsible for checking the compliance needs to be agreed upon and properly executed. The money collected due to the take-back requirements might not only be used to collect waste streams. The fees can also improve recycling facilities or awareness-raising campaigns (IPRO, personal communication, 2021). In the model, a distinction is made at what location of the collection vehicles should start. However, more decisions need to be made in reality regarding time, capacity and employees.

Furthermore, from the validation interview, it is possible that implementing take-back requirements does not only affect the improved collection capacity. For example, when recyclers know there will be a supply of waste, they can anticipate and increase recycling opportunities, also for waste streams that are harder to recycle and now end up in landfills (W4C, personal communication, 2021b). However, the model does not include these more indirect effects, which should be considered when implementing policies.

The establishment of the governance of the EPR instrument is therefore of great importance, and underestimating this can lead to unforeseen situations. For example, the construction of TPS3R facilities went very well, whereas the maintenance of the facilities was not adequately discussed, leading to non-operational facilities (McKinsey.org, personal communication, 2021). The model thus merely shows a result of the intervention when it is implemented in a certain way and properly managed. Therefore, more emphasis should be put on the actual formalization and implementation in the long run when realizing the take-back requirements.

9.2.2 Intervention 2 – advanced disposal fees

Advanced disposal fees have the goal to make the materials of (plastic) products more recyclable. For example, by rewarding producers that use recyclable materials, rather than materials that cannot be recycled, or only downcycled (which means after the end of a product's life, it cannot be formed into the same product or a product with better quality). This intervention results in

producers changing their (packaging) products to such an extent that they become more recyclable, which means there are more recyclable materials in the waste streams.

In the model, there has been a division in the recyclable waste percentages. In the base case, the waste streams consist of 20% recyclables, whereas the scenarios simulate percentages of 25, 30, and 35. The results show that this does not evenly decrease the recycling rate, as there is a limit on the collection capacity. In the validation interview, it was mentioned that the materials would also be of higher quality, which might attract recyclers. However, this effect is also dependent on the continuous availability of the waste streams.

When implementing advanced disposal fees in Indonesia, compliance and governance are again essential factors to consider. The establishment of the height of the fees should be thoroughly determined, as well as the collector of the payments. Even though it was confirmed by the validation interview (section 8.3.3), the assumption that the fees actually lead to more recyclable products and how long this transition takes can be questioned.

An implication of the ADF could also lead to producers that might go to other markets where no fee needs to be paid for the disposal of products (W4C, personal communication, 2021b). These types of possible effects need to be considered and are very important for (governmental) organizations that want to stimulate economic growth in Indonesia.

Another issue should be taken into account when implementing policies with a specific target, like ADF. A policy is made with a goal in mind. To achieve this goal, targets should be set for stakeholders to work towards. However, to achieve these targets, procedures change, affecting other system components (Afvalfonds Verpakkingen, personal communication, 2021). Therefore, it is essential to formulate the targets well to prevent inconsistencies in the targets and the overarching goal.

9.2.3 Intervention 3 – awareness-raising campaigns

The awareness of Indonesian citizens was mentioned many times as an important catalyst for change. Behavior change is challenging to accomplish, but can reduce plastic leakage in different life cycle phases. Right now, throwing away trash on streets or in rivers or burning it in backyards is a prevalent thing to do. Not only because no better options are available but also due to the lack of knowledge on the effects of these harmful end-of-life options. The awareness-raising campaigns should thus make Indonesian households aware of the negative consequences and stimulate them to reduce waste leakage in the environment. In the model, the awareness-raising campaigns focus on the motivation, capability, and availability of waste separation.

However, in real life, awareness of plastic waste leakage reduction comes down to more than just waste separation. The increased awareness can also result in less consumption, thus less waste production. Furthermore, people might litter less on the streets and use bins instead (W4C, personal communication, 2021b). These effects are not included in the model but make the implementation of this intervention and its impact more complex.

Moreover, in the model, there is a certain threshold in which the behavior of households changes. There is a distinction between high-medium-low motivation, which makes people separate all their waste, half of their waste, or no waste. In real life, however, behavior change is not as simple. It is a more gradual change than these 3 phases. Furthermore, it might take years to achieve behavior change, whereas this model only simulates a few months.

9.2.4 Combinations

Combining the take-back requirements with the advanced disposal fees increases the collection capacity and the share of recyclables in the waste stream of households. The graphs indicate that the combinations of interventions are similar to adding the result of the two single interventions. This is also visible for the combination of ADF with the awareness-raising campaigns. However, the interventions are not entirely independent from each other. For example, the ADF influences the collection system and the extra collection vehicles. The model simulates them together, which results in the system behavior and therefore does not show what the individual behavior exactly does.

The combination of take-back requirements with awareness-raising campaigns does show a much higher recycling rate than just adding individual interventions. This indicates the effectiveness of source sorting: the yield of recyclables is higher when households already separate their waste. This is due to the fact that fewer recyclables get polluted with other waste and the quality of the waste stream is thus higher.

Running all three interventions together, the collection and recycling rate increase, but less than the take-back requirements individually. The interconnections of the interventions can thus limit the effectiveness of an individual instrument. This shows that instrument combinations can be less than the sum of their parts. Whereas take-back requirements and awareness-raising campaigns result in a higher recycling rate together, adding ADF did not improve this. However, since ADF adjusts the recyclables in waste streams, the absolute number of collected plastic increased due to the ADF.

From all combinations, it can be seen that the take-back requirements make the most significant changes. Increased collection capacity is something that needs to be done to reach positive effects from the other instruments. However, the order of implementation is also of importance.

The start time of the combined interventions affects the results. Source separation is the first important factor that should be implemented for the benefit of the other interventions. Secondly, the collection should be improved. The advanced disposal fees should be implemented only when these two are running to ensure the extra sorted waste does not go to landfills but gets adequately disposed of instead. In this case, the communication EPR instrument should start, followed by legislative and financial instruments. This applies to the three interventions of this research, but it would be interesting to test it with more instruments.

9.3 Interpretation of results

The interpretation of the results will be discussed via the four contextual factors of Indonesia: little waste management infrastructure, high- and low-value plastics, informal sector, and compliance (see section 4.4). It can be read that these factors are also very much interlinked.

9.3.1 Little waste management infrastructure

Waste management is indicated to need a system approach. However, in a country with little waste management infrastructure, small steps should be taken at a time. In Indonesia, relatively little is done yet to incorporate the concept of Extended Producer Responsibility. It is a comprehensive concept and very difficult to implement everything at once. That is why the three proposed interventions could be a good start that shows some effects of implementing them individually and simultaneously. When (part of these) interventions are implemented and the

collection and recycling rates increase, it can stimulate producers, households, and governments to make waste management a higher priority. Capital and operational investments are needed for large infrastructural improvements. These need to be shared amongst all stakeholders involved, which can be done through EPR.

9.3.2 High- and low-value plastics

Most plastic debris comes from plastics with low economic value after their use phase because they are hard to recycle and therefore not captured. EPR was founded to establish a system where all types of waste are accounted for. However, voluntary EPR systems seem to target high-value plastics due to their economic profit when recycled. On the other hand, mandatory systems are hard to establish when there is little existing infrastructure and little compliance. Thus, a mandatory EPR system can follow a voluntary one once initial investments have been established. For this, compliance is essential and should be monitored by a third party.

Awareness of Indonesian citizens is another important aspect that can contribute to less pollution of hard to recycle plastics. End-of-life materials are seen as trash and not valuable. However, besides being able to recycle it, they should be placed in bins and not on the streets. The ease with which people throw things on the ground should be tackled by creating new waste disposal habits.

9.3.3 The informal sector

The informal sector is mainly present on Java and Bali island, since the population, and therefore the waste production, is highest, and the recycling facilities are mainly located here. They collect high-value plastics, as the only reason they collect waste is to earn money with it. For many informal waste pickers, their working conditions are poor and dangerous, but waste collection is still necessary to make a livelihood for their family. This research shows that implementing EPR can interfere with these waste workers, which can cause significant socio-economic effects. Trade-offs between interventions should therefore carefully be considered before implementation starts.

Integration of waste pickers with the formal system is an option, but this is difficult due to available financing (ADUPI & McKinsey.org, personal communication, 2021; Sembiring & Nitivattananon, 2010). Furthermore, the involvement of child labor makes many organizations not want to get involved with the informal sector (W4C, personal communication, 2021). Also, the relations of waste pickers with middlemen usually depend on long-standing loans, keeping them locked in the dependent relation (W4C, personal communication, 2021). Still, the informal waste pickers are the main contributors to collecting waste for recycling. So, they should be valued more rather than changed or avoided. Due to their critical working conditions, it is both essential and challenging to find possibilities of cooperation.

9.3.4 Compliance

Right now, there is no compliance with EPR regulations due to a lack of finance and human resources. This means companies do not get fined for not taking care of the end-of-life phase of their product. That is why the voluntary systems try to make a business case out of the waste, to convince companies to contribute. However, the goal of EPR is not making a profit out of waste but being responsible for the entire life cycle of a product. This contradiction is challenging to integrate into a system like Indonesia, where no sustainable collection systems are available. On the other hand, voluntary systems might be needed when mandatory systems will not be forced in the short term (Afvalfonds Verpakkingen, personal communication, 2021), which advocates for economically attractive options.

Thus, financial means for infrastructures and mandatory EPR systems require compliance. This needs to be examined by an external party, often a governmental organization. The establishment of such a governance structure, however, takes time.

9.4 Implications of results for policymakers, companies, and other countries

The results provide insights into the evaluation of EPR policy instruments, individually and simultaneously. These can be used by policymakers and implementation organizations that focus on improving waste management or reducing environmental pollution. The results provide insights into the complexity of implementing policy interventions. Moreover, it stimulates to consider combinations of interventions and take into account the time of implementation.

Furthermore, this thesis shows the benefits of simulating policy scenarios, which can be done for other policy interventions in the waste sector or others, too. Multiple scenarios can be designed and simulated in the model to test certain (combinations of) interventions.

For (Indonesian) brand owners, these results can provide insights into the necessity for close collaboration between different organizations. These collaborations need to be established to improve Indonesian waste management and reduce plastic pollution in the environment. For other organizations like Rebel Group, the results provide insights into the complexity of EPR instruments in a developing context. It can help advise local organizations to contribute to less waste pollution.

This research was done in the context of Indonesia. However, the results could be distributed to other countries with similar waste management practices. Little waste management infrastructure, plastic pollution, and large informal waste sectors can be found in more developing countries that consider implementing EPR instruments. Combining interventions can be beneficial for other countries as well. Furthermore, the timing of implementation applies not only to EPR instruments but also to other policy combinations.

The concrete recommendations based on these implications can be found in section 10.3.

9.5 Academic contribution – closing the rigor cycle

The overarching research approach of this thesis is the design science research of Hevner (2007). As explained in section 3.2, the rigor cycle connects the design of the artifact (the agent-based model) with the knowledge base. This knowledge base was laid out by first consulting literature to define the research problem and secondly analyzing the current literature of the field of study. In this section, the scientific gaps are revisited, and an explanation is given of how these gaps were filled.

9.5.1 Methodological contribution

Two main topics can be distinguished in literature: effects of Extended Producer Responsibility and simulating policy interventions to improve waste management.

Academic literature analyzed current EPR systems in different countries. Researchers presented the effects of implemented EPR schemes in Western countries and provided recommendations to develop these systems further (Leal Filho et al., 2019; Pires et al., 2015; Quoden & Grant, 2019).

Research on EPR in developing countries highlighted barriers and enablers for implementing EPR in countries with little waste management infrastructure (Gupt & Sahay, 2015; Hotta et al., 2009; Nahman, 2010; Ebo Tawiah Quartey et al., 2015). Research has also been done on EPR in Indonesia specifically, that presented either high-level recommendations (Tristiana et al., 2018) or did not include behavioral aspects like source separation and the informal sector (Destyanto et al., 2019). Only the last researchers analyzed the effects of specific EPR interventions. They developed a system-dynamic model that examined the effects of EPR interventions on the plastic sector as well. However, they did not integrate the informal sector or the household separation behavior, which both have significant effects on the plastic recycling quality and quantity.

Current literature on EPR in developing countries is mainly theoretical analyses, whereas there is demand for more context-specific pilots to improve waste management (Kaffine & O'Reilly, 2015). Some researchers analyzed waste management via an agent-based model, which can simulate these pilots. These researches use the ABM for purposes other than assessing EPR policy interventions specifically. This thesis combines household behavior (which is also done by Meng et al. (2018); Tong et al. (2018)) with informal sector behavior (García-Díaz & Moreno-Monroy, 2012; Gibson, 2012) and collection scenarios (Kerdlap et al., 2020). Meng et al. (2018) did include both the household and informal sector behavior, but used interventions that focused solely on household waste disposal. Combining the households, informal sector and collection scenarios results in a broader approach where tradeoffs between different types of interventions can be made. This, thus, fills the gap of simulating EPR interventions and integrating multiple perspectives in the formulation of EPR schemes. Furthermore, this research provided insights into trade-offs when implementing EPR instruments. It also showed that combining interventions can strengthen or weaken each other's effects.

9.5.2 Contribution to waste management policies

Moreover, the results of this study indicate that the timing of the interventions can influence the effectiveness of the results. This variable has been neglected in other EPR-related research to the author's knowledge. Other research mainly focuses on individual policy interventions. However, this research shows that implementing an EPR instrument before another could either stimulate or weaken its effect on the collection and recycling rate.

Besides new contributions, this thesis also confirms current literature on household behavior. Source sorting improves the quality of the waste streams, increasing the recycling rate (Leal Filho et al., 2019). Other results recommend implementing a life cycle approach, where multiple phases of the product's life cycle are covered in interventions to avoid burden-shifting. This, for example, means that ADF (upstream intervention) leads to less low-value recyclables, but when there is no improved collection capacity (downstream intervention), the waste still pollutes the environment by being burned or thrown away. Even though this leads to tradeoffs between interventions, it also gives insights into their complementariness. This reinforces previous studies that recommend a systems approach to waste management policy interventions (Kaffine & O'Reilly, 2015; Leal Filho et al., 2019).

9.6 Limitations of study

This thesis researched Extended Producer Responsibility and tried to apply that in a context where it is fairly new. As with any research, this thesis comes with shortcomings and weaknesses. This sub section goes into these and provides ways to interpret these limitations.

9.6.1 Generic

First, this thesis was conducted with limited time available. This means that the scope of this thesis has been established to fit within the 30 ECTS available. Since the thesis consists of both qualitative and quantitative components, no comprehensive literature review has been done. There was, unfortunately, no time to analyze possibilities for generalizing the results to other developing countries more thoroughly, which was the initial idea.

Secondly, due to the pandemic, no field research has been done. Analyzing the behavior of stakeholders is more difficult to capture via literature or online settings than it would be if you can experience it as a researcher yourself. Biases could occur during interviews, which you could have seen more explicitly if you were in the field. Furthermore, the language barrier probably undermined some information transfers. This also caused the interview with the waste picker association to be canceled.

A third limitation of this research is that the focus has not been on economic behavior at all. For example, there is no price for plastic materials in the model, nor decisions based on income level (besides the boolean of capability threshold). This decision was made not to make the model more complex. This would namely require more agents that are between the waste picker and recycler because this 'chain' determines the price level of recyclable materials (W4C, personal communication, 2021). There has also been no focus on the economic consequences or requirements of implementing EPR interventions, as this could require a whole thesis on its own. Even though the researcher tried to still capture the behavior of stakeholders in a good way, this limitation could make the results less accurate. Furthermore, adding economic behavior could provide more insights into the financial design of EPR instruments.

9.6.2 Making a model

"*All models are wrong; some are useful.*"

(George Box)

Making a model can never be a direct representation of reality and therefore always comes with assumptions. These assumptions need to be made explicitly and transparent, and there needs to be a clear modeling goal to still make it a useful model. Model assumptions are discussed in chapters 6 and 7, and a list of all assumptions can be found in Appendix E.

Observer bias occurs as a model-maker, as you design the model based on your own perception. Even though there are ways to limit subjectivity, you model with a goal in mind, which limits the researcher's objectivity. Also, as a user and interpreter of the model, biases occur, which affects the model's results. For example, the researcher could use the hypotheses of the model's outcomes to model in a certain direction. To limit this bias, the results are validated, as explained in chapter 8.3.

9.6.3 An agent-based model

An agent-based model has the advantage that it can simulate possible implementation strategies that are difficult to evaluate in real life. It takes much effort, time, and money to make pilots of such EPR interventions. Modeling this system can provide thousands of pilots where the initial settings can be changed over and over. These results can provide insights into where tradeoffs of EPR systems lie, which can be taken into account in real-life implementation. However, this agent-based model also has some limitations regarding its assumptions and scope, which will be

discussed below. An agent-based model is therefore used as a tool to identify effects rather than analyzing absolute results.

Assumptions

Making a model comes with many assumptions. Most of them are made to simplify the model behavior, leading to limitations of the interpretation of the results.

- Some behavioral thresholds that were set are determining the outcome. For example, the innovation level of households is influencing the separation of households quite a lot. Working with behavioral thresholds is always tricky, considering that human behavior is very dynamic and is not a clear 'switch' in real life. A sensitivity analysis clarifies and identifies this dependency (section 8.3.1), but this distribution should be analyzed in more detail for more accurate results.

- In the agent-based model, the household waste is divided into residuals and recyclables. However, in municipal solid waste, there are much more divisions. Most plastics are part of the recyclables, but waste pickers collect more than plastics. Furthermore, there are no distinctions based on the plastic type (HDPE, LDPE, PE, PET, etc.). Therefore, exact numbers should not be directly used to interpret the results but rather to analyze the relative outcomes with different interventions and strategies.

- Furthermore, in the TPS3R sorting centers, both recyclables and organic waste are separated from residuals. This is used for composting purposes. However, in the model, the end-of-use options are recyclables and residues only.

- No leakage is modeled while waste collectors pick up waste at households. This means all recyclables that get collected end up being recycled. However, there is always some leakage in reality, which also indicates that the numbers should not be taken literally.

- Even though one interview was held with a waste bank, they are not included in the model. This is because only a very small percentage of the waste collection goes via waste banks. They seem to emphasize sustainability awareness over significantly contributing to waste collection (Bank Sampah, personal communication, 2021).

- The capability threshold is determined randomly for households. Thus, they are not based on the location of households, even though it might be more realistic to have clusters of households that are capable of separating their waste and clusters that are not. This could also affect the strategies where to locate awareness-raising campaigns and collection vehicles.

Scope

First, the scope of the model is a part of a medium-sized Indonesian city. This geographical scope is chosen to be able to calibrate the model with other research. However, this also has implications for the generalizability of the results. Due to focusing on one location type, it is more difficult to generalize to other archetypes. As discussed in 9.4, there are possibilities to use some results for other countries.

On the other hand, an exact geographical location could for example, have improved the accuracy of collection vehicle routes. However, this would have required more knowledge of geographical information systems of the author. Furthermore, more specific data on collection routes at the city level would be needed.

Secondly, even though Households are the main contributors to plastic pollution, many recyclables can also be subtracted from industrial waste. These are not included in the model, but large volumes could be collected in that sector.

Thirdly, the options for the end of life of (plastic) products are limited to recycling or landfilling in this thesis. However, there are more ways of using waste streams. For example, composting and waste2energy are technologies that are explored in Indonesia. Especially since the share of organic waste is large in urban household waste, there are many composting activities initiated by local communities, including experiments with the black soldier fly (Pambudi, Dowaki, & Adhiutama, 2016; Rahmat et al., 2021; World Economic Forum, 2020). Furthermore, the Indonesian national government wants to focus on composting and waste2energy of waste streams that cannot be recycled. However, they emphasize that the start of these technologies is waste separation: "If we talk about composting, recycling or energy recovery rate, the key element at the beginning of this process is separation." (MoEF, personal communication, 2021).

10. Conclusion & Recommendations

This research investigates what effects the concept of Extended Producer Responsibility in Indonesia can have. Indonesia is an enormous country with little waste management infrastructure. Due to a lack of knowledge about the environmental problems this causes, Indonesia is the second-largest plastic polluter globally. EPR provides a financial scheme to support waste management in Western countries, and Indonesia has realized the opportunities EPR can provide. However, EPR is a broad concept, and its implementation in developing countries has little academic research as a backbone. Therefore, this thesis gives some insights into the effects of EPR interventions in Indonesia.

An agent-based model was made that simulates the (simplified) waste collection system of Indonesia. Three possible EPR interventions were implemented in the model, and the effect on the collection and recycle ratio were analyzed. In addition, the effects on the informal waste sector have been taken into account in the model, which has not been done before.

This chapter answers the formulated sub questions that help to answer the main research question. Then, recommendations are formulated. Lastly, ideas for further research are proposed.

10.1 Answering the sub questions

1. *What does the current plastic waste system in Indonesia look like, and what factors need to be taken into account when implementing EPR policies?*

Based on a system analysis, a visualization of the current plastic waste system has been made. There is a lack of awareness of the problems that waste mismanagement causes. This results in individuals throwing trash on streets, municipalities not seeing the urge to finance waste management, households not wanting to separate their waste, and producers not wanting to make large-scale investments when they do not directly see returns.

From literature research and stakeholder interviews, four factors are essential for implementing waste management policies in Indonesia.

Little existing waste management infrastructure
In medium-sized cities, there are some formal waste collection vehicles available to pick up municipal waste. However, still 55% of plastic waste does not get collected. It is difficult to convince Indonesian local governments to invest in their waste management and see the benefits of a less polluted environment. That is why in the short term, the interventions should not rely on existing formal waste management infrastructure.

Involvement of hard to recycle plastics
Many of the plastic pollution that flows in waters and soils are due to littering of hard to recycle plastics. These waste streams do not have a financial return because the recycling technologies in Indonesia cannot capture these types of plastics. This means neither municipal collectors nor waste pickers collect these items, which leaves them lingering in the environment. Therefore, it is important to actively promote the reduction of hard to recycle plastics, as their end-of-life stage is very harmful to the environment.

Involvement of the informal sector
The involvement of the informal sector is of great importance because in Indonesia, almost all the recycled materials are collected via informal waste pickers. Preferably, this network of informal

workers should be used for their expertise and network. It is, however, known that this integration is difficult. At least, their efforts should be taken into account, and competition should be avoided to not interfere with thousands of people's livelihoods.

Compliance
With many regulations in all countries worldwide, compliance is needed to be convincing in these rules. However, it requires knowledge, human resources, and financial means to realize compliance, which is not abundant in Indonesia. It is difficult to require this factor for policy interventions, as it is more of an overarching goal. However, based on literature and interviews, it does seem of great importance for Indonesian waste management practices.

2. *What EPR instruments are applicable for the Indonesian plastic waste system?*

An overview was made of possible interventions designed to achieve at least one of the two goals of Extended Producer Responsibility (relieve the burden on public waste management organizations & design for the environment). To define the interventions that would be evaluated in the agent-based model, three aspects were taken into account. First, an instrument in each instrument type (regulatory, financial and communication) should be chosen, as literature recommended a systems approach when implementing policies. Furthermore, when implementing EPR interventions, the complete life cycle of the plastic product should be taken into account. Therefore, three interventions were chosen that also focus on the product's upstream, downstream, and use phase. Lastly, the four criteria that were found in research question 1 were considered. The following three EPR instruments were used for the further analysis.

1. **Take-back requirements**
2. **Advanced disposal fees**
3. **Awareness-raising campaigns**

3. *How can the plastic waste system of a medium-sized Indonesian city be conceptualized in an agent-based model?*

Based on a UML diagram and BPMN-inspired flow diagram, a conceptual model of the Indonesian plastic waste system has been made. This was translated into an agent-based model in the programming language NetLogo. Five agents were included: households, informal waste pickers, municipal waste collectors, TPS3R (private) collectors, and the recycler/landfiller. The interactions of the agents with each other and their environment were modeled. Based on the behavior flows of the different agents in the model, the model simulated the system behavior.

4. *Based on the model, what effect do the EPR interventions have on the Indonesian plastic waste system?*

First, a baseline scenario was run to see the model outcomes when there are no interventions yet. It showed that the collection and recycling rates would decrease when nothing changes due to the increasing plastic consumption. Then, the three different interventions were individually implemented in the model.

Intervention 1 – take-back requirements
Take-back requirements resulted in private collectors that pick up waste separated when households source separate their waste and sort it before they bring it to landfills. This

intervention showed an increase in the collection and recycling rate as expected, but a reduction was visible in the quantity of waste picker's collection. There were three strategies on where to start the extra collection. The one based on household density achieved the highest collection and recycling percentages and targeted the waste pickers the most. The other two (based on household separation and household motivation level) were almost equally as effective.

Intervention 2 – advanced disposal fees
The second intervention, advanced disposal fees, results in a higher percentage of recyclables of the waste streams. There has been a division between how high the recyclable percentage is in the waste stream. In the base case, 20% of the waste is considered recyclable. Three scenarios are included: the percentage steadily increases to 25, 30, or 35%. Interestingly, the scenario of 25% recyclables results in a recycling rate decrease from the base case. The 30% scenario resulted in a lower recycling rate than the 25%, but the 35% scenario is similar to the 30% scenario, indicating a cap on the recycling sector (Figure 8.4).

Intervention 3 – awareness-raising campaigns
The third intervention focuses on the separation potential of households but does not result in more collection or recycling. – yet, because the source separation can result in better quality collected recyclables because it gets less contaminated with other waste. Two campaign strategies were analyzed. There was one strategy that differentiated between how long the campaign should take. After one week of campaigning, the percentage of households that started separating their waste increased a lot. However, after a few weeks, this decreased and leveled at a higher level than before. After one month of campaigning, the percentage increased to a higher percentage and eventually decreased again, but higher than after the one-week campaigns. The third option was monthly campaigns, where you see a more constant increase in the household separation percentage, which still fluctuates during the start and stop of the campaigns (Figure 8.6). For the strategy that focused on the campaign location, the location where the households are most dense resulted in the highest results.

Combining interventions
Combining interventions 1 and 2 resulted in similar effects of implementing intervention 1 individually. The combination of interventions 2 and 3 did not affect the collection and recycling rates much. For the combination of interventions 1 and 3, the collection rate was slightly lower than intervention one alone. This could be since the extra private collectors might take more time driving to households that separate their waste rather than going to the closest household. Furthermore, the recycling rate was higher when combining the interventions, which indicates the positive effects of source sorting. Moreover, when combining the take-back requirements and the awareness-raising campaigns, the strategy to place them in areas where households separate waste becomes more attractive than based on the household density.

When combining all three interventions together, the take-back requirements alone result in a higher collection rate than the combination. Initially, the recycling rate is also higher with take-back requirements alone. However, when using the location strategy based on separation density, the recycling rate of the combined interventions becomes higher than the take-back requirements individually.

Waste pickers collect more recyclables when take-back requirements are combined with any other instrument. Thus, the combined interventions improve the collection quantity of waste pickers, and the recycle rate but also limit the collection rates. This trade-off is important to consider for policymakers.

When varying the timing of implementing interventions, it became clear this is an essential factor to consider. For example, starting awareness-raising campaigns before the take-back requirements can result in higher collection and recycling rates. Furthermore, advanced disposal fees can better be implemented after the take-back requirements are in place. When implementing all three interventions in this order, the recycling rate becomes higher than when starting at the same time.

10.2 Answering the main research question

This thesis combines design-science research with agent-based modeling to evaluate policy interventions related to Extended Producer Responsibility in the plastic waste system of Indonesia. This is conducted to answer the following research question.

"*What are the effects of 3 selected EPR instruments on the key actors in the plastic waste system of a medium-sized city in Indonesia*?"

Based on literature analysis and interviews with stakeholders in the plastic sector, an agent-based model was designed for the Indonesian plastic waste system. Analyzing its results shows that the three interventions can complement each other and that trade-offs should be made.

The three EPR instruments are 1) take-back requirements, 2) advanced disposal fees, and 3) awareness-raising campaigns. The first instrument increases the collection and recycling rates of plastics and the total waste and decreases the amount collected by informal waste pickers. The advanced disposal fees result in more recyclables in household waste, and informal waste pickers can collect more. The awareness campaigns targeted the households and their willingness to separate their waste. This increased the quality of waste materials, which resulted in higher recycling rates when collection capacity increased.

Furthermore, three important conclusions can be drawn. First, from all combinations, it can be seen that the take-back requirements make the most significant changes. Increased collection capacity is something that needs to be done for the other instruments to be effective. However, this intervention also comes with the trade-off that it can cause adverse socio-economic effects for informal waste pickers, who play a vital role in the Indonesian recycling sector. Secondly, the timing of the interventions affects the results. Take-back requirements can better be implemented before advanced disposal fees, and the awareness-raising campaigns should happen before the take-back requirements. Thirdly, combining the interventions also affects decisions that need to be made, like the location of collection vehicles.

Concluding, this thesis fills two gaps in academic waste management research. First, it analyzes specific EPR instruments in Indonesia, which has not been done before. Single and combined instruments are compared while including important behavioral factors. Secondly, it provides insights into the effects of EPR because simulations were done. The simulation enables integrating multiple perspectives in the plastic waste system that are important in Indonesia, like the informal sector and other stakeholder behavior. Combinations of interventions were evaluated, showing the interconnectedness of interventions and providing insights into trade-offs between instruments.

10.3 Recommendations – closing the relevance cycle

The relevance cycle connects the artifact design with the environment. Before the agent-based model was created, a system analysis was done to analyze the Indonesian plastic waste environment. Large plastic volumes are scattered in streets and in water bodies that harm the environment. This thesis shows that Extended Producer Responsibility can influence the collection and recycling capacity to reduce plastic leakage to the environment. This section provides recommendations for policymakers, businesses, and other organizations.

First, when implementing EPR instruments, the **timing** of each intervention should be carefully considered, as it can affect the instrument's effectiveness.

Secondly, a **systems- and life-cycle approach** is recommended to prevent burden shifting. Increasing collection capacity is needed for less plastic littering, which is a downstream intervention. The recycling technologies in Indonesia are limited, and only high-quality waste streams can be converted to new materials. The availability of hard to recycle plastics should thus be limited to avoid leakage. This is an upstream intervention. Combining upstream and downstream interventions can thus result in more effective results.

Thirdly, combining the EPR instruments also comes with **interconnected effects** and **trade-offs**. For example, many informal waste workers manage most of the recycling activities in Indonesia. Interfering with this can have many socio-economic consequences for many waste workers. These trade-offs should be made clear and considered.

Fourthly, a better **responsibility division** between local, regional, and national organizations is needed. Multi-level legislation should support rather than hinder each other. Furthermore, the interventions, their goals, and responsibilities should be clearly divided and communicated. Parties responsible for the operational aspects of the interventions need to be established to prevent stagnating operations. Moreover, evaluations should take place regularly between different stakeholders to achieve coherent cooperation.

Fifthly, **awareness** among citizens about the harmful effects of improper waste disposal needs to be increased. This can result in less littering, more waste separation, and, if combined with increased collection capacity, higher recycling rates.

Sixthly, **producers need to take responsibility** for the entire life cycle of their products. This comes with financial consequences, which they need to account for. Now, the world pays for the harmful effects of the lack of waste disposal, whereas companies that put products on the market need to integrate this into their financial plan

Seventhly, the **informal sector** is undervalued, and more effort needs to be put into acknowledging their contributions to preventing environmental harm. They are responsible for almost all recycling activities in the country, which is impressive and needs to be supported. Improvements to their poor working conditions need to be made, and the stigma around waste workers should be detached.

Eighthly, the exact **height of the fees** needs to be determined. The effects on the Indonesian waste system are analyzed in this research, but not the (financial) effects of fees on small enterprises or large brand owners and their budgets. Neither is explored what investments are required for proper waste disposal.

Lastly, it is important to gather **multiple stakeholders together** when implementing EPR. It is advised to start implementing EPR on a small scale and expand it to multiple regencies and more

waste streams. A start is made by introducing the voluntary organization IPRO. Now, it is time for producers to take full responsibility for their product's life cycle; governmental organizations to support them by improving regulations and setting priorities; and Indonesian citizens to contribute to the community by reducing littering and starting source separation.

10.4 Ideas for further research

This research tries to give insights into the effects of Extended Producer Responsibility in Indonesia. However, this is a much more complex issue than can be captured in one thesis. Therefore, it is advised to use this research as a basis to try and find more recommendations for implementing EPR in Indonesia. Three directions are identified for further research.

First, the current model can be used by also analyzing interventions that might not be associated with EPR. The model simulates the Indonesian plastic waste system with a growing amount of waste in the coming years. The model could also simulate the effects of waste reduction strategies, analyze household separation and collection behavior when more local-collection initiatives are set up, or what happens when the collection capacity increases.

Secondly, the informal sector could be more elaborated on. Right now, there is no variation in waste picker availability. However, it is possible to imagine that more recyclable materials in household waste streams can result in more people seeing an opportunity to work in this field, creating more informal collection capacity. Adding waste picker's rationale could be added by including these economic incentives. This type of behavior could be validated with an interview with scavenger associations. Unfortunately, the language barrier was too significant to achieve this.

Furthermore, there is research that emphasized more inclusion of waste pickers in the formal waste system. This could limit the competition effect and provide more insights into the exact numbers of Indonesian waste workers. Even though literature mentioned this inclusion is quite challenging, ideas could be to provide them with collection carts to improve their capacity. Moreover, if waste pickers also pick up non-recyclables and bring those to TPS3R sorting facilities, they can start a collaboration (McKinsey.org, personal communication, 2021; Buch et al., 2021). The only difficult thing is that TPS3Rs usually do not have the resources to pay them for the waste, which is the main incentive for waste pickers (ADUPI & McKinsey.org, personal communication, 2021).

Thirdly, the perspective of producers could be emphasized more. When implementing EPR, one of the most important stakeholders is the producer. As can be seen in other developing countries, usually, there is a voluntary EPR system before a mandatory system (with sanctions when not complying) gets implemented. It would therefore be interesting to analyze the behavior of producers and when they will be involved with this voluntary EPR system. This could contribute to improving the (voluntary) EPR system and achieving higher results.

REFERENCES

Afvalfonds Verpakkingen. (n.d.). Taken van het Afvalfonds Verpakkingen. Retrieved from https://afvalfondsverpakkingen.nl/organisatie/taken-van-het-afvalfonds

Afvalfonds Verpakkingen. (2021). Tariefdifferentiatie kunststof. Retrieved May 20, 2021, from https://afvalfondsverpakkingen.nl/verpakkingen/tariefdifferentiatie-kunststof

Alberts, G. H. J., Luteijn, A. P., Lange, H. de, Smet, S. J. S. de, Terwindt, J. E., & Turhan, E. (2020). *Pantai Project*.

Aleluia, J., & Ferrão, P. (2016). Characterization of urban waste management practices in developing Asian countries: A new analytical framework based on waste characteristics and urban dimension. *Waste Management*, *58*, 415–429. https://doi.org/10.1016/j.wasman.2016.05.008

Alhanaqtah, V. (2018). *Integrating the Informal Sector for Improved Waste Management in Rural Communities*. 208–224. https://doi.org/10.4018/978-1-5225-7158-2.ch012

Anantakrishnan, L. (2021). Reflections on EPR-based Systems Targeting Multi-Layered Plastics. Retrieved April 20, 2021, from Alliance of Indian Wastepickers website: https://globalrec.org/2021/03/29/reflections-on-epr-based-systems-targeting-multi-layered-plastics/

Andrianisa, H. A., Brou, Y. O. K., & Séhi bi, A. (2016). Role and importance of informal collectors in the municipal waste pre-collection system in Abidjan, Côte d'Ivoire. *Habitat International*, *53*, 265–273. https://doi.org/10.1016/j.habitatint.2015.11.036

Aprilia, A., Tezuka, T., & Spaargaren, G. (2012). Household Solid Waste Management in Jakarta , Indonesia : A Socio-Economic Evaluation. In *ste Management - An Integrated Vision*. https://doi.org/10.5772/51464

Audi, P. (2019). *Evaluation for The Implementation of New Presidential-Regulation on Solid Waste Management In Jakarta , Indonesia*.

Barnes, D. K. A., Galgani, F., Thompson, R. C., & Barlaz, M. (2009). Accumulation and fragmentation of plastic debris in global environments. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 1985–1998. https://doi.org/10.1098/rstb.2008.0205

Berger, K. R., & Welt, B. (2005). *A Brief History of Packaging 1*. Florida.

Besluit regeling voor uitgebreide producentenverantwoordelijkheid. , 2 § (2020).

Borrás, S., & Edler, J. (2014). *The governance of socio-technical systems : explaining change*.

Brouwer, M. T., Thoden van Velzen, E. U., Ragaert, K., & ten Klooster, R. (2020). Technical Limits in Circularity for Plastic Packages. *Sustainability*, *12*(23), 10021. https://doi.org/10.3390/su122310021

Bryson, J. M. (2004). What to do when stakeholders matter: Stakeholder Identificatixon and analysis techniques. *Public Management Review*, *6*(1), 21–53. https://doi.org/10.1080/14719030410001675722

Cahill, R., Grimes, S. M., & Wilson, D. C. (2010). Extended producer responsibility for packaging wastes and WEEE – a comparison of implementation and the role of local authorities across

Europe. *Waste Management and Research*, *29*(5), 455–479. https://doi.org/10.1177/0734242X10379455

Castro, L. F., Cox, L. J., & Fukumoto, G. (2017). *Diffusion of an Agricultural Innovation : A Case Study Involving Dry Litter Technology in American Samoa Diffusion of an Agricultural Innovation : A Case Study Involving Dry Litter Technology in American Samoa*. (January).

Chaerul, M., Fahruroji, A. R., & Fujiwara, T. (2014). Recycling of plastic packaging waste in Bandung City, Indonesia. *Journal of Material Cycles and Waste Management*, *16*(3), 509–518. https://doi.org/10.1007/s10163-013-0201-2

Chaerul, M., Tanaka, M., & Shekdar, A. V. (2007). MUNICIPAL SOLID WASTE MANAGEMENT IN INDONESIA: STATUS AND THE STRATEGIC ACTIONS. In *Journal of the Faculty of Environmental Science and Technology* (Vol. 2).

Chaudhuri, A. (1994). *The Diffusion of an Innovation in Indonesia*. *3*(3), 19–26.

Chen, X. (2019). *Position Paper - Extended Producer Responsibility (EPR) for Plastic Disposal*. WWF.

Chiu, A. S. F., & Yong, G. (2004). On the industrial ecology potential in Asian Developing Countries. *Journal of Cleaner Production*, *12*, 1037–1045. https://doi.org/10.1016/j.jclepro.2004.02.013

Damanhuri, E., & Padmi, T. (2012). The Role of Informal Collectors of Recyclable Waste and Used Goods in Indonesia. *Post-Consumer Waste Recycling and Optimal Production*.

Darus, N., Tamimi, M., Tirawaty, S., Muchtazar, M., Trisyanti, D., Akib, R., … Ranggi, K. (2020). an Overview of Plastic Waste Recycling in the Urban Areas of Java Island in Indonesia. *Journal of Environmental Science and Sustainable Development*, *3*(2), 402–415. https://doi.org/10.7454/jessd.v3i2.1073

Davis, C., Nikolic, I., & Dijkema, G. P. J. (2010). Industrial ecology 2.0. *Journal of Industrial Ecology*, *14*(5), 707–726. https://doi.org/10.1111/j.1530-9290.2010.00281.x

De Jong, P., & Wolsink, M. (1997). The structure of the Dutch waste sector and impediments for waste reduction. *Waste Management and Research*, *15*(6), 641–658. https://doi.org/10.1006/wmre.1996.0117

Destyanto, A.R., Kirana, P. S., & Ardi, R. (2019). Model conceptualization of system dynamics for evaluating extended producer responsibility strategy in plastic waste management policy in Indonesia. *ACM International Conference Proceeding Series*, 106–109. https://doi.org/10.1145/3364335.3364344

Destyanto, Arry Rahmawan, Kirana, P. S., & Ardi, R. (2019). Model conceptualization of system dynamics for evaluating extended producer responsibility strategy in plastic waste management policy in Indonesia. *ACM International Conference Proceeding Series*, 106–109. https://doi.org/10.1145/3364335.3364344

Diggle, A., & Walker, T. R. (2020). Implementation of harmonized Extended Producer Responsibility strategies to incentivize recovery of single-use plastic packaging waste in Canada. *Waste Management*, *110*, 20–23. https://doi.org/10.1016/j.wasman.2020.05.013

Dijkman, R., Hofstetter, J., & Koehler, J. (2011). *Business Process Model and Notation*. Springer.

Ding, Z., Gong, W., Li, S., & Wu, Z. (2018). System dynamics versus agent-based modeling: A review of complexity simulation in construction waste management. *Sustainability (Switzerland)*,

10(7). https://doi.org/10.3390/su10072484

Dubois, M., Graaf, D. de, & Thieren, J. (2016). *Exploration of the Role of Extended Producer Responsibility for the circular economy in the Netherlands*. Retrieved from http://www.ey.com/Publication/vwLUAssets/ey-exploration-role-extended-producer-responsibility-for-circular-economy-netherlands/$FILE/ey-exploration-role-extended-producer-responsibility-for-circular-economy-netherlands.pdf

Ehrenfeld, J., & Gertler, N. (1997). Industrial Ecology in Practice. *Journal of Industrial Ecology*, *1*(1).

EIMPACK, & European Investment Bank. (2011). *Economic Impact of the Packaging and Packaging Waste Directive - literature review*. Retrieved from https://www.yumpu.com/en/document/read/39467927/eimpack-a-economic-impact-of-the-packaging-and-packaging-waste-

Enserink, B., Hermans, L., Kwakkel, J., Thissen, W., & Koppenjan, J. (2010). *Policy Analysis of Multi-Actor Systems*. The Hague: LEMMA.

Erkman, S. (1997). Industrial Ecology: an historical view. *Journal of Cleaner Production*, *5*(1–2), 1–10.

Eurostat. (2019). How much plastic packaging waste do we recycle? Retrieved from https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20191105-2

Fishbein, B. K. (1994). *Germany, Garbage and the Green Dot: Challenging a Throwaway Society*. Cincinnati, Ohio: Environmental Protection Agency.

Fostinone, L. A. (2016). *Packaging Waste in Remote Communities*.

García-Díaz, C., & Moreno-Monroy, A. I. (2012). Social influence, agent heterogeneity and the emergence of the urban informal sector. *Physica A: Statistical Mechanics and Its Applications*, *391*(4), 1563–1574. https://doi.org/10.1016/j.physa.2011.08.057

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy*, *33*(6–7), 897–920. https://doi.org/10.1016/j.respol.2004.01.015

Gentil, E. C., Gallo, D., & Christensen, T. H. (2011). Environmental evaluation of municipal waste prevention. *Waste Management*, *31*(12), 2371–2379. https://doi.org/10.1016/j.wasman.2011.07.030

Geyer, R., Jambeck, J. R., & Law, K. L. (2017). Production, use, and fate of all plastics ever made. *Science Advances*, *3*(7), 25–29. https://doi.org/10.1126/sciadv.1700782

Gibson, B. (2012). Trade, Employment and the Informal Sector: An Agent-based Analysis. *Margin*, *6*(2), 277–310. https://doi.org/10.1177/097380101200600208

Gupt, Y., & Sahay, S. (2015). Review of extended producer responsibility: A case study approach. *Waste Management and Research*, *33*(7), 595–611. https://doi.org/10.1177/0734242X15592275

Hevner, A., & Chatterjee, S. (2010). *Design Research in Information Systems* (22nd ed.; R. Sharda & S. Voß, Eds.). Springer.

Hevner, A. R. (2007). A Three Cycle View of Design Science Research A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems*, *19*(2).

Hopewell, J., Dvorak, R., & Kosior, E. (2009). Plastics recycling: Challenges and opportunities. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*(1526), 2115–2126. https://doi.org/10.1098/rstb.2008.0311

Hotta, Y., Hayashi, S., Bengtsson, M., & Mori, H. (2009). Extended Producer Responsibility in East Asia. In *Institute for Global Environmental Strategies, Japan*. Retrieved from http://marefateadyan.nashriyat.ir/node/150

Jambeck, J., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., … Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768-. Retrieved from https://science.sciencemag.org/CONTENT/347/6223/768.abstract

Johannes, H. P., Kojima, M., Iwasaki, F., & Edita, E. P. (2021). Applying the extended producer responsibility towards plastic waste in Asian developing countries for reducing marine plastic debris. *Waste Management and Research*, *39*(5), 690–702. https://doi.org/10.1177/0734242X211013412

Jones, D. G. B., & Tadajewski, M. (2016). *The Routledge Companion to Marketing History*. New York: Routledge - Taylor & Francis Group.

Kaffine, D., & O'Reilly, P. (2015). What Have We Learned About Extended Producer Responsibility in the Past Decade? A Survey of the Recent EPR Economic Literature. In *OECD Papers*. Retrieved from http://spot.colorado.edu/~daka9342/OECD_EPR_KO.pdf

Kallio, H., Pietil, A., Johnson, M., & Kangasniemi, M. (2016). *Systematic methodological review : developing a framework for a qualitative semi-structured interview guide*. https://doi.org/10.1111/jan.13031

Kedzierski, M., Frère, D., Le, G., & Bruzaud, S. (2020). Science of the Total Environment Why is there plastic packaging in the natural environment ? Understanding the roots of our individual plastic waste management behaviours. *Science of the Total Environment*, *740*, 139985. https://doi.org/10.1016/j.scitotenv.2020.139985

Kerdlap, P., Purnama, A. R., Low, J. S. C., Tan, D. Z. L., Barlow, C. Y., & Ramakrishna, S. (2020). Environmental evaluation of distributed versus centralized plastic waste recycling: Integrating life cycle assessment and agent-based modeling. *Procedia CIRP*, *90*, 689–694. https://doi.org/10.1016/j.procir.2020.01.083

Leal Filho, W., Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., & Voronova, V. (2019). An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. *Journal of Cleaner Production*, *214*, 550–558. https://doi.org/10.1016/j.jclepro.2018.12.256

Leal Filho, Walter, Saari, U., Fedoruk, M., Iital, A., Moora, H., Klöga, M., & Voronova, V. (2019). An overview of the problems posed by plastic products and the role of extended producer responsibility in Europe. *Journal of Cleaner Production*, *214*, 550–558. https://doi.org/10.1016/j.jclepro.2018.12.256

Li, W. C., Tse, H. F., & Fok, L. (2016). Plastic waste in the marine environment: A review of sources, occurrence and effects. *Science of the Total Environment*, *566–567*, 333–349. https://doi.org/10.1016/j.scitotenv.2016.05.084

Lifset, R., Atasu, A., & Tojo, N. (2013). Extended Producer Responsibility - National, International and Practical Perspectives. *Journal of Industrial Ecology*, *17*(2). https://doi.org/10.1111/jiec.12022

Lindhqvist, T. (2000). *Environmental Improvements of Product Systems Extended Producer*

Responsibility in Cleaner Production Policy Principle to Promote Environmental.

Mckerlie, K., Knight, N., & Thorpe, B. (2006). *Advancing Extended Producer Responsibility in Canada*. *14*, 616–628. https://doi.org/10.1016/j.jclepro.2005.08.001

Meng, X., Wen, Z., & Qian, Y. (2016). Multi-agent based simulation for household solid waste recycling behavior. *"Resources, Conservation & Recycling."* https://doi.org/10.1016/j.resconrec.2016.09.033

Meng, X., Wen, Z., & Qian, Y. (2018). Multi-agent based simulation for household solid waste recycling behavior. *Resources, Conservation and Recycling*, *128*, 535–545. https://doi.org/10.1016/j.resconrec.2016.09.033

Michie, S., Stralen, M. M. van, & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science*, *6*(42), 1–11. https://doi.org/10.1001/archderm.1985.01660070119033

Ministry of Environment and Forestry. (2020). *National Plastic Waste Reduction Strategic Actions for Indonesia*. Retrieved from https://wedocs.unep.org/bitstream/handle/20.500.11822/32898/NPWRSI.pdf?sequence=1&isAllowed=y

Ministry of Environment and Forestry Regulation No. P.75/2019 on Roadmap to Waste Reduction by Producers.

Ministry of Environment Forest and Climate Change India. *Uniform Framework for Extended Producers Responsibility (Under Plastic Waste Management Rules, 2016).* , (2020).

Mollaoglu, S., & Syal, M. (2015). *Diffusion of green building guidelines as innovation in developing countries*. *16*(1), 11–29. https://doi.org/10.1108/CI-09-2014-0045

Nahman, A. (2010). Extended producer responsibility for packaging waste in South Africa: Current approaches and lessons learned. *Resources, Conservation and Recycling*, *54*(3), 155–162. https://doi.org/10.1016/j.resconrec.2009.07.006

Nahman, Anton. (2010). Extended producer responsibility for packaging waste in South Africa: Current approaches and lessons learned. *Resources, Conservation and Recycling*, *54*(3), 155–162. https://doi.org/10.1016/j.resconrec.2009.07.006

Nandy, B., Sharma, G., Garg, S., Kumari, S., George, T., Sunanda, Y., & Sinha, B. (2015). Resources , Conservation and Recycling Recovery of consumer waste in India – A mass flow analysis for paper , plastic and glass and the contribution of households and the informal sector. *"Resources, Conservation & Recycling,"* *101*, 167–181. https://doi.org/10.1016/j.resconrec.2015.05.012

Nikolic, I. (2004). PhD thesis Co-Evolutionary Method For Modelling Large Scale Socio-Technical Systems Evolution. Retrieved from https://ejournal.poltektegal.ac.id/index.php/siklus/article/view/298%0Ahttp://repositorio.unan.edu.ni/2986/1/5624.pdf%0Ahttp://dx.doi.org/10.1016/j.jana.2015.10.005%0Ahttp://www.biomedcentral.com/1471-2458/12/58%0Ahttp://ovidsp.ovid.com/ovidweb.cgi?T=JS&P

Nkwachukwu, O., Chima, C., Ikenna, A., & Albert, L. (2013). Focus on potential environmental issues on plastic world towards a sustainable plastic recycling in developing countries. *International Journal of Industrial Chemistry*, *4*(1), 34. https://doi.org/10.1186/2228-5547-4-34

Nkwachukwu, O. I., Chidi, N. I., & Charles, K. O. (2010). Issues of Roadside Disposal Habit of Municipal Solid Waste, Environmental Impacts and Implementation of Sound Management Practices in Developing Country "Nigeria." *International Journal of Environmental Science and Development*, *1*(5), 409–418. https://doi.org/10.7763/ijesd.2010.v1.79

Oberlin, A. (2011). *The role of households in solid waste management in East Africa capital cities*. Wageningen University.

OECD. (2001). *Extended Producer Responsibility. A guidance maniual for governments organizations.* Paris: OECD.

OECD. (2011). *Horizontal Agreements in the Environmental Context*.

OECD. (2016). EPR- An updated guidance. In *Organisation for Economic Co-operation and Development- Guidance manual*.

OECD. (2018). Improving plastics management : trends , policy responses, and the role of international co-operation and trade. *Environmental Policy Paper No. 12*, (12), 20.

OECD, & Ministry of the Environment. (2014). The State of play on Extended Producer Responsibility (EPR): Opportunities and Challenges. In *Ministry of Environment*. Retrieved from http://www.oecd.org/env/waste/%5Cnhttp://www.oecd.org/environment/waste/Global Forum Tokyo Issues Paper 30-5-2014.pdf

Oosterveer, P., & Spaargaren, G. (2010). Meeting Social Challenges in Developing Sustainable Environmental Infrastructures in East African Cities. In B. van Vliet, G. Spaargaren, & P. Oosterveer (Eds.), *Social Perspectives on the Sanitation Challenge*. https://doi.org/https://doi.org/10.1007/978-90-481-3721-3_2

Pambudi, N. F., Dowaki, K., & Adhiutama, A. (2016). *Integrated Index in Consideration of Appropriate Plastic Recycling System in Waste Bank Operation*. *01018*.

Pires, A., Martinho, G., Ribeiro, R., Mota, M., & Teixeira, L. (2015). Extended producer responsibility: a differential fee model for promoting sustainable packaging. *Journal of Cleaner Production*, *108*, 343–353. https://doi.org/10.1016/j.jclepro.2015.07.084

Pires, Ana, Martinho, G., Ribeiro, R., Mota, M., & Teixeira, L. (2015). Extended producer responsibility: a differential fee model for promoting sustainable packaging. *Journal of Cleaner Production*, *108*, 343–353. https://doi.org/10.1016/j.jclepro.2015.07.084

Pouikli, K. (2020). Concretising the role of extended producer responsibility in European Union waste law and policy through the lens of the circular economy. *ERA Forum*, 491–508. https://doi.org/10.1007/s12027-020-00596-9

Quartey, E.T., Tosefa, H., Danquah, K. A. B., & Obrsalova, I. (2015). Theoretical framework for plastic waste management in ghana through extended producer responsibility: Case of sachet water waste. *International Journal of Environmental Research and Public Health*, *12*(8), 9907–9919. https://doi.org/10.3390/ijerph120809907

Quartey, Ebo Tawiah, Tosefa, H., Danquah, K. A. B., & Obrsalova, I. (2015). Theoretical framework for plastic waste management in ghana through extended producer responsibility: Case of sachet water waste. *International Journal of Environmental Research and Public Health*, *12*(8), 9907–9919. https://doi.org/10.3390/ijerph120809907

Quoden, J., & Grant, M. (2019). *Extended Producer Responsibility (EPR): Canadian Cleanfarms ' Success Built on Mix of Voluntary and Regulated EPR*.

Raharjo, S., Matsumoto, T., Ihsan, T., Rachman, I., & Gustin, L. (2017). Community-based solid waste bank program for municipal solid waste management improvement in Indonesia: a case study of Padang city. *Journal of Material Cycles and Waste Management*, *19*(1), 201–212. https://doi.org/10.1007/s10163-015-0401-z

Rahim, I. R., Nakayama, H., & Shimaoka, T. (2012). *Cost Analysis of Municipal Solid Waste Management in Major Indonesian Cities*. *68*(6), 79–88.

Rahmat, A., Ramadhani, W. S., Prasetyo, D., Aini, S. N., Yanfika, H., & Mutolib, A. (2021). *The composition of micronutrients and toxic elements in household waste compost uses black soldier fly larvae (Hermetia illucens)*. https://doi.org/10.1088/1755-1315/739/1/012004

Ratna, A., Takashi, P., & Takaoka, M. (2018). Plastic waste management in Jakarta , Indonesia : evaluation of material flow and recycling scheme. *Journal of Material Cycles and Waste Management*, *20*(4), 2140–2149. https://doi.org/10.1007/s10163-018-0753-2

Rogers, E. M. (1995). *Diffusion of Innovations* (4th editio). New York: The Free Press.

Rohracher, H. (2001). Managing the Technological Transition to Sustainable Construction of Buildings: A Socio-Technical Perspective. *Technology Analysis & Strategic Management*, *13*(1), 137–150. https://doi.org/10.1080/09537320120040491

Romenska, M. (2016). EPR for packaging: opportunities and challenges. *Expra*. Brussels, Belgium: Expra.

Rubio, S., Pereira Ramos, T. R., Rodrigues Leitao, M. M., & Barbosa-povoa, A. P. (2019). Effectiveness of extended producer responsibility policies implementation : The case of Portuguese and Spanish packaging waste systems. *Journal of Cleaner Production*, *210*, 217–230. https://doi.org/10.1016/j.jclepro.2018.10.299

Sasaki, S., & Araki, T. (2013). Employer e employee and buyer e seller relationships among waste pickers at fi nal disposal site in informal recycling : The case of Bantar Gebang in Indonesia. *Habitat International*, *40*, 51–57. https://doi.org/10.1016/j.habitatint.2013.02.003

Sasaki, S., & Araki, T. (2014). *Estimating the possible range of recycling rates achieved by dump waste pickers : The case of Bantar Gebang in Indonesia*. https://doi.org/10.1177/0734242X14535651

Sasaki, S., Araki, T., Tambunan, A. H., & Prasadja, H. (2014). Household income, living and working conditions of dumpsite waste pickers in Bantar Gebang: Toward integrated waste management in Indonesia. *Resources, Conservation and Recycling*, *89*, 11–21. https://doi.org/10.1016/j.resconrec.2014.05.006

Satapathy, S. (2017). An analysis of barriers for plastic recycling in the Indian plastic industry. *Benchmarking*, *24*(2), 415–430. https://doi.org/10.1108/BIJ-11-2014-0103

Sembiring, E., & Nitivattananon, V. (2010). Sustainable solid waste management toward an inclusive society: Integration of the informal sector. *Resources, Conservation and Recycling*, *54*(11), 802–809. https://doi.org/10.1016/j.resconrec.2009.12.010

Snyder, H. (2019). Literature review as a research methodology : An overview and guidelines. *Journal of Business Research*, *104*(March), 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Sudibyo, H., Budiman, A., Pradana, Y. S., & Wiratni, W. (2017). Municipal Solid Waste Management in Indonesia - A Study about Selection of Proper Solid Waste Reduction Method in D.I. Yogyakarta Province. *Energy Procediaia*, *143*, 494–499.

https://doi.org/10.1016/j.egypro.2017.12.716

Sulami, A. P. N., Murayama, T., & Nishikizawa, S. (2018). Current issues and situation of producer responsibility in waste management in Indonesia. *Environment and Natural Resources Journal*, *16*(1), 70–81. https://doi.org/10.14456/ennrj.2018.7

Tamakawa, H. (2006). The Packaging Recycling Act: The Application of EPR to Packaging Policies in Japan. *Positioning Techniques in Surgical Applications: Thorax and Heart Surgery - Vascular Surgery - Visceral and Transplantation Surgery - Urology - Surgery to the Spinal Cord and Extremities - Arthroscopy - Paediatric Surgery - Navigation/ISO-C 3D*, 13–17. https://doi.org/10.1007/3-540-30952-7_3

The Pew Charitable Trusts, & Systemiq. (2020). *Breaking the Plastic Wave*. Retrieved from https://www.pewtrusts.org/-/media/assets/2020/07/breakingtheplasticwave_summary.pdf

Tong, X., Nikolic, I., Dijkhuizen, B., van den Hoven, M., Minderhoud, M., Wäckerlin, N., … Tao, D. (2018). Behaviour change in post-consumer recycling: Applying agent-based modelling in social experiment. *Journal of Cleaner Production*, *187*, 1006–1013. https://doi.org/10.1016/j.jclepro.2018.03.261

Tristiana, E., Koeswahyono, I., & Fadli, M. (2018). Managing Policy of Extended Producer Responsibility (EPR) Implementation to Reduce Plastic Waste in Indonesia. *International Journal of Humanities and Social Science Invention*, *7*(07), 25–32. Retrieved from http://www.ijhssi.org/papers/vol7(7)/Version-2/E0707022532.pdf

UNEP. (2016). *Marine Litter Vital Graphics. United Nations Environment Programme and GRID-Arendal. Nairobi and Arendal.*

UNESCAP. (2019). *Closing the Loop - Innovative partnerships with informal workers to recover plastic waste , in an inclusive circular economy approach*.

United Nations Environment Programme. (2017). *Summary report - Waste Management in Asean countries*.

van Dam, K. H., Nikolic, I., & Lukszo, Z. (2013). Agent-Based Modelling of Socio-Technical Systems. In *Agent-Based Modelling of Socio-Technical Systems*. https://doi.org/10.1007/978-94-007-4933-7

Van Rossem, C., Tojo, N., & LindHqVist, T. (2006). "Extended" producer responsibility - Why not? In *The international institute for industrial environmental economics*.

Van Rossum, G., & Drake Jr, F. L. (1995). *Python reference manual. Centrum voor Wiskunde en Informatica Amsterdam*.

Vernay, A. L., Mulder, K. F., Kamp, L. M., & De Bruijn, H. (2013). Exploring the socio-technical dynamics of systems integration-the case of sewage gas for transport in Stockholm, Sweden. *Journal of Cleaner Production*, *44*, 190–199. https://doi.org/10.1016/j.jclepro.2012.11.040

Wiesmeth, H., & Häckl, D. (2011). How to successfully implement extended producer responsibility: Considerations from an economic point of view. *Waste Management and Research*, *29*(9), 891–901. https://doi.org/10.1177/0734242X11413333

Wilensky, U. (1999). *NetLogo*. Retrieved from http://ccl.northwestern.edu/netlogo/

Wohed, P., Aalst, W. M. P. Van Der, & Dumas, M. (2006). On the Suitability of BPMN for Business Process Modelling. *4th International Conference on Business Process Management*, 161–

176. Vienna.

Wong, G., Greenhalgh, T., Westhorp, G., Buckingham, J., & Pawson, R. (2013). RAMESES publication standards : meta-narrative reviews. *Journal of Advanced Nursing*, *69*(5), 987–1004. https://doi.org/10.1111/jan.12092

Wongthatsanekorn, W. (2009). A goal programming approach for plastic recycling system in Thailand. *World Academy of Science, Engineering and Technology*, *37*, 513–518.

World Bank Group. (2016). *Poverty & Equity Brief - Indonesia*.

World Bank Group. (2018). Indonesia Marine Debris Hotspot. In *Marine Pollution and Climate Change*. https://doi.org/10.1201/9781315119243-6

World Economic Forum. (2020). Radically Reducing Plastic Pollution in Indonesia : Industry Action Roadmap Indonesia National Plastic Action Partnership. *Global Plastic Action Partnership*, (March).

WWF. (2020). *Plastic packaging in South East Asia*. https://doi.org/10.1108/eb011552

Appendix A - International EPR instruments

The table below presents a non-exhaustive overview of different EPR instruments for (plastic) packaging in different countries around the world (Table A.1).

Table A.1 - A non-exhaustive list of global EPR instruments

EPR for packaging	Instrument	Set-up	Consumers
Developed countries			
The Netherlands	Mandatory take-back requirements (Dubois et al., 2016)	License fee for producers to PRO based on waste type and weight	Use collection system of municipality to discard packaging waste
Germany	Mandatory take-back requirements (Wiesmeth & Häckl, 2011)	License fee for producers to PRO based on waste type and weight	Use collection system of PRO to discard packaging waste
Canada	Deposit-refund system (Diggle & Walker, 2020)	Sales and imports are subjected to fee, which is collected by NGO. NGO is also responsible for collection of fee and disbursements.	None, municipalities are responsible for collection
UK	Mandatory tradable recycling credits (OECD, 2016)	Companies get PRNs (recovery notes) to show compliance with rules. Companies and Compliance Schemes can sell and buy these PRNs	None, retailers are responsible for collection
Japan	Mandatory take-back requirements (Tamakawa, 2006)	They can outsource it to a PRO, or do it themselves (rare). If they don't comply, they get a warning and otherwise a fine	Consumers are responsible for sorting waste. Municipalities collect and bring it to recyclers
Slovakia	Mandatory Advanced Disposal Fee (ADF) + Deposit-refund system (Gupt & Sahay, 2015)	Producers pay a fee to PRO. PRO and municipality organize recovery	Pay yearly MSW fee to municipality For beverage containers there is a DRS
Developing countries			
Taiwan	Deposit-refund system for PET (Gupt & Sahay, 2015)	PET manufacturers and importers pay Recycling Fund according to their sales. Gets redirected to consumers when they bring back the PET	Consumers get paid for returning PET bottles to collection point
South Africa	Voluntary Deposit-refund system for	**Voluntary** PRO pays collectors and consumers for supply of used cans	Consumers get paid for returning cans to PRO

	cans (Nahman, 2010)		
	Deposit-refund system for glass (Andrianisa, Brou, & Séhi bi, 2016)	Fillers pay a levy per ton of glass purchased from glass manufacturers. PRO provides collection infrastructure, payments to collectors and information provision	Consumers get cash for glass if they take their glass to scrap dealers or buy-back centers
	Advanced recycling fee for PET (Nahman, 2010)	Converters and bottlers pay a voluntary levy per tonne of PET resin purchased from resin producers and importers. Revenue generated is used to finance operational costs.	Consumers get cash for glass if they take their glass to scrap dealers or buy-back centers
India	Take-back requirements for packaging (Garlapati, 2016)	plastic industry was to be made responsible for retrieving empty packaging material and have proper disposal system.	
	1. Fee-based 2. PRO-based 3. Take-back and recycling targets 4. Plastic credit model (Ministry of Environment Forest and Climate Change India, 2020)		
Chile	PRO-based / take-back program (Sekhri, 2018)	The establishment, operation and maintenance of the waste receptors and storage facilities will be the responsibility of producers or their waste management systems,	Door-to-door collection OR bring to 'green points'
Brazil	Take-back system (Fostinone, 2016)	Financial responsibility with private sector to recover discarded products	
Egypt	Voluntary NGO / collection fee (Jaligot et al., 2016)	Proctor and Gample let Zabaleen boys buy shampoo bottles from Informal collectors and let them clean and shred and count them and sell them to workshops	-
Tunesia	Mandatory take-back program / disposal fee (UNEP, 2015)	Eco-Lef's (sort of PRO) operations include collection infrastructure and recycling activities. The law requires producers and importers to pay a levy of 5% of the value of the plastic goods and resins	-

Appendix B - Interviews

In order to gain more information on EPR and the role it can have in the plastic waste system, a number of experts in the field of producer responsibility were requested to be interviewed. The interviews that were held have a semi-structured setup. This means questions will be made in advance by means of an interview guide, but during the interview, the interviewer might not have asked them all and asked follow-up questions that were deemed relevant (Kallio, Pietil, Johnson, & Kangasniemi, 2016). An advantage of this approach, rather than having a structured interview, is that there is more room for reciprocity between the interviewee and the interviewer, leading to more in-depth discussions and more relevant outcomes (Galetta, 2012). On the other hand, with semi-structured interviews, the different answers of participants on the same questions can still be analyzed and coded because the questions are based on the interview guide, and the interviewer can steer towards certain questions (Holloway & Wheeler, 2010).

Participants were selected based on the Actor Map, in a way that of every stakeholder, an interview was held to get a more holistic view of the stakeholders, their interactions, and the system as a whole.

Most of the interviews were held in English, but the one with Afvalfonds Verpakkingen was held in Dutch. All participants were asked for their permission to record the online interviews. These are non-verbatim transcribed and made anonymously. On request, they were sent to the interviewee afterward. The interview recordings will only be accessible by the researcher herself and will be destroyed after completing the thesis. In the research report, a general job description will be used when referring to the interviewee. The anonymized transcripts of the interview will be added as an appendix of the research report.

The interviews will be analyzed using manual coding. Different answers can be compared, and they will be used to provide more context in the conceptual system.

B1 – Interview invite

As an example, the interview invite to the Ministry of Environment and Forestry is shown in Figure B.1 below. For each interviewee, the invite was adjusted slightly.

Date 04-05-2021
Contact person Mira Groot
Mobile phone +316 19 379 322
E-mail mira.groot@rebelgroup.com
Subject Interview master thesis

REBEL 1/1

TU Delft

Ministery of Environmental
Direktur Pengelolaan Sampah, Kementerian Lingkungan Hidup dan Kehutanan Republik Indonesia
E: tuditps@gmail.com

Mira Groot

Graduate Student Industrial Ecology
Graduate Intern Rebel Group
E: mira.groot@rebelgroup.com
M: +316 19 379 322

Salam hormat Bapak/Ibu,

Perkenalkan, my name is Mira Groot, a graduate student at the Delft University of Technology, studying Industrial Ecology. Currently I am doing research for Rebel Group as part of my master thesis project, focusing on the effects and opportunities of Extended Producer Responsibility (EPR) on the plastic waste system in Indonesia. My supervisors are Prof.dr. Warnier and Dr. Quist.

As the Ministry of Environment and Forestry is extensively working towards sustainable development in Indonesia, I am interested to learn more about the view of the MoEF on EPR and about the implications of the EPR legislation that was formulated in 2019. Your views are essential for our study, as the Indonesian governmental perspective is of great importance for this research, which is taking multiple viewpoints into account. The results are aimed to reduce the amount of plastic waste in the environment and provide insights in international EPR best practices.

Given your knowledge on the governmental side, it would be my honor to get the opportunity to schedule an interview with you in the next few weeks. Attached is some extra information on the research topic and data handling. Please do not hesitate to contact me via phone or email if you have further inquiries.

Thank you for reading this note and I look forward to hearing from you.

Yours sincerely,
Mira Groot

Figure B.1 - Interview invite example

B2 – Information sheet

Besides the invite, an information sheet was send to provide information on data handling during and after the interview. This was based on the GDPR rules of Delft university. The information sheet is presented in Figure B.2 below.

Contact person Mira Groot
Mobile phone +316 19 379 322
E-mail mira.groot@rebelgroup.com
Subject Interview master thesis

REBEL 1/2

TU Delft

Information sheet – Research Plastic Waste in Indonesia

Introduction and research purpose

Due to the increasing amount of population and plastic production, plastic waste increases too. Not all this waste gets collected and treated, so leakage of this waste occurs. The main purpose of this research is to reduce plastic leakage in Indonesia. This will be done by modelling the system and analyzing the effects of different interventions.

Benefits of participation

The research will be conducted to get a diverse perspective on the current plastic waste system in Indonesia. With your participation, multiple views can be taken into account and results can be better integrated in the Indonesian context. All results and a summary of insights and key learnings will be shared with you.

Data handling

For this research several interviews will be conducted through video interviews. These will be recorded and transcribed anonymously, which can be send to the interviewee afterwards on request with the possibility of rectification. The interview recordings will only be accessible by the researcher (Mira Groot) and after the completion of the thesis, these will be destroyed. A general job description will be used in the research report. The anonymized transcripts of the interview will be submitted along with the research report to the university and Rebel supervisors.

Changing terms

When you do not feel comfortable with any of these terms, please feel free to reach out to the researcher to find an alternative solution.

Withdrawal

It is possible to withdraw from the interview at any time, without having to give a reason.

Contact details

For further questions and information, you can contact the researcher, Mira Groot, via phone or email, see contact details on top of the page.

Consent Form for Interviews – Research Plastic Waste in Indonesia

Please tick the appropriate boxes	Yes	No
Taking part in the study		
I have read and understood the study information dated [DD/MM/YYYY], or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	☐	☐
I understand that taking part in the study involves a video-recorded interview. The interview will be transcribed anonymously, which can be send to the interviewee afterwards on request. The interview recordings will only be accessible by the researcher (Mira) and after the completion of the thesis, these will be destroyed. A general job description will be used in the research report. The anonymized transcripts of the interview will be submitted along with the research report to the university and Rebel supervisors.	☐	☐
Use of the information in the study		
I understand that information I provide will be used for the master thesis report of researcher Mira Groot.	☐	☐
I understand that personal information collected about me that can identify me, such as my name, will not be shared by the researcher.	☐	☐
I agree that my information can be quoted in research outputs.	☐	☐
Future use and reuse of the information by others		
I give permission for the anonymized interview transcript that I provide to be archived in the TU Delft repository so it can be used for future research and learning. All data is anonymized and only a general job description will be used in the research report.	☐	☐
Signatures	☐	

_____	_____	_____
Name of participant	Signature	Date

For participants unable to sign their name, mark the box instead of sign

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

_____	_____	_____
Researcher name	Signature	Date

Figure B.2 - Information sheet interview

B3 – Interview guide

An interview guide was prepared to give structure to the interviews and to be able to compare answers between participants afterward. The interviews were held with the goal of exploring the implementation of EPR in the context of the plastic waste system in Indonesia. The concrete goals for the interviews are as follows. *The first four goals have a more theoretical approach, whereas the last four focus more on the interactions and practical input for the agent-based model.*

1. Find out the main challenges of the Indonesian plastic system;
2. Find out strengths and challenges of EPR;
3. Find out what EPR measures are most suitable for the Indonesian plastic system;
4. Find out requirements for proper implementation of EPR in Indonesia.
5. Gain insights into interactions and dependencies between stakeholders in the current Indonesian plastic system;
6. Find out if and how EPR affects these interactions;
7. Gain insights into resources of stakeholders to influence others;
8. Validate conceptual system made by the author.

The interviewees were divided into two groups:

- Indonesian or Dutch organizations that are directly involved with EPR
    - Ministry, Indonesian PRO, (plastic) producers, Indonesian Packaging Association, Afvalfonds Verpakkingen (Dutch PRO for packaging). For Afvalfonds, the questions were more related to the Dutch context. The specific questions can be found in the interview transcript.
- Indonesian organizations that are directly involved with the plastic system and indirectly with EPR
    - Waste bank, recyclers, NGOs, Most of the interview questions were asked to all interviewees (first table in yellow), but there are also sections that were specific to the type of position or organization of the interviewee (second table in green). Since the interviews are semi-structured, the specific question might be adjusted according to the most relevant goal, and follow-up questions could be added during the interview to elaborate on some topics in more detail.

Interview questions

Organization	General	• Can you explain your role within **[organization]** • What is your goal towards plastic in Indonesia?
	Stakeholders	• Who do you collaborate with?
	Plastic system	• What do you think of this conceptual system (*show them*) and do you see more or different connections?
Plastic Waste	Plastic waste	• What do you think are the main challenges in the plastic system in Indonesia? • What role do you think the stakeholders have to minimize plastic pollution? • How do you see the difference between low- and high-value plastics?
	EPR	Depending on interviewee - See table below

Closing		Thank you for your valuable contribution. • Is there anything you would like to add? • Is there someone you think would be valuable to talk to? • If I have some questions regarding the interview, will it be ok to ask you later?

EPR questions per group

Questions for group 1	• What does EPR mean to you? • What do you think is needed to achieve a proper EPR system? • How do you think the new EPR regulation (explain if needed) can contribute to this? • What do you think are suitable EPR measures to be applied in Indonesia?
Questions for group 2	• Who should be responsible for the plastic waste that is being littered right now? • How do you think this can best be achieved? • How do you think they can be asked to participate towards less plastic pollution? • How do you think relations between stakeholders are changed when producers become more responsible for their end-of-life products?

B4 – Interview transcriptions

Every interview has been transcribed non-verbatim. Unfortunately, the interview with IPI, the scavenger organization, could not take place due to the language barrier. Therefore, some small correspondence has taken place to gain information on how the waste pickers work and their trade-offs. The transcriptions can be visible on request.

Appendix C - Actor analysis

Table C.2 represents the actors that are involved in the waste management system of Indonesia.

Table C.2 - Stakeholder overview

National Government
Ministry of Environment and Forestry
Ministry of Planning
Ministry of Public Works
Local government
Regional government (kabupaten)
Mayor of city (kota)
Village head (desa)
Non-governmental organizations
Global Rec (Global Alliance of Waste Pickers)
IPI (Indonesian Scavengers Union)
Gringgo (waste collection organization)
Waste 4 Change (manages and recycles waste)
INSWA (international solid waste association)
Adupi (plastic recycler association)
Indonesian Packaging Federation
NPAP (National Plastic Action Partnership)
Afvalfonds Verpakkingen (Dutch packaging association)
Brand-owners
Aqua Danone
Unilever
Coca-Cola
Nestle
Local interest groups
IPRO (Producer Responsibility Organization)
Bank Sampah (waste bank)
Non-organized interests
Households
Middlemen
Industries

The formal chart of waste management actors is presented in Figure C.3. The Indonesian national government set an EPR regulation in 2019. It mainly focuses on the responsibility of producers of plastic packaging towards 1) limiting waste, 2) recycling waste, and 3) reusing waste (Ministry of Environment and Forestry Regulation No. P.75/2019 on Roadmap to Waste Reduction by Producers, n.d.). The national government provides local governments with funding to carry out their cities' waste collection and processing services. Besides national funding, municipalities also receive payments from taxpayers. However, it is difficult to retrieve payments in some cases, as households are not always willing to provide waste management taxes. Experiments could be done by collecting waste management taxes at the same bill as electricity taxes. Local governments can furthermore influence households by promoting more sustainable behavior

through education and promotion activities. Households buy products with plastic packaging, which they can either sell to waste banks (bank sampah) or informal waste pickers. This also makes it difficult for governments to receive taxes for waste management since high-value packaging waste like PET, paper, and glass are economically valuable materials.

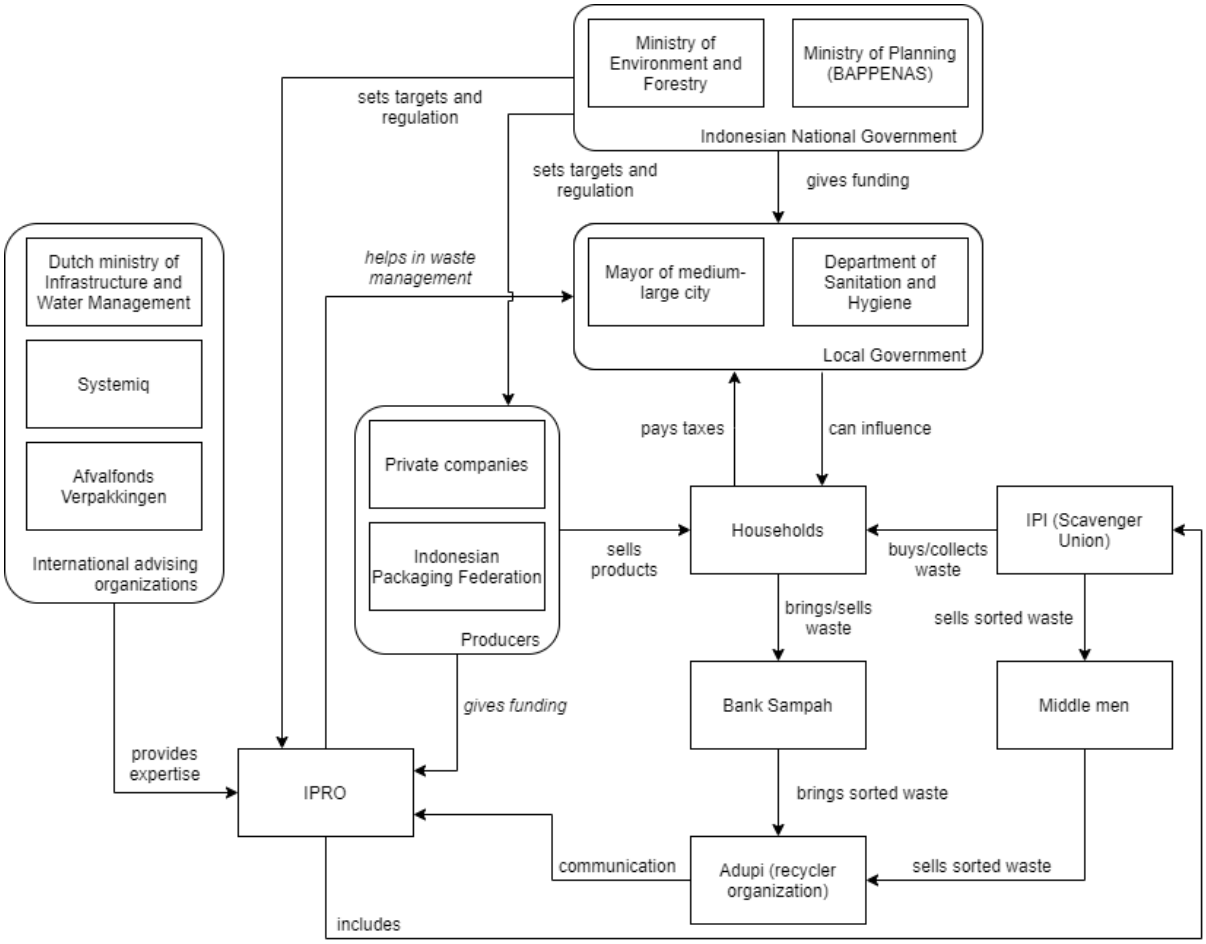
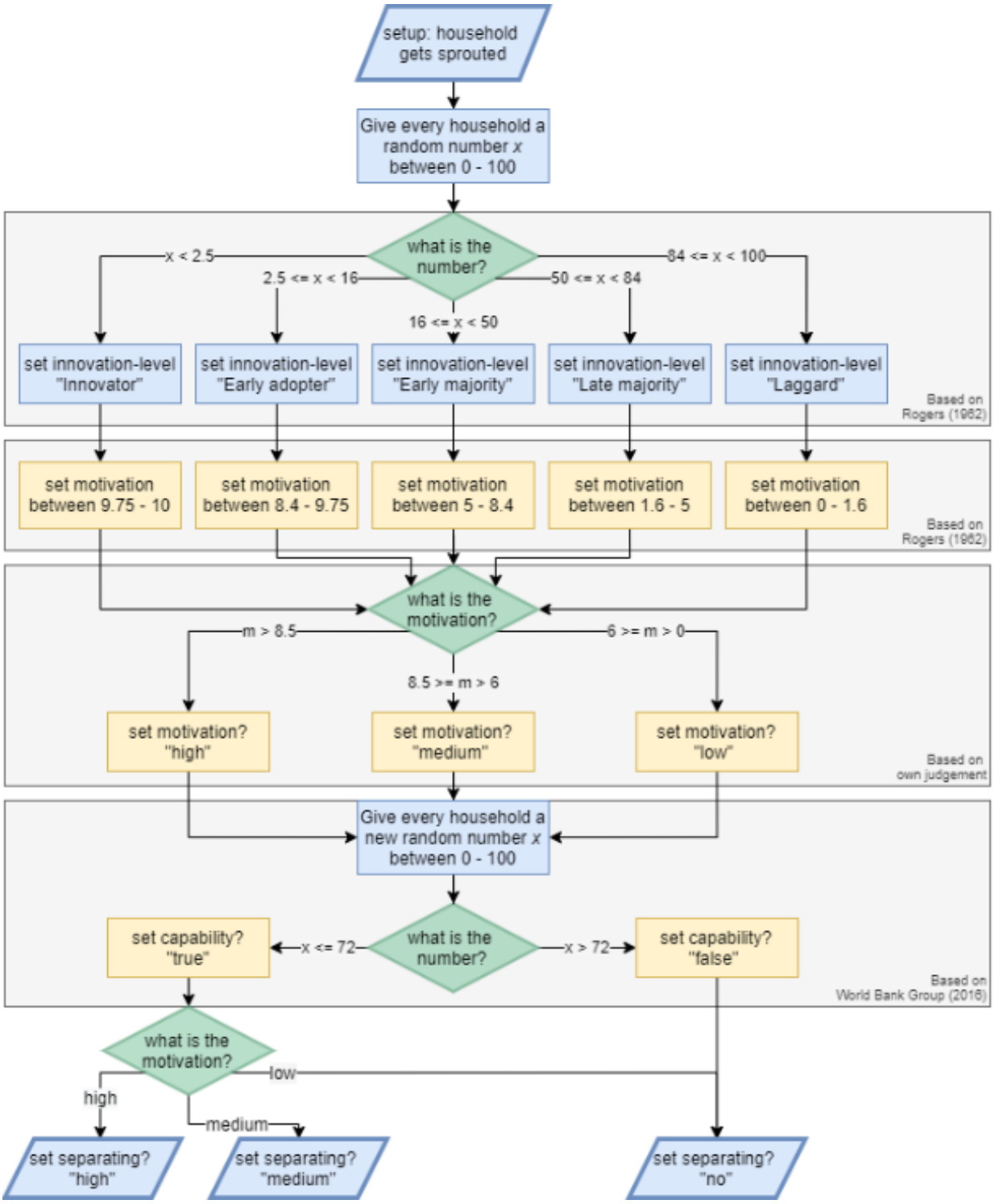
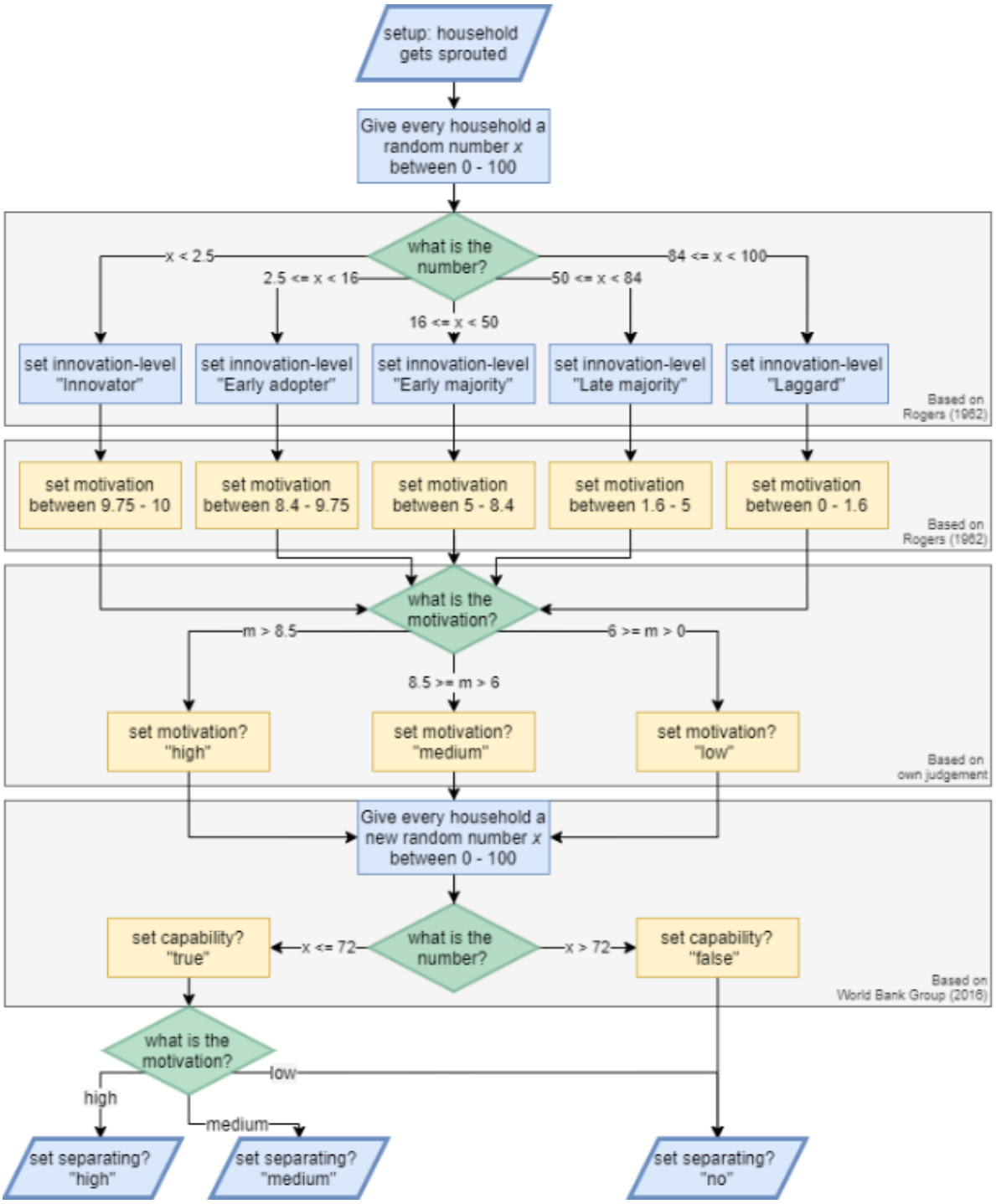
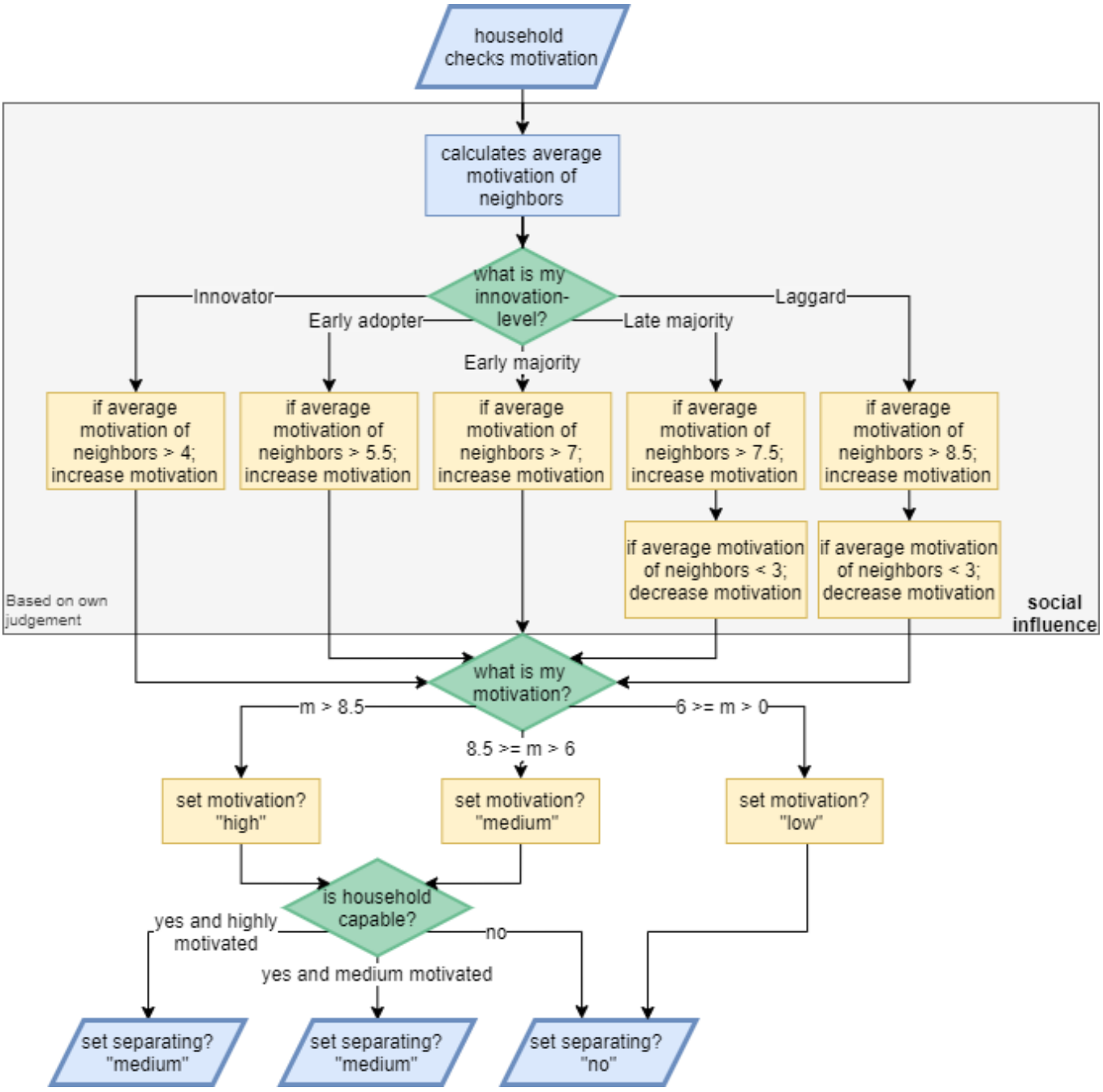


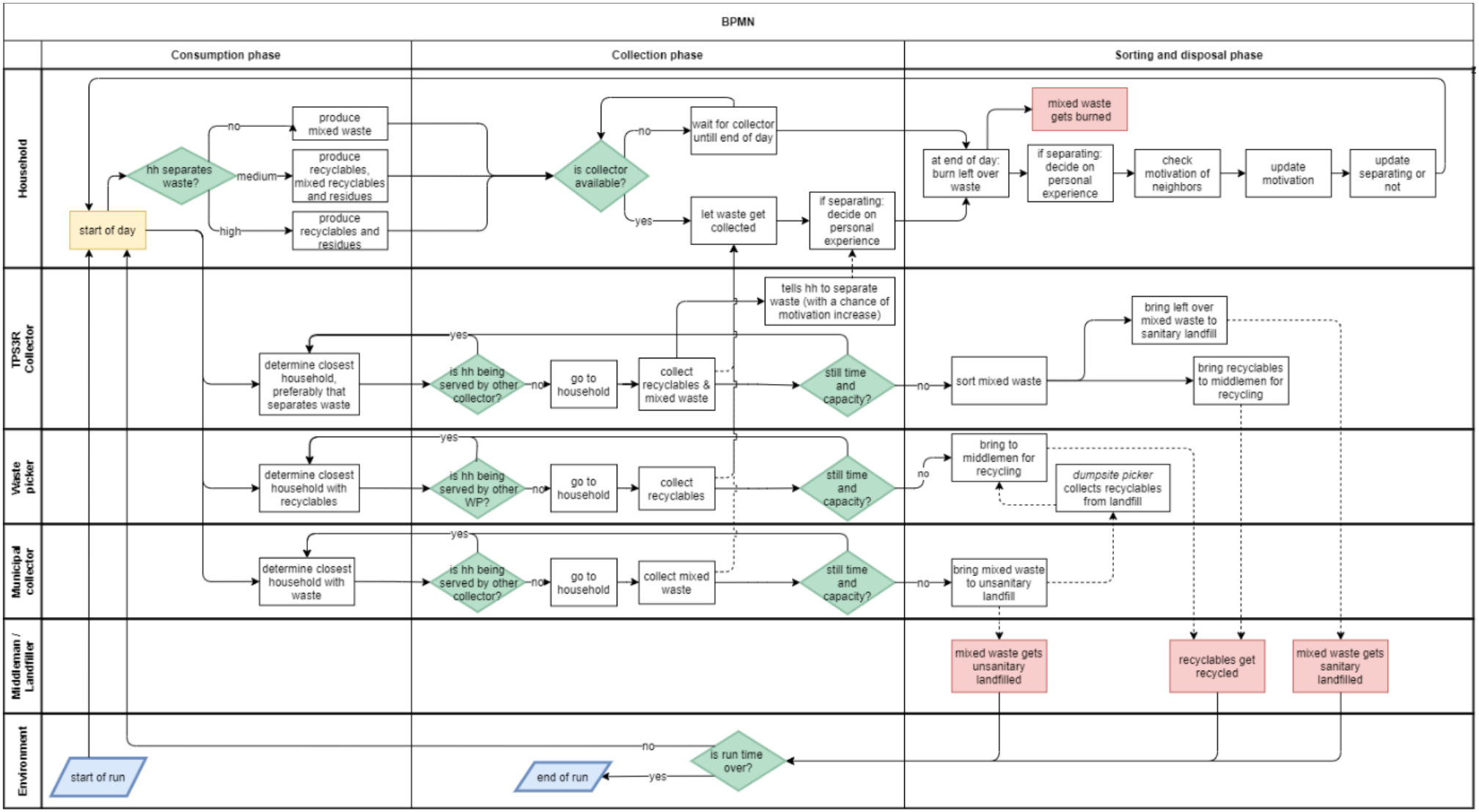
Figure C.3 - Actor map

Appendix D - Behavior flow diagrams




setup: household gets sprouted
Give every household a random number x between 0 - 100
what is the number?
x < 2.5
2.5 <= x < 16
16 <= x < 50
50 <= x < 84
84 <= x < 100
set innovation-level "Innovator"
set innovation-level "Early adopter"
set innovation-level "Early majority"
set innovation-level "Late majority"
set innovation-level "Laggard"
Based on Rogers (1962)
set motivation between 9.75 - 10
set motivation between 8.4 - 9.75
set motivation between 5 - 8.4
set motivation between 1.6 - 5
set motivation between 0 - 1.6
Based on Rogers (1962)
what is the motivation?
m > 8.5
8.5 >= m > 6
6 >= m > 0
set motivation? "high"
set motivation? "medium"
set motivation? "low"
Based on own judgement
Give every household a new random number x between 0 - 100
set capability? "true"
x <= 72
what is the number?
x > 72
set capability? "false"
Based on World Bank Group (2016)
what is the motivation?
high
medium
low
set separating? "high"
set separating? "medium"
set separating? "no"


household checks motivation
calculates average motivation of neighbors
what is my innovation-level?
Innovator
Early adopter
Early majority
Late majority
Laggard
if average motivation of neighbors > 4; increase motivation
if average motivation of neighbors > 5.5; increase motivation
if average motivation of neighbors > 7; increase motivation
if average motivation of neighbors > 7.5; increase motivation
if average motivation of neighbors > 8.5; increase motivation
if average motivation of neighbors < 3; decrease motivation
if average motivation of neighbors < 3; decrease motivation
Based on own judgement
social influence
what is my motivation?
m > 8.5
8.5 >= m > 6
6 >= m > 0
set motivation? "high"
set motivation? "medium"
set motivation? "low"
is household capable?
yes and highly motivated
yes and medium motivated
no
set separating? "medium"
set separating? "medium"
set separating? "no"


BPMN
Consumption phase
Collection phase
Sorting and disposal phase
Household
TPS3R Collector
Waste picker
Municipal collector
Middleman / Landfiller
Environment
start of day
hh separates waste?
no
medium
high
produce mixed waste
produce recyclables, mixed recyclables and residues
produce recyclables and residues
is collector available?
no
yes
wait for collector untill end of day
let waste get collected
if separating: decide on personal experience
mixed waste gets burned
at end of day: burn left over waste
if separating: decide on personal experience
check motivation of neighbors
update motivation
update separating or not
tells hh to separate waste (with a chance of motivation increase)
determine closest household, preferably that separates waste
yes
is hh being served by other collector?
no
go to household
collect recyclables & mixed waste
still time and capacity?
no
sort mixed waste
bring left over mixed waste to sanitary landfill
bring recyclables to middlemen for recycling
determine closest household with recyclables
yes
is hh being served by other WP?
no
go to household
collect recyclables
still time and capacity?
no
bring to middlemen for recycling
dumpsite picker collects recyclables from landfill
determine closest household with waste
yes
is hh being served by other collector?
no
go to household
collect mixed waste
still time and capacity?
no
bring mixed waste to unsanitary landfill
mixed waste gets unsanitary landfilled
recyclables get recycled
mixed waste gets sanitary landfilled
start of run
no
is run time over?
yes
end of run

Appendix E - Model assumptions

Scope	Assumption	Explanation
Behavioral aspects	1	Innovation level determines motivation thresholds
	2	Capability is a Boolean (capable or not)
	3	No behavior based on economics
	4	Dumpsite pickers do not interact, only capture from landfills
	5	There is no increase or decrease in informal collectors when more or fewer recyclables are available for collection
	6	No local community leaders or religious believes affects the behavior
	7	Waste collectors go to the closest household to pick up waste, whereas they might have specific routes. An exception is for TPS3R collectors, that first go to households which separate waste
Simplifying the model	8	No recycle losses or losses during transportation
	9	Household waste is divided in recyclables and residuals
	10	End-of-life phases consist of recycling and landfilling only
	11	No waste banks included due to the limited contribution to waste collection
	12	The capability Boolean is determined randomly rather than based on, for example, location
	13	Time to reach the recycler or landfill is not incorporated
	14	Only informal waste pickers are involved, whereas many more informal waste workers (middlemen, small bosses, big bosses, recyclers, etc.) are involved
	15	The capacity of trucks is set at 100 and 300 kg.
Interventions	16	Take-back requirements result in more TPS3R vehicles that collect waste separately from households
	17	Advanced disposal fees result in more recyclables in households' waste streams
	18	Awareness-raising campaigns target motivation for source separation only

Appendix F - Model parameterization

In Table F.3 below, all values for the parameters in the model are listed.

Table F.3 - Parameters of model

Level	Parameter	Value	Source
Model	Initial-amount-of-households	250	Own specification, based on World Economic Forum (2020)
	Initial-amount-of-waste-pickers	14	Own specification, based on World Economic Forum (2020)
	Initial-amount-of-municipal-collectors	24	Own specification, based on World Economic Forum (2020)
	Initial-amount-of-TPS3R-collectors	1	Own specification, based on World Economic Forum (2020)
	Initial-amount-of-middlemen	5	Own specification
	Recyclable percentage	20%	
Agent properties	Area to search for neighboring households	10	Own specification
	Area to find households for waste pickers	10	Own specification
	Area to find households for collectors	20	Own specification
	Capability threshold	72%	World Bank Group (2016)
	Innovation diffusion distribution: Initial innovators; early adopters; early majority; late majority; laggards	2.5; 13.5; 34; 34; 16 %	(Rogers, 1995)
	Maximum capacity waste pickers	4 + random 4 kg; 1/10th chance of 25 kg	(Ratna et al., 2018)
	Maximum capacity municipal collectors	100 kg	(Rahim, Nakayama, & Shimaoka, 2012)
	Maximum capacity TPS3R collectors	300 kg	(Rahim et al., 2012)
Motivation values	Threshold for high motivation (100% separation)	8.5/10	Own specification
	Threshold for medium motivation (50% motivation)	6/10	Own specification
	Motivation-decrease-personal-experience	0.2	Own specification
	Motivation-decrease-social-influence	0.1	Own specification
	Motivation-increase-social-influence	0.1	Own specification
	Probability		

Simplifying the model	Dumpsite picker collection rate	5%	(Sasaki, Araki, Tambunan, & Prasadja, 2014)
Interventions	1: number of collection vehicles	10	Own specification
	1: motivation-increase-tbr	0.25	Own specification
	2: adf-target	25, 30, 35	Own specification
	3: number of campaigns	5	Own specification
	3: radius-campaigns	10	Own specification
	3: motivation-increase-awareness-campaigns	0.2	Own specification
	Chance of awareness increasing for Innovators Early adopters Early majority Late majority Laggard	 90% 75% 60% 50% 40%	Own specification

Appendix G - Model calibration

The exact number of waste pickers and municipal collectors is very uncertain. Therefore, the numbers for the base case have been used to get relatable results for the numbers known for collection and recycling in Indonesia (World Economic Forum, 2020). Therefore, the ratios between the values of the parameters determine the outcome of the recycling and collection rate. In section 8.3.2, the model's outcomes are validated with numbers established in the literature. Here, the initial model values are explained by using the collection and recycling rate as reference points (Table G.4).

Table G.4 - Calibration values with other research

Level	Parameter	Value for base case	Source
Model calibration	Residential waste collection in Bandung (of total waste generated)	76%	(Sembiring & Nitivattananon, 2010)
	Informal waste collection in Bandung (of total waste generated)	13%	(Sembiring & Nitivattananon, 2010)
	WP collection (not DP) in Jakarta (of total plastic waste)	34%	(Ratna et al., 2018)
	Municipal collection in Jakarta (of total plastic waste)	54%	(Ratna et al., 2018)
	Informal recycling rate in a medium-sized city (of total plastic waste)	**12%**	(World Economic Forum, 2020)
	Municipal collection and TPS3R residuals in a medium-sized city (of total plastic waste)	**32%**	(World Economic Forum, 2020)
	Burning (and illegal dumping and leakage into seas) in a medium-sized city	**55%**	(World Economic Forum, 2020)
	WP collection & DP collection (of total plastic waste	7% & 8%	(World Economic Forum, 2020)
	TPS3R collection (of total waste generated)	1%	(World Economic Forum, 2020)
These result in			
	Ini-hh	250	
	Ini-wp	15	
	Ini-mc	23	
	Ini-tc	1	

Appendix H - Model verification

Three types of verification have been done on the model.

Code walk-through

The model was made iteratively. The code was walked through for every new implementation step to see whether the timing and syntax were used correctly. During some procedures, the Command Centre showed whether the correct behavior occurred Figure H.4.

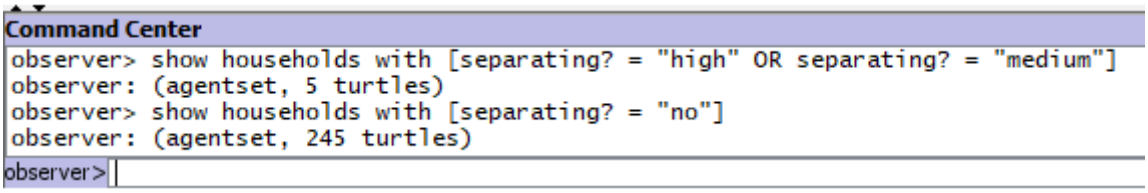


Figure H.4 - Example of code walk-through

Recording and tracking of agent behavior

Many times, individual agents were looked at in more detail. Especially when implementing new features and formulating new codes, the behavior was tracked by following agents via the "inspect" or "follow" function in NetLogo.

One example was during the integration of days when collectors did not stop at the end of the day. Instead of stopping when the working day was over, it was visible that they would go to new households until their capacity was full. However, based on interviews, it was known that waste pickers would end their day, even if their capacity had not been reached (IPRO, personal communication, 2021). Therefore, the hours-of-work variable was integrated. This, however, sometimes also resulted in that they would go to new households after they had dropped their waste at the middlemen or landfills. Therefore, the `waiting?` and `early?` variables were implemented. The agent is "early" when the capacity is reached before the end of the day. Moreover, the agents "wait" when the working day is over, but the day is not yet ended (see Figure H.0.5).

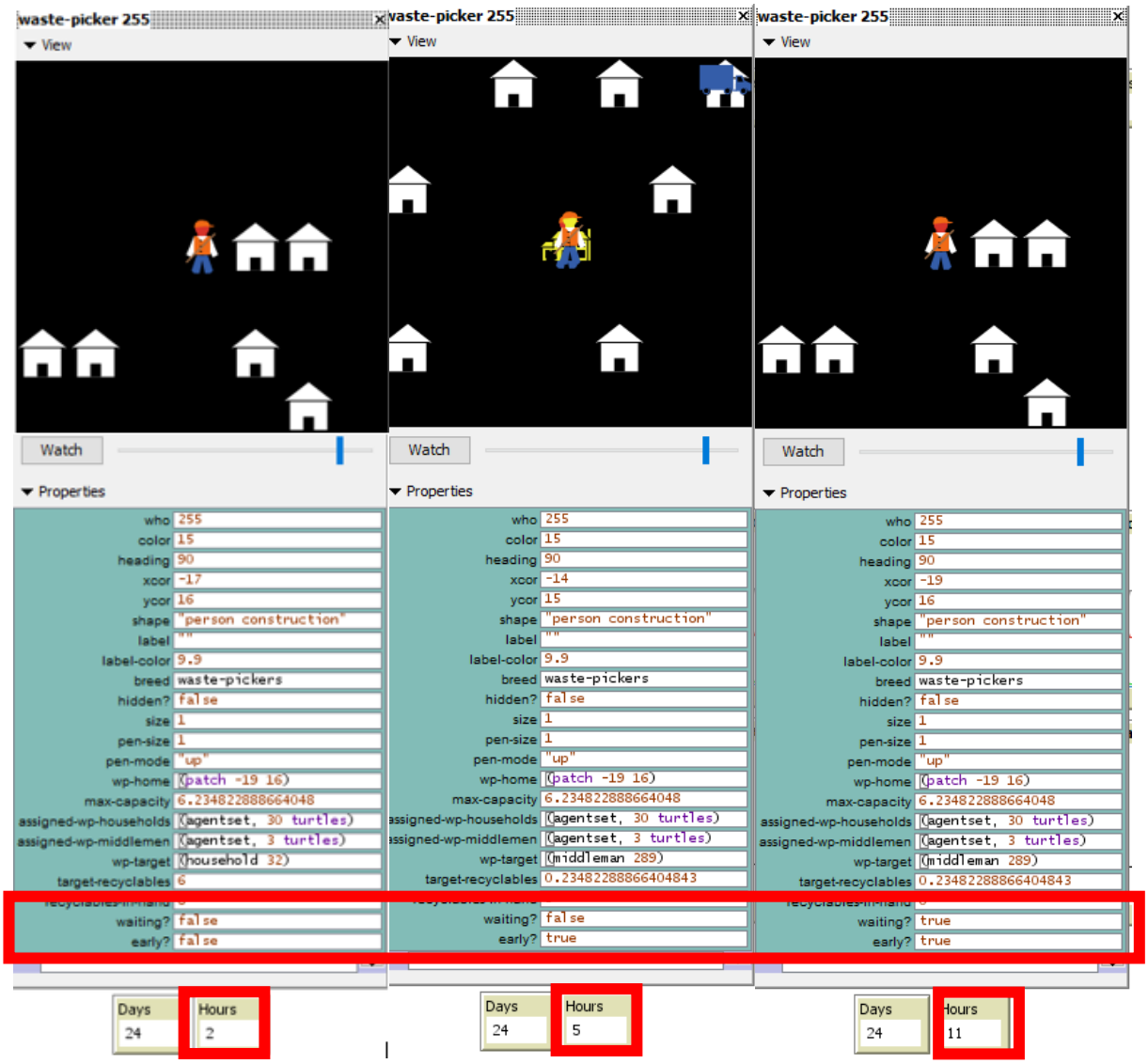


Figure H.0.5 - example of inspecting one agent at different time steps

Multi-agent testing

The behavior of multiple agents can be analyzed based on graphs in the model Interface (Figure H.0.6). The individual motivation can for example indicate at what moment in time the motivation increases and if this makes sense with the modeled content.

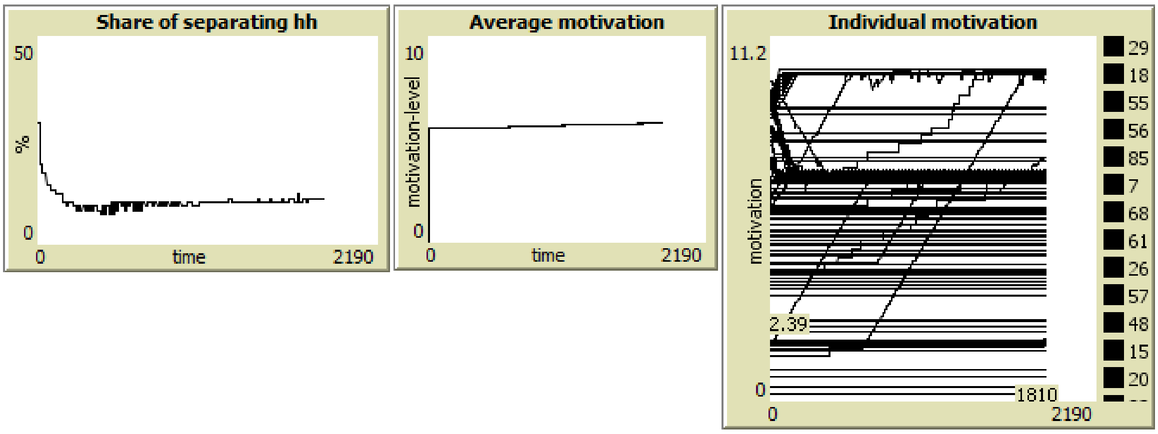


Figure H.0.6 - Graphs in the Interface can indicate agent behavior

Besides verification steps of the modeler, NetLogo also has some verification methods integrated into the model. During the run of the model, an error occurred (Figure H.7 - Example of error during a model run).

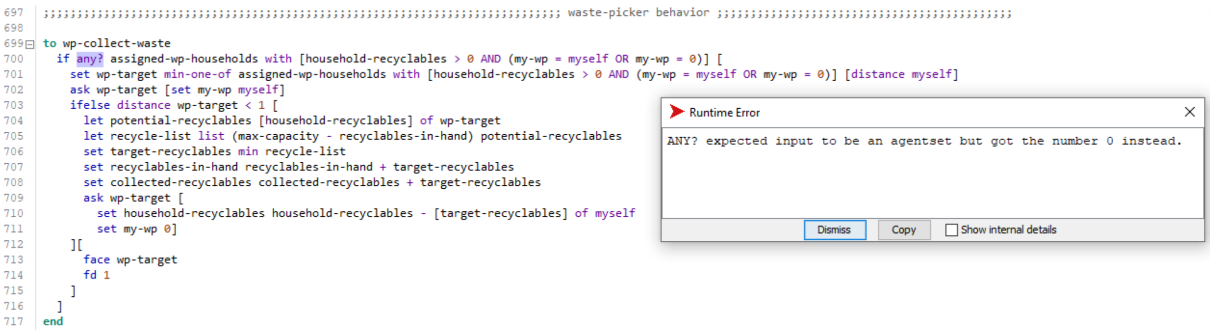


Figure H.7 - Example of error during a model run

It referred to that there were no assigned households. This could easily be fixed by implementing a line to ensure the agent still gets directed to action (even if it is doing nothing). It is important to mention that this error did not occur in every model run, but only sometimes. It is therefore essential to always simulate multiple runs.

Appendix I - Model results

Here, more model results are visualized.

I1 – BASE CASE

With the initial values determined in the model assumptions, the model is run for one year. Due to the size of the model, the runtime cannot be extended much longer. The graphs below show the results of the KPIs with a 95% confidence interval when the model repeats itself 50 times Figure I.8.

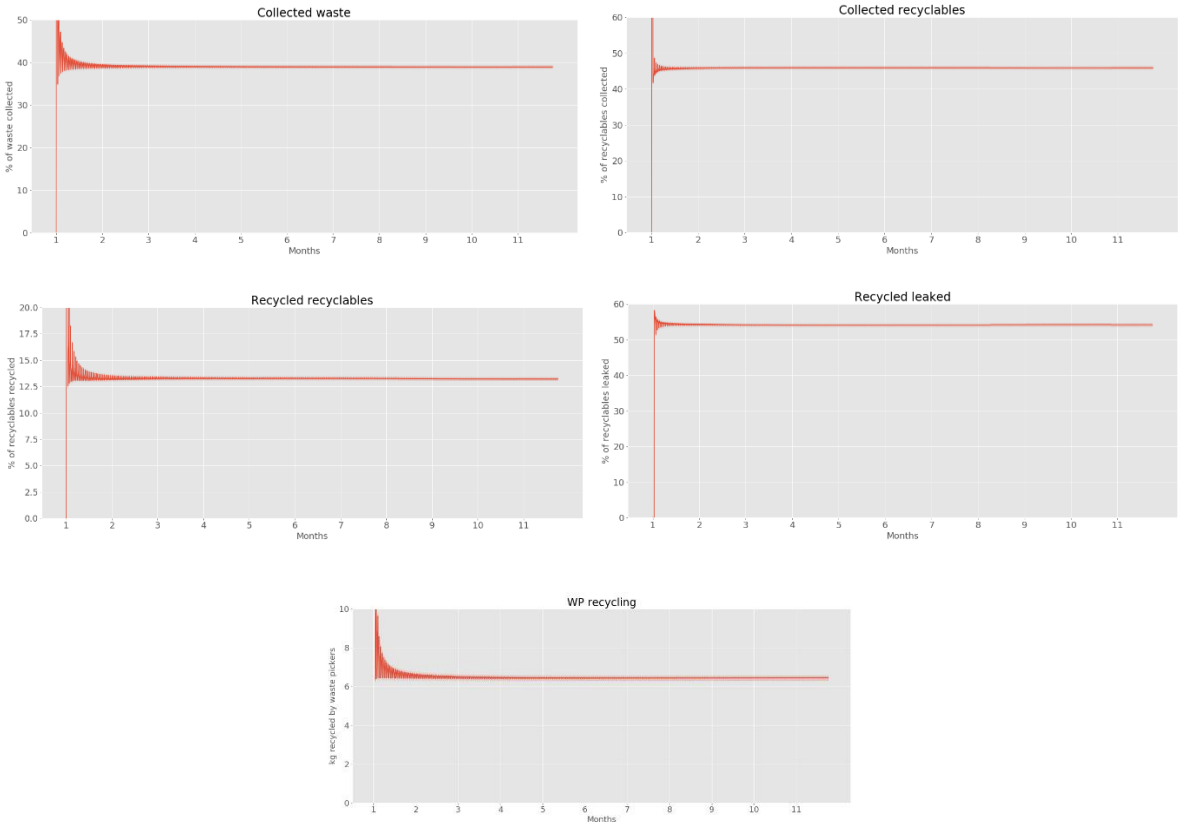
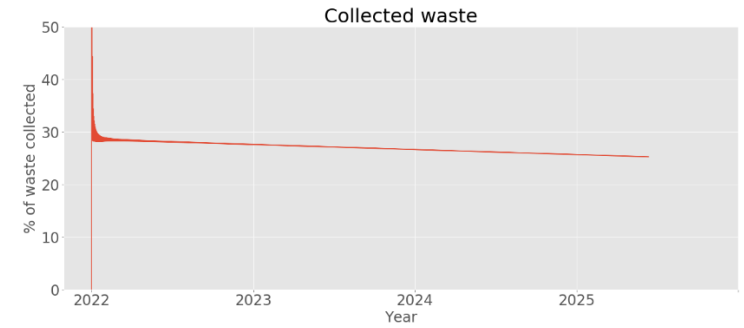
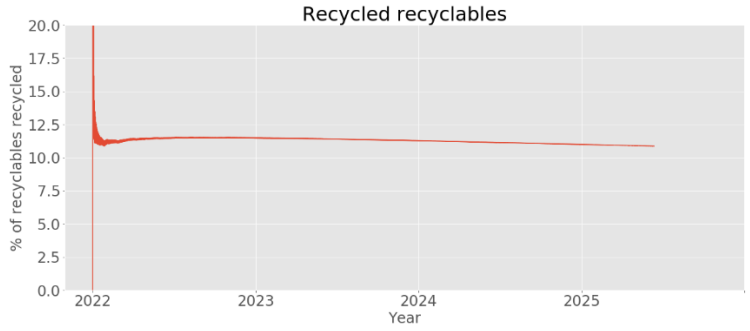
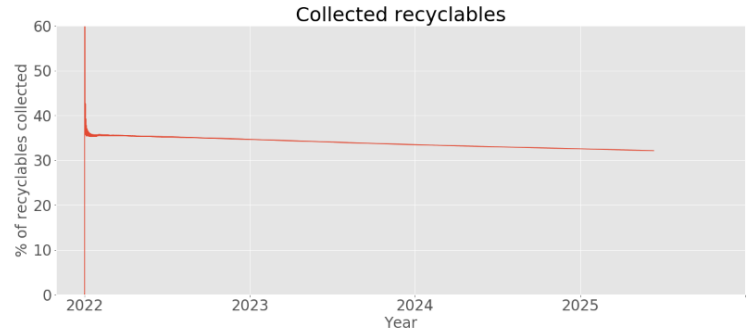


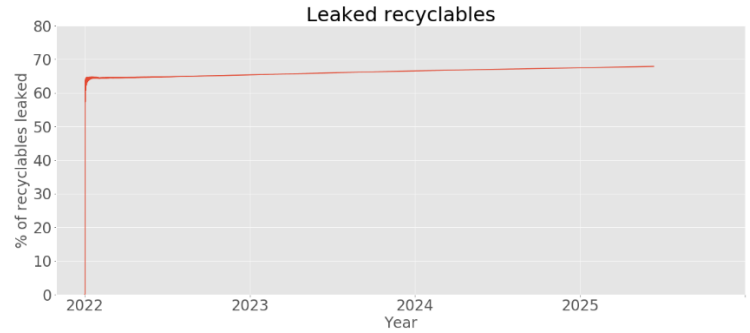
Figure I.8 - Base case: KPI over one year time

As the average run does not change much, the model is run for a longer time, but with only one repetition. The first three graphs below show the decrease of collection and recycling rate and the increase of plastic leakage over a time of four years (Figure I.9). The amount of kilograms waste pickers collect even slowly increases. This is because they can keep collecting recyclables without much competition, and there is more to collect from each household.


Collected waste
% of waste collected
0
10
20
30
40
50
2022
2023
2024
2025
Year


Recycled recyclables
% of recyclables recycled
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5
20.0
2022
2023
2024
2025
Year


Collected recyclables
% of recyclables collected
0
10
20
30
40
50
60
2022
2023
2024
2025
Year


Leaked recyclables
% of recyclables leaked
0
10
20
30
40
50
60
70
80
2022
2023
2024
2025
Year

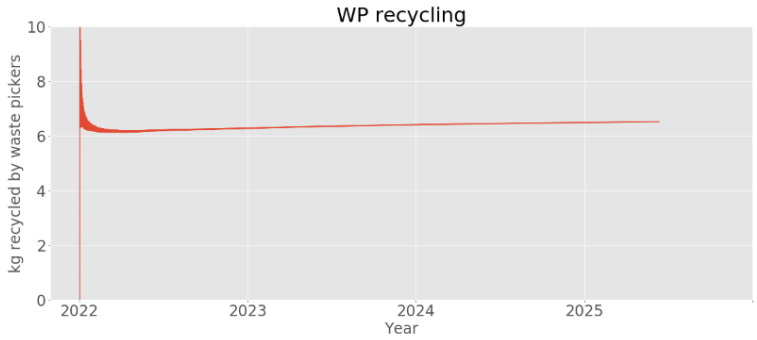


Figure I.9 – Base case: KPIs over four years time

I2 – INTERVENTIONS

Intervention 1

In Figure I.10, also the graphs of the KPIs collected and leaked recyclables are shown. The first shows similar effects as the waste collection, and the latter has an opposite effect.

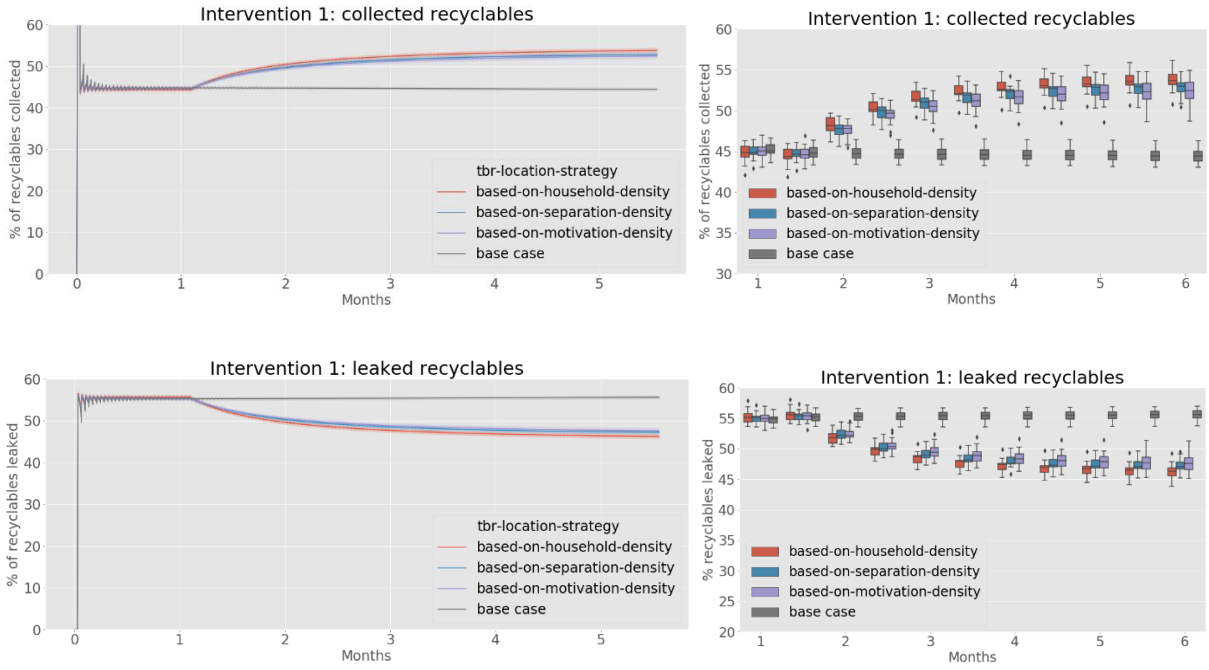


Figure I.10 – Line and boxplots of intervention 1, based on location strategy

Intervention 2

The following results show the effects of intervention 2, advanced disposal fees, on the KPIs (Figure I.11).

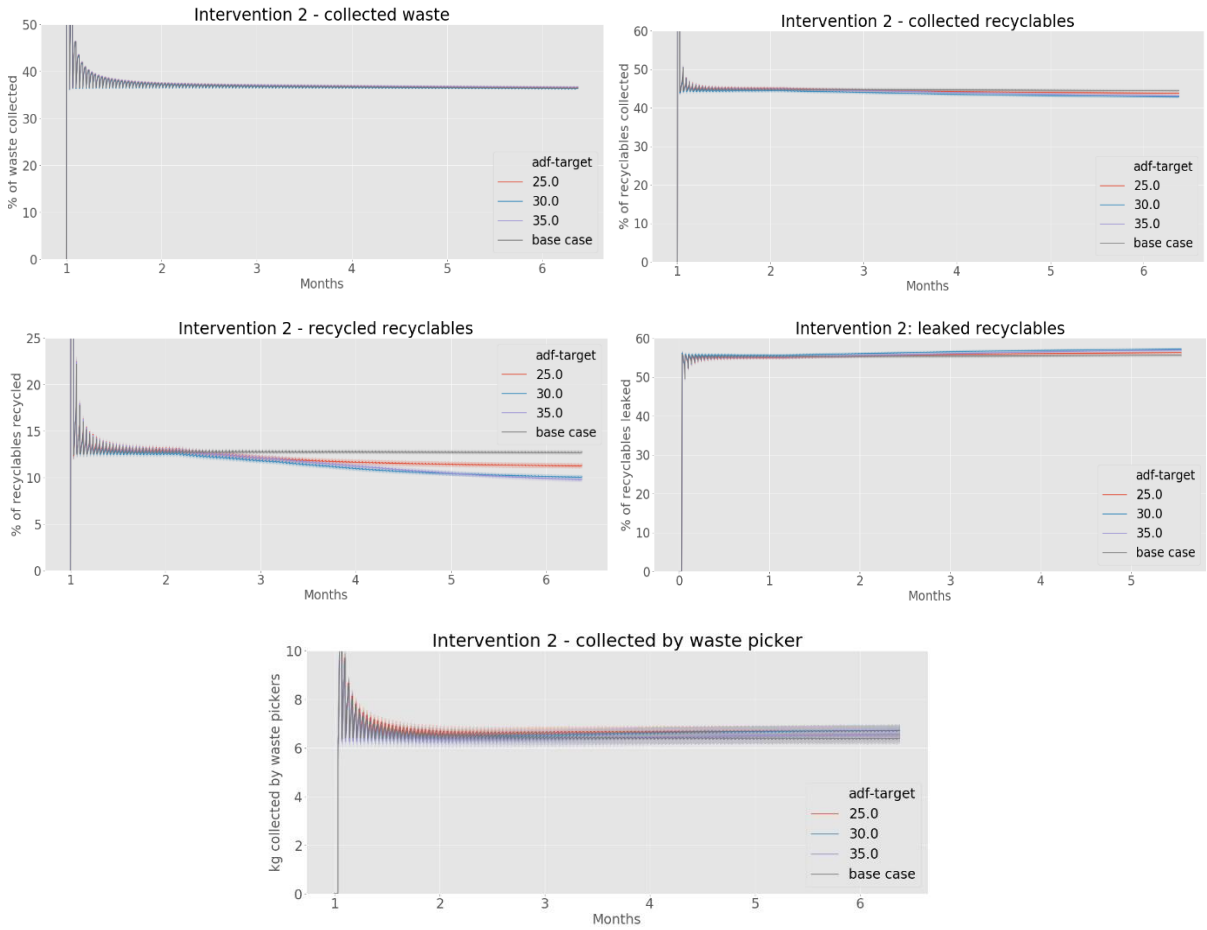


Figure I.11 - Line plots of intervention 1, based on adf-target

Intervention 3

The graphs for the KPIs of intervention 3 do not show any effect of the awareness-raising campaigns (Figure I.12 and Figure I.13). Only a possible small increase in recycle ratio could be found (Figure I.14).

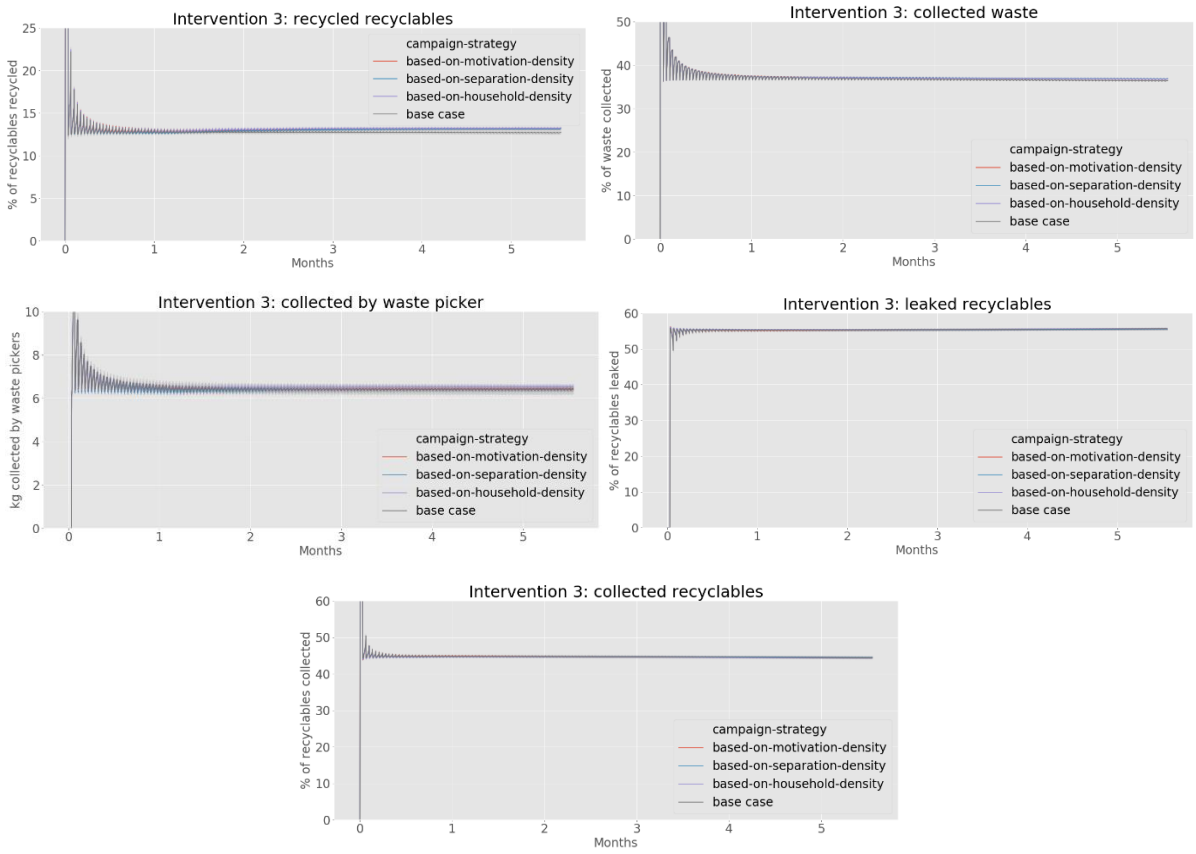


Figure I.12 - Line plots of intervention 3 based on campaign location strategy

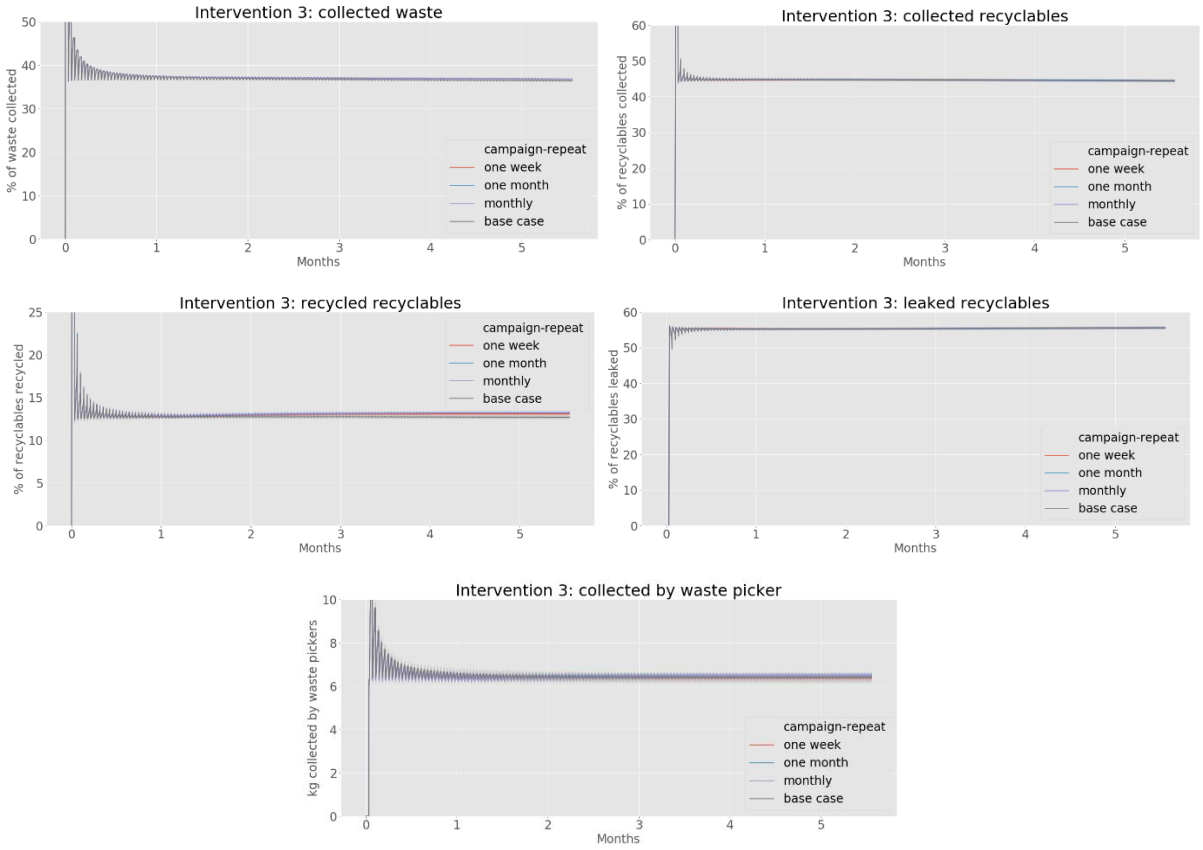


Figure I.13 – Line plots of intervention 3 based on campaign repetition strategy

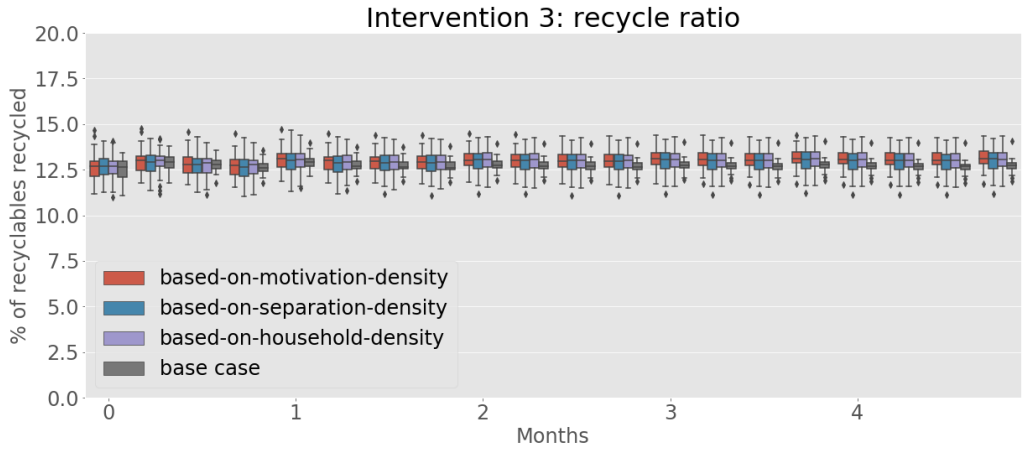
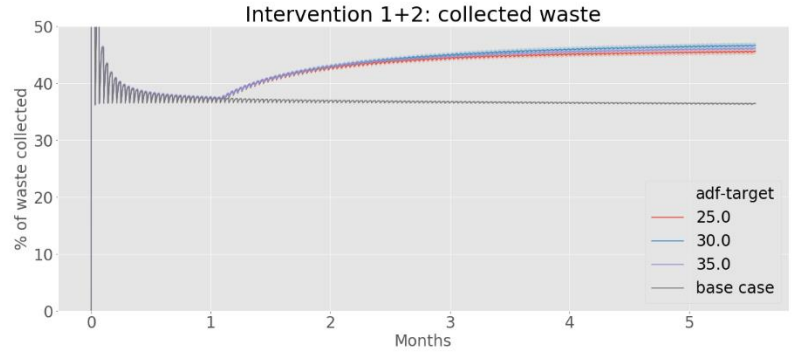


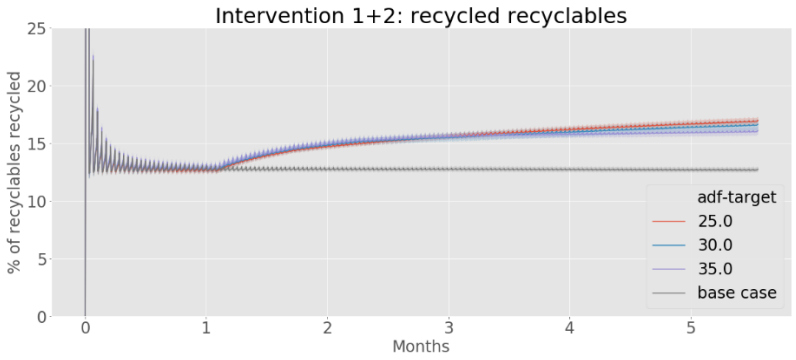
Figure I.14 - Boxplot of intervention 3

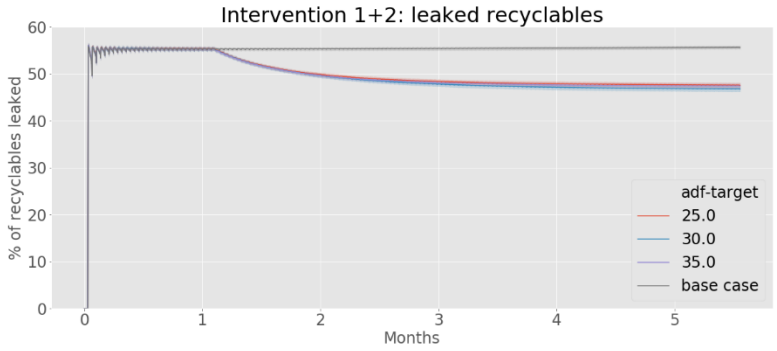
I3 – COMBINING INTERVENTIONS

Take-back requirements & ADF

There are only small changes visible in the graphs below for changing the ADF target (Figure I.15).







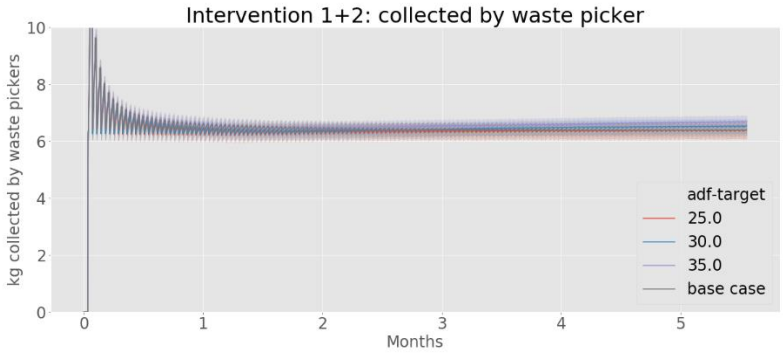
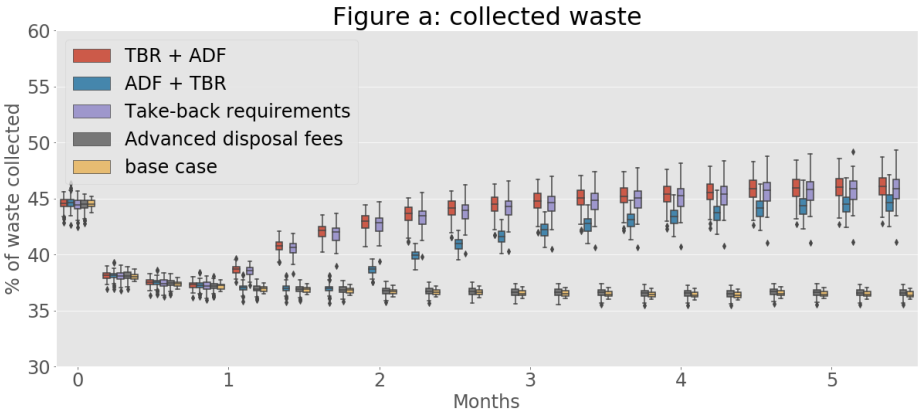
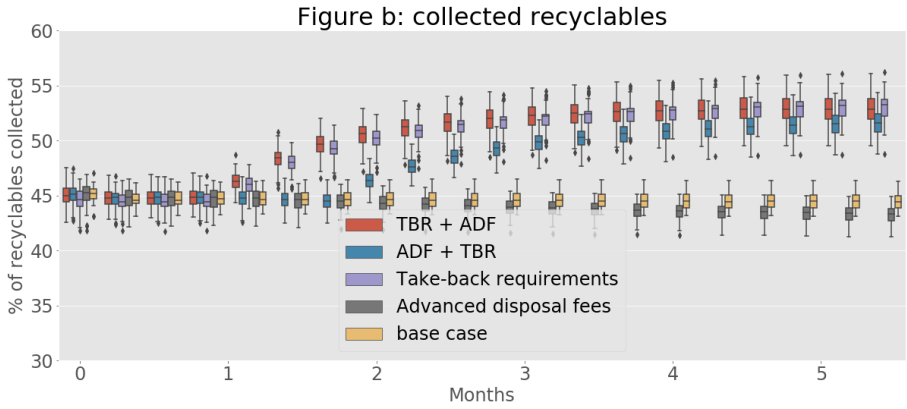


Figure I.15 Line plots of intervention 1+2, based on ADF target

The timing of the interventions was also varied (Figure I.16).





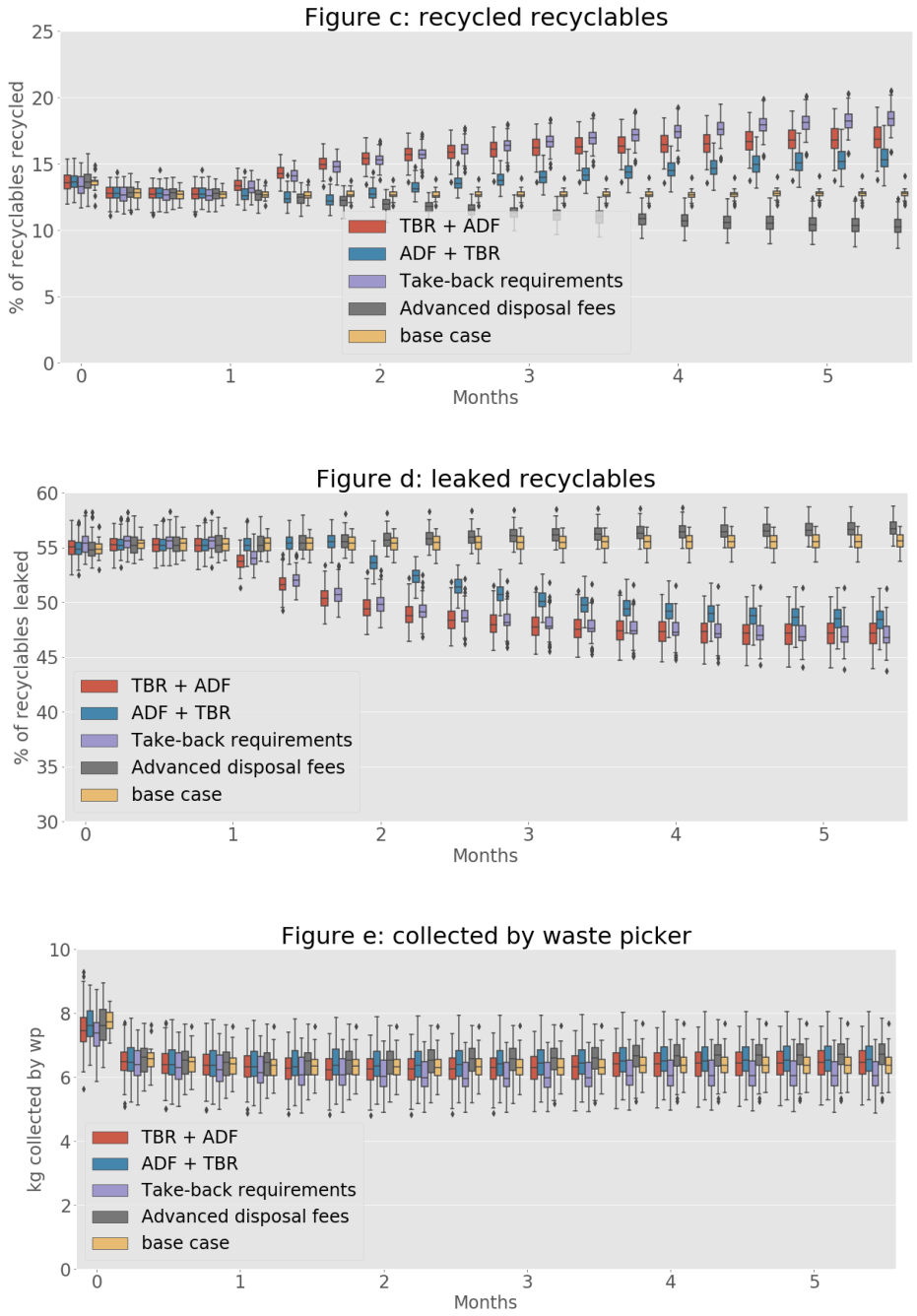


Figure I.16 - boxplots of combining intervention 1 and 2 with different start days

Take-back requirements & Awareness-raising campaigns

The graphs below show the outcomes on the KPIs when the first and third interventions are combined (Figure I.17 and Figure I.18).

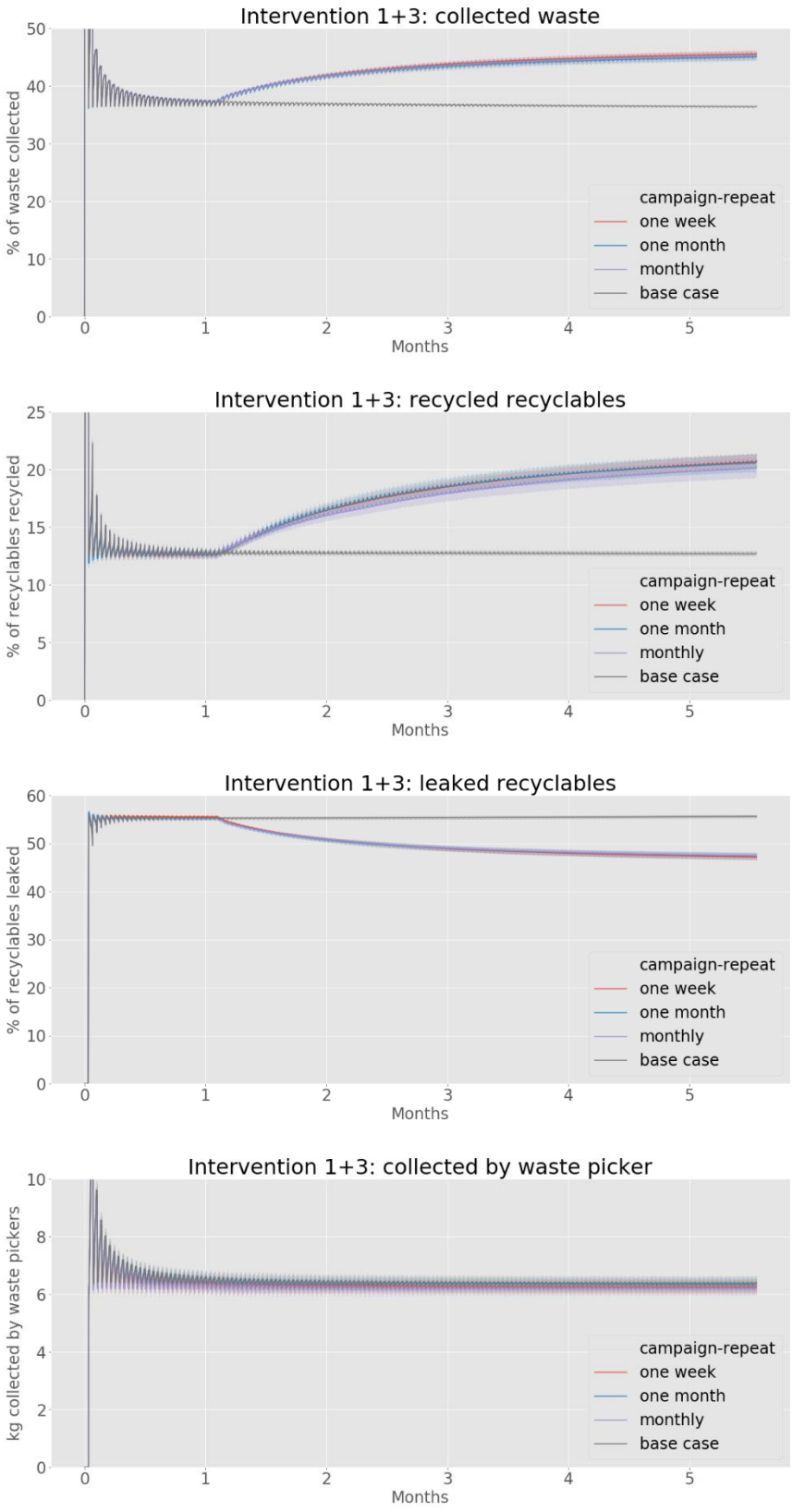


Figure I.17 - Line plots of intervention 1+3, based on campaign repetition strategy

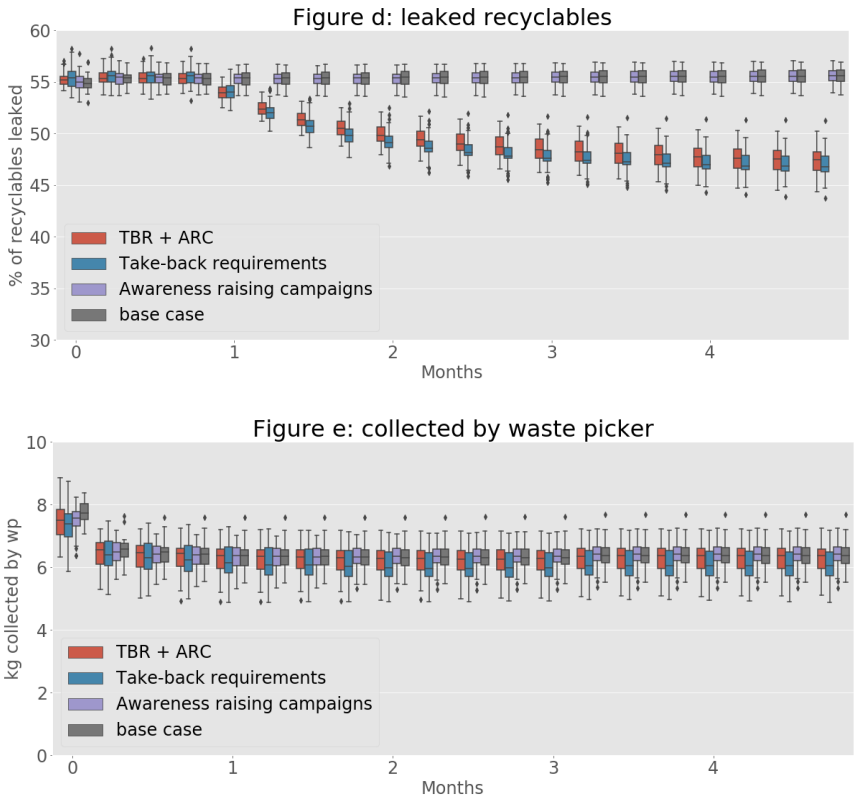
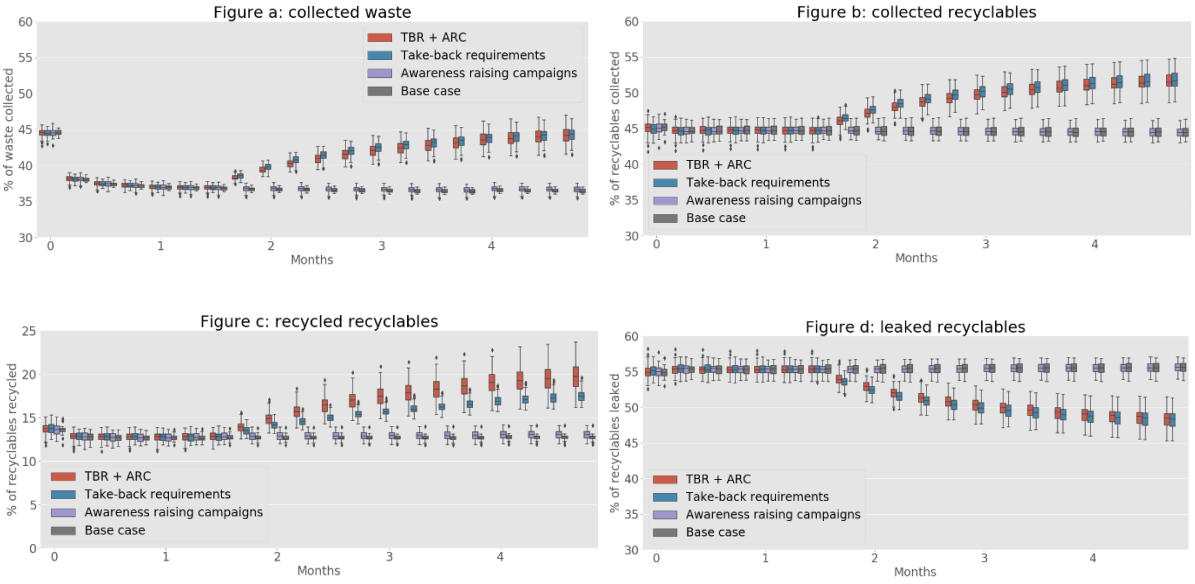


Figure I.18 - Other boxplots of intervention 1+3, compared with individual interventions

Figure I.19 below shows similar results, even when campaigns are started before the extra collection vehicles are placed.



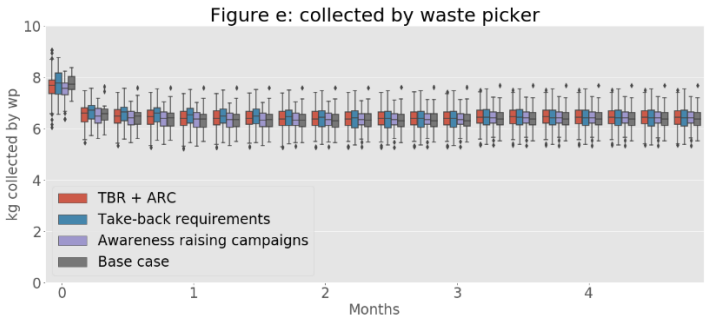


Figure I.19 - Boxplots when ARCs start before TBR

ADF & Awareness-raising campaigns

There are little effects of the combination of these two interventions, as can be seen in the graphs below (Figure I.20).

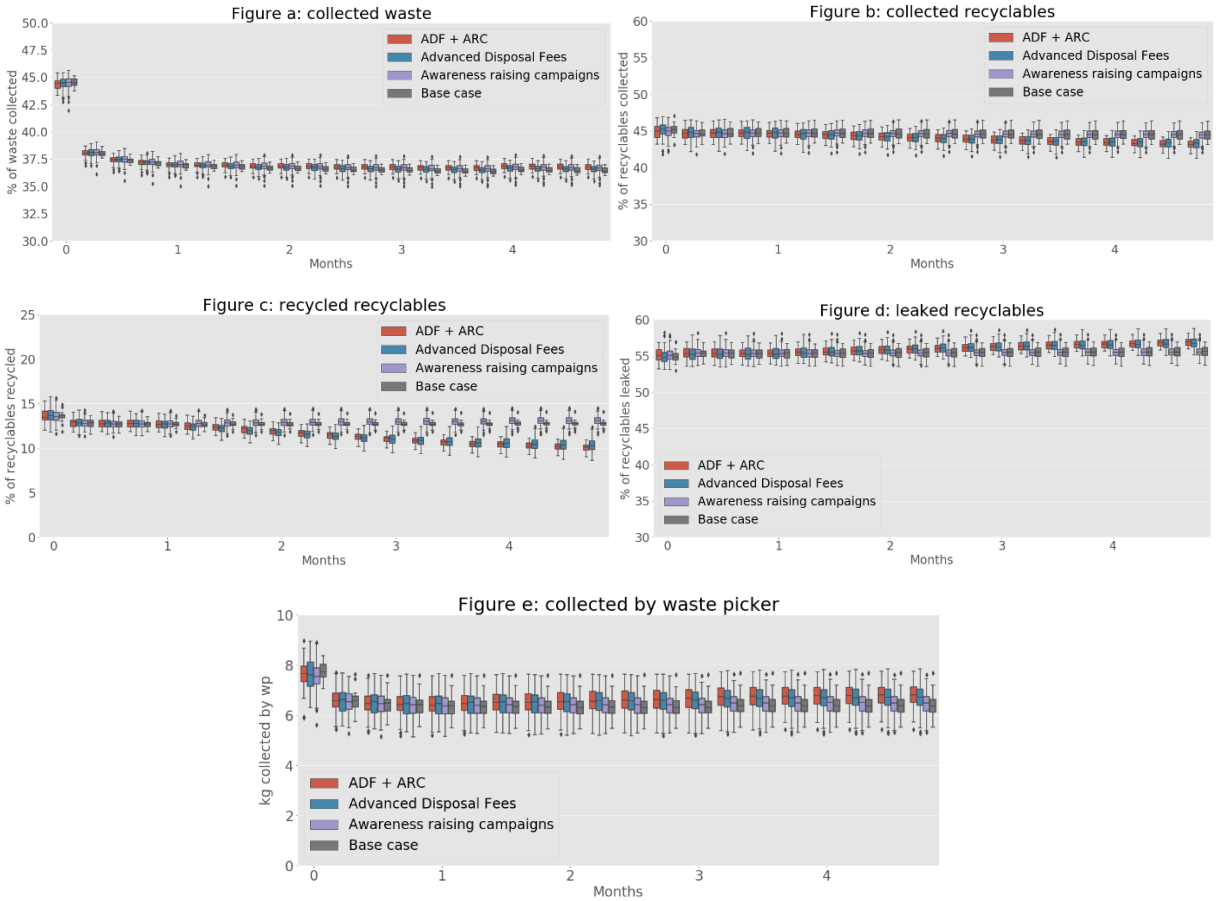


Figure I.20 - Boxplots of interventions 2+3, compared with individual interventions

Take-back requirements & ADF & Awareness-raising campaigns

In the graphs below, the interventions are implemented simultaneously and compared with the individual instruments (Figure I.21).

Figure a: collected waste

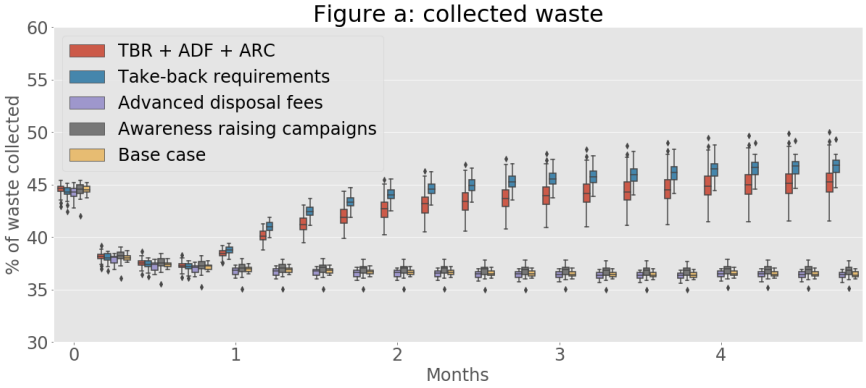


Figure b: collected recyclables

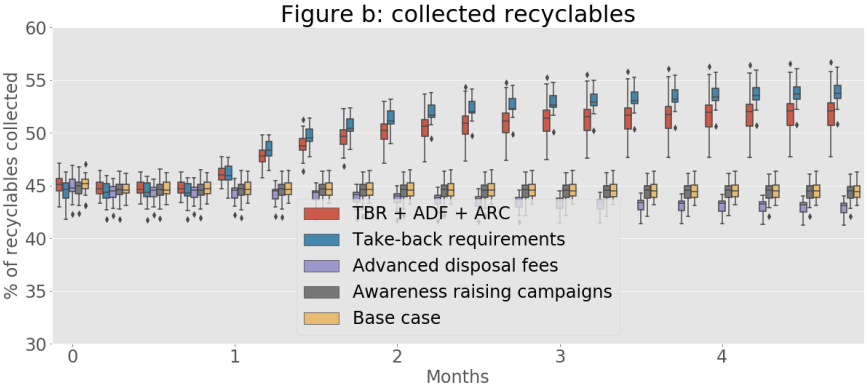


Figure c: recycled recyclables

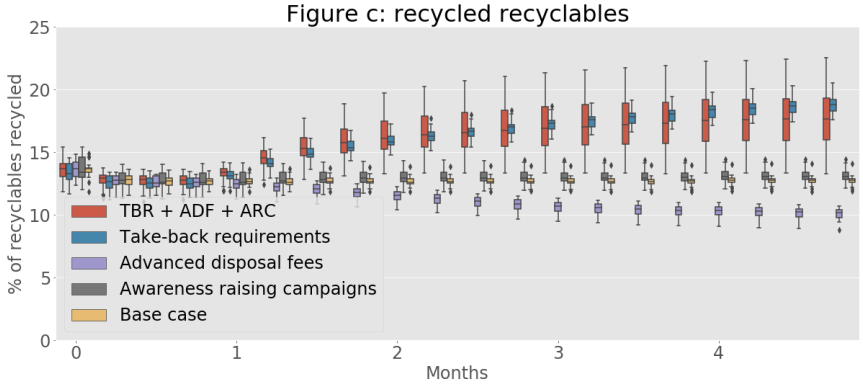
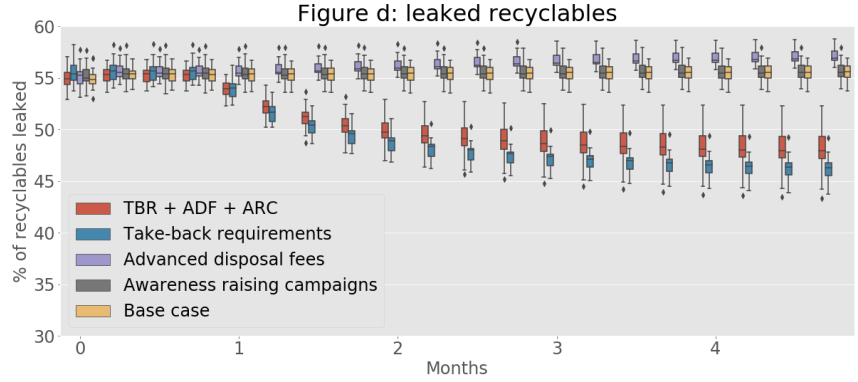


Figure d: leaked recyclables



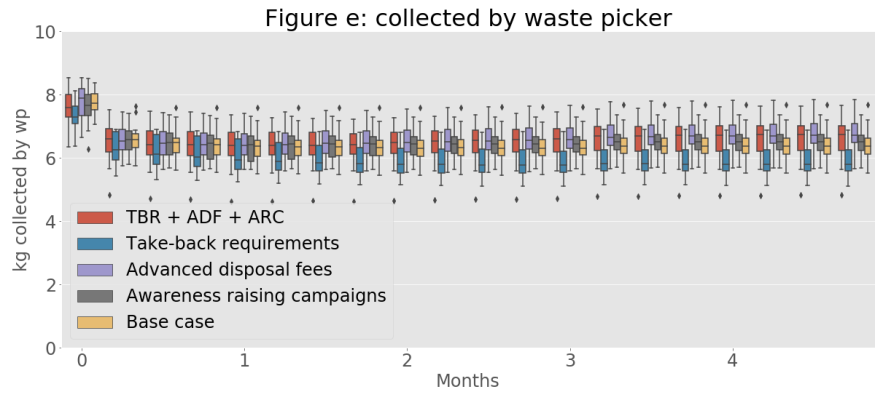
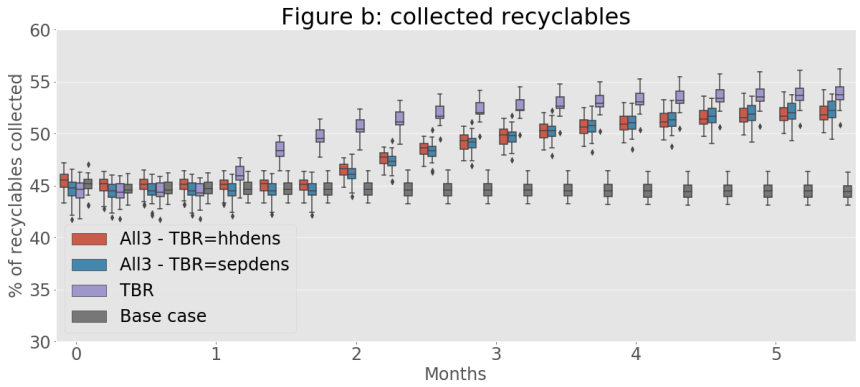


Figure I.21 - Boxplots of all three interventions, compared with the individual interventions

In the graphs below, the interventions are implemented in order of arc, tbr, adf and compared based on the location strategy of the take-back requirements (Figure I.22).



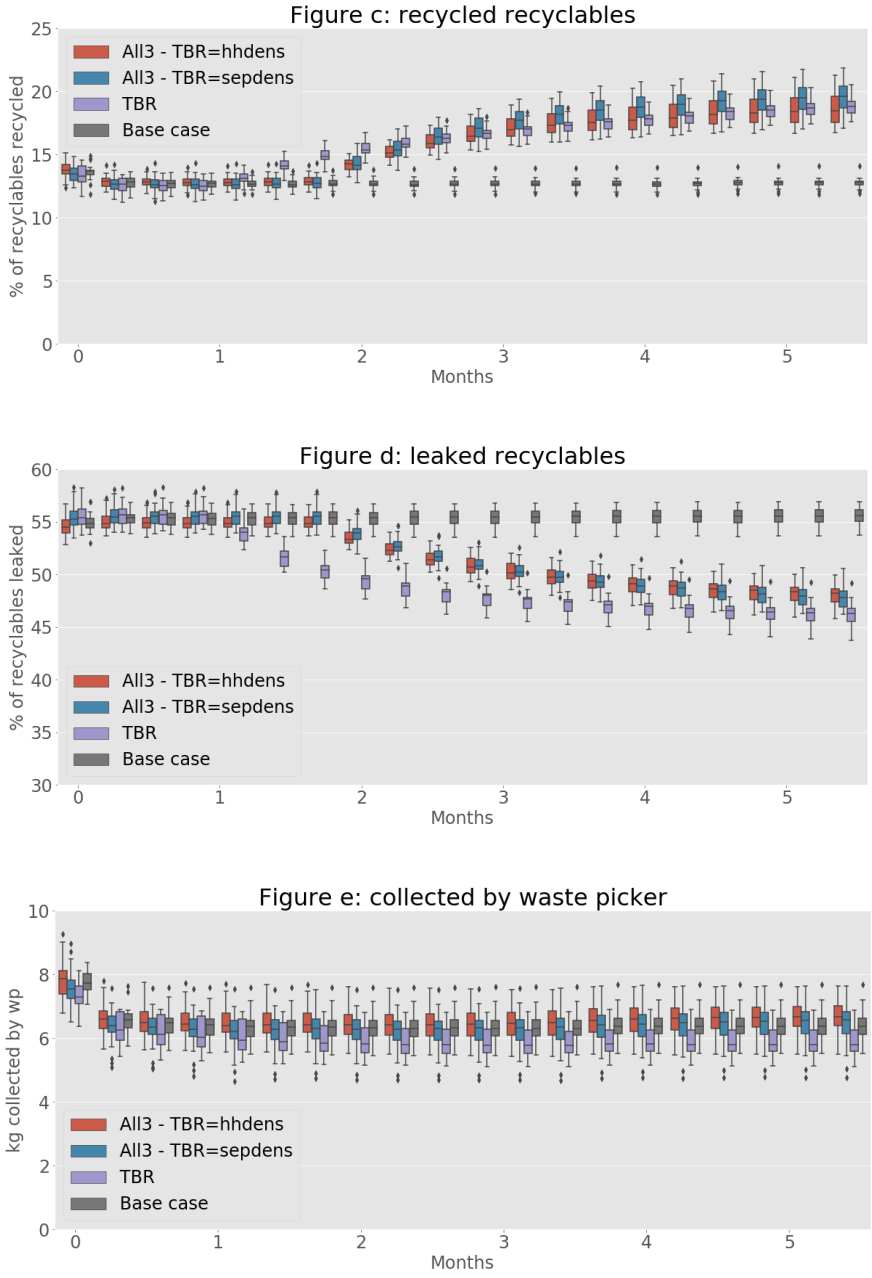


Figure I.22 - Boxplots of combined interventions, comparing tbr-location strategies with individual take-back requirements

Appendix J - Model validation

Three types of validation have been done on the model; see section 8.3. Here, the sensitivity analysis is explained here in more detail, and the slides of the validation interview have been attached.

J1 – Sensitivity analysis

To evaluate the values for chosen model parameters, a sensitivity analysis is done. In the sensitivity analysis, the values of the parameters in the base case are varied, and the outcomes are evaluated to determine the robustness of the model. As the variability of the initial number of agents is already shown in the calibration, this sensitivity analysis focuses on the behavior thresholds. The parameters that are varied are shown in Table J.5.

Research found that the category distribution of Rogers' innovation levels (Rogers, 1995) was different than he found when looking at knowledge and application of green building guidelines (Mollaoglu & Syal, 2015). Even though the diffusion of innovations has been researched previously in Indonesia with a similar distribution of Rogers (Chaudhuri, 1994), this could be outdated. Since in the agent-based model, the innovation level determines the motivation of households to separate a lot, the category distribution of Mollaoglu & Syal (2015) will be used to compare the results with.

The capability threshold has been set at 72%, as World Bank Group (2016) found that this percentage of Indonesian urban areas is considered non-poor. However, this cannot directly be translated into the "capability" of households to separate waste, as there can also be other factors than financial means contribute to the capability, such as knowledge.

Thirdly, the behavior of households to separate their waste is affected by the motivation of households. The three parameters that increase and decrease the motivation of households can be varied to analyze the effects.

Table J.5 - Experimental design of sensitivity analysis

Parameter	Parameter space	Replications
innovation-level division Innovators; early adopters; early majority; late majority; laggards	**2.5; 13.5; 34; 34; 16 %** 22; 25; 28; 19; 6 %	30
Capability threshold	62% - **72%** - 82%	30
Motivation-decrease-personal-experience	0.10 – **0.20** – 0.30	30
Motivation-decrease-social-influence	0.05 – **0.10** – 0.15	30
Motivation-increase-social-influence	0.05 – **0.10** – 0.15	30

All parameters do not influence the KPIs in the base case but only influence the household separation percentage.

The results show that the distribution level of Mollaogly & Syal (2015), with many more innovators and early adopters, more than double the household-separating percentage. This variable is thus quite sensitive to change (Figure J.23).

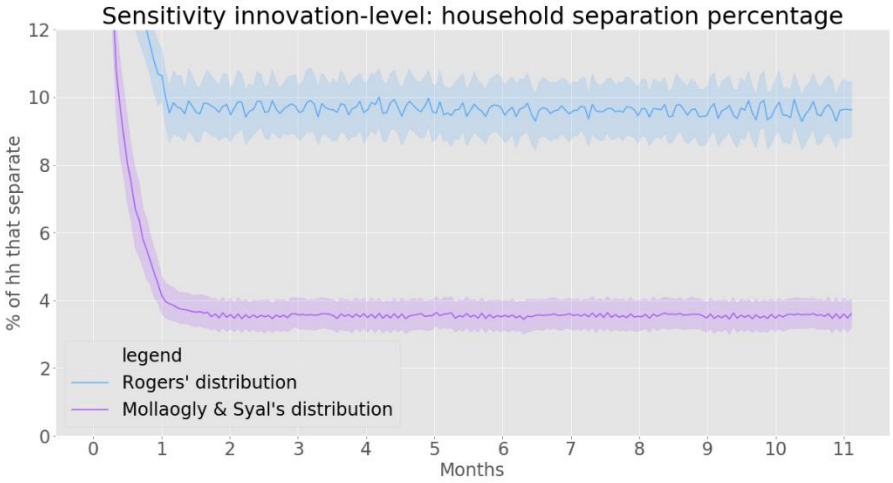


Figure J.23 - Line plot of sensitivity analysis of the innovation level distribution

The results show that a change in capability threshold does not show a clear effect on the percentage of households that separate in the base case (Figure J.24).

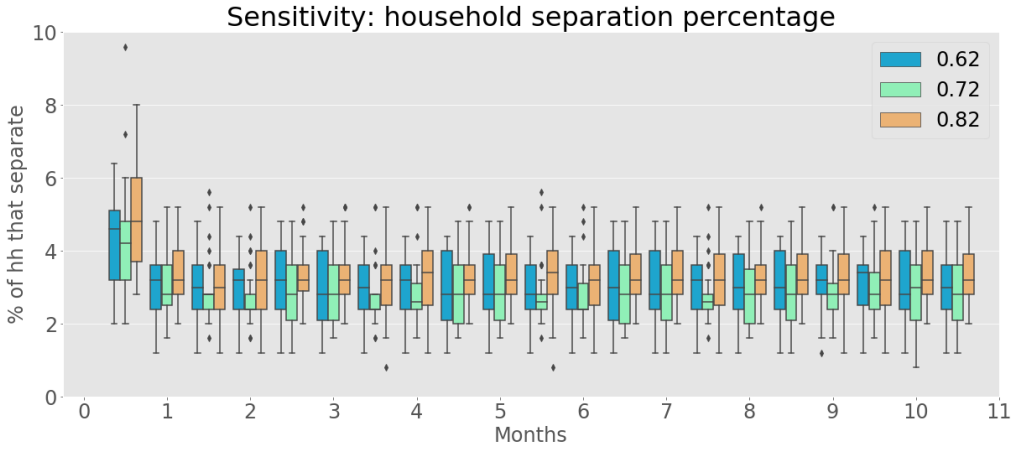
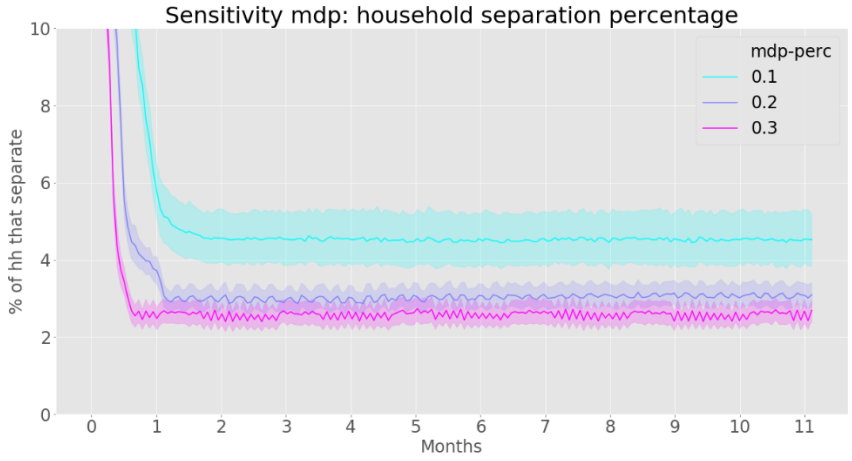
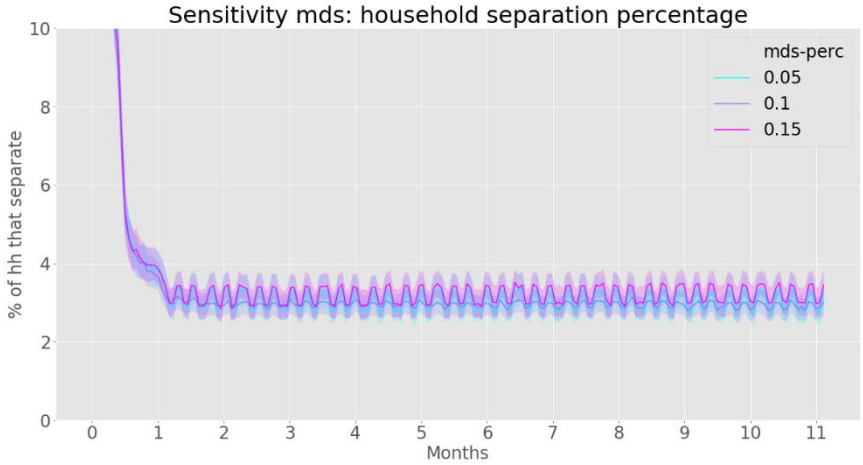


Figure J.24 - Boxplot of sensitivity analysis of the capability threshold

The results on the motivation parameters, show that the parameter `motivation-decrease-personal-experience` is quire sensitive to changes. The `motivation-decrease-social-influence` is not so sensitive to changes and `motivation-increase-social-influence` is somewhat sensitive to changes (see Figure J.25 below).





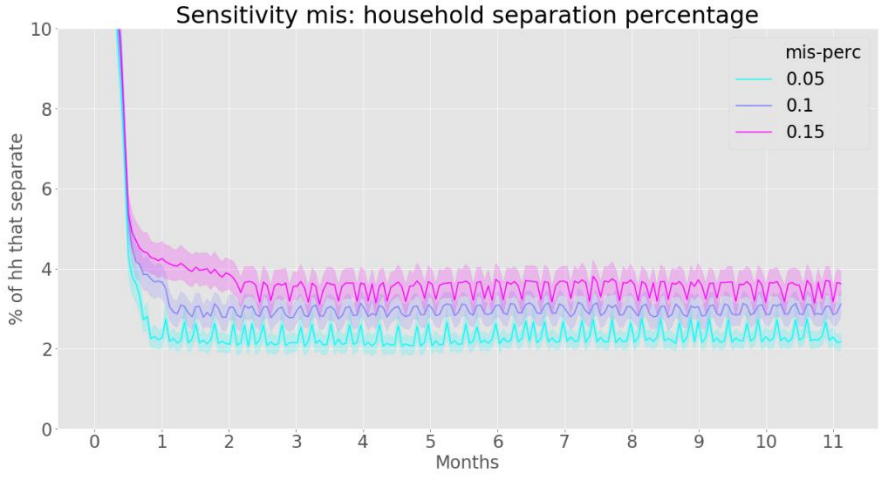
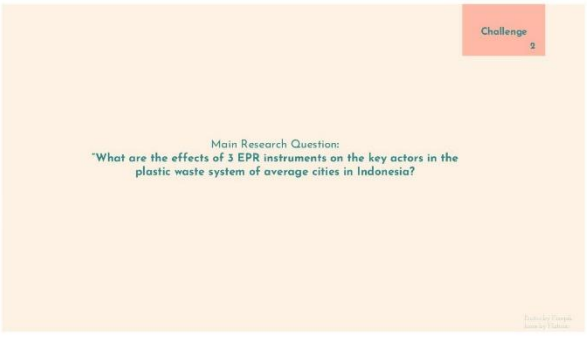
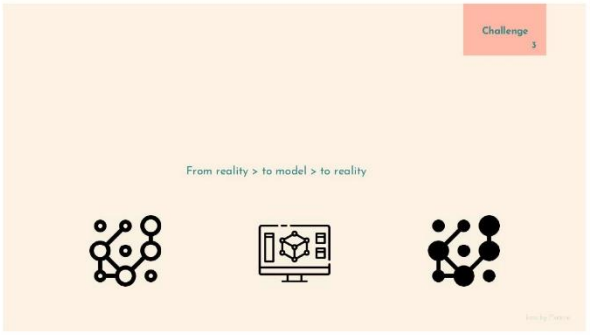
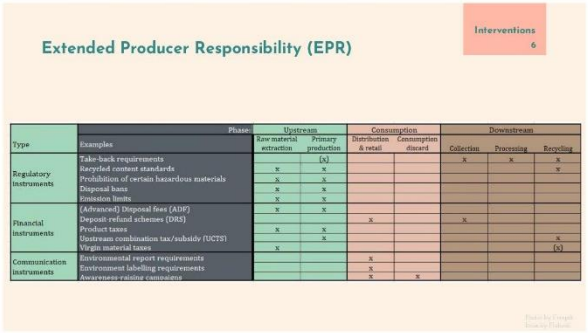


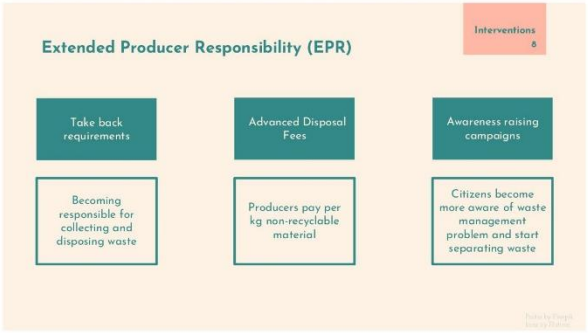
Figure J.25 - Line plot of sensitivity analysis of motivation parameters

J2 – Validation interview slides









Extended Producer Responsibility (EPR)

Interventions 9

Take back requirements

- More collection vehicles
- More recycle capacity?

Extended Producer Responsibility (EPR)

Interventions 10

Advanced Disposal Fees

- More recyclables in waste stream
- More informal collection?

Extended Producer Responsibility (EPR)

Interventions 11

Awareness raising campaigns

- More source separation
- Produce less waste?

Results

Intervention 1

Collection rate total waste

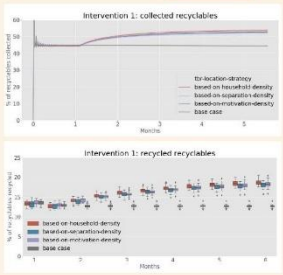
Collection rate recyclables

Recycle ratio

Leaked recyclables

Waste picker's collection

Results



Results

Intervention 2

Collection rate total waste

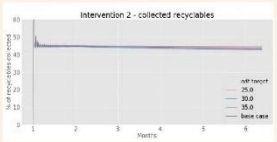
Collection rate recyclables

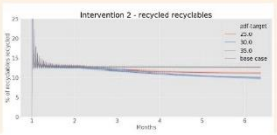
Recycle ratio

Leaked recyclables

Waste picker's collection

Results





Results

Intervention 3

Collection rate total waste

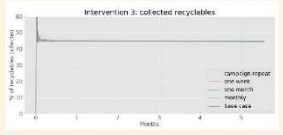
Collection rate recyclables

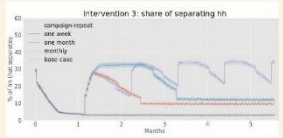
Recycle ratio

Leaked recyclables

Waste picker's collection

Results





TU Delft · Universiteit Leiden · ABBEL

Tackling plastic waste in Indonesia

How Extended Producer Responsibility can decrease plastic waste leakage