ENHANCING TEXTILE REUSE IN THE NETHERLANDS

An agent-based modelling study towards reuse rebound effects and value changes in the textile industry

Britt Ingeborg Zandbergen
4442547
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ENHANCING TEXTILE REUSE IN THE NETHERLANDS

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Britt Ingeborg Zandbergen
Student number: 4442547
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First supervisor:	Dr. ir. Jaco Quist
Chair & second supervisor:	Prof. dr. Martijn Warnier
External supervisors:	Nicolein Blanksma (Rebel)
	Wouter de Waart (Rebel)

TU Delft

PREFACE

Here it is, my thesis on enhancing textile reuse in the Netherlands. With this I conclude my Master's degree in Complex Systems Engineering and Management and my time at Delft University of Technology. During this period, I have learned a lot and really enjoyed all the projects that combined technological and societal challenges. At the interface between these two disciplines especially sustainability sparked my interest. This thesis brings these three topics together and makes an effort to move towards a more sustainable future.

Without the help of a lot of amazing people, this research could not have been realized. First of all, the interviewees that took the time to participate in this research. Thank you for your knowledge, enthusiasm, and important insights that guided me in the right direction. Second, all the Rebel colleagues who made me feel part of their team from day one. Thank you, for a helping hand when needed, the fun activities and your rebellious ideas.

Furthermore, I would like to thank my supervisors for their guidance during these past months. Jaco, your sharpness and knowledge about circular economy transitions and rebound ensured that the research became more thorough. Also, I would really like to thank you for your trust and encouraging words during our meetings. These made me believe more in myself. Martijn, your willingness to help and think along during this thesis was extraordinary. Even with your busy schedule, you were always eager to plan a meeting and think along. You provided me with new insights, while simultaneously challenging me to make my own decisions as a researcher. Nicolein, you have the talent to ask the appropriate analytical questions that were needed to keep the research on the right track. Thank you for your keen insights and encouraging words over the past few months. Wouter, from the start your enthusiasm was contagious. You were the one that really saw the practical relevance of this subject and wanted to guide it to the highest possible level. I have learned a lot from your ability to see a challenge from a modeling perspective and from our in-depth sparring sessions. Thank you!

Then to my parents and sister for standing by my side and being supportive of (almost) all the choices I made. To my friends, thank you for all the cozy dinners, beers on the terrace and entertaining distractions when I needed it. On a more substantive note, special thanks to my dad, Ires, Anouk and Julian who have contributed through proofreading or helping me with modeling.

This also marks the end of my life as a student. I am very grateful for everything I have learned and experienced within my studies, but especially beyond. I am curious and excited about what the future holds, but above all I look back on the past years with fond memories!

Britt Zandbergen
Rotterdam, June 2022

EXECUTIVE SUMMARY

Problem situation

In the past few decades the level of textile production and consumption has steadily increased. As the textile industry has the fourth largest impact on the environment and climate change, this growth is alarming. By prolonging the use period and therefore reducing the use of virgin materials, textile reuse is seen as one of the solutions to overcome this challenge.

In the coming years, the Dutch government aims for a strong growth in textile reuse. To achieve the government goals, behavioural change is necessary. However, it is currently unknown which changes in consumer values that determine textile reuse consumption are most effective. In addition, prior research has shown that reusing textiles carries the risk of not replacing primary production or slowing consumption cycles, as assumed. So-called rebound effects appear: increases in textile consumption efficiency are offset by increased levels of textile consumption. Most scholars, industry experts and policy makers do not account for these rebound effects, thereby overestimating the environmental benefits of reuse. Previous literature indicates that there is a lack of knowledge about the underlying assumptions and the causes behind these rebound effects.

Research question

Based on data from previous literature and nine semi-structured interviews, an agent-based model has been developed. This enables the effects of reuse and corresponding rebound effects to be quantitatively investigated. Subsequently, the model has been used to assess the effectiveness of value changes to enhance textile reuse. Enhanced textile reuse occurs if these value changes lead to an extended textile lifespan, increased number of textile wears and a decrease in the number of newly purchased textile items. The aim of this research is to provide in-depth understanding of textile reuse rebound effects and model-based advice on effectiveness of consumer value changes that reduce environmental impact, while accounting for consumer heterogeneity. This leads to the following research question:

Which consumer value changes are necessary to enhance textile reuse in the Netherlands, given the influence of rebound effects?

Research approach

In order to build the agent-based model the processes and flows within the system are identified and quantified. This quantification shows that consumers obtain reused (13%) or new textile items (87%). These reused textile items can be formally (66%) or informally (34%) reused. Formal reuse occurs if the reused textiles are obtained via a third party, informal reuse if this occurs from consumer to consumer.

To allow for consumer heterogeneity, four consumer segments and five consumer values are incorporated. The included consumer segments are: budget minimalist, casual minimalist, budget shopper and premium shopper. The values of price, environment and convenience are drivers and the values of ownership and convenience are barriers to purchase reused textiles. These consumer values are quantified for each consumer segment and result in a reuse percentage. This reuse percentage in- or decreases based upon the level of reuse percentage of the friends of the consumer.

Rebound effects are incorporated in the model in two ways. First, by means of the substitution effect. Reused textiles are insufficient substitutes for new textiles because they are of inferior quality. Therefore, the lifetime of the textile item in possession of an owner, decreases every time the item is reused. Second, by means of the income effect. Cost savings due to low-priced reused textiles are re-invested in more textile items. Therefore, the replacement rate is introduced, which determines whether the purchase of a reused textile item leads to the purchase of an additional item. The replacement rate depends upon the consumer segment, value of price and value of environment of the consumer.

Results

The results show that even though rebound effects occur textile reuse still leads to a decrease in the consumption of new textile items, thereby reducing virgin input and its impact on the environment. In addition, reuse leads to an increase in the lifespan of textile items and the number of times a textile item is worn. Lastly, textile reuse also leads to an increase in the number of owners of a textile item. This is important, because transferring a textile item from one consumer to another often requires additional activities with an environmental impact.

When textile items are reused, rebound effects occur. It is important to incorporate these rebound effects to safeguard the environmental and market integrity of the textile industry. Not incorporating rebound leads to an overestimation of:

1. The amount of textile items in possession by consumers in the Netherlands
2. The increase in lifetime and number of wears of textile items due to reuse
3. The decrease of new consumed textile items due to reuse.

The first two effects are apparent on a with the current level of reuse. The third effect only becomes apparent with higher levels of reuse in the future.

Additionally, the results show that an increase in the values of price and environment and a decrease in the value of convenience lead to enhanced textile reuse. The order of effectiveness of these value changes is in general price, convenience and environment. However, the effectiveness of these changes differs per consumer segment. When a change in the value of environment only applies to consumers who already perceive the environment as important, the increase in textile reuse due to the value change becomes less. This is not the case for the values of price and convenience.

Recommendations

Based on provided insights, recommendations can be made for industry experts, environmental impact modellers and policy makers. For industry experts it is important to realize that textile reuse always has to be considered in light of other circular economy strategies. In addition, rebound effects appear and should therefore be taken into account. Environmental impact modellers can incorporate these rebound effects, using a replacement rate and lifetime factor. Policy makers should primarily enhance textile reuse through price and convenience interventions. However, specific attention is needed to perverse incentives that limit the effectiveness of these interventions.

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1 INTRODUCTION

In the past few decades, the high rate of population growth, improved global income, and enhanced living standards have resulted in a steadily increasing level of textile production and consumption (Shirvanimoghaddam, Motamed, Ramakrishna, & Naebe, 2020). According to Ellen Mac Arthur Foundation (2017) the production of clothing has doubled globally in the last 15 years and the average number of times clothing is worn has decreased by 36%. From an environmental perspective, this growth is worrying because currently almost 6-10% of global greenhouse gas emissions originate from the textile industry (Niinimaki, 2018; Quantis, 2018). The European consumption of textiles has the fourth highest impact on the environment and climate change, after food, housing and mobility (European Commission, 2022).

By prolonging the use period and therefore reducing the use of virgin materials, textile reuse is seen as an important solution to overcome these challenges (Ekström & Salomonson, 2014). To reach a circular textile chain in 2050, the Dutch government aims for strong growth in textile reuse in the coming years (Rijksoverheid, 2021). Consumers have an indispensable role to play in this transition (Inretail, Modint, & VGT, 2019). Based upon values, acting as drivers and barriers, consumers decide whether they consume reused textiles or not (Silva, Santos, Duarte, Zidar, & Ci, 2021). Although behavioural change regarding these values is certainly needed it is still unknown which value changes are most effective to reach the government's goals.

In addition, recent studies indicate that reusing textiles carries the risk of not replacing primary production or slowing consumption cycles as assumed (Levanen, Uusitalo, Harri, Kareinen, & Linnanen, 2021). Circular economy rebound effects may occur, meaning that reuse activities, that lower impacts on textile consumption, also cause higher levels of consumption, reducing their benefit (Zink & Geyer, 2017). These effects evolve due to the complex reaction mechanisms of human behaviour (Siderius & Poldner, 2021). Different consumers make individual textile reuse choices, leading to unexpected outcomes at the system level (Levanen et al., 2021).

Most scholars, industry experts and policy makers do not account for these rebound effects, thus overestimating the environmental benefits of textile reuse (Sandin & Peters, 2018). Therefore, it is necessary to gain insight into the underlying assumptions and the causes behind these effects (Font Vivanco, McDowall, Freire-González, Kemp, & van der Voet, 2016; Levanen et al., 2021; Siderius & Poldner, 2021). This will provide knowledge about the reduction of new textile consumption, and thus virgin materials, due to reuse. Comprehensive understanding might ensure better use of the real environmental impact of textile reuse by businesses and policy makers. This means an increase in the truthfulness of environmental modelling studies for businesses and increased effectiveness of textile reuse

policies for policy makers. The geographical focus of this research is on the Netherlands, but the findings are informative for all developed countries around the world.

In this research, a bottom-up agent-based modeling (ABM) approach is used. This approach is chosen for four main reasons. Firstly, the literature argues that quantitative models are needed to study rebound effects in a real-world context (Siderius & Poldner, 2021). Font Vivanco et al. (2016) states that for this purpose ABM is an appropriate tool. Secondly, ABM is highly suitable for modeling complex adaptive socio-technical systems (van Dam, Nikolic, & Lukszo, 2013). The Dutch textile reuse industry can be seen as such a system. Different consumers have interactions with each other and perform their (reused) textile purchase behaviour. These interactions result in rebound effects, leading to unpredictable emerging patterns on the overall functioning of the system (Lüdeke-Freund, Gold, & Bocken, 2018). Thirdly, an agent-based model is capable of simulating individual agent behaviour and identifying emerging patterns of behaviour (Brannon, Thommesen, & Marshall, 2003). Lastly, agent-based models are suitable to test consumer value changes.

On the basis of insights from nine semi-structured interviews and data from previous literature, an agent-based simulation model has been established. Within this model, the consumption of new and reused textiles is predicted, based upon different consumer values. In addition, rebound mechanisms are incorporated. This enables the effects of reuse and corresponding rebound effects to be quantitatively investigated. Subsequently, the model simulates the effect of consumer value changes to enhance textile reuse. Enhancing textile reuse means that reuse leads to an extended lifespan, increased number of wears and a decrease in the number of newly purchased textile items. This creates in-depth understanding of textile reuse rebound effects and model-based advice on the effectiveness of consumer value changes that reduce environmental impact, while accounting for consumer heterogeneity. This leads to the following research question:

Which consumer value changes are necessary to enhance textile reuse in the Netherlands, given the influence of rebound effects?

This research has been conducted on the basis for a master degree in Complex Systems Engineering and Management (CoSEM). In addition, the research is carried out in cooperation with the consultancy company Rebel. For both CoSEM and Rebel this thesis is relevant. CoSEM focuses on a system design in a complex adaptive socio-technical system. As described, the Dutch textile reuse industry can be seen to be such a system. The research investigates the effectiveness of enhanced reuse, to reduce rebound and improve the environmental impact of the industry. By doing so, the research touches upon technological, social and institutional components. For Rebel, this research is relevant because the insights can be used for analysis and modeling purposes, as well as advice on textile reuse system changes to governments and businesses.

The structure of the remainder of this thesis is as follows. A state-of-the-art literature review on the topic is provided in chapter 2. Based on the research question, the research design including sub-questions is discussed in chapter 3. Chapter 4 entails the system identification, including an actor analysis and quantification of the textile reuse system. Chapter 5 and 6 provide a conceptualisation of the consumer behaviour and the modelled system. In chapter 7 the implementation of the model is discussed. Followed by the experimental setup in chapter 8 and the model results in chapter 9. Lastly, a discussion of the results, conclusions and recommendations can be found in chapters 10 and 11.

2 LITERATURE REVIEW

This chapter provides an extensive literature review, discussing important research topics and their relations. First, the life cycle of textiles and the possibilities for reuse within these stages are explained. Second, all reuse options are elaborated on in more depth. Third, rebound effects that might occur while reusing textiles are described. Fourth, replacement rates that partly assess the rebound effects are presented. Fifth, the Theory of Planned behaviour is discussed, allowing to explain and predict behaviour regarding textile reuse. Sixth, previous studies using simulation modeling in a textile reuse context are elaborated upon. Lastly, the literature review results in three knowledge gaps.

2.1 LITERATURE SELECTION PROCESS

Table 2.1: Literature selection process

Research topic	Search term	Found Scopus	Found Scholar
2.2 Life cycle of textiles	”supply chain” AND ”life cycle” AND (textile OR clothing OR apparel OR fashion OR garment) AND sustainability AND environmental	39	-
2.3 Textile reuse options	”second-hand” AND (textile OR clothing OR apparel OR fashion OR garment) AND ”circular economy”	15	-
	post-consumer AND (textile OR clothing OR apparel OR fashion OR garment) AND reuse	29	-
2.4 Rebound effects	reuse AND (textile OR clothing OR apparel OR fashion OR garment) AND ”circular economy” AND environmental AND effects	10	-
	(textile OR clothing OR apparel OR fashion OR garment) AND ”rebound effect”	23	-
2.5 Replacement rates	(textile OR clothing OR apparel OR fashion OR garment) AND ”replacement rate”	11	-
2.6 Consumer behaviour	”consumer behaviour” OR ”consumer segment” AND (textile OR fashion OR apparel OR garment OR clothing) AND reuse OR second-hand	27	-
	”theory of planned” AND behavior OR behaviour AND (textile OR fashion OR apparel OR garment OR clothing) AND reuse OR second-hand	4	-
2.7 Simulation modelling and textile reuse	”agent based modelling” OR abm OR ”agent based model” OR “system dynamics” AND (textile OR clothing OR apparel OR fashion OR garment) AND (”Circular Economy” OR reuse)	0	349
	”agent based modelling” OR abm OR ”agent based model” AND (textile OR clothing OR apparel OR fashion OR garment) AND consumer	7	-
	”agent based modelling” OR abm OR ”agent based model” AND post-consumer OR disposal AND reuse OR recycling	9	-

During the literature selection process the main search engine used was Scopus. Only when no papers could be found within Scopus, Google Scholar has been consulted. All articles have been sorted by relevance, after which the most important papers have been selected. Furthermore, backward and forward snowballing resulted in to be reviewed papers. Table 2.1 presents the used search terms, amounts of results per database and the papers selected. Exclusion criteria during the search process where: 1) papers with a one sided focus (e.g.

manufacturer), 2) reuse of specific materials, 3) consumer behaviour fully absent 4) one specific, not-generalizable research area 5) focus on only one reuse type (e.g., donation) 5) environmental or circular economy relation absent.

2.2 CORE CONCEPTS

Circular economy and reuse
According to Lüdeke-Freund, Gold, & Bocken (2018, p.3), the Circular Economy is "a regenerative system in which resource inputs and outputs such as waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops." By changing the current economy model from "linear" to "circular", excess waste generation is prevented and the full value of products can be gained (Shirvanimoghaddam et al., 2020). One of the main strategies to implement the circular economy, prominent in the textile industry itself and in the related literature, is reuse (Allwood, Ashby, Gutowski, & Worrell, 2011). Especially from a consumer point of view, this is one of the main fundamentals of the circular economy (Shirvanimoghaddam et al., 2020). In this research reuse is defined as the use of the original product function (e.g. clothing reused as apparel to cover the body) (Morley, Slater, Russel, Tipper, & Ward, 2006).

Textiles in the Netherlands
The textile industry is characterized by the economic activity whose objective is the production, design and sale of fibers, yarns, fabrics, clothing, and textile goods (Bullón Pérez et al., 2017). Since the 1980s, the worldwide industry has experienced tremendous growth, enabled by improved integration of supply chains and shorter lead times, providing a high turnover of cheap textiles (Norris, 2019). Almost all textile items are produced outside the Netherlands. This research focuses on 1) clothing and 2) home textiles (also known as, bed bath and kitchen textiles (BBK)) that are sold, used, and disposed of in the Netherlands. A detailed description of the textile reuse system in the Netherlands, including an elaborate stakeholder analysis, is presented in chapter 4

Post-consumer textiles
Post-consumer textiles referred to in this research are all textile items that do not remain in the possession of the original owner, regardless of the end destination (Laitala & Klepp, 2015). Three decades ago, all textile waste products ended up into incineration plants or landfill (Shirvanimoghaddam et al., 2020). Nowadays, circular strategies such as recycling and reuse are solutions to restore resources and use products to their highest value (Leonas, 2017). Thereby, enabling functionality of the product and materials in the post-consumer stage.

2.3 LIFE CYCLE OF TEXTILES

According to Luján-Ornelas et al. (2020) the life cycle of textile items can be divided into six life cycle stages: 1) fibre and textile production, 2) design, 3) clothing production, 4) retail, 5) use, and 6) disposal. Reuse can occur between and within the last three stages (see figure 2.1).

Fibre and textile production
The life cycle of all textile products begins by obtaining fibres, whether natural or synthetic

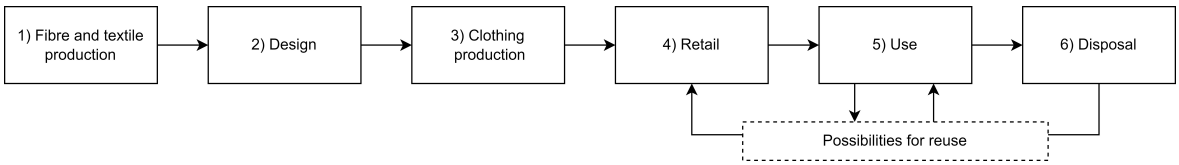

Figure 2.1: Life cycle stages for textile products (adapted from (Luján-Ornelas et al., 2020))

(Lund, van der Velden, Persson, Hamedi, & Müller, 2018). These fibres are known to cause negative environmental effects. Large amounts of water and pesticides are used to obtain natural fibres and large amounts of fossil resources for the derivation of synthetic fibres (Sandin, Roos, & Johansson, 2019). The subsequent process is the spinning of yarn, after which fabric manufacturing is carried out, by weaving, knitting, dyeing, finishing, washing, and drying (Lund et al., 2018). These processes have a considerable environmental impact due to their intensive consumption of electricity (Luján-Ornelas et al., 2020).

Design

At this stage, the designer decides what the textiles and garment products will look like. Luján-Ornelas et al. (2020) argue that designers play an essential role in the transition to a circular and sustainable textile industry. They influence the use and origin of resources, the duration, and the final disposable strategies of the textile products (Luján-Ornelas et al., 2020). The design of clothes with maximum durability and longevity is essential to enable reuse and the transition to a circular industry.

Clothing production

Once the fabric is ready, the cutting and sewing starts to produce the clothing or textile product (Lenzo, Traverso, Salomone, & Ioppolo, 2017). 69% of the clothing production companies are located in Asia, followed by 29% in Europe and 2% in Africa. Because the Netherlands does not produce its own textiles, all items used in the Netherlands are imported.

Retail

When the clothing and textile items have been produced, they are transported, exported, and distributed to first-hand retailers in the Netherlands (Luján-Ornelas et al., 2020). The Dutch retail sector consists of 'first-hand retail' and 'resale retail', selling respectively new and reused textile items. The 'resale retail' market consists of second-hand shops, vintage shops, swap shops, online platforms, and flea markets (see also section 2.4). Second-hand shops exist for a long time in the Netherlands but the 'resale retail' market is increasing. Since 2010, the market has grown by 7% resulting in 2541 resale shops, including online.

Use

At this stage, the consumer makes use of the textile product. A large part of the environmental impact in the products' use phase is caused by the water and electricity consumption during the washing, drying and ironing cycles (Busi, Maranghi, Corsi, & Basosi, 2016). Worldwide clothing use - the average number of times a garment is worn before it ceases to be used - has decreased by 36% compared to 15 years ago (Ellen Mac Arthur Foundation, 2017). Reuse is one of the strategies to increase textile utilisation.

Disposal

Consumers dictate the lifespan of their clothing by determining the point at which a textile

item is no longer desired (Laitala & Klepp, 2011). Textile products are often disposed of long before they lose their functionality (Keßler, Matlin, & Kümmerer, 2021). Consistent with other studies, Degenstein, McQueen, and Krogman (2021) found that physical damage is the biggest motivation for clothing disposal. Followed by inadequate size, changes in taste, lack of space and changes in style and fashion (Domina & Koch, 2002).

2.4 TEXTILE REUSE OPTIONS

As shown in figure 2.1 reuse occurs within the retail, use and disposal life cycle stages of textiles. Reuse is characterized by two main processes. Firstly, the disposal of textile items, because the disposal options determine if a textile item is reused, recycled or incinerated. Secondly, obtaining reused textiles via informal or formal exchange.

2.4.1 Textile disposal

Post-consumer textile disposal can be divided into: discarding, donating / giving, and trading (Kwon, Choo, & Kim, 2020; Wai Yee, Hassan, & Ramayah, 2016). Figure 2.2 shows the disposal options for consumer textiles in the Netherlands, based on previous studies (Bukhari, Carrasco-Gallego, & Ponce-Cueto, 2018; Fortuna & Diyamandoglu, 2017; Keßler et al., 2021). From a circular perspective, the order of preference for waste prevention is; direct reuse; recycling; incineration and eventually landfilling (European Commission, 2018; Laitala & Klepp, 2011). .

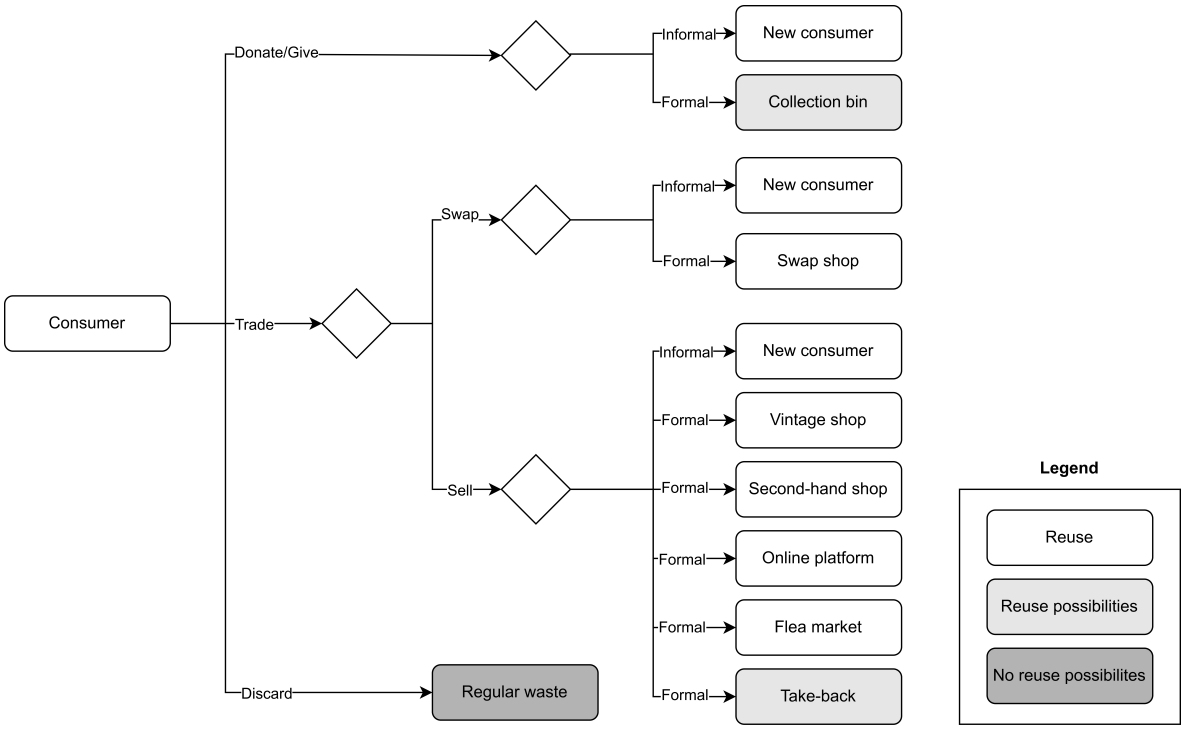

Figure 2.2: Textile disposal options in the Netherlands

Donate and give
When clothing is disposed of for non-monetary reasons, this can occur in a formal or informal manner (Laitala & Klepp, 2017). Formal by donating textiles to charities via collection bins and informal by giving them away to family and friends.

In the Netherlands, people are encouraged to collect clothes they do not wear any longer and to bring them to collection bins (Siderius & Poldner, 2021). These bins are operated by commercial (e.g., Curitas, Sympany) or non-commercial (e.g., Salvation Army) companies. In general, consumers donate items they consider no longer fashionable, gently worn, too small, or no longer desired (Stall-Meadows & Goudeau, 2012). There is, however, a discrepancy in how consumers perceive clothes that are acceptable for collection bins and those they believe are more suitable for regular waste (Laitala & Klepp, 2011). Ha-Brookshire and Hodges (2009) found that consumers were unlikely to donate clothing that they would not wear themselves, reinforcing the idea that consumers have difficulty differentiating between clothing suitable for resale and those suitable for donation.

Trade
Clothing disposal for pecuniary reasons also occurs in a formal or informal manner (Laitala & Klepp, 2017), via selling or swapping (Shirvanimoghaddam et al., 2020). Via informal channels, swapping and selling takes place directly from person to person (Fortuna & Diyamandoglu, 2017). Via formal channels, swapping and selling practices occur via swap shops, second-hand shops, online platforms, flea markets and take-back schemes (Dos Santos & Campos, 2021). Take-back schemes are initiatives where customers donate their unwanted clothing to retailers to be reused or recycled (e.g. H&M). According to (Degenstein et al., 2020) swapping and take-back schemes are less popular disposal options. Probably these options are unavailable, unknown, or inconvenient to consumers (Degenstein et al., 2021). Fashion-sensitive consumers are more likely to choose alternative disposal methods such as reselling or swapping (Weber, Lynes, & Young, 2017).

2.4.2 Obtaining reused textiles

The previous section described the textile disposal options in the Netherlands. Reuse occurs if a new consumer obtains a textile item that is previously disposed of by another consumer. This can occur in an informal or formal manner.

Informal
Informal reuse occurs in a variety of forms. People give away items to friends, family or other acquaintances, participate in swapping parties, inherit clothing, donate clothing via social media and so on (Cruz-Cárdenas, González, & Gascó, 2016). Laitala and Klepp (2017) argue that the informal market is unjustly unexposed and perceived as unimportant. They studied the informal clothing market in Norway and found that the scope of informal exchange exceeds the formal market, indicating the importance and size of the informal market.

Formal
Formal reused textiles are obtained via a third party; second-hand shops, vintage shops, swap shops, flea markets and online platforms. Second-hand shops have been around for years and the number of stores is still growing (Hekkert, Reike, Rainville, & Negro, 2021). These shops are commercial (e.g. het Goed) or non-commercial (e.g. Leger des Heils) and often fulfill a social function. These are, for example, reintegration programs and clothing collections for low-income people (Kort, Vink, & De Waart, 2021). In addition to obtained textile items from customers, second-hand stores sell a small amount of textiles previously disposed of in collection bins (Hopstaken, van der Schalk, van der Maesen, & Custers, 2020). Officially, vintage shops distinguish themselves from second-hand shops by selling

clothing produced before 1990 (Kort, van der Vusse, & van Grootel, 2020). In practice, this difference is less visible and the two definitions are often used interchangeably. Swap shops (e.g, The Swapshop) and flea markets (e.g. Ijhallen) cover a small part of the market.

For several years, there has been a continued growth of online platforms where consumers act as sellers and customers (e.g., Vinted, The Next Closet, Sharedrobes, Poshmark, Marktplaats, Ebay) (Hekkert et al., 2021). These platforms have caused a huge increase in second-hand textiles but are often not yet profitable due to high investments in marketing campaigns (Hekkert et al., 2021). Additionally, some existing business-to-consumer platforms also sell reused items (e.g., Zalando, Nak-d).

2.5 REBOUND EFFECTS

Recent studies showed that reusing textiles carries the risk of not replacing primary production or of slowing consumption cycles as assumed (Levanen et al., 2021). Extended use does not automatically mean that the user's collection of clothes remains the same, nor does reselling automatically lead to increased use time. If many people buy second-hand garments because they are cheap, primary production may not be affected (Levanen et al., 2021; Siderius & Poldner, 2021). These are so-called rebound effects: increases in consumption efficiency are offset by increased levels of consumption (Zink & Geyer, 2017).

This section will elaborate upon these rebound effects. The background of rebound effects, from energy economics will be discussed. Followed by an explanation of circular economy rebound. Lastly, the rebound effects that might occur because of textile reuse are investigated.

2.5.1 Energy efficiency rebound

Rebound effects descends from the more thoroughly researched "energy efficiency rebound" (Font Vivanco et al., 2016). In energy efficiency literature, the rebound effect denotes the mechanism where increased efficiency makes consumption of some goods (e.g., energy or transportation) relatively cheaper, increasing the consumption of the good. This leads to a decrease in the environmental benefit of the increased efficiency and may even lead to "backfire", where the increase in use is proportionally larger than the efficiency increase, leading to higher net environmental impacts (Font Vivanco et al., 2016; Zink & Geyer, 2017).

According to Greening, Greene, and Difiglio (2000) rebound effects can be characterized in five main ways 1) the substitution effect, 2) the income effect 3) secondary effects, 4) economy-wide effects and 5) transformational effects. The first two effects, sometimes also referred to as direct rebound effects, are micro effects that occur on the level of a single consumer. The last three effects are macro effects that result from the interaction between different actors (e.g., producers and consumers) within the economy.

2.5.2 Circular economy rebound

Also within the circular economy rebound effects might occur (Hertwich, 2005). However, the mechanisms of circular economy rebound are slightly different from those of

the energy efficiency rebound (Hertwich, 2005). The circular economy rebound can allegedly manifest itself in two main ways. The first has to do with insufficient substitution (micro-economic), the second with the effect of secondary goods on prices (micro- and macro-economic) (Font Vivanco et al., 2016; Zink & Geyer, 2017).

Rebound attributed to insufficient substitution
Secondary goods, such as reused or recycled products, may be insufficient substitutes for primary goods. Because the products or fibers are previously used the products might be of inferior quality or are otherwise less desirable to users (Zink & Geyer, 2017). For example, recycled plastics rarely compete directly with primary materials due to degradation of the quality and shortening of fiber lengths during, use, collection, and reprocessing (Allwood, 2014).

Rebound attributed to price effects
Next to the previously mentioned circular economy rebound effect. Rebound effects also happen when increased secondary production activity impacts prices (Zink & Geyer, 2017). In order to convince consumers to purchase the lower quality item, sellers offer them at a discount relative to the primary product (Zink & Geyer, 2017). The buyers are now comparatively wealthier (the income effect) and can purchase more products than they could before. From then on, it becomes important how consumers will spend the money saved (Hertwich, 2005). In literature, it is often assumed that the money saved is spent on different goods in the same proportion as the average expenditure. But, it is even better to assess the extra expenses based on the marginal expenditures of consumers within different income categories (Hertwich, 2005).

However, it is not necessary for the secondary good to be cheaper in order for it to impact prices and, therefore to lead to rebound. Because secondary goods compete in the same markets as primary goods, the supply of goods increases (Zink & Geyer, 2017). Economics suggests that as the supply of a good increases, both prices will decrease. Therefore, the demand for the primary and secondary good increases as consumers perceive themselves as comparatively wealthier (the income effect) (Zink & Geyer, 2017). The result is that an increase in circular economy activities may prevent some primary production, but it is likely to be lower than an 1:1 replacement (Zink & Geyer, 2017).

2.5.3 Reused textiles rebound

Zink and Geyer (2017) argue that the circular rebound attributed to 1) insufficient substitutability and 2) price effects occurs within all activities of the circular economy: recycling, reuse, repair and refurbishment. For reused textiles, this is not different. Because the focus of this research, is based upon consumer behaviour the micro-economic rebound effects related to textile reuse will be further discussed.

The substitution rebound effect occurs if reused textiles are insufficient substitutes for new textiles because they are of inferior quality or are otherwise less desirable to users (Zink & Geyer, 2017). Because reused textile items are already worn, they have, for example, a shorter use time due to degradation in the quality of the textile items. Or people just perceive reused textiles as less desirable, compared to new textile items.

The rebound effect due to price effects occurs in two main ways. Firstly, reused textiles are often priced lower than new textile items. Therefore, the demand for another good

or service might increase because consumers are now comparatively richer (the income effect) (Sorrell & Dimitropoulos, 2008). For example, cost savings due to low-priced reused textiles are re-invested in even more textile items (Sonnberger & Gross, 2018). Secondly, because of the supply of reused textiles, the total supply of textile items increases, leading to a decrease in the price of both new and reused textiles. Both effects, result in a reused textile item not replacing a new textile item one on one.

The textile industry shows a high vulnerability to rebound effects, as well as a great potential avoiding it. According to Ellen Mac Arthur Foundation (2017) there are three main reasons for this phenomenon: 1) the popularity of circular strategies to reduce environmental problems in the industry; 2) the insatiable demand for textile products; and 3) the high levels of substitution of reused textiles in relation to textile products from primary production.

Rebound effects are often omitted from life cycle analysis, and corporations benefit from this lack of disclosure by promoting thickened environmental achievements (Atherton, 2007; Chalmers, Brander, & Revoredo-Giha, 2015). Therefore, it is essential to recognize and account for rebound effects to protect both environmental and market integrity in the industry (Siderius & Poldner, 2021).

2.6 REPLACEMENT RATES

To assess rebound effects, a critical factor is the replacement rate; the degree to which the purchase of second-hand clothing and household textiles replaces the purchase of similar new items (Nørup, Pihl, Damgaard, & Scheutz, 2019b). The replacement rate is an essential factor in determining the overall benefits of reuse, as it indicates how often new clothes are substituted, i.e. production that could be avoided (Vadenbo, Hellweg, & Astrup, 2017). In other words, the higher the replacement rate, the more benefits to the Circular Economy.

Most scholars assume a 1:1 replacement rate without justification, which is problematic (Sandin & Peters, 2018). Studies identifying actual textile replacement rates are conducted, but are limited (Castellani, Sala, & Mirabella, 2015; Farrant, Olsen, & Wangel, 2010; Stevenson & Gmitrowicz, 2012).The most often cited research about replacement rates is that of Farrant et al. (2010). They found replacement rates in Sweden and Estonia ranging from 60-85%, depending on the place of reuse. This means that the purchase of 100 second-hand garments would save between 60 and 85 new garments. Research on replacement rates in the Netherlands is absent.

All publications employing replacement rates have found that the choice of replacement rate influences the results considerably (Sandin & Peters, 2018). Dahlbo, Aalto, Eskelinen, and Salmenperä (2017) conclude that replacement rates as low as 50% may still result in environmental benefits for textile reuse. Similarly, Schmidt, Watson, Roos, Askham, and Poulsen (2016) found environmental benefits for textile reuse for replacement rates as low as 10%. This is the case because the collection, processing and transport of second-hand clothing has insignificant environmental impacts compared to the savings that are achieved by replacing virgin clothing (Farrant et al., 2010).

2.7 CONSUMER BEHAVIOUR

Circular economy rebound effects mainly occur because of behavioural economic forces and are the consequence of the lack of change in our behaviour (Siderius & Poldner, 2021). Adopting reused textiles as inferior products and re-investing the money saved lowers the expected environmental benefits. The complex reaction chains of the cause and effect of human behaviour determine how rebound effects evolve (Siderius & Poldner, 2021). Therefore, to study rebound effects related to textile reuse understanding and predicting consumer behaviour is essential. To understand consumer behaviour towards reused textiles, insights in pivotal and intrinsic factors that may lead to or prevent consumers from adopting this behaviour are needed (Silva et al., 2021). However, the connection between people and textiles can be quite complex and personal, with a high degree of subjectivity (Silva et al., 2021). Drivers and barriers for adopting reused textiles differ per consumer type (Lang & Joyner Armstrong, 2018). Moreover, behaviour is dynamic and might change over time.

2.7.1 Pro-environmental behaviour theories

The complex nature of human behaviour is described and predicted by various theoretical frameworks from several disciplines (Parajuly, Fitzpatrick, Muldoon, & Kuehr, 2020). More than 80 different theories exit across the field of psychology, economics and sociology (Darnton, 2008). This study focuses specifically on behavioural theories and models, that are linked to pro-environmental behaviour. The most common theories of pro-environmental behaviour are categorized as rational choice, moral and economic models (Turaga, Howarth, & Borsuk, 2010). In table 2.2 these models and most common theories are described and explained.

Table 2.2: Theories of pro-environmental behaviour

Model	Model description	Common theory	Theory description
Rational choice	Pro-environmental behaviours are the result of 'rational choices' made with the aim to maximize personal benefit (Bamberg, 2013).	Theory of Planned Behaviour (TPB)	Intentions to perform certain behaviour, can be predicted from attitudes towards the behaviour as well as subjective social norms and perceived behavioural control. The actual behaviour is the result of these intentions combined with individuals perception of behavioural control (Ajzen, 1991).
Moral	Moral norms are a strong driver of pro-environmental practices (Davis, Hennes, & Raymond, 2018). Beliefs about environmental impacts and the effectiveness of one's action, influence those norms (Stern, 2000).	Value-beliefs-norms (VBN) theory	VBN provides a social-psychological framework for studying normative factors promoting sustainable attitude and behaviours, which links personality traits, beliefs about human-environment relations and the sense of moral obligation to pro-environmental behaviours. (Stern, 2000)
Economic	Individuals are utility-maximizers whose behaviour can be influenced through incentives (Nnorom, Ohakwe, & Osibanjo, 2009). Pro-environmental behaviours are modeled as the 'private provision of public goods' (Saphores, Ogunseitan, & Shapiro, 2012).	Willingness-to-pay (WTP)	Indicates how much individuals are willing to pay for environmental improvements. WTP may vary with socio-economic factors, and also reflects some degree of altruistic motives and moral values (Turaga et al., 2010).

From the theories presented in table 2.2, the Theory of Planned Behaviour (TPB) is chosen to explain and predict reused textile purchase behaviour and rebound effects. TPB has proven to be an efficient theory to represent individuals' decision-making processes within

an agent-based model (Scalco, Ceschi, & Sartori, 2018). Firstly, TPB is able to consider individual, social and external factors in conjunction with its environment. Therefore, it is a valuable resource for multidisciplinary work between psychology and computer simulation (Scalco et al., 2018). Secondly, the framework is able to take jointly individual preferences and social influence in account. This is consistent with the examination of emergent behaviour from individual decision-making usually investigated by means of agent-based models (Scalco et al., 2018).

2.7.2 Theory of Planned Behaviour

The theory of planned behaviour (TPB) has been shown to explain a wide range of consumer behaviour. Components of TPB capture the primary determinants to explain and predict the behaviour in context of textile reuse (Lang & Joyner Armstrong, 2018; Xu, Chen, Burman, & Zhao, 2014). According to TPB, the behavioral intention is assumed to be influenced by the joint effect of attitude, perceived behavioural control and subjective norm (Ajzen, 2015). The attitude towards behaviour and perceived behavioural control are considered personal factors, while subjective norm is identified as a social factor (Lang & Joyner Armstrong, 2018).

Personal factors
An individual's attitude towards performing a specific behaviour is related to the beliefs that performing the behaviour will lead to particular results. Perceived behavioural control reflects the perceived ease or difficulty of performing the behaviour in question (Lang & Joyner Armstrong, 2018). The personal factors, attitude, and perceived behavioural control describe the drivers and barriers to adopt reused textiles. Important drivers for purchasing reused textiles are low prices, environmental concerns, treasure hunting and a desire to be unique (Bardhi & Arnould, 2005; Guiot & Roux, 2010; Liang & Xu, 2018; Yan, Bae, & Xu, 2015). Important barriers are the condition of the used textile, worries about contamination and germs, previous ownership, availability of stores and lack of choice (Belk, 1988; Hiller Connell, 2010; Žurga, Hladnik, & Tavčer, 2015).

Social factors
The subjective norm, the social factor of TPB, is the individual's perception of the social pressure placed on them to perform the behaviour in question (Lang & Joyner Armstrong, 2018). Research has shown that friends and family have an effect on the consumption pattern of consumers (Noble, Haytko, & Phillips, 2009). If consumers have friends who purchase second-hand clothing, this could lead to an interest in buying second-hand clothing themselves (Janigo & Wu, 2015). This also works the other way around, consumers observe others with a negative attitude towards reused textiles and adopt this behaviour as theirs (Nordlund & Garvill, 2002). This shows that the behaviour of consumers is greatly determined by the attitudes and behaviours of their social networks.

Intention - behaviour gap
Several previous studies have found a positive relationship between attitude and reused textile purchases (Hamari, Sjöklint, & Ukkonen, 2016; Xu et al., 2014). However, other studies argue that environmental purchase intentions do not translate into actual purchasing behaviour (Morwitz, Steckel, & Gupta, 2007). Although increasing numbers of consumers have positive attitudes towards sustainable apparel, they commonly end up not purchasing those products (Morwitz et al., 2007). Researchers have tried to understand this gap between intention and actual behaviour. According to Bray, Johns, and Kilburn (2010) this

gap can be partly explained because of price experience, lack of information and quality perception. Additionally, perceived behavioural control, value, knowledge (Wander, 2000) and social norms (Do Valle, Rebelo, Reis, & Menezez, 2005) could explain the discrepancy.

2.8 SIMULATION MODELLING AND TEXTILE REUSE

Simulation modelling can provide insights in the effects of textile reuse in the Netherlands. These models are needed to grasp and visualize the complexity within the system (Siderius & Poldner, 2021). According to Franco (2017) system dynamics and agent-based models (ABMs) are especially suitable to quantitatively study the interactions within CE, with or without intervention. ABM can be used to model the purchase and disposal behaviour of textiles by consumers (Brannon et al., 2003; Joung, 2013; Rauh, Schenk, & Schrödl, 2012; Tong et al., 2018). System dynamics is often used when individual agent behaviour is not monitored. Within the textile industry it can be used as an integrated model for energy, resource and water systems (Abbas, Chiang Hsieh, Techato, & Taweekun, 2020). Because of the consumer behaviour focus of this research, the more bottom-up approach of ABM is better suitable. There are no textile related ABMs in the current literature with either a reuse, CE, disposing, or post-consumer focus. There are however ABM studies that focus on textile purchase behaviour of consumers in general. Additionally, there are ABM studies that investigate post-consumer waste disposal within other industries. These studies are summarized in table 2.3

Table 2.3: Related agent-based modelling studies

Theme	Reference	Conclusion
Agent-based modelling in the textile industry	(Rauh et al., 2012)	Agent-based approaches provide an elaborate instrument to model consumer behaviour regarding shopping activities (e.g., textiles).
	(Brannon et al., 2003)	An agent-based model of a textile marketplace enables to observe the system in action under various sets of parameters and variable settings.
Agent-based modelling of post-consumer waste	(Tong et al., 2018)	Agent based modelling and the Theory of Planned Behaviour (TPB) are suitable to test the policy effectiveness of interventions in recycling programs.
	(Skeldon et al., 2018)	Agent-based models can be used to explore policy settings of food waste recycling.

Agent-Based Modelling in the textile industry

Previous research analyzed the textile market by means of an ABM (Brannon et al., 2003; Rauh et al., 2012). Rauh et al. (2012) studied the potential of agent-based modelling for the locational choices of consumers for their fashion shopping activities. They argue that consumption is a complex process, because of its contingent, context-specific, path-dependent, dynamic, non-linear and open-ended character. Agent simulation is perfectly suitable to grasp these complex processes in a formal way. Brannon et al. (2003) investigate the feasibility of ABM to simulate aspects of the textile marketplace. They encountered that ABM provides a new mode for subjectivity, liking, and more attribute-based considerations in purchase decisions. It makes the connections between textile products; consumer's attitudes, beliefs, and preferences; and constraints on purchase decisions more transparent.

These ABM researches focus on the purchasing behaviour of consumers within the textile industry but do not include the environmental aspects of buying textiles and post-consumer disposal options.

Agent-Based Modelling of post-consumer waste
Agent-based models on post-consumer textiles are absent. There are however ABM models present that study post-consumer waste within other industries. According to Joung (2013) attitudes towards waste recycling (e.g. paper or plastics) are good predictors of clothing disposal behaviours, such as reuse. Therefore, ABM studies from other industries can be helpful for the ABM study towards reuse of textile items.

Tong et al. (2018) focused on the behavioural change of households in China to increase waste separation and recycling with an ABM. Their research confirmed the effectiveness of many factors that affect recycling activities, such as opportunities and knowledge to recycle, the time for recycling, and the distance to recycling facilities. In conclusion, their research showed the large potential that agent-based simulations have to explore the effectiveness of policy interventions in recycling programs. Skeldon et al. (2018) studied how ABM can be used in a policy setting, with an example from the biowaste industry. They concluded that an ABM is capable of exploring the impact of financial incentives on food waste. The fundamentally dynamic nature of an ABM approach is used to demonstrate that policy outcomes depend not just on current policy levels, but also on the historical path taken.

These studies show that ABMs are suitable to model disposal options of post-consumer waste. Overall, the ABM studies focusing on the textile industry and post-consumer waste, show that an agent-based research provides deeper understanding of the textile waste system. The reuse of post-consumer textiles requires such an approach due to its socio-technical, complex and adaptive character.

2.9 KNOWLEDGE GAPS

Scholarship is paying greater attention to consumer behaviour as textile consumption increases and several studies have been performed on the effects of reuse (Degenstein et al. (2020); Farrant et al. (2010); Laitala and Klepp (2011); Levanen et al. (2021)). However, quantitative research examining consumer behaviour on rebound effects of textile reuse is absent. Furthermore, research on textile reuse within the Netherlands as a research domain is rare.

Currently, literature on the circular economy rebound is lacking (Siderius & Poldner, 2021). Especially with a specific focus on reuse and the textile industry. Zink and Geyer (2017) initiated the term circular economy rebound and attempted to unify and connect future studies around this topic. In doing so, an explicit call for the body of research on this subject was launched. Font Vivanco et al. (2016) also denotes the need for more insights on the underlying assumptions and causes behind the rebound effect. Furthermore, Levanen et al. (2021); Sandin and Peters (2018) argue for more research on rebound effects specifically related to textile reuse. This results in the first knowledge gap; a better understanding of assumptions and causes behind the rebound effect from textile reuse is necessary.

Siderius and Poldner (2021) state that for the proper description of rebound effects, approaches beyond economics are needed. They propose that quantification models are necessary to place rebound in a real-world context (Siderius & Poldner, 2021). According to Franco (2017) the dynamic behaviour of the Circular Economy within the textile industry can be quantitatively studied at the macro-, meso- and micro levels using agent-based modelling. More research is recommended to build different scenarios to quantitatively explore

the transition of the textile industry to a Circular Economy. Especially for circular economy rebound analysis, agent-based modeling is an appropriate analytical tool (Font Vivanco et al., 2016). This results in the second knowledge gap; an agent-based model to study rebound effects in a real-world context is necessary.

Furthermore, more attention should be paid to the choices and preferences of different consumers. Buying, using and disposing of textiles contains a complicated socio-cognitive process to which we attach diverse personal values (Laitala, 2014; Levanen et al., 2021). Reuse strategies will not achieve their potential if they do not consider heterogeneous consumers (Levanen et al., 2021). Polizzi di Sorrentino, Woelbert, and Sala (2016) argue that especially for rebound effects, incorporating consumer behaviour is essential. However, currently there are no simulation studies that study behavioral change towards improved textile reuse incorporating heterogeneous consumers. This results in the third knowledge gap; behavioural change regarding textile reuse should be studied with respect to heterogeneous consumers.

3 RESEARCH APPROACH

This chapter elaborates upon the chosen approach and methods used for this research. First, the chosen agent-based modelling approach, resulting in related sub-questions is discussed. Followed by an explanation of the methods and tools used to answer the sub-questions. Subsequently, data collection, processing and management procedures are presented. Lastly, the limitations of the research methods used are discussed.

3.1 AGENT-BASED MODELLING

The main research question is answered using an agent-based modelling approach. This approach is suitable as there is a lack of knowledge on the interaction of different elements within the complex textile reuse system. Using a modelling approach, we can explore how textile reuse creates rebound effects and how this influences the textile consumption pattern of consumers. The model enables the effects to be quantitative, making it possible to measure how the system works. The model implemented can be run with different scenario's to create insight in the sensitivity of the system and its relations. Eventually the model can be used to steer the system in the preferred direction, based on predefined Key Performance Indicators (KPI's). These KPI's provide insight into the effects that are necessary to enhance textile reuse.

For this research the framework of van Dam et al. (2013) has been used. The framework consists of ten practical steps for creating and using an agent-based model of a socio-technical system (van Dam et al., 2013):

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

The main research question is broken down into five sub-questions, that cover the steps provided by the framework of van Dam et al. (2013):

1. **What does the current Dutch textile reuse system look like?**

2. **Which concepts and performance indicators are needed to accurately model the Dutch textile reuse system?**

3. **How should the Dutch textile reuse system be implemented in an agent-based model?**

4. **What is the influence of textile reuse rebound effects on the purchase behaviour of consumers?**

5. **Which value change are needed to improve textile reuse?**

3.2 RESEARCH METHODS

In this section, for each sub-question the data needed to answer the question and the research method used to collect the data are discussed. As described in the previous section, all sub-questions cover one or more steps of the agent-based modeling framework. This creates a comprehensive flow of the research approach. This research flow is depicted in figure 3.1.

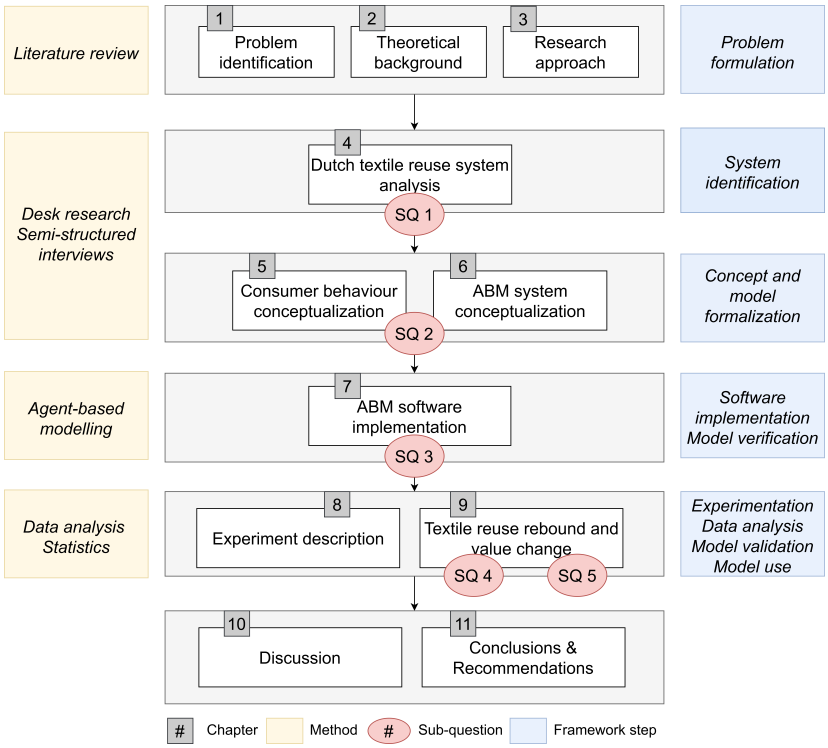

Figure 3.1: Research flow diagram

1. What does the current Dutch textile reuse system look like?

This sub-question is presented in chapter 4 and covers steps 1 and 2 of the framework. The problem formulation of step 1 was already partly performed in chapters 1 and 2. This sub-question is answered by means of three main elements: 1) system 2) actors 3) factors. For the first element, data about the flows and processes of the Dutch textile reuse system are identified and quantified. For the second element, data is needed on the stakeholders involved, their relationships, and interactions. For the third element, important factors

are necessary in terms of issues and challenges regarding the Dutch textile reuse system. To collect the data, desk research and semi-structured interviews have been conducted. See section 3.3 for detailed information about these data collection methods. The data is processed by means of a stakeholder analysis (Enserink et al., 2010) and Material Flow Analysis. See section 3.4 for a detailed description of these data processing methods.

2. Which concepts and performance indicators are needed to accurately model the Dutch textile reuse system?

This sub-question is presented in chapter 5 and 6 and covers step 3 and 4 of the framework. Data needed for this sub-question are concepts that enable modelling heterogeneous consumer behaviour. These concepts lead to consumer values that have been made quantitative to be interpretable by the model. Subsequently, concepts about textiles, interaction between agents, and the environment are needed. Resulting in an overarching system conceptualization. Furthermore, the Key Performance Indicators (KPI's) that are necessary to eventually answer the main question are explained. Desk research is conducted to identify the concepts from previous studies. To verify and supplement the concepts found, semi-structured interviews are held. See section 3.3 for detailed information about these data collection methods. To process the model, several flow diagrams and the Business Process Model Notation (BPMN) are used. See section 3.4 for more information.

3. How should the Dutch textile reuse system be implemented in an agent-based model?

This sub-question is presented in chapter 7 and covers step 5 and 6 of the framework. The outputs of question 1 and 2 are needed to implement the data about the Dutch textile reuse system and the conceptual model into the agent-based model. Verification is performed to analyse whether the model is correctly implemented. This includes debugging software, looking for an incorrect implementation of conceptual models, and checking calculations (Xiang, Kennedy, Madey, & Cabaniss, 2005). Methods used for this verification process are animation and graphical representation.

4. How do rebound effects influence the Dutch textile reuse system?

Question 4 and 5 are both presented in chapter 8 and 9, and cover steps 7, 8 and 9 of the framework. Data needed to answer this question is the agent-based model implemented as output of sub-question 3. To answer the question, experiments to provide insight in the general model behaviour are set-up and performed. The results provide insight in the general behaviour of the model, variation in the level of reuse and the occurrence of rebound effects. To analyse the model outputs, data analysis and statistics are performed using Python and Excel. For the validation step, a sensitivity analysis is performed. In addition, results are compared to real-world data and are tested by experts working in the field (Xiang et al., 2005).

5. Which value changes are needed to improve textile reuse?

This sub-question builds upon the findings of sub-question 4 and is also presented in chapter 8 and 9. Sub-question 4 identifies how reuse and corresponding rebound effects evolve in the system. In order to decrease rebound effects and to stimulate textile reuse, behavioural change is necessary. This can be guided by a change consumer values, identified in sub-question 2. This change can be initiated by interventions. The results of this sub-

question, provide insight in which value changes are needed to reach a preferred textile reuse system.

3.3 DATA COLLECTION

For data collection, two main methods have been conducted; desk research and semi-structured interviews. This section describes in-depth how these methods led to the gathered data to answer the sub-questions.

3.3.1 Desk research

To answer the first and second sub-question, data is collected through desk research. The main tools used are the Scopus and Google Scholar databases. In addition to academic sources, 'grey' literature has been analyzed. 'Grey' literature are research documents written for a non-academic purpose (SAGE, 2017). Typically, it is the product of research by an organization, often one within the realm of governance.

For sub-question 1, the study of Bakker (2021b) is used mainly to quantify flows and processes within the system. This report is drafted by Royal Haskoning DHV and monitors the textile industry in 2018. This makes it possible to measure the circular progress of the industry in the coming years. If the flows could not be determined based upon the study of Bakker (2021b), other sources have been consulted.

For sub-question 2, the study of Gwozdz, Nielsen, and Müller (2017) is used for consumer segmentation and to define the numerical values for each consumer. If the numerical score could not be determined based only on the study of Gwozdz et al. (2017), an educated assumption has been made.

3.3.2 Semi-structured interviews

To provide a coherent overview of the textile reuse system in the Netherlands nine semi-structured interviews were conducted. The organizations of the interviewees and their tasks are presented in table 3.1. The interviews are used to gain insight in the current textile reuse system, the relations between stakeholders, textile purchase and disposal behaviour, Key Performance Indicator's and the influence of rebound effects. They were able to verify the information found during the desk research and supplement it with information from their industry experience or research. All interviews lasted 60 minutes and were conducted via Teams. The interviews are approved by the Human Research Ethics Committee from the TU Delft. Consequently, all interviewees have given their informed consent to participate in this research. The protocol and the interview guide can be found in appendix A.

3.4 DATA PROCESSING AND MANAGEMENT

To appropriately process the data, several methodologies and frameworks have been used. For sub-question 1, the system is analyzed inspired by a Material Flow Analysis. This is an analytical method to quantify flows and stocks of goods within a system (Brunner & Rechberger, 2004). Within the same sub-question actors are analyzed as described by Enserink

Table 3.1: Interviewees

Organization	Task description
Haagse Hogeschool	Educational institute that conducts research on Circular Fashion. Also, performed specific research towards rebound effects within the textile industry.
D&B	Institute that researches psychologic behaviour within all kind of industries. Specifically, researched sustainable consumption behaviour towards clothing, on behalf of the ministry of Infrastructure and Water Management.
Milieu Centraal	Consumer organization providing information about sustainability. Perform research regarding the impact of the textile industry and consumer behaviour.
Curitas	Textile collection and sorting company. Is particularly concerned with circularity in the textile industry.
Modint	Textile trade association. Closely involved in rolling out the Extended Producer Responsibility within the industry.
The Swapshop	Clothing store where you can hand in your clothes in exchange for Swaps. With these swaps you get a discount on items in the store.
Het Goed	Thrift store with several locations in the Netherlands. Has a strong social and sustainable character by offering affordable reused items.
OLX	Network of leading marketplaces present in more than 30 countries. Among others, clothes and textile items are sold via the platform.
De Correspondent	Journalistic platform that writes about the social and environmental effects of the clothing industry.

et al. (2010). The actor analysis consists of the following steps: problem formulation, inventory of the involved actors, exhibiting the formal chart, and determining the interests and power of all actors. For sub-question 2, model behaviour is visualized by means of several flow diagrams. This enables to separate steps of a process in sequential order. Furthermore, the interaction between model entities is visualized inspired by the Business Process Model Notation (BPMN). Allowing to describe and clarify processes with a high abstraction level (García-Holgado, García-Peñalvo, Hernández-García, & Llorens-Largo, 2015).

The gathered data is managed in several ways. Logically, all analyzed data used in answering the main and sub-questions is written down in this thesis report. The report will be available via the TU Delft education repository. The pseudonymzed interview transcripts are backed-up on the TU Delft OneDrive and available for the thesis committee. The agent-based model code, used data and Python scripts are publicly available via this Github page: https://github.com/Brittzandbergen/textile-reuse-thesis. After completion of the thesis, all interview recordings and other collected personal data will be destroyed. The Data Management Plan for this thesis project is approved by the Technology Policy and Management data steward.

3.5 LIMITATIONS OF RESEARCH METHODS

Desk research provides the opportunity to objectively use the knowledge of others. The disadvantage is however that the information found in literature is not fully representative for the problem situation at hand. In order to generalise the data to the specific problem situation, assumptions have to be made which will be communicated properly. **Semi-structured interviews** provide very rich information and offer the opportunity to probe additional information, justify previous answers and establish a connection between sev-

eral topics. However, interviews are time-intensive and cannot be generalized (Queirós, Faria, & Almeida, 2017). The limitations of **agent-based modelling** are the level of abstraction and complexity (Crooks & Heppenstall, 2012). If the level of abstraction is too simple, key variables might be missed. Too much detail and the model will have too many constraints and will become overly complicated. While doing **data analysis** one runs the risk of drawing conclusions based on coincidental results. Therefore, the model should be run extensively to ensure that the final results are significant.

3.6 CONCLUSION

This chapter introduced the five sub-questions that will lead to answering the main research question. In this research the agent-based modelling approach of van Dam et al. (2013) has been used. To answer the first and second sub-question desk research and semi-structured interviews have been conducted. These research methods are used to identify the system, quantify consumer values and conceptualize the system components. For sub-question 3 these concepts are implemented in the agent-based model. The outcomes of the models will be used to answer sub-question 4 and 5, by means of data-analysis. The next chapter provides the identification of the system and will answer sub-question 1.

4 SYSTEM ANALYSIS

To understand how reuse and rebound effects evolve it is important to gain insight in the current Dutch textile reuse system. This chapter analyzes the system in three main ways. Firstly, the system is quantified inspired upon a material flow analysis. Secondly, an actor analysis is performed to provide information on the range of actors and their relationships within the system. Lastly, factors are identified that guide a deeper understanding of the issues and challenges the system is currently facing.

4.1 DUTCH TEXTILE REUSE SYSTEM

In this section, the current Dutch textile reuse system is quantified. Based on previous literature and input from the interviews processes and textile flows of the reuse system are determined and quantified. A visualization of the quantified system is depicted in figure 4.1. In appendix B a description of the flows, processes, and assumptions made during the calculations can be found.

4.1.1 Quantifying the system

The implementation of the system analysis follows the approach of a material flow analysis. The system analysis as depicted in figure 4.1 however shows the flows of the system on the level of goods, instead of on the level of materials. The investigation consists of a system defined by system boundaries in time and space and of flows that link processes (Brunner & Rechberger, 2004). A process is defined as the transformation, transport, or storage of textile products. Flows show the ratio of mass per time (tonnes per year) (Allesch & Brunner, 2015). Processes are depicted as squares and flows as arrows.

Because the most reliable data can be found for the year 2018 this year is chosen as a reference. The flows are depicted in tonnes textiles per year. The following sections will individually discuss the processes and corresponding flows of the system.

Production
This process consists of the production of virgin materials into new textile items. Bakker (2021b) reports that 343 kton of textiles were produced and put on the Dutch market in 2018. The flow consists of 72% imported consumer clothing, 20% imported bed bath and kitchen textiles (BBK) and 8% imported workwear. Almost all textile items are produced outside the Netherlands (Bakker, 2021b). Therefore, production within the Netherlands is left out of scope.

First-hand retail
First-hand retail concerns the process of textile products entering the Netherlands until it

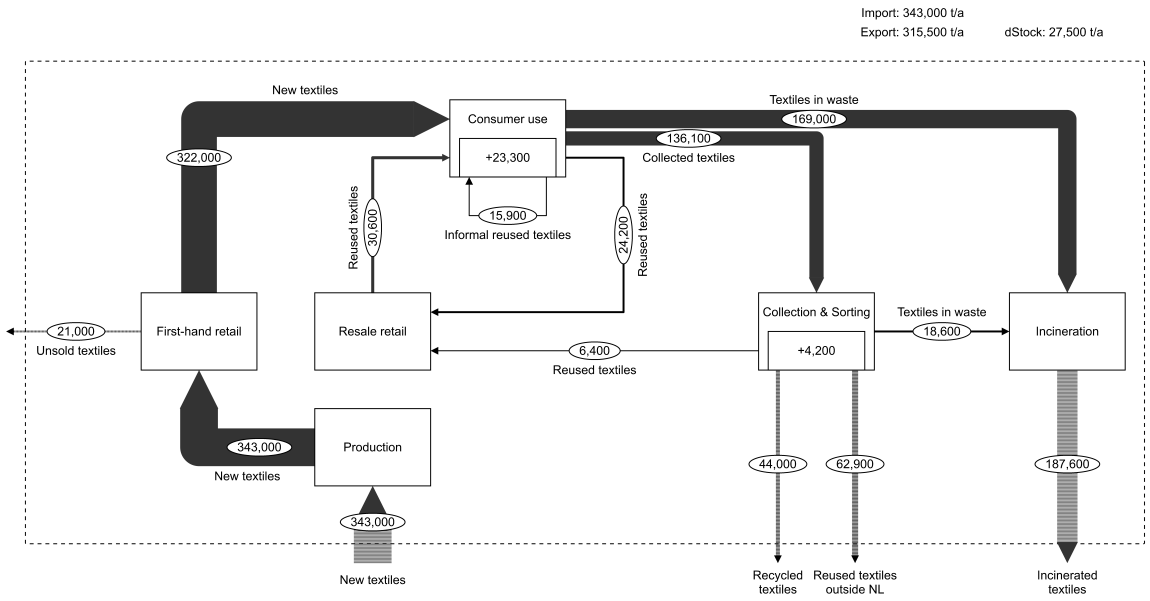

Figure 4.1: Quantification of Dutch textile reuse system, in tonnes (2018). See appendix B for a detailed explanation.

reaches the consumer. For every textile flow it differs how many steps are taken from intermediaries, wholesalers, online shops and physical shops (Bakker, 2021b). Of all imported textiles 6% is unsold (Kort et al., 2020). Simplified, it is assumed that these 21kton of textiles leave the system. In reality, these textiles are being stored, donated, sold, fiberised, or incinerated (Wijnema, 2016).

Resale retail

The resale retail process contains the sale of formally reused textiles through resale retailers. This market can be segregated into second-hand shops, vintage shops, online platforms, and other (e.g., take-back schemes and flea markets). No data is available about the distribution of these different types within resale retail. Busi et al. (2016) estimated that 17% of all textiles in Norway are reused through user-to-user channels, through direct exchange, second-hand shops, or on the Internet. This does not include reused textiles collected via collection bins. It is assumed that this also applies to the Dutch market. Subtracting the informal reused textiles (see the following section) results in 24.2 kton reused textiles directly from the consumer to resale retail. According to Hopstaken et al. (2020) 6.4 kton textiles is reused in Dutch second-hand shops after collection and sorting. Bakker (2021b) argues that all the textiles collected and bought in second-hand shops are sold. Therefore, it is assumed that all reused textiles from the resale retail market are reused by consumers.

Consumer use

This process contains the consumption of new, informal reused, and formal reused textiles, as well as the disposal of unwanted textiles. Consumers obtain textiles via the first-hand market, resale market and informal exchange. Knowledge about informal reused textiles is limited. Laitala and Klepp (2017) argue however that the informal sector is important and probably even more important than the formal market. Morley et al. (2006) state that in the UK 5% of all disposed clothes are given away directly between family members and friends, without involving a third party. Assuming that this is the same in the Netherlands, 15.9 kton of textiles are informally reused per year. As discussed in section 2.4 consumers have in general four textile disposal options; informal reuse, formal reuse, collection bin,

or regular waste. According to Hopstaken et al. (2020) 169 kton of textiles disposed end up in Dutch regular waste. These textiles are eventually incinerated. 136.1 kton of textiles are separately collected via collection bins. These textiles are processed by collection and sorting companies (Hopstaken et al., 2020). As discussed earlier, the other disposal options; informal and formal reuse are respectively 15.9 kton and 24.2 kton. Calculating the total in and outflows leads to a stock of 23.3 kton. These textile items are piled up in closets.

Collection & Sorting
This process consists of the collection and sorting of textiles by collectors and sorters. The research of Hopstaken et al. (2020) shows that after collection and sorting 53% of the textile items is reused. Accordingly, 6.4 kton of textiles is reused in the Netherlands (e.g., sold to second-hand shops). The other part, 62.9 kton is reused outside the Netherlands, e.g. in Africa and East-Europe. Of the sorted textiles, 33% is suitable for recycling (44 kton). The remaining part, 14% (18.6 kton) eventually ends up in regular waste and gets incinerated. The research of Hopstaken et al. (2020) results in a balance difference of 4.2 kton (3%) between the inflows and outflows. This is due to 1) stockpiling, 2) inaccuracy of the respondents, and 3) double counting (Hopstaken et al., 2020).

Incineration
Incineration concerns the process of burning textiles to produce energy. Rijkswaterstaat (2019) researched the distribution of textiles in the regular waste flow in 2018. They found that of the textiles in regular waste, 28.6% could have been reused and 29.4% was suitable for recycling. This means that 49 kton of textiles could have been reused if it would not have been thrown away with regular waste. In total 187.6 kton of textiles is incinerated in 2018.

4.1.2 Results

The system analysis showed that the Dutch textile reuse market in 2018 consists of 46.5 kton textiles, 13% of the total textile market. Another 13% of all disposed of textiles in the Netherlands, where reused outside the Netherlands. The Dutch reuse market includes 34% informal reused textiles and 66% formal reused textiles. Formal reused textiles are for 21% obtained via collection (bins, campaigns, door-to-door etc.) and for 79% via direct resale from consumers. Eventually 164.6 kton of textiles was incinerated, of which 34,6 kton (21%) was still suitable for reuse.

4.2 ACTOR ANALYSIS

An actor analysis is performed to provide information on the range of actors involved in the Dutch textile reuse system. It is important to be aware of the interest and objectives of the actors involved, because they will be affected by changes in the system or will have the means to carry out these changes (Enserink et al., 2010). In appendix C an overview of all involved actors, including their interests and power, can be found.

Figure 4.2 shows the formal chart of the Dutch textile reuse system. In appendix C an enlarged version of this chart can be found. A formal chart provides insight into the characteristics of the actors and their mutual relationships. This insight is essential to understand the actors and their environments (Enserink et al., 2010).

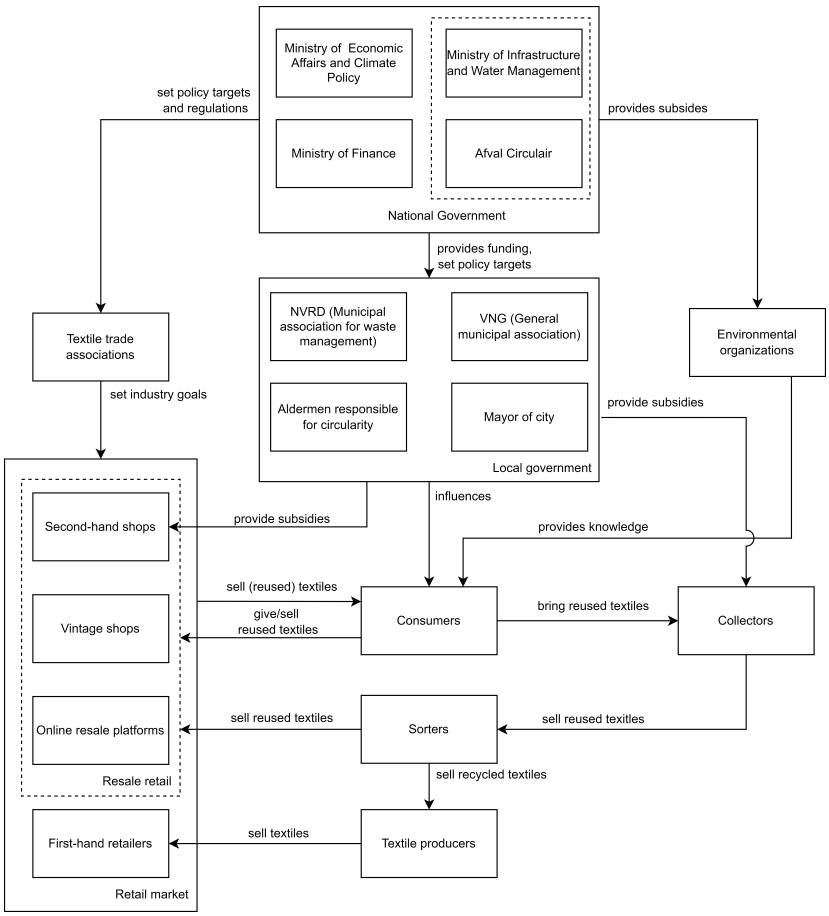

Figure 4.2: Formal chart of the Dutch textile reuse system

National government

The ministry of Infrastructure and Water Management (I&W) aims for a circular textile chain in 2050 (Rijkswaterstaat, n.d.). In order to reach this aim 75% of all disposed of textiles should be reused or recycled in 2030 (Rijksoverheid, 2021). Of which at least 15% should be reused within the Netherlands. Within the Ministry of I&W, Afval Circulair performs, supports, and monitors the circular textile policy (Rijkswaterstaat, n.d.). They are responsible for the policy objectives and regulations regarding the management of textile waste in the Netherlands. In addition, they (financially) support with the development and execution of initiatives and projects that contribute to a circular textile chain (Rijkswaterstaat, n.d.). For financial support, Afval Circulair is dependent on the Ministry of Finance, as they oversee the responsible and effective expenditure of government resources (Government of the Netherlands, n.d.-b). The Ministry of Economic Affairs and Climate Policy deals with the business climate of the Netherlands, while paying attention to nature and the living environment (Government of the Netherlands, n.d.-a). The objectives of the three ministries may possibly collide and even within the Ministries there may be different interests among actors. Buying less and stimulating reused textiles is favourable from a Circular Economy perspective, but requires governmental resources and may limit the business opportunities of retailers.

Local government

Municipalities are governed by the Board of Mayor and Aldermen. The Mayor has the ultimate responsibility over the city's policy and the execution of the policy of the national government. The Alderman responsible for Circularity in the specific city wants to contribute

to a circular textile reuse chain and wants to implement the policy goals of the national government on a local level (Gemeente Amsterdam, 2021). But also on a local level there might be diverging interests within the municipalities. Providing funding to circular activities means that there are less financial resources for other important initiatives. However, these diverging interests can also come together. A good example is the tailor initiative of Reflow. Due to this initiative, citizens of Amsterdam with less economic resources get a 40% discount on clothing repairs at the tailor's (Tonya Sudiono, 2022). Thereby bringing three interests together; poverty reduction, employment opportunities for tailors and clothing lifetime extension. The Municipal association for waste management (NVRD) and General municipal association (VNG) are umbrella organisations for respectively Municipal waste management and Municipalities in general. Both parties are involved in implementing circular textile policies.

Retail market

To give substance to the government's goals, textile trade associations published the sector plan 'Clothing and Textile' in 2019. Important elements in this plan, focused on reuse, are a more efficient collection and sorting infrastructure and the introduction of Extended Producer Responsibility (Inretail et al., 2019). In 2018, approximately 50 Dutch businesses in the textile sector signed the Dutch Agreement on Sustainable Garment and Textile (AGT). Thus, they commit to reduce risks and take responsibility for productive activities inside or outside the country (SER, 2016).

Resale retail

The resale retail market is characterised by businesses that sell 'second-hand' textile items to consumers. A detailed description of the resale retail market can be found in section 2.4.2. In short, the market is divided into: second-hand shops, vintage shops and online resale platforms. Second-hand shops enable consumers to buy reused textiles at affordable prices. These shops are commercial (e.g. het Goed) or non-commercial (e.g. the Salvation Army). Vintage shops offer consumers the opportunity to buy unique vintage items (e.g. the Episode). Officially, vintage shops distinguish themselves from second-hand shops by selling clothing produced before 1990 (Kort et al., 2021). In reality, this distinction is not so obvious. Examples of known online platforms are Vinted, The Next Closet, Sharedrobes, Poshmark, Marktplaats, Ebay and OLX.

First-hand retail

First-hand retailers are businesses that sell new textile items directly to consumers (e.g. H&M, Zara, The Sting). Not all first-hand retailers are part of a circular textile chain. Their main interest is making profit. However, some first-hand retailers are contributing to the reuse system by additionally selling reused textiles or adopting take-back schemes. An example is the cooperation between resale retailer Het Goed and first-hand retailer Zeeman. Since recently, Zeeman provides textile collection bins within their shops. Het goed sorts the clothing and determines whether the items are suitable for reuse or recycling. Part of the clothing items are sold back to Zeeman, which in turn sells these items in its shops (Zeeman, n.d.). Thereby broadening the assortment of reused textiles and creating awareness among consumers (Het Goed, personal communication, 2022).

Consumers

The consumer has an indispensable role in the transition to a circular textile industry. They are the first component in the value chain of textiles used (Inretail et al., 2019). Based on various factors consumers decide how they dispose of their used clothes and whether they

are interested in buying reused textiles. Eventually, this largely determines the effect of reuse and the size of the textile reuse system.

Collectors and Sorters
Collectors collect clothing that consumers dispose of in collection bins throughout the city (Sympany, 2022). Most collectors have their own sorting company. The items disposed in the bins are sorted manually with respect to quality by the sorters. They determine whether the items are: sold to second-hand shops within the Netherlands (8%), exported for reuse outside the Netherlands (45%), recycled (33%) or incinerated (14%) (Hopstaken et al., 2020). The business model of the sorting companies depends on the items that are still suitable for reuse. By reselling these items, collectors and sorters earn money. The other items, result in higher processing cost, and therefore only cost money (Curitas, personal communication, 2022). Due to the growth of the textile market reuse, consumers try to sell or donate their best textile items. Therefore, the quality of items in the collection bins decreases, which impacts the business model of collectors.

Textile producers
Producers have an important role in the transition to a circular textile chain. This is due to three main reasons. First, they have the ability to produce long-lasting textiles. This allows for reuse possibilities and, in general, increases the textile lifespan of clothing items (Inretail et al., 2019). Second, they have the ability to use recycled materials for the production of their textiles. Third, the choice of materials (e.g., recycled) determines the environmental impact of the final item. However, there is little transparency regarding the production process of textile items. This is mainly due to the fact that the market is very internationally oriented (Rebel, personal communication, 2022). Almost all Dutch textiles are produced outside the Netherlands, of which 71% outside Europe (Bakker, 2021b). This makes it difficult for the Dutch government and other organisations to steer the textile production process in a circular direction.

4.3 ISSUES AND CHALLENGES

During the desk research and interviews, several issues and challenges of the Dutch textile reuse system became apparent. This section provides an overview of these issues and challenges. It should be noted that this list is not conclusive and that there are undoubtedly more factors. However, it presents a good starting point and an impression of the most important factors found during the study.

1. **Textile disposal with residual waste** - Currently, a lot of textile items end up in regular waste and are therefore incinerated. Section 4.1.1 showed that in 2018 169 kton textiles ended up with regular waste. According to Rijkswaterstaat (2019) 29% of these items was reusable and 29% was suitable for recycling. This means that 49 kton of textiles could have been reused. This amounts to approximately 122.5 million textile items [1].

2. **Unused textiles** - People own a lot of clothes they never wear. Maldini et al. (2017) estimated that the average Dutch consumer owns 50 clothing items that were not worn in the past year (approximately 30%). Meaning that, about 880 million clothing

1 Assuming an average textile weight of 400 grams. Based upon a combination of Bakker (2021b) and Maldini, Duncker, Bregman, and Piltz (2017).

items are gathering dust.[2] These items might however be useful to other consumers (The Swapshop, personal communication, 2022).

3. **Cannibalizing existing sales** - Buying reused textiles should become more mainstream (Curitas, personal communication, 2022). For example, regular retailers offering consumers access to used clothing (e.g., H&M, Zeeman). However, for these companies this becomes most profitable when these items are sold as additional products, not cannibalizing existing sales (McKinsey & Company, 2014; Zink & Geyer, 2017). This means that introducing textile reuse concepts to profit-maximizing firms is likely to result in rebound (Zink & Geyer, 2017).

4. **Informal reuse** - Policy makers, researchers and industry experts often do not pay attention to informal reuse. Laitala and Klepp (2017) argue however that the informal market might exceed the formal market. [3] In addition, informal exchange involves minimal environmental impact because it does not require retail premises, transport or collection and sorting processes. Therefore, more attention should be paid to promoting informal reuse.

5. **Transition towards buying less** - From an environmental perspective it is best to just stop buying clothes (D&B, personal communication, 2022). Almost every Dutch citizen has more than enough clothing items in their closet (The Swapshop, personal communication, 2022). However we keep consuming, because buying less is not part of our consumer behaviour. To become truly sustainable, we will have to break through this pattern.

6. **Availability** - The issues with reused textiles differ for men and women. For men, there are just not enough reused clothing items available yet (De Correspondent, personal communication, 2022).

7. **Price of alternatives** - Currently, fast-fashion is just way too cheap. Therefore, reused textiles can not compete within this market (De Correspondent; Modint, personal communication, 2022). The true environmental costs are not incorporated in the price of clothing produced, leaving an incentive to continue buying more and more new textiles.

8. **Online platform expansion** - Online platforms create a convenient way to sell and buy reused clothing. Currently, these platforms are expanding to other countries (e.g., France). This increases the supply of reused textiles, but also causes additional transport movements (De Correspondent, personal communication, 2022). This is not favourable from an environmental perspective.

9. **Increased turnover rate** - Reuse options where you can sell your worn clothing items create a new balance in continuing to buy new clothes, while knowing you can discard them for money. If you know you have the option to discard the clothing item in exchange for money, this might create an incentive to buy the clothing item in the first place. Because this option is available, you may also discard the item more easily than you would have done otherwise. This increases the turnover rate of clothing items (Haagse Hogeschool, personal communication, 2022).

2 Assuming that 17.6 million people live in the Netherlands (CBS, 2022).
3 According to their research in Norway.

4.4 CONCLUSION

This chapter answered subquestion 2 in three ways; a quantification of the system, an actor analysis and issues and challenges the system is currently facing. Firstly, the quantification showed that within the Netherlands 13% of all textile items is reused. This percentage consists of 34% informal and 66% formal reused textiles. Secondly, the actor analysis indicated that the involved actors can be categorized in the national- and local government, resale- and first-hand retail market, consumers, collectors and sorters and textile producers. Lastly, there are 9 main issues and challenges the Dutch textile reuse system is currently facing: regular waste disposal, unused textiles, cannibalizing existing sales, informal reuse, transition towards buying less, availability, price of alternatives, online platform expansion and increased turnover rate. The next chapter will partly answer sub-question 3, by means of a conceptualization and quantification of consumer behaviour.

5 CONSUMER BEHAVIOUR CONCEPTUALIZATION

A conceptualization of consumer behaviour regarding reused and non-reused textiles is essential to model the behaviour in a realistic way. In this chapter, consumer segments are introduced including their drivers and barriers for reused textile purchase. First, textile purchase behaviour will be explained. Second, consumer segments are presented based on previous literature. Third, important consumer values are described regarding reused textile purchases. Fourth, these values are quantified per consumer segment, based on previous literature and interviews. The quantifications make it possible to model consumer behaviour in a quantitative agent-based model. Fifth, the purchasing score and how the consumer values led to this score is elaborated upon. Lastly, the connection between the values and rebound effects is explained.

5.1 REUSED TEXTILE PURCHASE

As described in section 2.7 consumer behaviour determines whether or not reused textiles are purchased and how rebound effects evolve. Therefore, the consumer has an indispensable role to play. To predict reused textile behaviour, it is essential to gain insight into consumers personal interests and values.

Consumer behaviour on reused textiles can be described using demographic and psychographic variables (Roberts, 1996). However, studies show that psychographic variables have been more successful in explaining pro-environmental purchase behaviour than demographic variables (Domina & Koch, 1998; Roberts, 1996). Consumer behaviour can be predicted based on understanding of these values. In order to maximize the positive effects of reuse, it is important to understand the different consumer types and their drivers and barriers to purchase reused textiles.

5.2 CONSUMER SEGMENTS

Every person is unique, has its own behaviour and underlying values. Consequently, textile consumers are heterogeneous and make different choices about their textile consumption. Therefore, it would be unrealistic to model one type of consumer. However including all possible consumers with their individual behaviour is not possible. To prevent the model from being overly complex, incomprehensible and unfeasible simplification is needed. Consumer segmentation is a suitable way to achieve simplification in a comprehensive way (Onwezen, 2018). Consumer segmentation, refers to the classification of consumers that are similar in one or more characteristics (Onwezen, 2018). The numbers and the composition of groups are often unknown upfront. Consumer segmentation is applied and studied in multiple disciplines, including the textile industry.

Several studies identified consumer segments based on their level of fashion apparel and shopping styles (Cardoso, Costa, & Novais, 2010; Kim, 2006; Ko, Kim, Taylor, Kim, & Kang, 2007; Sarabia-Sanchez, de Juan Vigaray, & Hota, 2012). These studies investigated shopping behaviour of consumers and determined segments based upon this shopping behaviour. This provides insight in how different consumers behave in the textile market. However, within these studies, a sustainability perspective is absent. Therefore, these studies are not suitable for segmenting consumers when including the shopping behaviour of reused textiles. There are some studies that incorporate sustainability in clothing and shopping styles, however these studies are limited and do not incorporate reuse (Domina & Koch, 1998; Gwozdz et al., 2017; Koszewska, 2013). Only the study of Gwozdz et al. (2017) incorporated the reused and second-hand shopping styles of consumers.

5.2.1 Consumer segmentation approach

Due to time constraints, it was not possible to conduct a survey and perform consumer segmentation specific to this research. However, the study of Gwozdz et al. (2017) provides a segmentation of consumers based on shopping styles, including purchases of reused clothing. Furthermore, they discuss several important properties of these segments, such as income, average clothing expenditure, level of environmental apparel, and different clothing acquisition modes. These properties are valuable to gain a comprehensive understanding of the different segments. The segmentation of Gwozdz et al. (2017) provides a clear segmentation of consumers, with sufficient background information to study the content of these segments.

Therefore, this segmentation is chosen to determine the purchase behaviour of reused textiles by consumer type. The study segmented consumers from Germany, Poland, Sweden and the United States. This study is chosen because of the large group of respondents (N = 4617) and the diversity of four Western countries. Other studies are omitted because they do not incorporate second-hand behaviour (Koszewska, 2013) or only include female respondents (Domina & Koch, 1998).

5.2.2 Consumer segments

Gwozdz et al. (2017) identified five different consumer segments. These segments have been modified for the purpose of this research in two ways 1) the two smallest consumer segments are combined 2) the initial names have been adapted. This results in the following four consumer segments: budget minimalist, casual minimalist, budget shopper, and premium shopper. The relative size of the consumer segment is, respectively, 43%, 27%, 21% and 9%. Details about the consumer segments are shown in figures 5.1, 5.2 and 5.3.

The consumer segments can be summarized as follows:

- **Budget minimalists** - Possesses a low amount of fashion items bought primarily from budget brands and second-hand stores and also has the lowest income.
- **Casual minimalists** - Consumes a similar amount of clothing items as budget minimalists. These consumers enjoy however a higher income, spend more and buy somewhat higher priced clothing items.

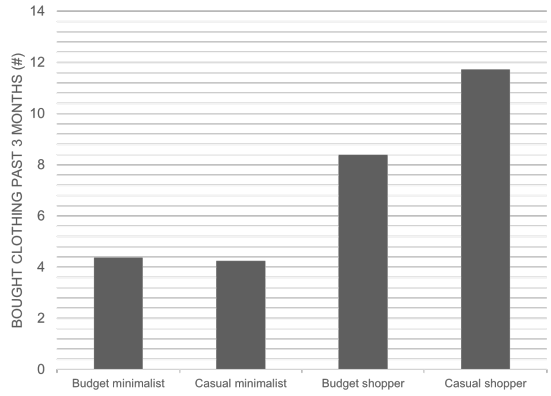

Figure 5.1: Clothing bought per consumer segment (past 3 months)

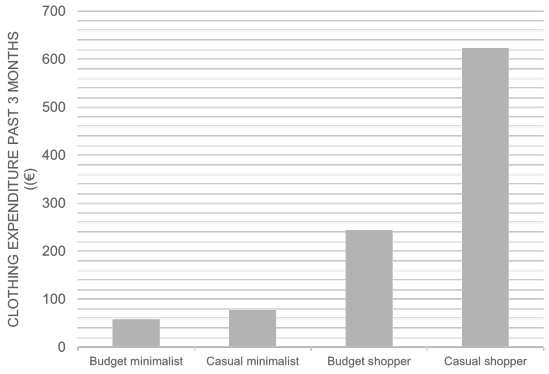

Figure 5.2: Clothing expenditure per consumer segment (past 3 months)

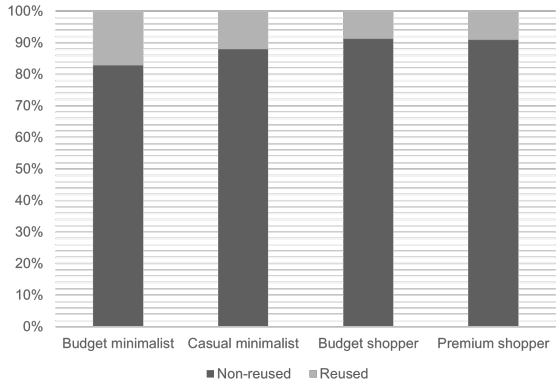

Figure 5.3: Distribution of reused and non-reused clothing per consumer segment

- **Budget shopper** - This group embodies the fast fashion consumer, having a comparatively high consumption rate but a strong preference for budget brands.
- **Premium shopper** - Reports a high clothing purchase rate, mainly from very high priced brands.

5.2.3 Limitations

Using the consumer segmentation of Gwozdz et al. (2017) has some limitations. During the use and interpretation of the segmentation, care should be taken. First, the results are based on respondents from other countries than the Netherlands. Contributing to the reliability of the segmentation's is however the average amount of reused clothes (13%), as this is similar to the size of the reuse market in the Netherlands as identified by the MFA (see section 4.1.1). Second, the segmentations are based upon clothing purchase behaviour while the research focuses upon textiles. Clothes however cover the largest part of the Dutch textile industry (CBS, 2021b). Third, the segmentation does not cover all important values related to textile purchases. Although it includes environmental aspects, it still misses important values identified by interviews and literature review. Fourth, the combination of the last two segments partly detracts from the k-means clustering analysis used by Gwozdz et al. (2017).

5.3 CONSUMER VALUES

As described in section 2.7, previous literature indicates low prices, environmental concerns, treasure hunting and need for uniqueness as important drivers to buy reused textiles (Bardhi & Arnould, 2005; Guiot & Roux, 2010; Liang & Xu, 2018; Yan et al., 2015). Accordingly, condition of the used textile, worries about contamination and germs, previous ownership, availability of stores and lack of choice are marked as important barriers (Belk, 1988; Hiller Connell, 2010; Žurga et al., 2015). Values identified in the literature are reviewed during interviews. Consequently, the values price, environment and uniqueness are indicated as most important drivers and the values convenience and ownership as barriers (The Swapshop; D&B; Curitas; Het Goed; Milieu Centraal, personal communication, 2022). The value uniqueness also contains the need for treasure hunting, while the value convenience contains among others the availability of shops and the lack of choice.

Each consumer however weights these values differently. Therefore, consumers have a different numerical score for each value. This score indicates how much each consumer value influences the decision to buy reused textiles. In this section the values will be explained as well as the importance of each value per consumer segment.

5.3.1 Quantification

In order to implement the consumer behaviour in an agent-based model, related consumer values need to be quantified. This enables the model to calculate relations within the system based on formulas and numerical scores. To find a realistic numerical estimate for each consumer value per consumer segment, prior literature and available data in the study of Gwozdz et al. (2017) has been consulted. Prior literature indicates the relative difference in importance of consumer values, resulting in a bandwidth for the numerical scores. The study of Gwozdz et al. (2017) is used to determine the numerical value per consumer segment within this bandwidth. If the numerical score could not be determined based on the study of Gwozdz et al. (2017) only, an educated assumption has been made. Consumer values indicate the importance in the decision to purchase reused textiles and are defined as values between 0 and 1. A score of 1 means that the value weighs heavily in the decision to purchase reused textiles.

The resulting consumer values and average numerical scores per consumer segment are presented in table 5.1. The following paragraphs provide an explanation for all numerical scores per consumer value. In appendix D a detailed explanation of the approach and assumptions for the quantification can be found.

Table 5.1: Average numerical consumer values per segment

	Budget minimalist	**Casual minimalist**	**Budget shopper**	**Premium shopper**
Value of price	0.85	0.75	0.65	0.45
Value of environment	0.3	0.45	0.45	0.6
Value of uniqueness	0.4	0.55	0.55	0.6
Value of convenience	0.4	0.65	0.7	0.65
Value of ownership	0.4	0.4	0.4	0.4

5.3.2 Value of price

The value of price refers to the extent to which the cost differences between the reused and non-reused textiles affect the purchase decision. Affordable prices are a major motivation for consumers to buy reused clothing (Guiot & Roux, 2010). According to Edbring, Lehner, and Mont (2016) low prices are the main reason to buy second-hand products for 47% of the consumers. Especially consumers with a lower income purchase reused clothing because of the price (Yan et al., 2015). However, frugality also motivates the search for low prices and cheap products (Cervellon, Carey, & Harms, 2012). Many consumers buy second-hand because they think it is a waste to spend money on clothes. This is a matter of principle rather than a lack of economic resources. (D&B; The Swapshop, personal communication, 2022). It can be stated that the value of price positively influences the reused purchase behaviour (Guiot & Roux, 2010; Yan et al., 2015). Consumers with a high value of price are more likely to purchase reused textiles compared to consumers with a low value.

The level of income and average expenditure per piece of clothing determines the value of price (Yan et al., 2015). Data on these values is used to examine the relative values per consumer segment (see appendix D). The budget and casual minimalist have the highest value of price. Although the income of the budget shopper is comparable to the casual minimalist, the value of price is lower due to a higher expenditure. The premium shopper has the lowest value, after which the budget shopper follows. Therefore, the scores for the value of price assigned to the budget minimalist, casual minimalist, budget shopper and premium shopper are, respectively: 0.85, 0.75, 0.65 and 0.45.

5.3.3 Value of environment

The value of environment represents the extent to which environmental concerns affect the reused purchase decision. In their study Bianchi and Birtwistle (2012) found that environmental concerns are important for people when purchasing textiles. But environmental reasons alone do not automatically lead to pro-environmental behaviour (D&B, personal communication, 2022). Other values, such as convenience and price, tend to prevail (Paço, Leal Filho, Ávila, & Dennis, 2021). According to Edbring et al. (2016) environmental reasons are the main driver for buying second-hand for 14% of the people. The value of environment positively influences reused purchase behaviour (Guiot & Roux, 2010).

Data about the environmental apparel consumption scale (EAC) are used to determine the value of environment (see appendix D). The EAC value is the highest for the premium shopper. The budget shopper and casual minimalist have the same EAC value, which is a bit lower than the casual shopper. Lastly, the budget minimalist has the lowest value EAC value. Therefore, the scores for the value of environment assigned to the budget minimalist, casual minimalist, budget shopper and premium shopper are respectively: 0.3, 0.45, 0.45, 0,6.

5.3.4 Value of uniqueness

The value of uniqueness refers to the extent to which a consumer's tendency to be different from others affects the reused purchase decision (Lang & Joyner Armstrong, 2018). This need for differentiation is related to the creation of a style, seeking originality and acceptance in order to enhance one's image (Keller, Bearden, & Hunter, 2001; Sherry, 1990).

Being unique is one of the most important driver to buy reused clothes (D&B, personal communication, 2022). In the study of Edbring et al. (2016) uniqueness was the main driver to purchase reused products for 25% of the people. The value of uniqueness positively influences reused purchase behaviour (Guiot & Roux, 2010; Joyner Armstrong, Connell, Lang, Ruppert-Stroescu, & LeHew, 2016).

The usage of non-conventional modes of shopping indicates the value of uniqueness (Guiot & Roux, 2010; Roux & Korchia, 2006; Xu et al., 2014). Data about the apparel mode e is partly used to determine the different values per consumer segment (see appendix D). The premium shopper has the highest value of uniqueness, followed by the casual minimalist. The budget minimalist has the lowest value of uniqueness, after which the budget shopper follows. It is, however, assumed that the value of uniqueness is equal for the casual minimalist and budget shopper. Therefore, the scores for the value of uniqueness assigned to the budget minimalist, casual minimalist, budget shopper, and premium shopper are, respectively: 0.4, 0,55, 0.55 and 0.6.

5.3.5 Value of convenience

The value of convenience represents the extent to which the ease of finding what you are looking for affects the reused purchase decision. In general, reused clothes are harder to obtain, compared to new clothes (Geurtsen, Crox, Venhoeven, & Jansen, 2020). This is due to two main reasons 1) the availability and accessibility of second-hand shops, and 2) difficulty to find your style and size within a shop (D&B, personal communication, 2022). According to the survey of (Žurga et al., 2015) 36% of the respondents indicate that there are not enough second-hand shops available, 18% says that the offer within second-hand shops is not what they are looking for. The value of convenience negatively influences the reused purchase behaviour (Paço et al., 2021; Žurga et al., 2015). Consumers with a high value of convenience are less willing to put extra effort into the search for reused textiles. Therefore, they are less likely to purchase reused textiles.

Convenience is the principal value for consumers to shop online (Jiang, Yang, & Jun, 2013; Silva et al., 2021). Therefore, data about the online apparel acquisition modes is used to determine the different values of convenience per consumer type (see appendix D). The share of online apparel acquisition is highest for the budget shopper, followed by the premium shopper. The budget minimalists has the lowest share of online apparel acquisition, after which the casual minimalist follows. However, it is assumed that the value of convenience for the casual minimalist and premium shopper are equal. Therefore, the scores for the value of convenience assigned to the budget minimalist, casual minimalist, budget shopper and premium shopper are respectively: 0.4, 0.65, 0.7 and 0.65.

5.3.6 Value of ownership

Value of ownership refers to the extent to which previous ownership of reused textiles determines the reused purchase decision. Reused clothes trigger concerns about contamination, germs and the transfer of diseases (Belk, 1988; Xu et al., 2014). Knowing that clothes have been worn generates concerns about the hygienic conditions of garments (Laitala & Klepp, 2018). Furthermore, this relates to a desire to buy new products instead of reused one's (Edbring et al., 2016). In their study Žurga et al. (2015) found that previous ownership was the most important barrier for 31% of the people. The value of ownership negatively

influences reused purchase behaviour (Geurtsen et al., 2020; Yan et al., 2015; Žurga et al., 2015).

The consumers segmented by Gwozdz et al. (2017) show no differences related to the value of ownership. This means that consumers are assigned a value of ownership independent of their segment. In appendix D this is explained in more detail. Consequently, the scores for the value of uniqueness follow a normal distribution with an average of 0.4 and a standard deviation of 0.2.

5.3.7 Limitations

Due to time constraints, no survey could be conducted to determine the numerical values of the consumer segments. Therefore, the approach used has some limitations. First, the literature consulted to define barriers and drivers is mainly focused on clothing. Second, the factors available in the study of Gwozdz et al. (2017) do not correspond directly to the values identified in the literature. Therefore, several assumptions have been made to be able to use the data. For example, the value of uniqueness is based upon the acquisition modes 'boutique and swapping'. In reality however this value is based upon many other aspects as well. Third, to cope with the limited data, several assumptions have been made.

5.4 REUSE PURCHASING SCORE

In the previous section, the numerical scores for the consumer values were quantified for each consumer segment. In the model each consumer falls within one of those consumer segments. In reality, however, not every consumer can be defined specifically as part of a specific consumer segment. In order to not shortchange this heterogeneity, randomness is added to the model. The numerical values defined in the previous section are the mean of a normal distribution with a standard deviation of 0.1. This means that all consumer values are different for each consumer, although they fall within the same consumer segment.

The consumer values influence the so called reuse purchasing score. The percentage reused textiles of consumers relies on this score. The purchasing score is calculated by adding the drivers and subtracting the barriers for the purchase of reused textiles (see formula 6.1). A schematic overview of the influence of consumer values on the reuse purchasing score is provided in figure 5.4

$$RPS = VP + VE + VU - VC - VO \tag{5.1}$$

The reuse purchasing score is calculated at the start of the model run and does not change during the run. The reuse purchasing score is converted into a percentage reuse per consumer. This percentage however does change during the model run and is influenced by social interaction. More information on how the reuse percentage per consumer is determined can be found in chapter 6).

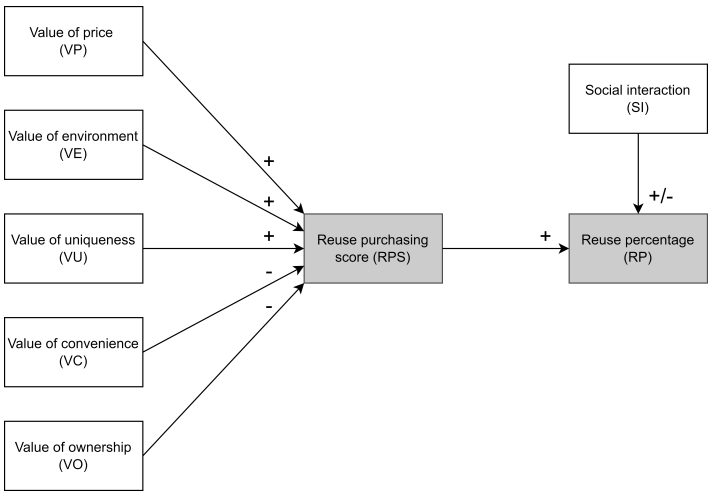

Figure 5.4: Schematic overview of the influence on the percentage textile reuse

5.5 REBOUND EFFECTS

The values defined in the previous section describe the drivers and barriers to the purchase of reused textiles. The numerical values per consumer segment predict the percentage of purchased reused textiles. However, this does not describe how rebound effects occur when performing reused textile purchase behaviour. Therefore, more information about consumer behaviour on rebound effects is needed (Font Vivanco et al., 2016).

As described in section 2.7 the rebound effects for reused textiles on the consumer level consist of 1) imperfect or insufficient substitution, and 2) price and income effects (Siderius & Poldner, 2021; Zink & Geyer, 2017). Rebound effects are partly assessed by means of the replacement rate, the degree to which the purchase of second-hand textiles replaces the purchase of new items (Nørup, Pihl, Damgaard, & Scheutz, 2019a). Furthermore, rebound effects are estimated basted on a degradation in the lifespan of the textile due to the use of a previous owner. To implement these rebound effects in an agent-based model, several assumptions need to be made. The interviews provided a detailed understanding on how these rebound effects evolve and how this should be translated into the agent-based model. This section discusses the assumptions made for the second rebound effect, the price-and-income effect, translated into a replacement rate. The first rebound effect, imperfect or insufficient substitution, is not related to consumer behaviour and will therefore be discussed further in chapter 7.

5.5.1 Replacement rate

The replacement rate differs for each consumer (Farrant et al., 2010). Consumers buying reused textiles because they need them will have a higher replacement rate than consumers looking for unnecessary additional things in second-hand shops (Farrant et al., 2010). Some consumers will save money compared to the textile item they would have bought otherwise. Which is re-spend differently by each consumer (Hertwich, 2005). The rebound effect and the replacement rate greatly depend on the consumer segment and values (Haagse Hogeschool, Modint, MilieuCentraal, The Swapshop, personal communication, 2022).

Consumer segment
Consumer expenditures are important when assessing rebound effects (Hertwich, 2005). Circular Economy strategies often lower the frequency of use and the average expenditure of the product in question (Hertwich, 2005). From an environmental perspective it becomes important how the consumers will use the money saved.

For textiles, it is especially important what a reused textile item substitutes. Reused textiles are not necessarily cheaper than new fast fashion items (Het Goed, personal communication, 2022). Therefore, it is important what a consumer would have bought instead of a reused item. Consumer segments with low expenditures would presumably have bought a similarly priced item. Consumer segments with high expenditures might have bought a higher-priced item. Meaning that consumer segments with a high expenditure have extra money to re-spend on additional textiles. This leads to the first assumption:

1. Consumer segments with low textile expenditures have a higher replacement rate than consumer segments with high textile expenditures.

Value of price
Next to the average expenditure for each consumer segment, the value of price also assesses the replacement rate. A high value of price means that the cheap price of the reused textile item weighs heavily in the choice to buy the item. Purchasing reused textiles because they are cheap will eventually lead to more textile consumption and therefore corresponds to a higher replacement rate (Haagse Hogeschool, personal communication, 2022). Consumers with a relatively high value of price presumably have more money to spend on additional textiles, leading to a higher replacement rate. The value of price depends on the consumer segment. Low expenditure consumer segments have a higher value of price, compared to segments with a high expenditure. To prevent double counting, the difference of the value of price for each consumer with the average of the corresponding segment determines the decrease in replacement rate. This means that consumers who have a relatively high value of price, within their consumer segment, will presumably have more money to reinvest in additional textiles. This leads to the second assumption:

2. Consumers with a relatively high value of price have a lower replacement rate compared to other consumers within their consumer segment.

Value of environment
Consumers that mind the environment have a different behaviour than the average consumer (Thiesen et al., 2008). Consumers with a high value of environment are presumably more aware of their textile shopping behaviour and are less likely to reinvest the saved money in additional textiles. They are more likely to use their savings on things that are good for the climate, instead of additional textile items (Thiesen et al., 2008). This means that for them, the chance that purchase of a reused textile item leads to the purchase of an additional new item is less. This leads to the third assumption:

3. Consumers with a high value of environment have a higher replacement rate compared to consumers with a low value of environment.

5.6 CONCLUSION

This chapter partly answered sub-question 2. After conducting a literature review, consumer segmentation is chosen based on the research of Gwozdz et al. (2017). The four identified consumer segments are the budget minimalist, casual minimalist, budget shopper and premium shopper. The consumer values price, environment, and uniqueness have been identified as drivers for purchasing reused textiles, while the values convenience and ownership are identified as barriers. For all consumer segments the relative importance of the values is determined and quantified. These values lead to a reuse purchasing score that reflects the reuse percentage of consumers. The individual level of rebound is influenced by the consumer segment, value of price, and value of environment of the consumer. Based upon prior literature and interview insights, assumptions about the relative in- and decrease of the replacement rate for each consumer have been determined. The following chapter will present the overall model conceptualization.

6 MODEL CONCEPTUALIZATION

This chapter entails the model conceptualization and model formalization of this research. Firstly, the Key Performance Indicators that allow evaluating the performance of the model over time are identified. Hereafter, the agents and objects in the model are presented. Subsequently, the model entities textiles and consumers are described in-depth.

6.1 KEY PERFORMANCE INDICATORS

The goal of the agent-based model is to provide insight into the effects of reuse on the consumption pattern of newly bought textile items in the Netherlands. Key Performance Indicators (KPI's) are output variables that allow evaluating the performance of the model over time. They can be used to assess the current effects of textile reuse and the result of value changes. The KPI's are based on insights from desk research and the interviews.

Percentage of reused textiles
The percentage of reused textiles indicates how many of the textile items owned by consumers are reused items. This denotes the size of the Dutch textile reuse market. The quantification of the Dutch textile reuse system presented in chapter 4 showed that currently the reuse market covers 13% of the total market. The percentage of reused textiles is measured as a percentage compared to the total number of textile items.

Service lifespan
The service lifespan indicates the duration of the period that the textile item functions and can be used, including the possession by initial and subsequent owners (Klepp et al., 2020). The service lifespan starts when the first owner acquires the item and ends when the last owner discards it (Klepp et al., 2020). Reuse enables prolonging the service lifespan of textile items, which is favourable from an environmental perspective. The service lifespan is measured in years.

Number of wears
The number of wears indicates the number of times a textile item is used. From an environmental perspective, prolonging the use period is not enough if an textile item is never worn (The Swapshop; Milieu Centraal, personal communication, 2022). The number of wears is partly related to the number of textiles a user owns. In a large wardrobe, it is likely that each textile item will be used less frequently and will thus last longer (Klepp, Laitala, & Haugrønning, 2019). The number of wears is crucial for determining the environmental impact of textile reuse (Klepp et al., 2020). The number of wears is measured in duration of wears for all owners.

Number of owners
Reuse possibilities create a cheap and convenient way of changing your wardrobe with a high turnover rate (Haagse Hogeschool, personal communication, 2022). This is mainly due to the ease of disposal and acquisition of textiles, including financial incentives. A change of owner has a negative impact on the environment compared to items used as many times but by one user only, due to the need for additional transport, sorting, and collection (Farrant et al., 2010). The number of owners is measured over the total lifespan of a textile item.

New consumed textile items
Prolonging the use period does not automatically mean that the consumer's collection of textiles remains the same (Levanen et al., 2021). Rebound effects occur if the lifespan of a textile items increases, but the consumption of new textile items remains the same (Siderius & Poldner, 2021). To measure these effects the new consumed textile items is an important variable. The amount of new consumed textiles is measured in the number of textile items per year.

6.2 AGENTS AND OBJECTS

An agent-based model consists of *agents* and *objects*. Entities capable of independent decision making are agents, all others are objects. All entities have *states* that describe and specify the object. Agents perform certain *behaviour* based on rules, which causes state changes. The *environment* is the background in which the behaviour takes place (van Dam et al., 2013).

Section 4.2 analysed the most important actors of the Dutch textile reuse system. The actors consumers and second-hand retailers will be explicitly modelled. From now on, these actors will be referred to as agents. First-hand retailers, collectors, and textile producers will be implicitly modelled. Meaning that their actions and behaviours are incorporated but they are not represented as a specific entity in the model. Governmental agencies are not incorporated in the model, they have the ability to steer the system in the preferred direction via policies and regulations. These will be tested during the modelling experimentation phase.

There are three main entities within the model:

1. **Textiles** - Items owned by consumers. Officially an object. However, textiles are treated in the model as agents because they are individually represented and conduct specific activities.

2. **Consumers** - Individual agents that perform (reused) textile consumption behaviour.

3. **Second-hand retailers** - Agent that possesses reused textile items.

The following sections describe the first two model entities in more detail. Because second-hand retailers play a minor role within the model, these are not individually discussed. However, the activities they perform will be mentioned in the consumer section. To eventually implement the concepts within the modelling environment, several assumptions have been made. An overview of all important model assumptions can be found in appendix F.

When a specific assumption is mentioned within the following sections, a reference will be made to the corresponding section within appendix F.

6.3 TEXTILES

Within the model, all textile items are represented as agents. They are owned by a consumer and can be reused or non-reused.

6.3.1 Lifespan definitions

The textiles have certain lifespans, amount of wears and owners. An overview of the lifespan definitions is shown in figure 6.1

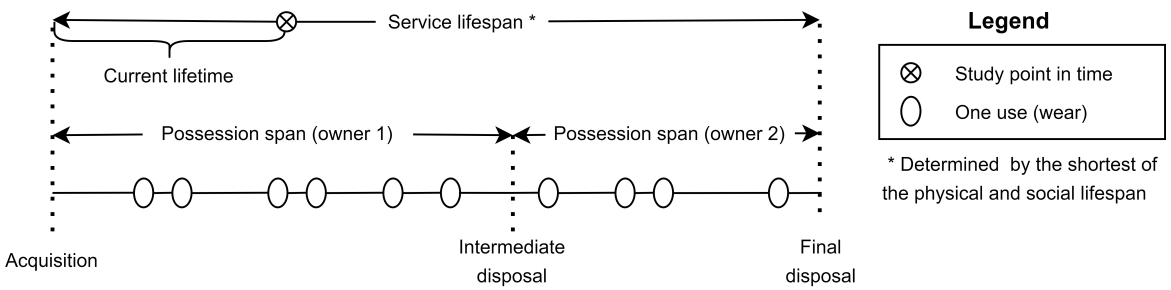

Figure 6.1: Schematic overview of textile lifespans (adapted from (Klepp et al., 2020))

Service lifespan
The service lifespan as explained in section 6.1 indicates the duration of the period that the textile item functions and can be used, including the possession of initial and subsequent users (Klepp et al., 2020). According to Klepp et al. (2019) the assumption can be made that the service lifespan can be calculated by multiplying the current service lifespan of a textile item. The service lifespan is determined by the shortest of the physical and social lifespan. The physical lifespan denotes the time the textile item can be put into use in the technical sense (Klepp et al., 2020). The social lifespan denotes the time that the garment is considered socially acceptable (Klepp et al., 2019). It is important to make a distinction between the social and physical lifespan because it determines whether the item could have been given an additional second life when disposed of (Modint, personal communication, 2022).

Possession span
The possession span denotes how long the owner possesses the garment in question Klepp et al. (2019). When the possession span for the specific textile item is reached, the item is disposed of by the current owner.

Wears
As explained in section 6.1 the number of wears indicates the number of times a garment is used (Klepp et al., 2020). This can be measured during the possession or lifespan of the textile item. The possession span is different for each textile item and consumer. At a certain study point in time, a textile item has a current amount of possession and lifespan wears.

6.3.2 Textile setup

When a textile item is produced, this item is linked to a specific owner. Furthermore, the item acquires a specified possession span and wears for that specific owner. The amount of possession wears is dependent on the predefined possession span. It is assumed that the possession span also determines how often a textile item can be worn by one owner, which is related to the quality of the item. The duration of the possession span and wear determine how long the textile item remains in the possession of the current owner. See an overview of the assumptions made in appendix F.3.

6.3.3 Lifespan decrease

Each day consumers wear several of their textile items; for these items, the current possession wears increases. For all items, the current possession span of the item increases. These variables indicate how long the item is in possession of the owner and how often the item is worn. When the current possession span or wears is greater than the predefined possession span and wears, the textile item is disposed of by the current owner. Unless formal or informal reuse is chosen as disposal option, the textile item dies and leaves the modelled system. See appendix F.3 for an overview of the assumptions made. When textile items are reused, these items acquire a new owner. Due to wear and possession by the previous owner, the possession span of this textile item is no longer equal to that of a similar new item. This relates to rebound due to imperfect or insufficient substitution, as identified by (Zink & Geyer, 2017). In this study, the possession span of the textile item with the new owner decreases compared to the possession span of the previous owner. This leads to the following assumption:

4. The possession span and wears of the textile item decreases every time the item changes owner (substitution effect)

This assumption is validated during the interviews. The interviewees stated that a reduction in possession span due to reuse seems reasonable. The assumption of the amount of reduction is based on research on textile reuse from ThredUP (2019), Farrant et al. (2010) and WRAP (2017). The research of ThredUP (2019) assumes that 30% of the textile lifetime is completed when a textile item is reused. WRAP (2017) however argues that a lifespan decrease of 50% seems reasonable when a textile item is reused. Farrant et al. (2010) assumes that reused garments are worn just as long as new clothes. As there is a great deal of uncertainty about the exact reduction, an educated assumption of 30% decrease has been made for this research. See Appendix F.4 for the assumptions made.

6.4 CONSUMERS

In the model, all consumers are represented as autonomous agents. They own textiles, buy new textiles and dispose of their old ones.

6.4.1 Consumer setup

At the beginning of the model, each consumer is added to a consumer segment. Depending on the consumer segment, consumers own values that determine their reused purchasing score. This score represents a percentage of textile reuse (see section 6.4.5). In addition, consumers have a social network which influences this score (see section 6.4.6). The amount of textiles a consumer owns is determined based on its consumer segment and reflects the size of the consumer's closet. The amount of textile purchases per year is also defined based on the consumer segment. See appendix F.1 and F.2 for the assumptions.

6.4.2 Textile disposal

If the possession span or possession wears of the textile item with the current owner is reached, the textile item is disposed of. Textiles are disposed of following the averages of the Dutch textile reuse system, determined in section 4.1.1. This results in the following disposal distribution: informal reuse (5%), formal reuse (9%), collection bin (39%) and regular waste (49%). The textiles recycled, incinerated and reused outside the Netherlands are monitored but leave the modelled system. All textile items can only be reused once. This assumption is added to prevent unrealistic long textile lifetimes in the scenario's with high levels of reuse. Therefore, all reused textiles leave the modelled system after the possession span with the second owner. See appendix F.3 for the assumptions made.

Informal reuse
Textile items that are disposed of via informal reuse are directly transferred from the previous owner to one of his friends. This is the friend with the greatest current textile need and a percentage of reuse greater than zero (see appendix F.3).

Formal reuse
Resale retailers possess formally reused textile items. From all textile items 9% is brought directly to the resale retailers. Furthermore, 5% of the textiles disposed of in collection bins end up with resale retailers. The textile items in possession by resale retailers acquire a new owner if a consumer decides to purchase a reused textile item (see appendix F.3).

6.4.3 Textile purchase

All consumers have a current textile need, which increases with their daily textile need. If the current textile need reaches the threshold to buy one textile item, the consumers purchases a non-reused or reused textile item. This choice depends upon the reuse percentage of the consumer. When a non-reused textile item is purchased, a new textile item is created and added to the closet of the consumer. When a reused textile item is purchased, one of the textile items in possession of the resale retailers is added to the closet of the consumer. See appendix F.2 for the assumptions.

The purchase of a reused item by the new owner might lead to the purchase of an additional textile item. The reused textile item is potentially cheaper than a new item, leading to money saved that can be reinvested in an additional item. This relates to rebound due to the income effect, as identified by (Zink & Geyer, 2017). In this study, the replacement rate of the new owner determines whether a new item is bought (see section 6.4.4). This leads to the following assumption:

5. The replacement rate determines whether the purchase of a reused textile item leads to the purchase of an additional item (income effect)

This assumption is based upon previous research about circular economy rebound effects as described in section 5.5. The assumption is validated during interviews. Some interviewees indicated that they were not familiar with rebound effects and therefore could not indicate whether these occurred within the industry (OLX; het Goed; Curitas; The Swapshop; D&B, personal communication, 2022). Other interviewees argued that it is very likely that rebound effects occur. They could not make statements about the magnitude of these effects but indicated that the existence of rebound effects in the form of replacement rates is very likely (Haagse Hogeschool; MilieuCentraal, personal communication, 2022). Two interviewees argued that rebound effects are definitely present within the industry and that the magnitude of the replacement rate is often underestimated (Modint; De Correspondent, personal communication, 2022). However, they also argued that it is difficult to make this explicit and that their statement was based on gut feeling.

6.4.4 Replacement rate

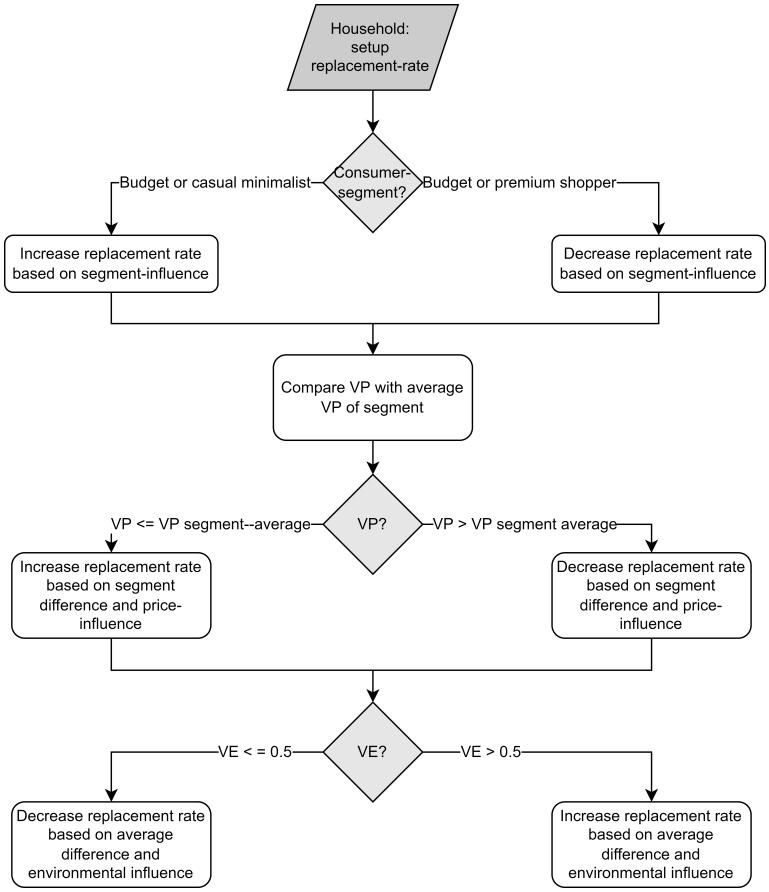

Figure 6.2: Flow diagram replacement rate

The replacement rate differs per consumer and is dependent on their consumer segment, value of price and value of environment. The initial replacement rate can be varied in the model. Based on the assumptions discussed in section 5.5, the replacement rate increases and decreases for each consumer. In the user interface of the model, the magnitude of the in- or decrease can be varied by means of a slider. See appendix F.4 for the assumptions

made. Figure 6.2 shows the flow diagram to determine the replacement rate per consumer, an enlarged version can be found in appendix E.

This approach is chosen because it provides an easy way to adapt the in- and decrease of the replacement rate. Farrant et al. (2010) argue that the magnitude of the replacement rate is very uncertain and therefore this uncertainty must be taken into account in the replacement rate estimation. Two other options were considered. Firstly, another option would be to define the replacement rate based upon each consumer segment. However, this would lead to insufficient differences between consumers within segments. Secondly, the replacement rate could be determined based on the percentage of textile reuse by consumers. However, interviewees argued that the intention with which consumers buy reused textiles is probably more important for the replacement rate than the amount of reused textiles consumers buy.

6.4.5 Reuse percentage

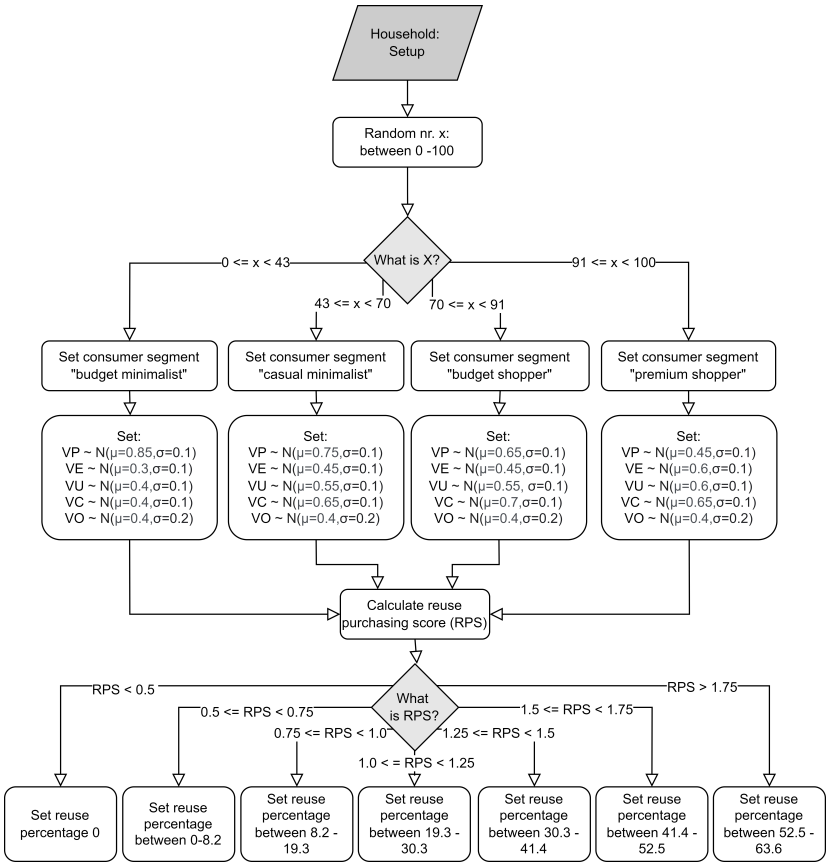

Figure 6.3: Flow diagram reuse percentage

The reuse adoption score of consumers is converted into a percentage of reuse using data from the study of (Gwozdz et al., 2017). According to (Gwozdz et al., 2017) consumers acquire on average 13.24 % reused textiles, with a standard deviation of 12.65%. Subtracting 5% informal reuse, leaves on average 8.24% reused textile purchases. The percentage of reused textiles is assumed to follow a normal distribution. This makes it possible to convert every specific adoption score to a specific percentage of reuse. See F.1 for the assumptions made. Figure 6.3 shows the flow diagram to determine the reuse percentage of consumers, an enlarged version can be found in appendix E.

This approach is chosen because the study of Gwozdz et al. (2017) provides a mean and standard deviation of the percentage of reused textiles purchases. This data is perfectly suitable for the development of a standard distribution. In addition, the mean and standard deviation of the reuse purchasing score were easily calculated. Other statistical distributions could also have been chosen, for example the Gamma or Poisson distribution. However, these distributions did not lend themselves well to this purpose. The gamma distribution is particularly useful in estimating success probabilities and the Poisson distribution expresses the probability of a given number of events occurring in a fixed time interval (Peacock & B, 2001). Furthermore, it is more robust to couple two random distributions instead of a random distribution with another statistical distribution, thereby avoiding unnecessary complexity.

6.4.6 Social influence

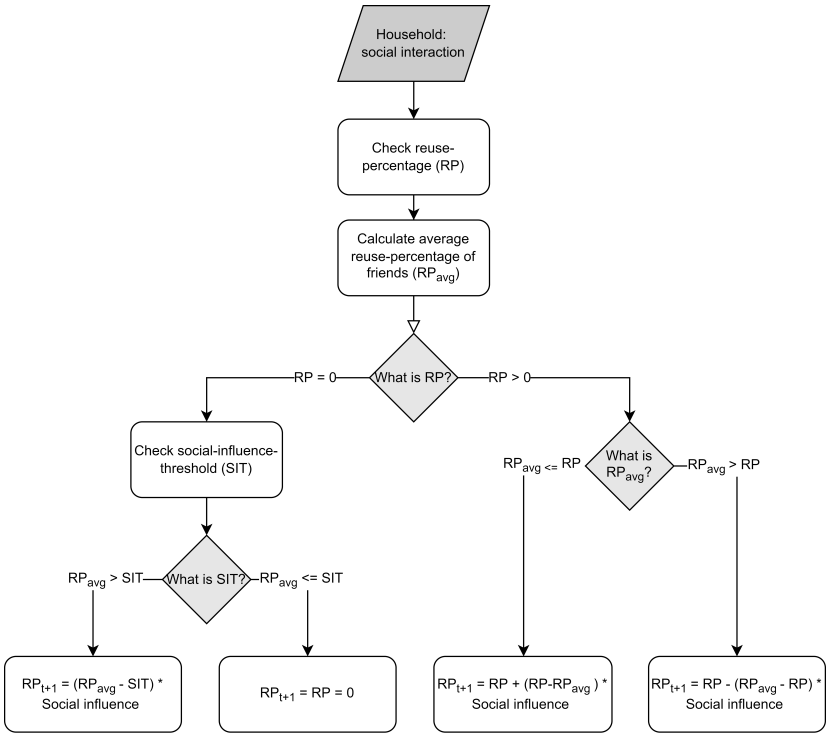

Figure 6.4: Flow diagram social influence

As discussed in section 2.7 the behaviour of consumers is influenced by the behaviour of their social network. According to (Polizzi di Sorrentino et al., 2016) human behaviour is best understood within a social context, as it is often shaped by the presence and behaviour of others. That is, drivers of behaviours are explained not only by people pursuing their own self-interest but also by the perceived behaviour of others (social norm). For pro-environmental behaviour, such as adopting reused textiles, this is an extremely important aspect (Polizzi di Sorrentino et al., 2016). Literature about reused textiles concur on this effect. Janigo and Wu (2015) argue that if consumers have friends who buy reused textiles, this will lead to an interest in buying reused textiles themselves (Janigo & Wu, 2015). But this also works the other way around, consumers observe friends with a negative perception towards reused textiles and adopt this behaviour as theirs (Nordlund & Garvill, 2002). To include social influence in the model, a social network is established. Each consumer is part of the social network and has at least one connection to another consumer. The con-

nections of consumers are called friends and are established based on the initial location of the consumer.

Each day, consumers calculate the average percentage of reused textiles of their friends (RP_{avg}). The difference between the calculated percentage and the own reuse percentage of the consumer (RP), determines whether the percentage of reuse of the consumer increases or decreases. The greater the difference, the greater the in- or decrease of the reuse percentage. The strength of this effect is uncertain, therefore the social influence (SI) factor is added. This value can be varied to determine the strength of social interaction. If the percentage of reuse of the consumer is zero, the percentage of reuse only increases if the average percentage of reuse of the friends is greater than a certain threshold. This is added because this consumer shows resistance to buying reused textiles. This barrier can only be resolved once the social influence of the friends is large enough. See appendix F.2 for the assumptions made.

If the reuse percentage is greater than zero and greater than the threshold, the new reuse percentage is calculated by means of formula 6.1. Figure 6.4 shows the flow diagram of the social influence of consumers, an enlarged version can be found in appendix E

$$RP_{t+1} = RP_t + (RP_{avg} - RP_t) * SI \tag{6.1}$$

This approach is chosen because the literature as described in section 2.7 argues that consumers are influenced by their social network. Therefore, the average reuse percentage of all friends determine the social influence of the consumer. Another option could have been to determine the social influence based upon the most influential friends. For example, friends with a relatively high or low reuse percentage. However, this would result in a few consumers that determine the overall social influence. The literature describes however that consumers are influenced by all of their friends, also the moderate ones. In addition, because of the high level of uncertainty of the social influence regarding reused textiles, a slider with the magnitude of social influence is added. This magnitude could also have been determined per consumer, for example based upon the amount of friends they have within their social network. This would result in consumers with few friends adapting their percentage of textile reuse less quickly than consumers with a lot of friends. However, in reality, one very good friend might have as much influence as several friends combined.

6.5 CONCLUSION

Together with chapter 5 this chapter answered sub-question 2. The Key Performance Indicators of the model are the service lifespan, number of wears, number of owners, new consumed textiles and percentage reused textiles. The model consists of the entities textiles, consumers and second-hand retailers. Textile items are conceptualized based upon their service-lifespan and amount of wears which consists of the sum of respectively, the possession span and possession wears of different owners. Every time the textile item is reused, the possession span and wears of the textile item decreases (substitution effect). Textile items are disposed of by consumers on the basis of the following options: informal reuse, formal reuse, collection bin and regular waste. Consumers buy reused or non-reused

textiles based upon their reuse percentage. When a reused item is purchased, the replacement rate determines if the purchase leads to the purchase of an additional item (income effect). In addition, the social network of the consumer influences the percentage of reuse. The next chapter describes how the conceptualized model is implemented in the Netlogo software.

7 MODEL IMPLEMENTATION

In this chapter the model implementation is explained. Firstly, the model interaction is presented on the basis of a BPMN-inspired conceptual model. Secondly, the implementation within the software modelling environment is discussed. Lastly, the verification steps are elaborated upon.

7.1 MODEL INTERACTION

The interaction between entities, as described in chapter 6, is represented and visualised in figure 7.1. A larger version can be found in appendix E. The visualisation is inspired by the Business Process Model Notation (BPMN). BPMN-diagrams allow describing processes with a high abstraction level and are therefore useful in describing a large variety of systems (García-Holgado et al., 2015). The figure consists of three 'swimming lanes' showing the entities of the model. The start and end of the process are depicted as circles. Activities are shown as rectangles and represent the tasks performed by an entity. Gateways, displayed as diamond shapes, indicate the decision points of entities that can adjust the process pattern flow. The lines show the main order of the activities performed, within entities (solid) and between entities (dashed).

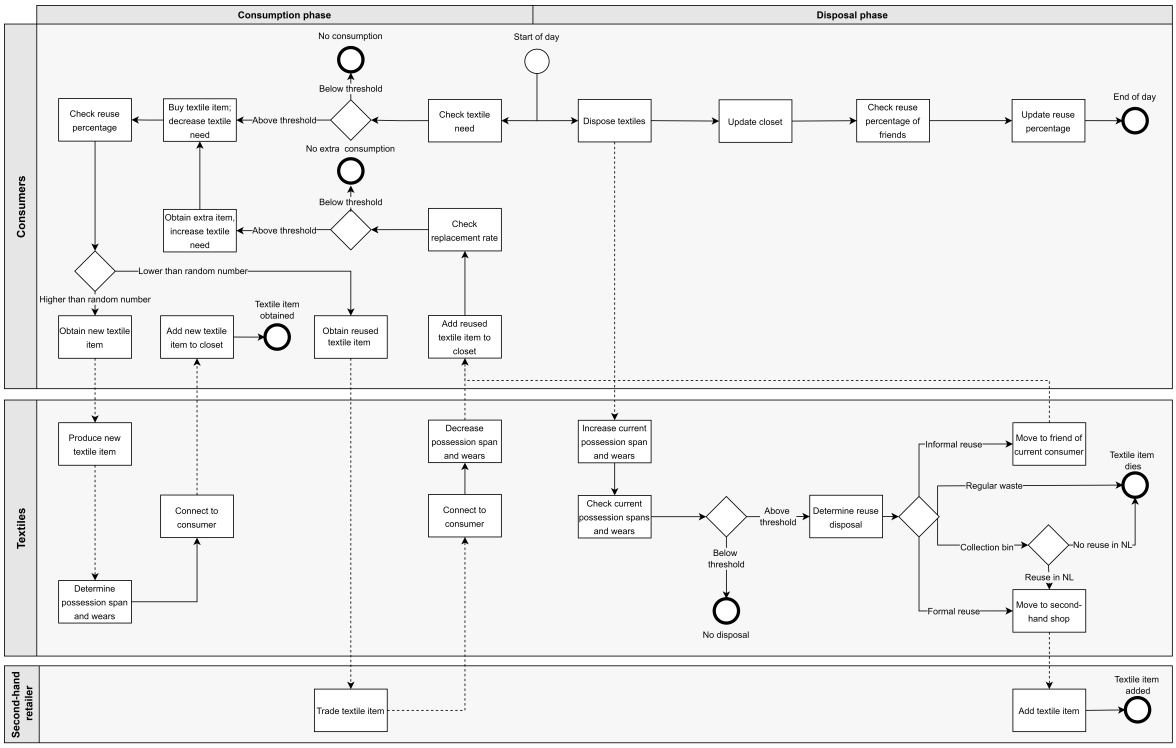

Figure 7.1: BPMN-inspired conceptual model

7.2 SOFTWARE IMPLEMENTATION

The conceptual model described in the previous chapter and presented in figure 7.1 has been implemented in the Netlogo 6.2.2 software. This thesis report does not discuss the description of the model code. Readers interested in the model code can consult the documentation that is published on this Github page: https://github.com/Brittzandbergen/textile-reuse-thesis.

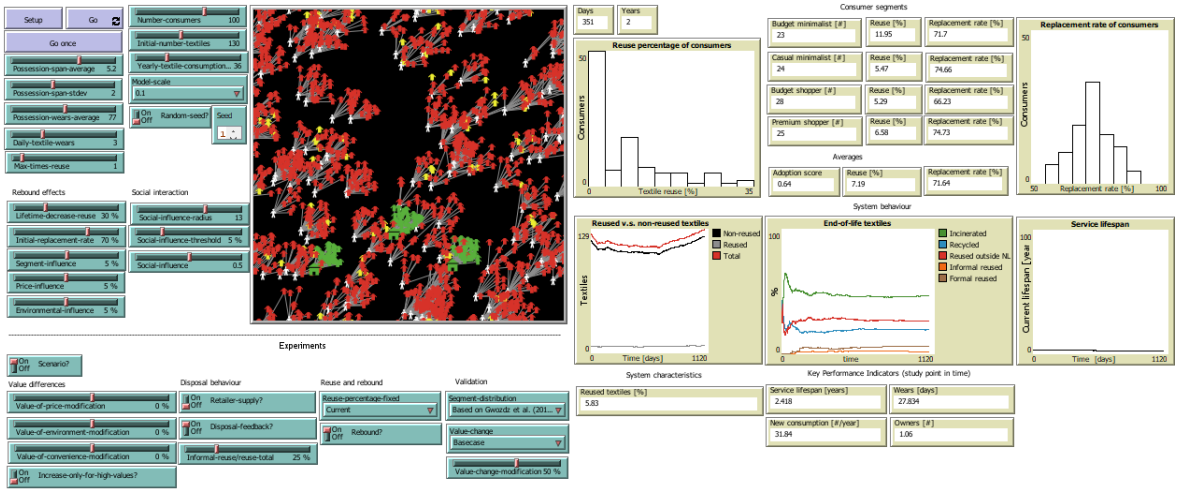

Figure 7.2: Netlogo interface

The Netlogo model interface is shown in figure 7.2. The figure shows the visualisation of the model behaviour in the middle. On the left, the model inputs are displayed as buttons, sliders, switches, and choosers. On the right, the model outputs are visualized as monitors and graphs.

7.2.1 Time sequence

The model run starts by pressing the setup button in the top left corner. All model variables are then initialized and the model entities obtain their properties as described in chapter 6. By pressing the go button, one model run starts. The model run ends by pressing the go button again. The model runs in time steps, where each time step represents a period of one day. This time sequence is chosen because every day there is a possibility that consumers perform certain behaviour (e.g., purchasing textiles). With time steps of one hour the model would have to run for a very long time before generating results. One month, and the results would not be specific enough. Within a month consumers would buy and discard too many items.

The model runs in discrete time steps. Each time step, the model runs all activities of all agents sequentially. This means that the next time step starts when all agents have performed their activities. This is an abstraction of reality, because in real-life agents behave simultaneously. Therefore, it is important to consider the order in which agents perform activities (van Dam et al., 2013). This is spcifically important for the social interaction process. If consumer A always proceeds before consumer B, this means that the in- or decrease of the reuse percentage of consumer A is always updated before B. To prevent this from happening, the order in which consumers perform their activities is chosen randomly.

7.2.2 Parametrization

Parametrization entails the process of selecting suitable initial model parameter values. This is an important process because the model outcomes are generally sensitive to the set of initial values chosen (van Dam et al., 2013). Especially the parametrization of the consumer values was a difficult process. These variables are very uncertain and hard to obtain because behavioural research often does not translate these values into quantitative scores. Therefore, the parametrization of the consumer values is extensively discussed in chapter 2.7. An overview of the complete parametrization can be found in appendix G.

7.3 VERIFICATION

Verification entails checking whether all relevant entities and relationships from the conceptual model have been translated into the programming software correctly (van Dam et al., 2013). The verification process took place during software implementation and after finalization of the model. The agent-based model was constructed iteratively and the model was checked in every step to see whether it was implemented in accordance with the design. After finalization of the model, the verification steps described by van Dam et al. (2013) were applied. These steps entail code walk-through, recording and tracking of agent behaviour, interaction testing limited to minimal model and multi-agent testing. The execution of these methods is described in appendix H, with the conclusion that the model has been correctly implemented.

7.4 CONCLUSION

This chapter answers sub-question 3. The BPMN-inspired conceptual model shows the interactions of the model. This enables to program the interactions in the modeling software Netlogo. The verification process concluded that the model is correctly implemented. The next chapter presents the experimental setup for the programmed agent-based model.

8 EXPERIMENTATION

In this chapter the process of the ABM experimentation is discussed. The chapter is divided into two parts. Firstly, the experiments that are run to gain insight in general model behaviour are presented. The outcomes of the experiments provide insight into the textile reuse behaviour within the Netherlands and the occurrence of rebound effects. Secondly, the chapter presents experiments that are run to measure the effect of value changes. This provides insight into how value change can lead to preferable reused textile behaviour.

All experiments consist of different variations of parameter settings. A combination of specific parameter settings is called a scenario. All scenario's are run multiple times to prevent randomness within scenario's. These runs are called replications.

8.1 GENERAL MODEL BEHAVIOUR

This section describes the different experiments performed to provide insight in the general model behaviour. Firstly, the experimental setup of these experiments is presented. Secondly, the general model behaviour experiments are elaborated upon.

8.1.1 Experimental setup

The experiments performed to gain insight into the general behavior of the model are presented in table 8.1. The table shows for every experiment the parameters that are changed, the value range of these parameters, the model run time, number of scenarios and the replications per scenario.

Table 8.1: Experiments base case

Experiment	Parameters	Value range	Run time	Number of scenario's	Replications per scenario
Base case	Initial parametrization	-	100 years	1	50
Reuse variation	Reuse percentage	[0-100 %]	75 years	6	20
Rebound	Random-seed Reuse percentage Rebound?	Fixed [0-100%] On, Off	75 years	4	20

8.1.2 Experiment description

Base case
In the base case, the model was run 50 times with the parametrization as described in ap-

pendix G. This experiment provides insight in the effects of the Key Performance Indicators in the current situation.

Reuse variation
During this experiment, the model is run with six different average percentages of reuse. The experiment provides insight in how the level of reuse influences the Key Performance Indicators over time.

Rebound effect
The rebound effect experiment shows the influence of rebound effects on the Key Performance Indicators. Chapter 2 describes rebound effects from textile reuse are often omitted in academic literature and modelling studies. This experiment indicates the difference between including and excluding these rebound effects, with different percentages of reuse. To properly compare the outcomes, the random seed for all the scenario's is set equal. This means that for all scenario's the same starting conditions are chosen. Therefore, the differences between results due to randomness are omitted.

8.2 VALUE ANALYSIS

This section describes the approach for testing the effect of values on the behaviour of consumers. Firstly, the necessity for this analysis is discussed by explaining the need for behavioural change. Secondly, the experimental setup for the value analysis is presented. Lastly, the value experiments are elaborated upon.

8.2.1 Behavioural change

The literature review in chapter 2 describes the current behaviour regarding reused textiles based on the Theory of Planned Behaviour. This theory presupposes that behaviour is influenced by the joint effect of three determinants: attitudes, perceived behavioural control and subjective norms (Ajzen, 1991). According to the theory these three determinants lead to an intention, which leads to certain behaviour. However, in this research this is simplified and the intention-to-behavior step is omitted (see chapter 10). The attitudes and perceived behavioural control are incorporated into drivers and barriers to purchase reused textiles. This results in a percentage reused textiles which is influenced by social interaction, reflecting the subjective norm of the theory. The current goal of the Extended Producer Responsibility for textiles, defined by the Dutch government, is that in 2030 75% of all disposed of textiles should be reused or recycled (Rijksoverheid, 2021). To reach this aim there is a clear need to change the current behaviour regarding reused textiles. This behavioural change can be achieved by producing alterations in behavioural intentions, directed at one or more of the determinants of the theory of Ajzen (2006). As in this research, these determinants are represented as consumer values, the changes in these consumer values could lead to preferred behavioral change.

The experiments of the value analysis are set up in such a way that the distribution of the values is adjusted. These value changes can be used to design interventions. The value changes presented do not target all five identified consumer values. The values uniqueness and ownership are more difficult to stimulate by external interventions. This is also reflected in the categorization of interventions, as presented in appendix I. Therefore only

the three values: price, environment and convenience are incorporated in the experimental set up.

8.2.2 Experimental setup

Every scenario is run for a time period of 75 years and is replicated 20 times. Within every scenario the value change is set after 15 years. Providing insight into the actual effect of the value change on the Key Performance Indicators in comparison to the current situation. Table 8.2 presents the different scenario's, including the category, parameters, values and the number of scenario's this creates.

Table 8.2: Experiments value analysis

Category	Experiment	Parameters	Value change	Number of scenario's
Price	Price increase	Value of price	0%, 25%, 50%, 75%, 100%	5
Environment	Environment increase	Value of environment	0%, 25%, 50%, 75%, 100%	5
Convenience	Convenience increase	Value of convenience	0%,-25%,-50%,-75%,-100%	5
Combination	Value combination	Random-seed	Fixed	5
		Value of price	+50%	
		Value of environment	+50%	
		Value of convenience	-50%	
	Value combination high values	Random-seed	Fixed	5
		Value of price	*If value* $>$ *0.5 then* +50%	
		Value of environment	*If value* $>$ *0.5 then* +50%	
		Value of convenience	*If value* $>$ *0.5 then* -50%	
	Consumer segment difference	Random-seed	Fixed	16
		Segment-distribution	4 consumer segments	
		Value of price	+50%	
		Value of environment	+50%	
		Value of convenience	-50%	

8.2.3 Experiment description

Price/ environment/ convenience increase
In these experiments the values of price, environment and convenience are independently adjusted. This provides insight into the influences of the values on the KPI's over time. Thereby giving an idea of the effectiveness of these value changes. Because the value of price and environment are drivers for purchasing reused textiles, these values increase. This means that the importance of this value in the decision to purchase reused textiles increases, leading to more reused textiles. For the value of convenience, this is different. This value is reduced because it is a barrier for purchasing reused textiles. Therefore, the importance of this barrier to buying reused textiles decreases, leading to more reused textiles.

Value combination
In this experiment, the values of price, environment and convenience are independently adjusted with 50%. To properly compare the outcomes, the random seed for all the scenario's is set equal. This experiment provides insight into the effect of the values on the Key Performance Indicators. This allows the value changes to be compared with each other.

Value combination high values
In this experiment the values of price, environment and convenience are only adjusted if

the consumer value is already above a certain threshold. Some value changes only target consumers who already consider this value to be important. For example, a reduction in price of reused textiles might not lead to more reused textile consumption by consumers who did not perceive price as important in the first place. Therefore, only consumers that perceived that specific value are targeted by the value change. To properly compare these outcomes, the random seed for the scenario's is fixed as well. This experiment provides insight in the value change if only consumers are targeted that already perceive the specific value as important.

Consumer segment difference
In this experiment, the value changes are compared for the four consumer segments. In every scenario there is only one consumer segment, meaning that all consumers are part of this specific segment. In addition, the values are individually adjusted with 50% for every scenario. To properly compare the outcomes, the random seed for the scenario's is fixed as well. This experiment enables to investigate the effect of value changes for the different consumer segments.

8.3 CONCLUSION

This chapter partly answered sub-question 4 and 5. Two types of experiments are run; one to provide insight in the general model behaviour and the second to test the effect of value changes. The first experiment, is used to provide an in-depth understanding of the performance of reuse on the Key Performance Indicators and the occurrence of rebound effects. The second experiment is used to gain knowledge about the effectiveness of different value changes. The next chapter presents the results of the performed experiments.

9 RESULTS

In this chapter, the results of the experiments are presented, followed by an interpretation of the outcomes. Firstly, the experiments performed to provide insight in the general model behaviour are discussed. Secondly, the experiments of the value analysis are presented. Lastly, the steps performed for the validation analysis are elaborated upon.

9.1 GENERAL MODEL BEHAVIOUR

This section provides insight on the general model behaviour over time. The most important results are discussed in the following sections, all other model results can be found in appendix J.

9.1.1 Base case

The Base case experiment provides insight into the development of the Key Performance Indicators over time with the initial parametrization. This section starts with an elaborate description of the characteristics of the model results. The total run time, warm-up time and the choice of the visualization of the results are discussed. Lastly, the development of the percentage of reused textiles over time is elaborated upon.

Run time
All experiments are run for at least 75 years. This provides insight into the model behaviour over a long period of time. However, it must be noted that future behaviour (e.g., population growth, textile consumption) is not incorporated in the model. Therefore, the results should be interpreted as if the current scenario were stretched out over a long period of time. The results provide insight in this current scenario, but do not reflect an expected future perspective.

Warm-up time
The agent-based model consists of a large number of parameters. The established Key Performance Indicators are influenced by these parameters, and therefore the model should be calibrated before the model results can be interpreted (Zhang, Li, & Zhang, 2020). This results in a warm-up time of the model. An example of the warm-up period is illustrated in figures 9.1 and 9.2. Figure 9.1 shows the development of the consumption of new textile items in the first three years, for one model run. Figure 9.2 indicates the average consumption of new textile items of 50 model runs for the total run time of 100 years. The example in figure 9.1 shows that during the first months, the consumption of new textile items fluctuates just above zero. After that period, the consumption of new increases with some peaks and valleys until after one and a half years it remains a stable increase. It must be noted that this figure illustrates the warm-up time for one specific model run. However,

for each model run the warm-up time might differ. Figure 9.2 indicates that on average the consumption of new textiles has reached an equilibrium after almost 15 years.

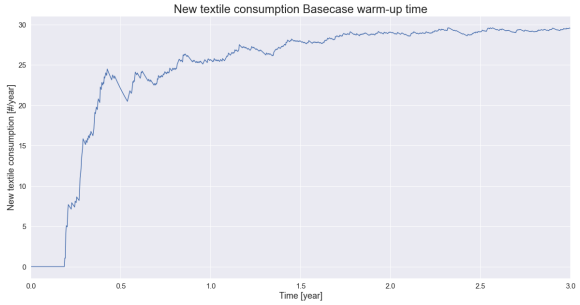

Figure 9.1: Line graph new consumption base case 3 years (one run)

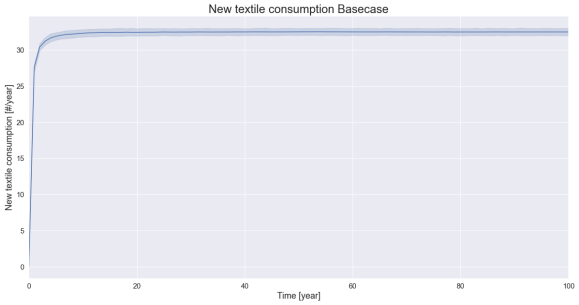

Figure 9.2: Line graph new consumption base case 100 years (50 runs)

Visualization of results

In figures 9.1 and 9.2 the warm-up period is only illustrated for the consumption of new textile items. However, this behaviour occurs for all Key Performance Indicators. All model results in this chapter are visualized for at least 75 years. Due to the decision to visualize this long run duration, the warm-up period is often not clearly visible. This is not a major problem when interpreting the results, as the equilibrium is particularly important. However, it is important to realize that in the period before this equilibrium, the model also exhibits behaviour to calibrate the parameters.

Percentage reused textiles

Figure 9.3 and 9.4 show, respectively a line graph and a boxplot of the percentage of reused textiles over a time period of 100 years.

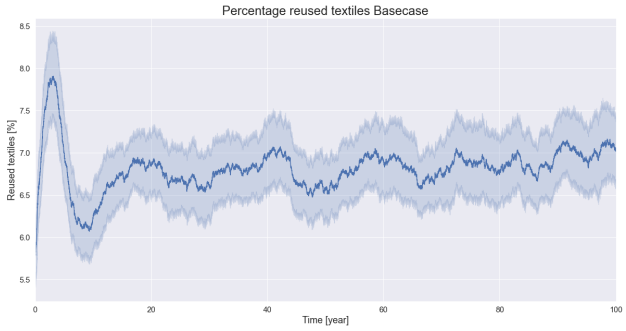

Figure 9.3: Line graph percentage reused textiles basecase

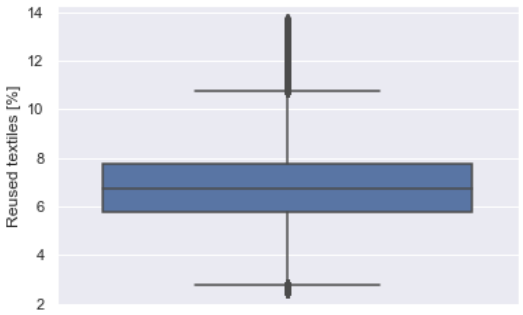

Figure 9.4: Boxplot percentage reused textiles basecase

Figure 9.3 indicates that when in equilibrium, the percentage of reused textiles shows some variation but remains a steady line. The variation can be explained because of emergent behaviour within the model. Consumers do not purchase an evenly amount of reused textiles but this is dependent upon social interaction. In addition, the total amount of reused textile items in the textile reuse system fluctuates because of rebound effects. Reused textiles are disposed of earlier than new textile items (substitution effect) and do not always displace a similar new item (income effect). Figure 9.4 shows that the reuse percentage lies between 6 and 8% for 50% of the time.

The results of the percentage of reused textiles indicate that under current circumstances, the percentage of reuse in the Dutch textile reuse system will remain stable over time. How-

ever, to reach the government's aim of achieving a circular textile chain in 2050 an increase in textile reuse is necessary (Rijkswaterstaat, n.d.). Therefore, the results emphasize the need for behavioural change to increase the amount of reused textiles. The results of value change to improve the levels of reuse are elaborated upon in section 9.2.

9.1.2 Reuse variation

The reuse variation experiment gives insight in the development of the Key Performance Indicators over time with different levels of reuse. The most important results of the Reuse variation experiment will be discussed in this section, all other model results can be found in appendix J.

New textile consumption
Figure 9.5 and 9.6 show the variation in the percentage of reuse on the level of new textile items consumed in the Netherlands.

Figure 9.5: Line graph new consumption reuse variation

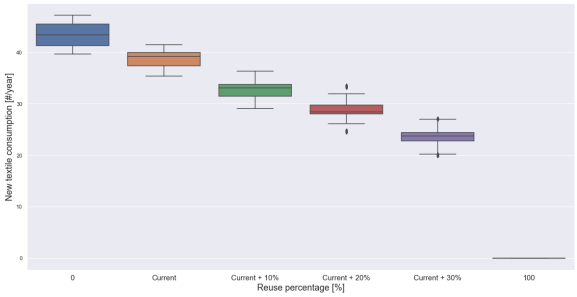

Figure 9.6: Boxplot new consumption reuse variation

The figures clearly indicate a dependency of the level of reuse on the consumption of new textile items. This shows that, although rebound effects occur, an increase in reuse still leads to a decrease in newly consumed items. Therefore, the amount of virgin input is reduced, which limits the environmental burden of the textile industry.

Figure 9.5 shows interesting behaviour with respect to the 100% reuse scenario. The line stops on average after 8 years. This is the case because textile items can only be reused once, to prevent unrealistic long textile lifetimes within the model. As a result, there are no more textile items that consumers can wear (see assumption F.5). This indicates that 100% textile reuse is not a viable scenario. We will always need some input of new textile items. However, this also indicates that we have enough clothes in our closet to last a couple of years if we properly reuse them.

In the 100% reuse scenario, textiles leave the modeled system quickly because they can only be reused once. The Key Performance Indicators (KPI's) are only measured for the textiles within the system. This creates distorted results because the lifetime and number of wears are only measured for the items within the system and therefore these variables increase rapidly. To avoid confusion and ambiguity, this scenario is omitted from the figures below. The results are for completeness shown in appendix J.

Textile lifespan
Figures 9.7 and 9.8 show the service lifespan of textiles, with different percentages of reuse.

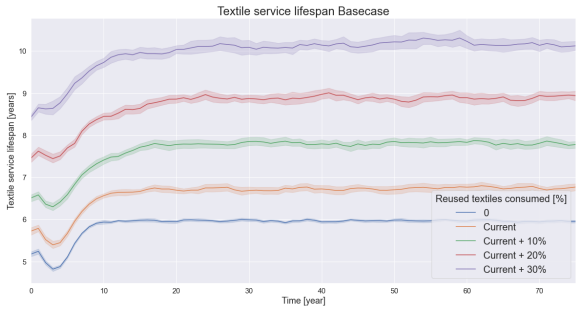

Figure 9.7: Line graph service lifespan reuse variation

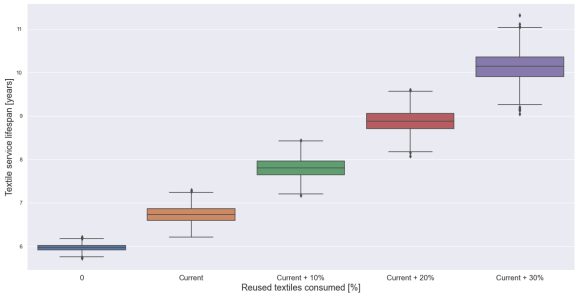

Figure 9.8: Box plot service lifespan reuse variation

The figures show that an increase in reuse leads to an increase in the service lifespan. Indicating that because of reuse, the textile item obtains a second item. Therefore, the average lifespan of all textile items in the system increases.

Number of wears

Figures 9.9 and 9.10 show the number of wears of textiles, with different percentages of reuse.

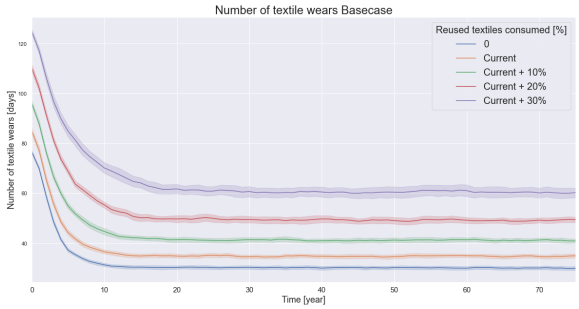

Figure 9.9: Line graph number of wears reuse variation

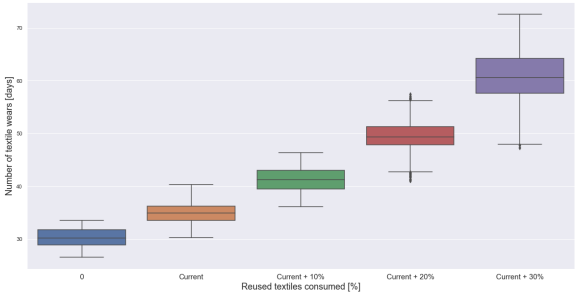

Figure 9.10: Box plot number of textile wears reuse variation

The figures show that an increase in reuse leads to an increase in the number of times a textile item is worn. This indicates that textile reuse not only leads to an increase in the lifespan of textile items, but that overall the items are also worn more often. This is the case, because most of the times the reused textile item replaces a new textile item. In these cases, the item is not an additional item in the closet and therefore the total amount of items in the closet remains stable.

Number of owners

Figures 9.11 and 9.12 show the number of owners of textile items, with different percentages of reuse.

The figures show that an increase in reuse also leads to an increase in the number of owners. This is logical, because reused items are possessed by more than one consumer. It is however understand that a change in owner often leads to additional activities that potentially have an environmental impact (e.g. collection, sorting and transport).

Figure 9.11: Line graph number of owners reuse variation

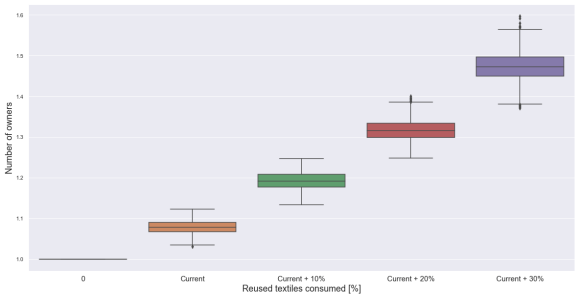

Figure 9.12: Box plot number of owners reuse variation

9.1.3 Rebound effects

Figure 9.13 until figure 9.20 give insight in the development of the Key Performance Indicators over time, with and without rebound assumptions. In the scenario where rebound is true, the two rebound assumptions lifetime decrease (substitution) and replacement rate (income), are active. In the rebound is false scenario, the rebound assumptions are set inactive. Meaning that the results are presented without rebound. The results give insight in the difference in the outcomes when rebound assumptions are and are not incorporated. The results will be discussed per Key Performance Indicator.

Percentage reused textiles

Figure 9.13 and 9.14 show the level of reused textiles in the system, while indicating the level of rebound.

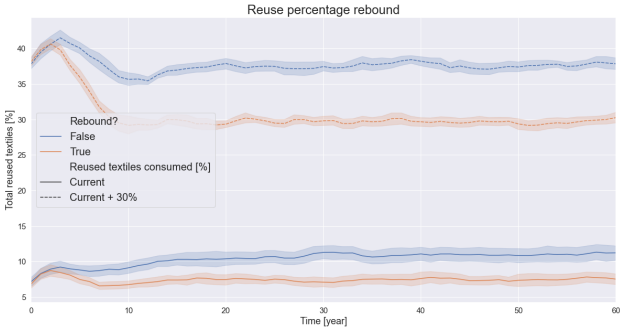

Figure 9.13: Line graph percentage reused textiles rebound

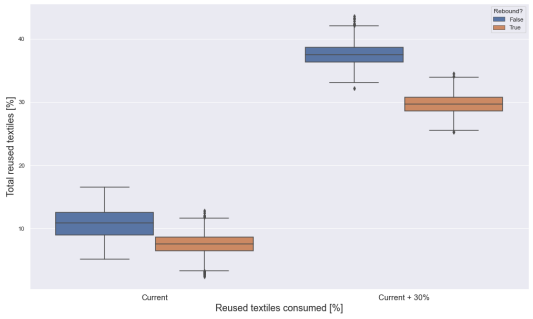

Figure 9.14: Boxplot percentage reused textiles rebound

There is a clear distinction between the percentage of reused textiles in the system in the active and in the inactive rebound scenario. This difference can be explained by the fact that reused textiles within the rebound scenario are degraded sooner because of the shorter possession span (substitution effect). This effect is also visible when looking closer at the active rebound scenario. The current percentage of reuse is around the 13%. However, within the scenario where rebound is active the reuse percentage measured within the system is less, around the 8%. This indicates that due to rebound, the level of reused purchases by consumers does not reflect the total percentage of textile reuse within the industry.

New textile consumption

Figures 9.15 and 9.16 show the amount of newly consumed textiles with different reuse percentages, while indicating the level of rebound.

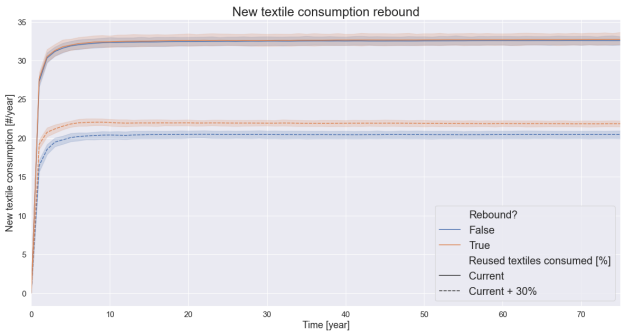

Figure 9.15: Line graph new consumption rebound

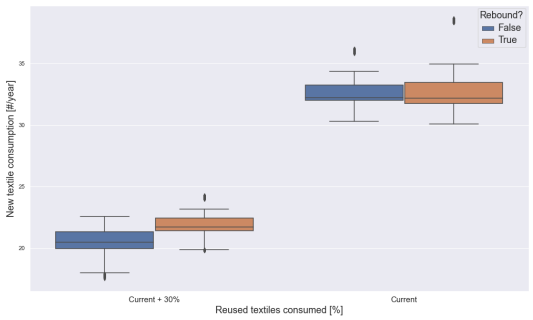

Figure 9.16: Boxplot new consumption rebound

The figures show different behaviour for the current and increased reuse scenario. In the current scenario, there is almost no difference in the consumption of new textile items with or without rebound. However, for the increased reuse scenario this difference is clearly visible. The results show that in the current situation, rebound effects have no major effect. But with higher levels of reuse, rebound effects become apparent. This means that the reduction in new textile consumption due to reuse might be overestimated if rebound effects are not incorporated. This is because rebound effects cause the purchase of a reused textile item to lead in some cases to the purchase of an additional item (income effect). In figure 9.16 for the current level of reuse, the median is almost equal and the 50% confidence intervals overlap. For the increased level of reuse scenario, the confidence interval does not overlap. Indicating that there is an apparent difference between the two scenarios.

Total service lifespan

Figures 9.17 and 9.18 show the total service lifespan with different reuse percentages, while indicating the level of rebound.

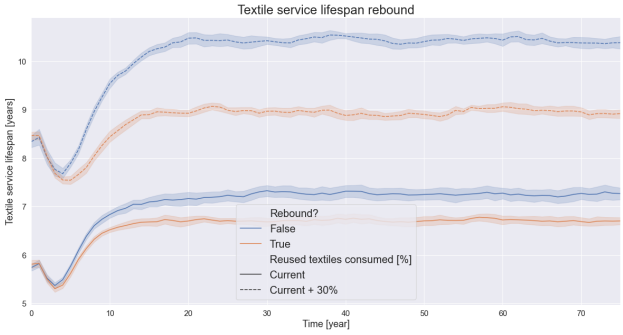

Figure 9.17: Line graph service lifespan rebound

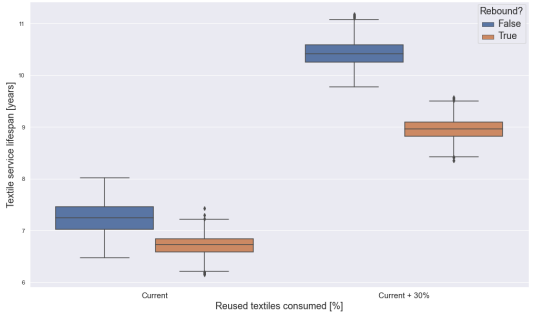

Figure 9.18: Boxplot service lifespan rebound

There is an apparent difference between the service lifespan in the rebound scenario's. The service lifespan is considerably higher in the scenario where the rebound effects are inactive. The difference is largest for the scenario with the highest level of reuse. The larger service span can be explained because of the degradation in lifespan when the item is used by the next owner (substitution effect). In the scenario with more reuse, there are more textile items that are possessed by more than one owner during their lifetime. Therefore, a decrease in lifetime due to reuse occurs relatively more often. The boxplots in figure 9.18 do not overlap, indicating that there is a difference between the two groups.

Amount of wears

Figures 9.19 and 9.20 show the amount of wears with different reuse percentages, while indicating the level of rebound.

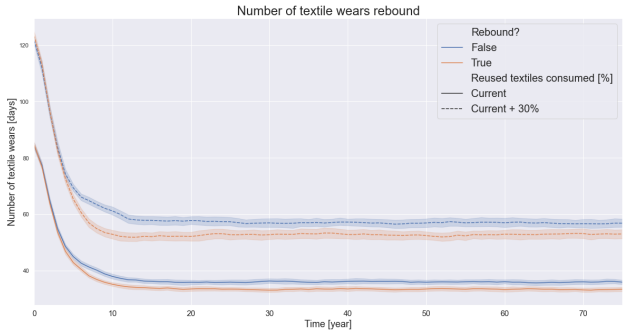

Figure 9.19: Line graph amount of wears rebound

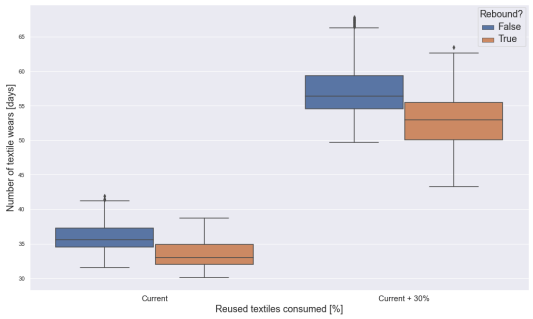

Figure 9.20: Boxplot amount of wears rebound

The amount of textile wears is comparatively higher for the scenario where the rebound effects are inactive. However, the difference is smaller compared to the service lifespan variable. This is because the textile items are mostly disposed of because they exceed the possession span instead of the possesion wears. This will be discussed further in chapter 10. The possession wears is because of this often not a determining factor. As a result, the rebound effect is more visible in the service lifespan of textiles than in the number of wears.

Number of owners

Figures 9.19 and 9.20 show the amount of owners, while indicating the level of rebound.

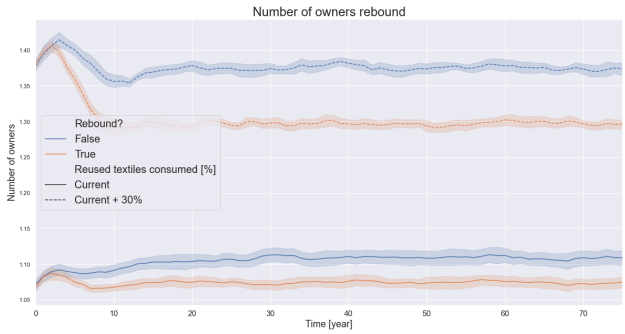

Figure 9.21: Line graph owners rebound

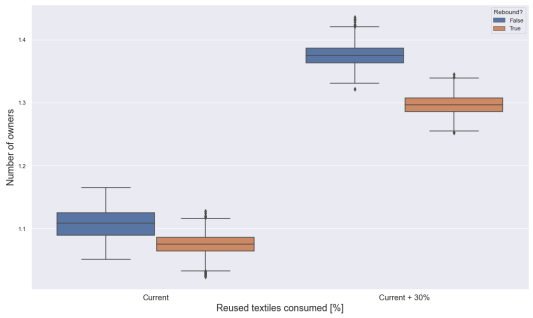

Figure 9.22: Boxplot owners rebound

The results show that the number of owners is apparently higher in the scenario where the rebound effects are inactive. This can be explained because in the scenario with rebound, reused textile items are degraded sooner because they have a shorter possession span (substitution effect). Because they are reused, these items have two owners which causes the average number of owners to go up. However, in the scenario with rebound these items leave the system sooner. Therefore, the average number of owners of the total amount of textiles seems higher in a scenario where rebound effects are not incorporated.

9.1.4 Interpretation

The results show that to reach a circular textile chain by 2050, textile reuse is necessary. Even though rebound effects occur textile reuse still leads to a decrease in the consump-

tion of new textile items, thereby reducing virgin input and its environmental effects. In addition, reuse leads to an increase in the lifespan of textile items and the number of times a textile item is worn. This indicates that the textile item is often not an additional item in your closet, but it is really worn. The increase in reuse also leads to an increase in the number of owners of a textile item. This is important, because transferring a textile item from one consumer to the other often require additional activities with an environmental impact (e.g. collection, sorting and transport).

Although reuse still seems to be beneficial it is important to incorporate rebound effects to safeguard the environmental and market integrity of the textile industry. This has two main reasons. Firstly, not incorporating rebound effects leads to an overestimation of the amount of textile items in the Netherlands. The amount of consumed reused textiles does not correspondent to the amount of items possessed by consumers. Because reused textiles have a shorter lifespan, which ensures that they will be discarded earlier by these consumers. Secondly, not incorporating rebound effects leads to an overestimation of the increase in the lifetime of textiles and the number of times an item is worn. Currently, the overestimation of the reduction in new consumed textile items when rebound effects are not incorporated is minor. However, with higher levels of reuse, the effects are clearly visible. Indicating that with an increase in reuse, not incorporating rebound will almost certainly result in an overestimation of the reduction in new consumed textiles.

Based upon these insights several recommendations are made. These can be found in section 10.5.

9.2 VALUE ANALYSIS

This section presents the effect of value changes on the Key Performance Indicators over time. The most important results are discussed the following sections, all other model results can be found in appendix J.

9.2.1 Price increase

This experiment shows the effect of an increase in the driver of price to purchase reused textiles.

Total reused textiles
The figures 9.23 and 9.24 show that there is a clear relationship between the increase in prices and the amount of reused textiles. This indicates that an increase in the importance of price to purchase reused textiles results in an increase in the percentage of reused textiles. Doubling the value even leads to a tripling of the total percentage of reused textiles.

New consumption
The figures 9.25 and 9.26 show a relationship between the value of price and the consumption of new textile items. The reduction is less notable than the increase in total reused textiles. This can be explained by rebound effects. In some cases, the purchase of a reused textile item also leads to the purchase of an additional new item. Thereby reducing the impact of a value of price increase on the consumption of new textile items.

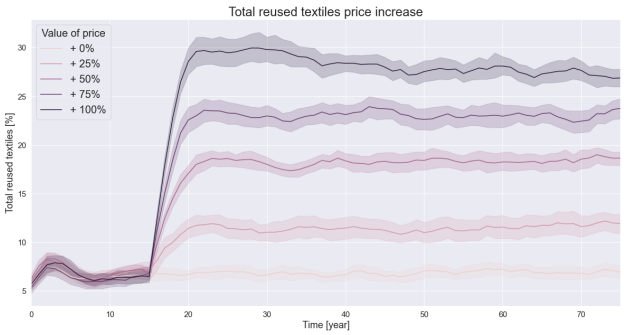

Figure 9.23: Line graph total reused textiles price increase

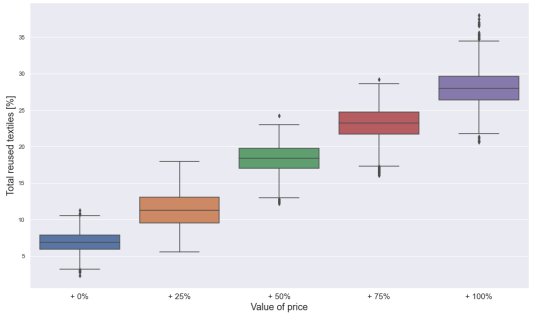

Figure 9.24: Boxplot total reused textiles price increase

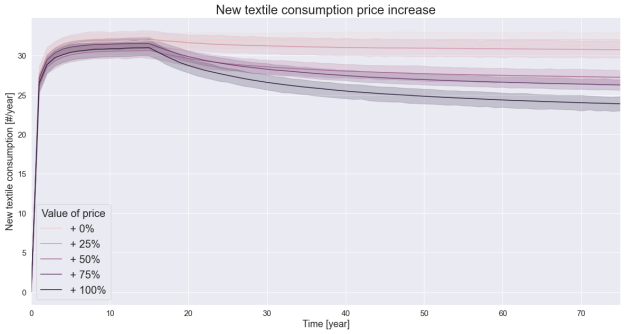

Figure 9.25: Line graph new consumption price increase

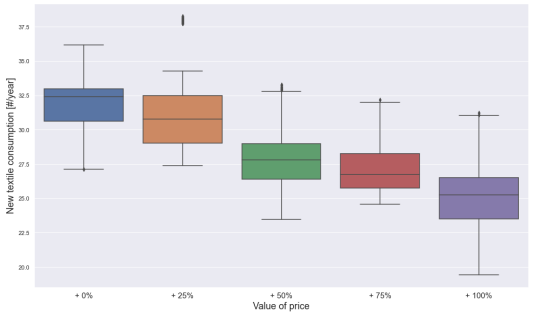

Figure 9.26: Boxplot new consumption price increase

9.2.2 Environment increase

This experiment shows the effect of an increase in the driver of environment to purchase reused textiles.

Total reused textiles

The figures 9.27 and 9.28 show that there is a clear relationship between the value of environment and the percentage of reused textiles. A doubling of the value of environment leads to more than a doubling of the percentage of reused textiles. This increase is however less than with the value of price. Indicating that with the same increase in values, the value of price has a greater effect on the total amount of reused textiles.

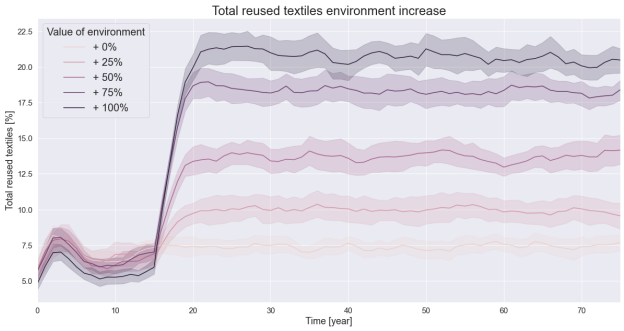

Figure 9.27: Line graph total reused textiles environment increase

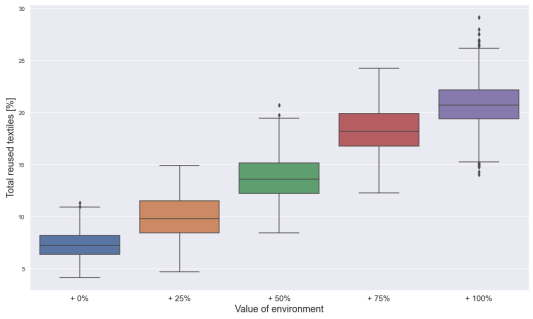

Figure 9.28: Boxplot total reused textiles environment increase

New consumption

The figures 9.29 and 9.30 show that an increase in the value of environment leads to a

reduction in new textile items. This effect is, however, minor, and the reduction is not visible in all scenario's. Indicating that the value of environment has to increase to a large extent, before the effects become obvious.

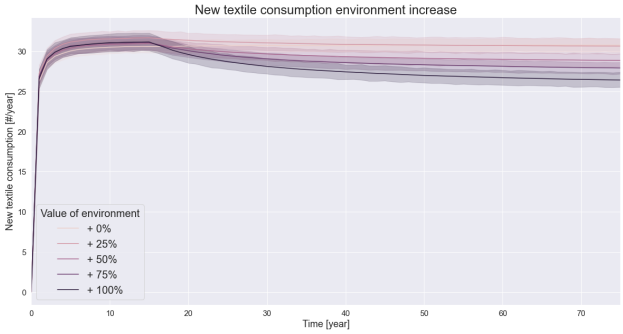

Figure 9.29: Line graph total reused textiles environment increase

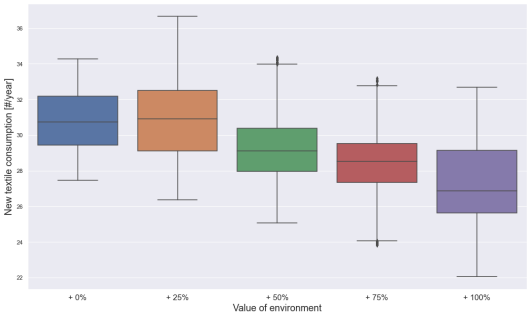

Figure 9.30: Boxplot total reused textiles environment increase

9.2.3 Convenience increase

This experiment shows the effect of a decrease in the barrier of convenience to purchase reused textiles.

Total reused textiles

Figures 9.31 and 9.32 show that there is a clear relationship between the decrease in convenience and the amount of reused textiles. This indicates that a decrease in the importance of convenience to purchase reused textiles results in an increase in the percentage of reused textiles. A reduction of 100% even leads to a tripling of the total percentage of reused textiles.

New consumption

The figures 9.33 and 9.34 show a relationship between the value of convenience and the consumption of new textile items. The reduction is more apparent than with the environmental increase experiment. Indicating that a decrease in the value of convenience has a stronger effect than an increase in the value of environment on the consumption of new textile items.

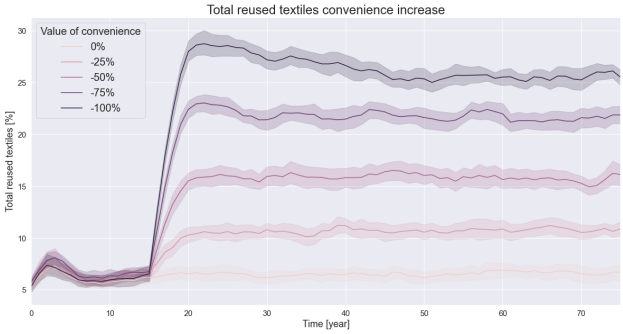

Figure 9.31: Line graph total reused textiles convenience increase

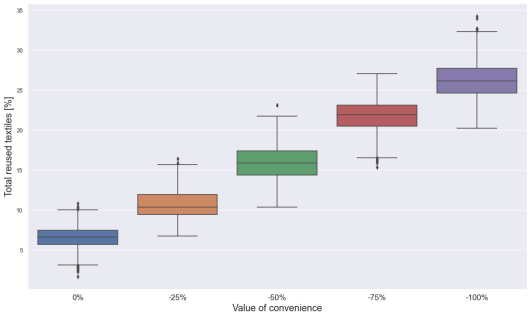

Figure 9.32: Boxplot total reused textiles convenience increase

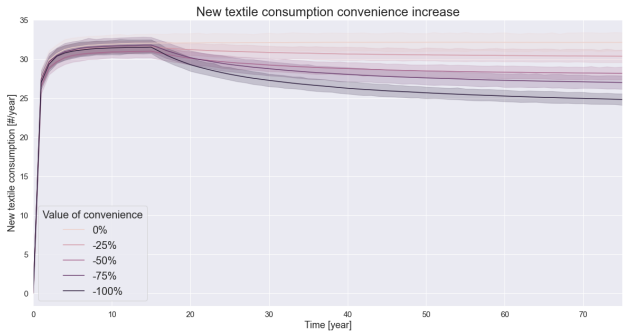

Figure 9.33: Line graph new consumption convenience increase

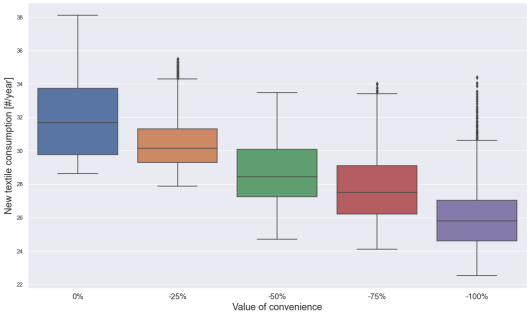

Figure 9.34: Boxplot new consumption convenience increase

9.2.4 Value combination

This experiment compares the changes in the values of price, environment and convenience.

Total reused textiles
Figure 9.35 shows that an adjustment of all values leads to an increase in the percentage of reused textiles. Looking at figure 9.36 a comparison between the values can be made. The figure shows that there is a clear distinction between the value of price and the value of environment. The effect of the price value on the amount of reused textiles is notably greater than the effect of the value of environment. Also, the value of convenience is notably more effective than the value of environment. However, the value of price and the value of convenience overlap, indicating that the difference between the two value adjustments is minor.

This means that value changes of price, environment and convenience are effective in increasing the consumption of reused textiles. A value change of price shows the highest increase and is therefore preferable. A decrease in the value of convenience shows a somewhat less increase, although this difference is minor. The value change of environment is the least effective compared to the values of price and environment.

New consumption
Figures 9.37 and 9.38 show that an adjustment of the values leads to a reduction in new consumed textile items. The reduction is almost equal for the values price and convenience and somewhat less for the value of environment. However, these differences are minor.

This means that value changes of price, environment and convenience are effective to decrease the consumption of new textile items. The choice of value does not appear to have a notable effect. This is interesting because increasing the value of price results in a lower replacement rate. Whereas increasing the value of environment results in a higher replacement rate. However, at the system level these differences in intentions with which people buy reused textile items does not happen to have a notable effect.

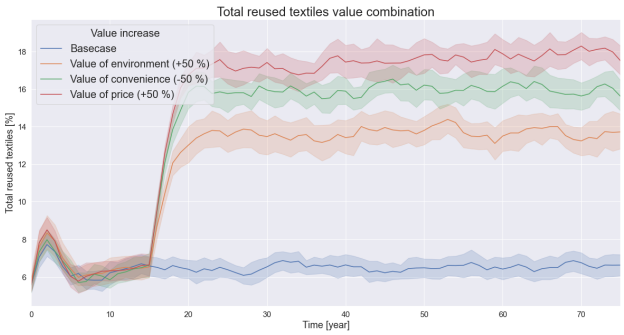

Figure 9.35: Line graph total reused textiles value combination

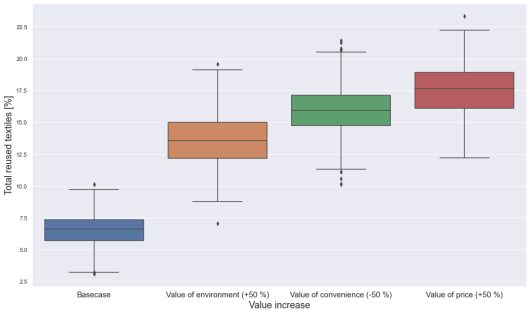

Figure 9.36: Boxplot total reused textiles value combination

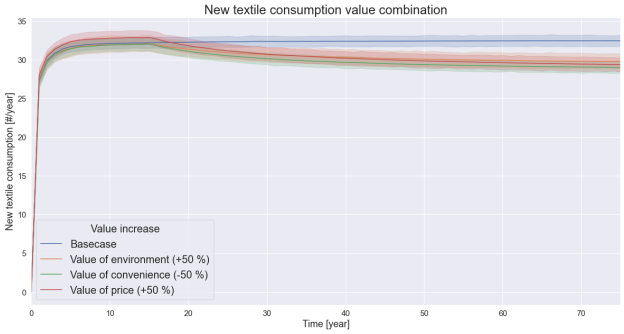

Figure 9.37: Line graph new consumption value combination

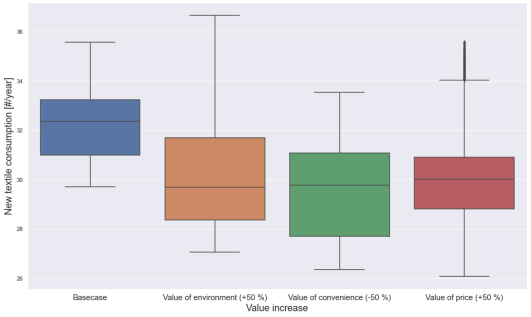

Figure 9.38: Boxplot new consumption value combination

9.2.5 Value combination with only high values

The figures 9.39, 9.40 show the effect of an adjustment in the values of price, environment and convenience. In the 'false' scenario, all consumer values are increased by 50%. However, one could argue that only consumers that already perceive the specific value as important are influenced by a value change. For this reason, also the 'true' scenario is added, the value increase only happens if the consumer perceives the value as important, i.e. the value is already above 50%.

Total reused textiles

Figure 9.39 shows that the difference between the true and false scenarios is the largest for the value of environment increase. This indicates that for the increase in the value of environment, it matters most whether only environmentally minded consumers are targeted or all consumers. For the value of price and convenience, there is a small difference between targeting all consumers or only those who already perceive the value as important.

New consumption

The distinction between the increase in the values price and convenience compared to the value of environment shows similar behaviour for the consumption of new textile items in figure 9.40. This indicates that if only environmentally minded consumers are targeted by a value change of environment, the reduction in consumption is minor. However, the extent of the reduction is less than the percentage of reused textiles.

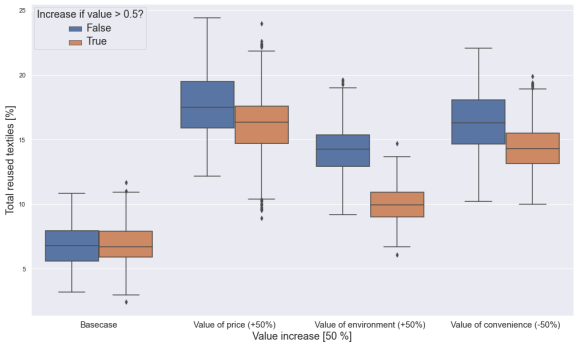

Figure 9.39: Boxplot reused textiles value combination high values

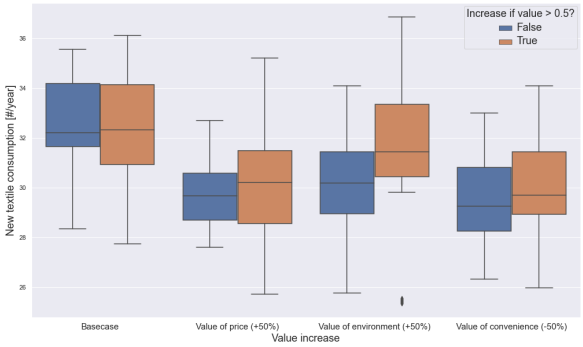

Figure 9.40: Boxplot new consumption value combination high values

9.2.6 Consumer segment difference

The figures 9.41 and 9.42 show the effect of value changes for the four consumer segments.

Total reused textiles

Figure 9.41 indicates that for the budget and casual minimalist, an increase in the value of price is most effective. However, for the budget and premium shopper the value change of convenience prevails. The value changes of price and convenience is for almost all consumer segments more important than a value change of environment. Only for the premium shopper the value of environment is more important than the value of price. The value of environment is for none of the segments the most important value change. However, the relative difference of the value change of environment is largest for the premium shopper and casual minimalist.

New consumption

Figure 9.42 shows that the consumption of new textile items is way higher for the budget and premium shopper compared to the budget and casual minimalist. For all consumer segments, the value changes decrease the consumption of new textile items. Between the value changes there are differences in the magnitude of reduction in new textile items. However, these differences are minor.

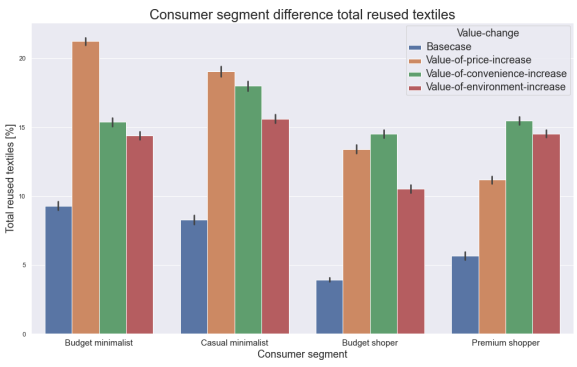

Figure 9.41: Bar chart total reused textiles segment difference

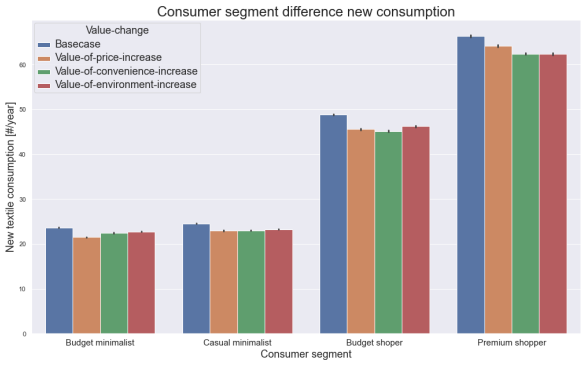

Figure 9.42: Bar chart new textile consumption segment difference

9.2.7 Interpretation

An increase in the values of price and environment and a decreases in the value of convenience leads to an increase in the amount of reused textiles. Even with a value increase of 25%. For the value of price and convenience a value adjustment of 50% leads to a notable decrease in the consumption of new textile items. For the value of environment the value change should be at least 75%. With regard to the most effective value change, the value of environment has the highest effect on the total reused textiles. Followed by the value of convenience. The value of environment is the least effective in increasing the amount of reused textiles. However, the decrease in new consumed textiles due to all three value changes is similar. This indicates that no additional rebound effects related to the replacement rate are notable at the system level.

When only consumers who already perceive the environment as important are targeted by the value change, the increase in reused textiles due to an increase in the value of environment is even less. For the value of price and convenience, the change in effects is minor.

The effect of value changes differs per consumer segment. For almost all consumer segments, a change in the value of price and convenience leads to the largest increase in the percentage of reused textiles. Only for the premium shopper, a change in the value of environment is more effective than an increase in price. This indicates that in general, the price and convenience value changes are most effective, but notable differences appear between consumer segments.

To increase the amount of reused textiles, value changes of price, convenience and environment will be effective. However, value changes of price, and convenience will in all likelihood lead to the largest increase in reused textiles. This is even more true when only consumers who already perceive environment as important are targeted by the value change. However, notable differences in the effect of value changes are apparent per consumer segment. In general, value changes of price and convenience are preferred over those that target environmental awareness. The interventions that can be designed using the value changes are described in appendix I.

Based upon these insights several recommendations are made. These can be found in section 10.5.

9.3 VALIDATION

Validation concerns the process of determining whether the model has been built properly to answer the main question (van Dam et al., 2013). According to Sargent (1998) and van Dam et al. (2013) there are several approaches and techniques to determine whether a simulation model is valid. Within this research three validation approaches and techniques have been conducted: sensitivity analysis, literature comparison and expert validation. Within the time available these where the best and maximum possible. With more time other validation techniques would have been available. This is further discussed in chapter 10. All validation steps are discussed in-depth in appendix K, a conclusion of the analysis can be found below.

9.3.1 Sensitivity analysis

The sensitivity analysis is performed for four model parameters; consumer segment distribution, social influence factor, lifetime decrease reuse and the initial replacement rate. During the sensitivity analysis the values for the parameters have been adapted in order to determine the level of sensitivity of the parameters. The level of adaptation can be found in appendix K.

Consumer segment distribution
The distribution of the consumer segments; budget minimalist, casual minimalist, budget shopper and premium shopper is varied. The results show that the model is sensitive to an adaptation in the distribution of consumer segments. This is understandable because each consumer segment has different reuse percentages and different purchase behaviour. This will be reflected upon in chapter 10.

Social influence factor
The factor that determines how much a consumer is influenced by its social network is varied. The results show almost no correlation between the total amount of reused textiles and the social influence factor. Probably because the effect is so small, it is balanced out by randomness. This indicates that the choice of the social influence factor has a minor impact on the model results.

Lifetime decrease
The lifetime decrease variable represents the rebound assumption covering the imperfect substitution of reused textiles. The factor determines the decrease in possession span with the second owner compared to the first owner. The results show a direct relationship between the lifetime decrease factor and the total amount of reused textiles, as well as the service lifespan. This is an important insight because the choice of the factor is uncertain. As discussed in chapter 6, ThredUP (2019), WRAP (2017) and Farrant et al. (2010) all make different assumptions about the value of this variable. This uncertainty should be taken into account when interpreting the results and will be further discussed in chapter 10.

Replacement rate
The replacement rate represents the rebound assumption covering the price effect due to textile reuse. The replacement rate indicates the chance that the purchase of a reused item leads to the purchase of an additional textile item. The results show almost no relation between the replacement rate and the consumption of new textile items. Possibly, the level of reuse within the system is not high enough to notice the reduction in new textile items consumed. The reduction that might be present is likely to be cancelled out due to randomness.

Maximum reuse
A critical assumption during this research is that all textile items can only be reused once. For the current reuse scenario, an increase of the maximum times an item can be reused has no effect on the Key Performance Indicators. However, with higher levels of reuse the service lifespan is lower compared to the scenario's where textile items can be reused more often. This will be reflected upon in chapter 10.

9.3.2 Literature comparison

The model results showed that there is an average percentage of 7.8% of reused textiles in the system. For this validation step, this variable is analysed in comparison with literature. Maldini et al. (2017) estimated that 6% of the textiles in possession of Dutch owners are reused. This percentage is slightly lower than the results of the model outcome. This could be explained because the data from Maldini et al. (2017) are from 2017. Over the past year the reuse market has been growing and for this research the most recent retrievable data has been used. de Wagenaar, Galama, and Sijtsema (2022) found that on average 17% of the wardrobe consists of reused items. This difference can be explained in two ways. Firstly, the study of de Wagenaar et al. (2022) incorporates international data. Therefore, high- and low-income countries are included. This could result in a higher percentage, as a lot of reused textiles from high-income countries are reused in low-income countries. Secondly, the respondents to the survey of de Wagenaar et al. (2022) already have a certain interest in circularity. Therefore, based on their interests, they could already be consuming more reused textiles than average consumers.

9.3.3 Expert validation

Two separate sessions with three experts have been conducted for this validation step. The experts where two employees of Rebel and an employee of the textile trade association Modint. The aim of the session was to systematically review the model assumptions, mechanisms and outcomes (van Dam et al., 2013).

Lifespan
The experts argued that it is important to make a clear distinction between the physical and social lifespan. The results do not indicate whether the item is disposed of because the physical or social lifespan has been reached. This will be reflected upon in chapter 10.

Imperfect substitution
The assumption that the lifetime of a textile item is reduced every time the item is reused does not always apply. Especially for reused textiles it might often be the case that the first owner possessed the item shorter than the second owner. However, experts agreed that one may not say that a reused textile item lasts twice as long as a new item. Therefore, this value is incorporated in the sensitivity analysis as presented in appendix K.1.

Reuse variation
One of the experts argued that the reduction in new consumed items due to reuse seemed high. He mentioned that there is clearly a reduction in in new due to reuse, but also stated that it would be interesting to see what this reduction is exactly. Two other experts argued that the assumption that a textile item cannot be reused more than once, is not always applicable. Therefore, this value is incorporated in the sensitivity analysis as presented in appendix K.1.

Concluding
Overall, the experts argued that most outcomes looked credible. They also mentioned that the model outcomes and the approach chosen lead to greater understanding of textile reuse and rebound effects. In addition, they found that it was possible to interpret the

results within the model reality created, which is useful understanding the real world phenomena.

9.4 CONCLUSION

Together with chapter 8 this chapter answered sub-questions 4 and 5. The results showed that although rebound effects occur, textile reuse still leads to an increase in the lifespan, number of wears and owners of textile items, as to a reduction in the consumption of new textiles. Not incorporating rebound effects leads to an overestimation of the increase in textile lifespan due to reuse. With higher levels of reuse, not incorporating rebound also leads to an overestimation of the consumption of new textile items. To increase the percentage of reuse in the Netherlands, a value change in price and convenience is most effective, and a value change in environment least. This difference becomes even more apparent if only consumers are targeted who already perceive the values as important.

The model is shown to be sensitive to the distribution of consumer segments and the lifetime decrease factor. With higher levels of reuse, the assumption that reused textiles can be reused only once is also sensitive. The percentage of reused textiles in the system is compared to literature. This indicated that there is a range of diverse percentages but the model percentage falls within this range. The experts commented in particular on the different lifespans, the lifetime decrease variable and the reuse variation scenario. The next chapter will reflect upon the research performed.

10 DISCUSSION

In this chapter different reflections on the research performed are presented. Starting with a reflection on the validity, generalizability, and the methodology of the research. This is followed by recommendations based upon the model results. The final section elaborates upon the limitations of this study, in terms of critical assumptions, general limitations and model limitations.

10.1 REFLECTION ON MODEL VALIDITY

In section 9.3 and appendix K the validation process for this research is described. Validation is a complex and time intensive process. Within this thesis maximum validation was carried out as far as time constraints permitted. This section describes validation approaches that could have been conducted if more time would have been available.

A first additional validation step could have been historic replay. Historic replay consists of scenario experiments that describe the path from some past point to the current world (van Dam et al., 2013). From the scenario people, actions and situations are translated into the model. The experiments explore whether the emergent patterns from the real world in the past are present in the model outcomes. Some degree of validity can be claimed if the emerging patterns from the experiments correspond to the trajectory described in the scenario (van Dam et al., 2013). For this research, this would mean that data from textile reuse value changes, disposal and consumption from the past are implemented in the model. This data can be obtained from previous surveys and modelling studies. When outcomes and end states of the model resemble the current state in the real-world system, this would support validation.

A second, strong but labour intensive additional validation step could be replication. Creating a second agent-based model with a different system decomposition, or a model using a different modelling technique and comparing the outcomes, can be a rich source of validation (van Dam et al., 2013). For this research, another graduate student could build, for example, a system dynamics model to study whether the outcomes are in line with the outcomes of this thesis.

A third additional validation step could be validating the data. Insufficient, inappropriate or inaccurate data is frequently the reason that attempts to validate a model fail (Sargent, 1998). General data and behavioural data of the problem entity are necessary. Within this research, behavioural data is based upon prior literature and assumptions. In addition, there is uncertainty about the rebound assumptions; 1) lifetime decrease due to reuse and 2) replacement rate. With enough time, consumer behaviour research could be performed to check whether the consumer segmentation and quantitative consumer values are accurate.

In addition, research would be performed to the useful life of reused textile items. Lastly, research towards the replacement rate in the Netherlands could be conducted to check whether these correspond to the values found for other countries.

Due to time restrictions, the accuracy and completeness of the model cannot be fully guaranteed. Because the model is not maximally validated. This means that the model results can be used solely for qualitative insight, not for quantitative precision. However, the objective of this research was never to provide statements about precise numbers. With results and input parameters validated through a sensitivity analysis, comparison to literature and expert validation, the model remains useful in providing insight in the qualitative effects of rebound and value changes of the system.

10.2 REFLECTION ON THE GENERALIZABILITY OF RESULTS

This section reflects upon the generalizability of the results. The way in which the results may be interpreted is reflected upon. Additionally, the generalizability of the results to other countries than the Netherlands is presented. Lastly, the generalizability of the consumer segmentation methods is discussed.

10.2.1 Qualitative insights

Section 9.3, appendix K and the previous section discussed the validation process of this research. The model was considered valid to properly model relative changes in model outcomes. However due to limited validity, the outcomes cannot be used for quantitative precision. This means that the exact model outcomes cannot be generalized directly. An example of such an outcome is the precise reduction in new textile consumption due to an increase in reuse. The results of the model showed that reuse leads to a substantial reduction in consumption of new textile items. However, improved data validity is necessary for the precise input of the social interaction effect and the two rebound assumptions 1) lifetime decrease due to reuse 2) replacement rate in the Netherlands. With improved model validity, the % reduction of new consumption with an % increase of reuse could be given.

10.2.2 Other countries

The model is established based on previous studies and input parameters specifically for the Netherlands. Therefore, these quantitative inputs cannot be generalized directly to other countries. However, the general model outcomes are informative for developed countries all over the world. The reduction of new consumed textile items due to reuse and the occurrence of rebound effects take place because of behavioural economic forces, unattached to a specific country (Siderius & Poldner, 2021). The relative effectiveness of value changes is based on the importance of values according to international literature. This indicates that the qualitative rebound and value change outcomes could be generalized to other developed countries around the world.

10.2.3 Consumer segmentation

The consumer segmentation of Gwozdz et al. (2017) is employed in this study. Within society and academic publications other segmentation methods are used to divide consumers. The findings of this study reveal that there are significant differences between these segments. These findings, however, cannot be applied in the same way to other segmentation methods. The findings of this study, on the other hand, can be used to make broad statements about the effectiveness of value changes in general. This is useful for policies aimed at all consumers within the Netherlands.

10.3 REFLECTION ON THE METHODOLOGY

This section reflects on the methodology used for this research. The necessity of agent-based modelling as a research approach is discussed. Subsequently, the reflection on the approach used for the quantification of consumer behaviour is presented.

10.3.1 Agent-based modelling

Chapter 1 describes that agent-based modelling is used for four main reasons 1) literature expressed the need to study rebound effects with quantitative simulation models 2) capable of modelling complex adaptive socio-technical systems 3) suitable for modelling individual consumer behaviour 4) possibilities to test and evaluate value changes.

Throughout the research, it became clear that the approach chosen appeared to meet all of these criteria. However, one could argue that an agent-based modeling approach was not required for the final conclusions. Extensive desk research and in-depth interviews could have been used to assess the impact of value changes and rebound effects. Because of limited validity and uncertain input data, the quantitative insights generated by the model are not generalizable to the real-world system, as discussed in the previous section. Furthermore, the relative differences in rebound effects and value changes may be a model artifact due to the low reliability of input data. However, the developed agent-based model has still added value for three reasons.

First, creating the model was an important step in the research process. The model allowed the system to be structured in a way that made it easier to understand. Based on this enhanced understanding, the correct conclusions could be drawn. Second, the application of an agent-based model has increased the reliability of rebound and value change research. The ability to simulate what is proposed in the literature improves the validity of these theories. Third, and most importantly, the agent-based model allowed value changes and rebound effects to be quantitative and visual. Although no firm conclusions can be drawn from these quantitative results, the modelled rebound and value changes have made it possible to visualize how these effects and changes play a role and where the impact of these phenomena takes place. Thereby the tangibility of these occurrences is improved, instead of rebound and value changes being a qualitative and indistinct concept.

In conclusion, the agent-based modeling approach did not provide new undiscovered insights. However, the developed agent-based model did lead to enhanced understanding, reliability and tangibility of rebound effects and value changes.

10.3.2 Quantifying consumer behaviour

Normally, behaviour research uses qualitative methods to describe and predict consumer behaviour. However, for this research quantitative behavioural aspects where necessary in order to be interpretable by the model. The quantification was derived from the Theory of Planned Behaviour. Within the Theory of Planned Behaviour several other quantification methods could have been used. The consumer segmentation is an important basis for the quantification. These segments could have been formed based upon other characteristics. For example, based upon the dominance of consumer values within these segments. The quantification of consumer values, could also have been performed differently. For example, by selecting values that are important to a certain consumer segment and quantifying those. This means, that some consumers determine their purchase decision fully based upon these values. In addition, other pro-environmental behaviour theories could have been applied. For example the Value-beliefs-norms (VBN) theory as described in section 2.7. In conclusion, however, it can be stated that the quantification chosen has been shown to be effective.

10.4 LIMITATIONS OF THIS STUDY

When performing research assumptions are made throughout the process. These assumptions might lead to limitations, which can be divided into general and model limitations. This section discusses the assumptions and limitations of this research. The assumptions made during the system analysis, quantification of consumer behaviour and the implemented model, can be found respectively in appendix B, appendix D and appendix F.

10.4.1 Critical assumptions

Although using assumptions is inevitable in every modelling research it is important to be transparent about these assumptions and to reflect upon them. This section will discuss the most critical assumptions in light of this transparency and reflection.

Rebound in general
The first critical general rebound assumption is that only rebound effects are incorporated at the consumer level. Meaning that rebound effects occurring on a macro-economic level where not considered. These are for example rebound effects that occur because reused textiles create an additional market next to the existing textile items, increasing the supply of these items and therefore decreasing the price. The second assumption is that within this research rebound effects result in more textile consumption. However, in reality, consumers could also buy other products or services. The third assumption is that income scales are not considered in the rebound analysis. In most rebound literature, the income scale of a consumer determines how the additional money due to a circular economy activity is re-spent.

Rebound due to imperfect substitution
It is assumed that every time a textile item changes owners the possession span of the textile item is shorter with the second owner. During the validation session the experts argued, that this might not always be the case. It could very well be that the first owner possesses the item rather short and therefore decides to offer the item for reuse. According to the sensitivity analysis in appendix K the model results are sensitive to the choice of this

variable. In addition, there is disagreement within the literature of ThredUP (2019), WRAP (2017) and Farrant et al. (2010) about the choice of value for this variable.

Maximum amount of reuse
Another very important assumptions is that all textile items can only be reused once. However, in reality some textile items can never be reused and some multiple times. All depending on the quality and the current lifetime of the item. The sensitivity analysis in K showed that with higher percentages of reuse, the results are somewhat sensitive to the choice of this value.

Static textile consumption and disposal
Within this research it is assumed that the consumption and disposal of textile items is static. This leads to the assumption that all consumers have a yearly textile consumption need that does not fluctuate. It is also assumed that this consumption is independent upon the amount of textiles a consumer already has. Subsequently, it is assumed that disposed of textiles follow a fixed distribution. This distribution is therefore independent on the consumer characteristics (e.g. consumer segment and values).

Social network and interaction
It is assumed that the social network of the consumer remains the same during one simulation run. This means that consumers do not make new friends and that they are always influenced by the same consumers. In addition, it is assumed that every friend within their social network influences the reuse percentage of the consumer equally.

10.4.2 General limitations

This section discusses the general limitations of this research. These limitations are mainly consequences of time restrictions or scope of study and could not have been avoided. However, it is important to mention these limitations and to incorporate them when interpreting the results.

Clothing compared to textiles
Although this study is focused on the textile industry, a lot of prior literature about clothing has been used. This is especially the case for the consumer segmentation of Gwozdz et al. (2017) and the determination of the consumer values. No official data about the distribution of the clothing industry compared the textile industry is available. However, it is often assumed that 80% of the fibers of textile consumption is for clothing, the other 20% is for household textiles (Modint, personal communication, 2022). Indicating that the use of clothing data represents the largest part of the textile industry

Textile reuse outside the Netherlands
Within this research only textile reuse within the Netherlands is incorporated. However, the quantification of the reuse system showed that half of all textile items disposed of in the Netherlands are reused outside the Netherlands. The rebound effects for these items may appear differently because they are exposed to a different market.

Consumer behaviour conceptualization
The conceptualization of the consumer segments and values is based upon prior literature and educated assumptions. With more time available an in-depth consumer survey could provide more insight in the consumer segments and scores for the consumer values. The

research is based upon four consumer segments and five consumer values. In reality, there might be other consumer segments and consumer values that influence the consumption of reused textiles of consumers. In addition, quantifying consumer behaviour is a very complex process because human activity is not based on quantitative factors. Even with more extensive research, modelling consumer behaviour will always bring a certain degree of uncertainty.

Theory of Planned Behaviour
The Theory of Planned Behaviour is used as a knowledge base for this research. However, a simplified version of this theory has been applied. The theory prescribes that attitudes, subjective norm and perceived behavioural control together lead to an intention (Ajzen, 2006). This intention might eventually lead to certain behaviour, but this is also influenced by perceived behavioural control. According to the research of Geurtsen et al. (2020) the intention to purchase environmentally friendly clothing does not always lead to environmentally friendly consumption behaviour. For this research, the theory is simplified and the sum of drivers and subtraction of barriers to purchase reused textiles automatically leads to reused textile behaviour. Eventually, this results in the same percentage of reused textiles as identified by Gwozdz et al. (2017). Therefore, for the base case scenario the adapted use of the Theory of Planned Behaviour does not result in large differences. For the change in values however this might lead to implications.

10.4.3 Model limitations

This section discusses the model limitations of this research. These are mainly the consequence of simplification that is needed to grasp real world phenomena in a modelling context. These limitations should be incorporated when the results are interpreted.

Data availability
Limited data is available about consumer behaviour regarding reused textiles and the system in general. The percentage reused textiles and disposal options are based upon the quantification as identified in chapter 4. However, limited data are available, especially about the informal reuse market and the size of online platforms. There is also no specific research performed about rebound effects of textile reuse. Therefore, all rebound assumptions and the corresponding numerical values are based on the limited data from previous research and insights from the interviews. There is currently no unambiguous value for the reduction in lifetime due to reuse, nor is there information about replacement rates in the Netherlands.

Stochasticity
Within the agent-based model randomness is added in several setup and go procedures. Because of this, a model run is never exactly the same. This is favourable because it allows the researcher to identify emerging patterns of behaviour during multiple runs. Therefore, the tendency of the model for several parameter combinations can be identified. However, because of the randomness interpreting the model results was sometimes complicated. While comparing the value changes, some changes where canceled out due to randomness. For these experimental setups, the random-seed was set fixed, thereby creating the same starting positions for these model runs. However, even with a random-seed many runs need to be performed over a long period of time to result in valid results.

Physical lifespan and social lifespan
Within the model no specific distinction has been made between the physical lifespan and the social lifespan. The Key Performance Indicator, service lifespan, is the shortest of the physical or social lifespan. However, it is very hard to determine whether the consumer is disposing of the textile item because he/she is tired of it or because of wear and tear. However, it is certain that if a textile item is reused, the first owner disposed of the textile item because of the service lifespan, not the physical lifespan. With accurate data about the physical and social lifespan of textile items, reuse possibilities can be better estimated. When interpreting the results of this research, it is important that it is uncertain if the service lifespan reflects the possesion span or the social lifespan.

Generic textiles
Within the model no distinction has been made between different textile products. However, rebound effects presumably appear differently for these different item types. For example, the chance that the purchase of the reused item leads to an additional new item might be different for table linen compared to a simple t-shirt. In addition, the eventual environmental impact of the extra item consumed also differs. Incorporating the actual distribution of textile items in the Netherlands, including the related rebound effects, will therefore presumably lead to other, more precise results.

Reuse variation
Within the reuse variation experiment the values remain stable over time, only the percentage of reused textiles increases by the same percentage for all consumers. This provides insight into the effect of reuse on the Key Performance Indicators, without this being attributable to value change. However, in reality, an increase in reused textiles will always be accompanied by value changes. But for now it is uncertain which value change this will be. It is therefore important to note that the reuse variation scenario does not include a value change, although in reality this will always be the case.

Value change related to interventions
Within the value change experiments, only three values are incorporated. Although most interventions can be designed for these value changes, interventions that target the other two values are possible. It must also be noted that after an increase in values, the values might decrease as time goes by. For example, an awareness campaign targeting the value of environment might decrease over time. Additionally, the literature prescribes that values remain stable over time, but someone's attitude changes. The attitude is derived from these values and can change. Additionally, these values can have influence on the attitudes. With more time, this complex process between values and attitudes could have been incorporated. Furthermore, this research is focused on value changes, which can be used to design interventions. However, the model could also have been adapted to test real interventions. For this research, this approach is due to time restrictions not chosen . Therefore, additional research is needed that assesses interventions that target the researched value changes.

Static model behaviour
As no dynamics are incorporated in the model that simulates future behaviour, the model shows statically behaviour when run for a long time period. Examples of these dynamics are population growth numbers and textile consumption. These dynamics are not incorporated due to time restrictions and uncertainty regarding the magnitude of these effects. Because of the absence of dynamics, the model experiments end up in an equilibrium, re-

flecting the situation in the current scenario. Therefore, the model is unsuitable to express an expected future perspective. Although no dynamics are incorporated, there is a lot of individual behaviour within the model that assesses the current scenario. Such as, the consumption behaviour of consumers based upon their values. The model is therefore well suited to assess value changes and rebound effects in the current situation.

Calculating Key Performance Indicators
The Key performance Indicators (KPI's) are measured for each time step. This makes it easy to see how these KPI's evolve over time and it is immediately understandable what the effect is of certain parameter changes on the KPI's. However, the service lifespan and amount of wears are usually measured once the textile item is incinerated or recycled. In order to still be able to determine these values per time step, the current lifespan and amount of wears of the item are doubled in accordance with the research of Klepp et al. (2019). Assuming that in general measured over all items, the item will continue to be worn for as long as it has been worn. However, this may result in different outcomes for these Key Performance Indicators and should be incorporated when the results are interpreted.

Relationship between lifespan and number of wears
The results show contrasting behaviour for the service lifespan and amount of wears of all textile items. A textile item almost never reaches the amount of wears, as defined by Klepp et al. (2019). This happens because the item is often disposed of when the possession span has been reached. Therefore, the amount of wears is overruled by the service lifespan. This occurrence might have various reasons. Firstly, it could be the case that the data from Klepp et al. (2019) is not fully accurate because their survey is based upon self-reporting. Therefore, consumers could have overestimated the amount of times they have worn the item or underestimated the lifespan of the item. Secondly, the model uses the data from Maldini et al. (2017) for the amount of possessed and consumed textile items by a consumer. It could be the case that this data does not perfectly align with the data provided by Klepp et al. (2019) leading to these unexpected outcomes. Lastly, this phenomenon could be due because of the made assumptions. For example, it could be the case that the assumption about the amount of items a consumer wears is too low. Increasing this number would lead model to results that are closer related to the findings of Klepp et al. (2019). Presumably, the amount of wears will therefore be higher than the results now show.

10.5 RECOMMENDATIONS

This section discusses the recommendations based upon this research. The recommendations are divided into three types of recommendations; general recommendations, recommendations for environmental impact modellers and recommendations for policy makers.

10.5.1 General

The results show that reuse is in general beneficial in reducing the amount of newly purchased textile items. This is useful because eventually this leads to a reduction in virgin inputs. However, reuse should never be the ultimate goal. It should be seen as a means towards a circular textile chain. The real underlying problem with textiles is over con-

sumption, due to the fast fashion model. This must be addressed by changing lifestyles and consumption patterns, in which reuse can play a role. If consumers would wear their clothes as long as possible, until the physical lifespan has been reached this would be preferable over reuse. In addition, people should buy less clothes and should wear the items they have more often. These strategies will eventually be more effective than reusing textiles. Reuse will therefore always have to be considered in the light of other circular economy strategies.

The ultimate circularity goal should be that people wear everything that they have as long as possible so they do not have to buy new clothes. However, from a psychological point of view, this is almost not viable. People have an intrinsic urge to keep buying textile items, to match their image (D&B, personal communication, 2022). The huge societal shift towards more circular textile consumption cannot be reached immediately. Therefore, small steps in the right direction are necessary. The research of Geurtsen et al. (2020) showed that currently reused textiles suit best to the intrinsic textile needs of people (e.g., price, availability and image). When people consume reused textile items they are already transferring into a more sustainable consumption pattern. Even if they did not buy reused textiles because of environmental reasons, they are acting in a sustainable manner. This will eventually become part of their identity and habit (D&B, personal communication, 2022). Eventually, this will make the step towards buying less smaller, because consumers are already adopting sustainable behaviour.

The first step as part of this circularity transition is never perfect (D&B, personal communication, 2022). Because the problem is deep-routed, several additional effects occur. Rebound can be seen as a clear example of these effects. The results of this research showed that rebound effects do occur, but reuse is still favourable from a sustainable perspective. Indicating that reuse can still contribute to the goal of less virgin inputs for textile items.

10.5.2 Environmental impact modellers

In this section the value of this research to modellers of environmental impact is presented. Several companies, including Rebel, calculate the environmental impact of governmental organisations and other businesses. The findings of this research are useful to companies that will perform future modelling studies in general and within the textile industry.

- **Make use of a substantiated replacement rate** - The replacement rate, the degree to which the purchase of reused textiles replaces the purchase of similar new items, should be used in modelling studies at all times. Currently, several modelling studies and scholars assume a 1:1 replacement rate without justification. the choice of the replacement rate should be weighed in each modelling study, and depends upon the scope of the study. In this research, a replacement rate of 70% has been used, based upon the research of Farrant et al. (2010). It should however be noted that, this replacement rate is based upon research within Sweden and Estonia. There is currently no research towards replacement rates in the Netherlands.

- **Make use of a lifetime factor** - Because a reused textile item is already worn before, the lifetime of the textile item will be different compared to the lifespan of a similar new item. This should be incorporated into the modelling study. In this research, textile items are conceptualised based on the possession span and number of wears.

This enables to decrease the lifetime every time the item is reused. In this research, the lifetime decrease due to reuse is estimated to be 30%, based upon research of ThredUP (2019), WRAP (2017) and Farrant et al. (2010).

- **Incorporate human behaviour** - For modelling studies it is essential that human behaviour is taken into account. Rebound effects mainly occur because of behavioural economic forces (Siderius & Poldner, 2021). When these behavioural aspects are not incorporated, the environmental impact of circular strategies might be overestimated. Numerical scores for consumer values have been proven to be a useful methodology to incorporate human behaviour into a quantitative model.

- **Distinguish between consumers** - There is not one specified type of consumer. All consumers are different and buy or do not buy reused textiles for various reasons. These different intentions also determine how rebound effects evolve, and thereby the sustainable impact of the purchase in question. Therefore, it is important to specify different type of consumers. Consumer segmentation has been proven to be useful to make this distinction.

10.5.3 Policy makers

In this section the recommendations for policy makers are discussed. The Dutch government aims for a circular textile chain in 2050, in which reuse plays a major role. To achieve this objective with maximum effectiveness, the findings of this research are useful.

- **Stimulate reuse through changes in the value of price and convenience** - The results show that increasing the driver of price and decreasing the value of convenience is in general most effective to increase the percentage of reused textiles. This means that in general it is most effective to deploy interventions targeted at these value changes.

- **Be aware that stimulating the value of price leads to increased rebound** - Rebound effects appear more if consumers buy reused textiles for price reasons, instead of convenience or environmental reasons. The least rebound appears if consumers buy reused textiles for environmental reasons. However, changes in the value of price are more effective than changes in the value of environment. When only consumers that already perceive the value as important are targeted, the reduction of consumption of newly consumed textiles is higher for the value of price compared to the value of environment. This indicates that although rebound effects are more apparent with an increase in the value of price instead of the value of environment, it is still more effective to stimulate a value change of price.

- **Do not underestimate informal reuse** - Currently all circular textile policies are targeted at formal reuse (e.g., EPR, Reflow). However, a large percentage of the reused textiles are informally reused (34%). This means that they transfer from consumer to consumer, without an additional third party. In most cases, informal reuse is preferable from an environmental perspective. Informal reuse, does namely not require retail premises, transport or collection and sorting processes. It would therefore be of great added value if reuse policies also try to stimulate informal reuse.

- **Be aware of the risks of excluding some reuse possibilities in the Extended Produced Responsibility (EPR)** - In the proposed Extended Producer Responsibility

(EPR) for textiles several obligations are included. For 2030 75% of all disposed of textiles must be reused or recycled (Rijksoverheid, 2021). Of which at least 15% should be reused within the Netherlands. However, informal reuse and reuse via online platforms are not included in these numbers. If, informal reuse and online platforms are continue to rise this will impact the quality of disposed of textile items. Eventually, this will also have an impact on whether reuse is possible or not. In order to do justice to this, it is important to account for or at least monitor these reuse possibilities.

- **Be aware of the difference in reuse percentages** - It greatly matters whether one: 1) measures the consumption of reuse, 2) the disposal of textile items that might be reused or 3) the percentage of reused textiles within the system. The results showed that the percentage of reused textile consumption does not correspond to the percentage of reused textiles within the system. This is the case because reused textiles are earlier degraded and therefore have a shorter lifespan. Also, measuring reuse on the disposal side gives potentially other results, compared to the other two options. A textile item brought to a second-hand shop might not be automatically reused. Another consumer has to buy it first, before the item really obtains a second life. If the second-hand shop eventually uses the item for something else (incineration or recycling), the marked reused item is then eventually not reused. This indicates, that for monitoring whether the policy obligations are reached it matters in which way reuse is measured.

- **Watch out for perverse reuse incentives** - Maximizing the percentage of reuse might eventually lead to unwanted effects. To reach the Extended Producer Responsibility obligations, retailers will try to reuse as much textiles as possible. This could create incentives to dispose of textiles more often than originally intended. From an environmental perspective, this is not preferable. It would be best if the consumer tried to wear the item as long as possible. Only if the consumer really does not wear the item anymore, it should be reused by a consumer. Therefore, it is important to incorporate objectives within the extended producer responsibility that counteract these effects. An example of such an objective is that textile items should be worn as long as possible. This can be monitored by random sampling, measuring the estimated lifespan of the textile item. If textile items are worn for a very short period of time, this indicates that the consumer disposed of the item too soon.

- **Realize that there is a tendency for retailers to not cannibalize existing sales** - First-hand retailers that additionally sell reused textiles ensure better availability of reused textiles. This is favorable for decreasing the value of convenience barrier. However, for these retailers this becomes most profitable when the sell of reused items is seen as an additional market to their regular business, not cannibalizing existing sales (Zink & Geyer, 2017). This creates near-certain a rebound effect and thus an environmentally undesirable outcome. Stimulating textile reuse, through first-hand retailers should therefore try to mitigate these effects.

10.6 CONCLUSION

This chapter reflects on the performed research and discusses the main assumptions and limitations made. The reflection on the methodology concluded that agent-based modelling was the right research approach. Due to limited data availability and time restric-

tions, the model results can only be used for qualitative insight. Nonetheless, the general model outcomes can be generalized to other developed countries over the world. Several assumptions and limitations of the model are presented. These limitations are mainly consequences of time restrictions, scope of study and simplifications and could not have been avoided. Based upon the research outcomes, several recommendations can be given to environmental impact modellers and policy makers.

11 CONCLUSIONS

This final chapter presents the conclusions of this research, by answering the subquestions and main research question. Based on these conclusions, the scientific and social contributions are discussed. Lastly, the recommendations for further research are elaborated upon.

11.1 MAIN RESEARCH QUESTION

In this research an agent-based modelling study have been applied to provide in-depth understanding of textile reuse rebound effects and a model-based advise on consumer value changes, while accounting for consumer heterogeneity. Resulting in the following main research question, which will be answered in this section:

Which consumer value changes are necessary to enhance textile reuse in the Netherlands, given the influence of rebound effects?

Based on literature and interviews, this research identified the Dutch textile reuse system, including rebound effects and related consumer behaviour. The identified system is implemented in an agent-based model that simulates textile items, as well as the reuse behaviour of heterogeneous consumers.

The results show that to reach the aim of a circular textile chain in the Netherlands, improved textile reuse is necessary. Even though rebound effects occur, reuse decreases the consumption of new textile items and increases the lifetime and number of wears of the item. Indicating that because of reuse less virgin input is needed to create textile items. Although these effects are beneficial, textile reuse also leads to an increase in the number of owners. This should be considered, because transferring textile items from one consumer to another often leads to additional activities with an environmental impact.

When textile items are reused, rebound effects occur. To safeguard the market and environmental integrity of the industry, it is important to take these effects into account. Rebound effects occur differently for other levels of reuse in the system. With the current level of reuse rebound effects occur in two ways. Firstly, not incorporating rebound effects leads to an overestimation of the amount of textile items in the Netherlands. Secondly, not incorporating rebound effects leads to an overestimation of the lifespan of textile items and the number of times a textile item is worn. With higher levels of reuse, a third rebound effect becomes apparent. In this case, not incorporating rebound effects leads to an overestimation of the reduction in new consumed textile items.

Behavioural change is required to enhance textile reuse. Despite the fact that each consumer reacts differently to a value change, the overall order of efficacy of this adjustment is: price, convenience, and finally the environment. The effectiveness of a change in the value of price and convenience is the same if the behavioural change only applies to consumers who already perceive the value as important. However, the effectiveness of a change in the value of the environment, diminishes. The findings reveal that in general value changes of price and convenience are preferred over value changes of environment.

11.2 RESEARCH SUBQUESTIONS

The research five research questions, as discussed in chapter 3 are answered in this section. After answering the main research question, these subquestions go more in-depth into specific conclusions.

1. What does the current Dutch textile reuse system look like?

Based on desk research and interviews, the Dutch textile reuse system is analyzed in three ways: 1) system quantification 2) actor analysis 3) issues and challenges.

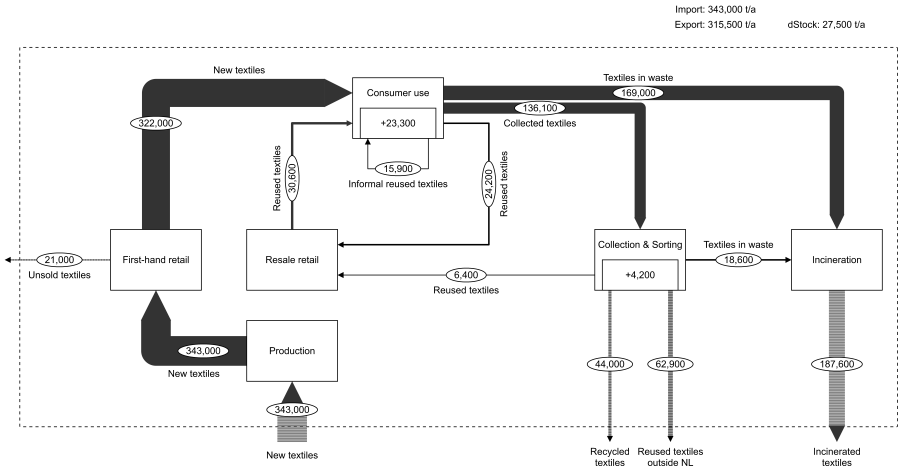

Figure 11.1: Quantification of Dutch textile reuse system, in tonnes (2018).

First, the processes and flows of the system are quantified and visualized in figure 11.1. Of all disposed of textiles in the Netherlands, 13% is reused within the Netherlands. Of these reused items, 34% is reused from consumer to consumer (informal) and 66% via a third party (formal). Additionally, 13% of all textile items are reused outside the Netherlands.

Second, the actors involved in the system can be categorized in: the national- and local government, resale- and first-hand retailers, consumers, collectors, sorters and textile producers. There are diverging interests between and within these actors and cooperation is difficult by the international nature of the system.

Third, the system currently faces nine issues and challenges: regular waste disposal, unused textiles, cannibalizing existing sales, informal reuse, transition towards buying less, availability, price of alternatives, online platform expansion and increased turnover rate.

2. Which concepts and performance indicators are needed to accurately model the Dutch textile reuse system?

Four consumer segments and five consumer values are needed to model consumer behaviour. The included consumer segments are: budget minimalist, casual minimalist, budget shopper and premium shopper. The consumer values consists of three drivers and two barriers that determine the purchase decision of reused textiles of consumers:

- Value of price - driver representing the importance of the cost difference between reused and non-reused textiles
- Value of environment - driver representing the importance of environmental concern
- Value of uniqueness - driver representing the importance of a consumer's tendency to be different from others
- Value of convenience - barrier representing the importance of the ease of finding what you are looking for
- Value of ownership - barrier representing the importance of previous ownership of reused textiles

Rebound effects are conceptualized in two ways. Firstly, the time a textile item is possessed by one owner decreases every time the item changes owner. This rebound effect is related to imperfect and insufficient substitution. Secondly, the replacement rate determines whether the purchase of a reused textile item leads to the purchase of an additional new item. This rebound effect is related to the income effect. The replacement rate differs for each consumer and is dependent upon the consumer segment, value of price and value of environment.

Five Key Performance Indicators that allow to evaluate the performance of the model over time are determined. These are: percentage reused textiles, new consumed textile items, service lifespan, number of wears and number of owners.

3. How should the Dutch textile reuse system be implemented in an agent-based model?

The model consists of three entities: textiles, consumers and second-hand retailers. The interaction between these entities is represented and visualized in figure 11.2. These model interactions are implemented in the Netlogo 6.2.2. software.

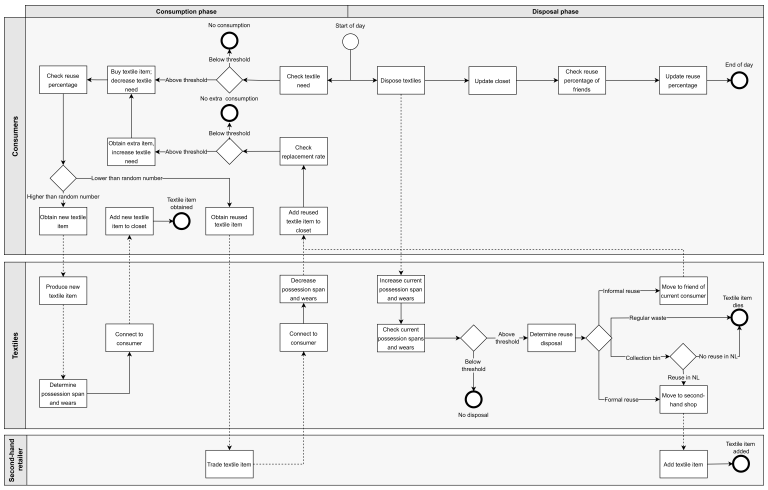

Figure 11.2: BPMN-inspired conceptual model of the agent-based model

4. How do rebound effects influence the Dutch textile reuse system?

With the current level of reuse rebound effects evolve in two ways. Firstly, not incorporating rebound effects leads to an overestimation of the amount of textile items in the Netherlands. Reused textiles have a shorter lifespan compared to new textile items, which means that these items are discarded earlier by consumers. Secondly, not incorporating rebound effects leads to an overestimation of the lifespan of textile items and the number of times a textile item is worn. With more reuse in the system another rebound effect becomes apparent. In this case, not incorporating rebound effects leads to an overestimation of the reduction in new consumed textile items.

Although rebound effects occur, textile reuse still leads to a decrease in the consumption of new textile items, thereby reducing virgin input needed for the production of textile items. Additionally, textile reuse leads to an increase in the number of owners, lifespan and amount of wears of textile items. This indicates, that reuse results in textile items being used and worn more often. Although these effects seem beneficial, the increase in number of owners should be considered. Transferring the textile item from one consumer to the other, often leads to additional activities with environmental impact (e.g. collection, sorting and transport).

5. Which value changes are needed to improve textile reuse?

Increasing the value of price and environment and decreasing the value of convenience leads to an improvement of textile reuse. The value of price is most effective, followed by the value of convenience. The value of environment is least effective. When a value change only applies to consumers who already perceive the value as important, the increase in textile reuse due to the value change becomes less. This is not the case for the value of price and convenience. The effect of value changes differ per consumer segment. For almost all consumer segments a change in the value of price and convenience is most effective. Only for the premium shopper, a value of environment change is more effective than a change in the value of price.

11.3 SCIENTIFIC CONTRIBUTION

This research contributes to scientific literature in two ways. Firstly, the research contributes to the identified knowledge gaps in chapter 2. Secondly, the research supplements and extends previous literature as described in chapter 2.

11.3.1 Contributing to the knowledge gaps

Based on the insights from the literature review in Chapter 2 three knowledge gaps are established:

1. A better understanding of assumptions and causes behind the rebound effect from textile reuse is necessary
2. An agent-based model to study rebound effects in a real-world context is needed
3. Behavioural change regarding textile reuse should be studied with respect to heterogeneous consumers

This section discusses how this research contributes to the identified knowledge gaps.

Regarding the first knowledge gap, this research identified that on a consumer level two rebound effects occur from textile reuse. These are rebound related to insufficient substitution and income. For textile reuse these are translated into two assumptions: lifetime decrease due to reuse (substitution) and replacement rate (income). The research also elaborates on the causes behind the rebound effects. Indicating that the intention with which people buy reused items determines the level of rebound. These intentions are also incorporated in the model. This research contributes to the literature because no prior research has been conducted on rebound effects of textile reuse. Furthermore, this study contributes to the explicit call of Zink and Geyer (2017) to expand research on rebound effects.

Concerning the second knowledge gap, this research has proven that an agent-based model is useful to study rebound effects in a real-world context. No prior research has been performed before that simulated circular economy rebound effects or textile reuse. Although the model is simplified and based on many assumptions, emerging behaviour from rebound effects is uncovered, from which conclusions about rebound effects and value changes can be drawn. The assumptions that have been implemented in order to model rebound effects, are useful for future studies within other disciplines that assess quantitative rebound effects. The study contributes to the literature because the emergent behaviour of the model provides insight into how rebound effects evolve in general, and especially for textile reuse.

Regarding the third knowledge gap, this research incorporated consumer behaviour by studying consumer values that determine the consumption of reused textiles. In addition, social interaction has been included. Consumer heterogeneity is incorporated, by using the consumer segmentation of Gwozdz et al. (2017). In order to model the behaviour of these segments an innovative approach has been applied that quantitatively estimates the reused textile consumption of consumers. The final agent-based model was able to provide conclusions about the most effective value change regarding textile reuse on a system level. While contributing to this knowledge gap, the scientific literature is expanded in two ways. Firstly, this research builds upon the already existing study of Gwozdz et al. (2017). Secondly, the methodology used for the quantification of consumer values can provide valuable insights for future consumer behaviour studies.

11.3.2 Expanding the existing literature

Next to the knowledge gap contribution, this research also contributes to scientific literature by other means, thereby creating additional scientific value.

First, previous literature highlights the existence of the intention and behaviour gap regarding reused textile purchases. However, there is disagreement on the extent to which this gap occurs. Hamari et al. (2016); Xu et al. (2014) found a positive relationship between attitude and reused textile purchases. However, Morwitz et al. (2007) argue that environmental purchase intentions do not translate into actual purchase behaviour. Based upon this research one could argue that the discrepancy is dependent upon consumer values. The results show, that intentions to purchase reused textiles because of price and convenience lead to more textile purchase behaviour than environmental intentions. This indicates that environmental intentions are often overruled by other intentions, such as price and convenience.

Second, no research has been conducted before that identified the textile reuse system in the Netherlands. The quantitative system, actor analysis and issues and challenges described in chapter 4 therefore have a valuable scientific contribution. This system identification contributes to the literature by showing how the flows and processes within the system evolve, the influence and interaction of stakeholders and the risks and opportunities that are lying ahead.

Third, the bottom-up agent-based modelling approach that has been applied is a scientific contribution. The agent-based model build can be used for other purposes related to reuse. For example, assessing the effects of the quality of textile items on the progression of reuse and rebound effects.

Lastly, this research provides valuable information for the research of Klepp et al. (2019). As described in chapter 10 implementing the possession span and number of wears resulting from their research led to interesting model behaviour. This provides valuable scientific information on the sensitivity of the results of the study of Klepp et al. (2019).

11.4 SOCIETAL CONTRIBUTION

Currently, there is a lot of uncertainty regarding the environmental impact of textile reuse and the influence of related rebound effects. This study is helpful for decision makers and stakeholders within the textile industry because it provides an in-depth understanding of how textile reuse evolves and how rebound effects occur. Thereby, protecting the environmental and market integrity of the industry. In addition, the developed agent-based model can be used to advise policy makers on the most effective value change to enhance textile reuse. Lastly, the research is beneficial for modelers that model the environmental impact of businesses and products, especially within the textile industry.

The results of this research show that from an environmental perspective reuse is beneficial. Indicating that it is important to enhance textile reuse in the Netherlands. However, reusing textiles should be seen in light of the larger transition toward a circular textile chain. Textile reuse should never be the final goal, but is a means to reach the ultimate goal in small, manageable and realistic steps. As part of this transition, the reuse of textiles leads to rebound effects. To do justice to the actual environmental impact of textile reuse, these rebound effects should always be incorporated. This is a societal contribution because until recently the extent to which rebound effects occurred was unknown. This research provides understanding of the magnitude of these effects and how these influence the effectiveness of textile reuse.

In addition, the results show that to enhance textile reuse it is most effective to target the value of price, followed by convenience and finally environment. Although, rebound effects are more apparent with an increase in the value of price instead of environment, it is still more effective to stimulate a price value change. This is a valuable societal contribution because the sensitivity between these value changes was previously unknown. These insights contribute to improved effectiveness of textile reuse policies.

Lastly, the research shows that it is of great importance in environmental impact studies to incorporate human behaviour and rebound effects. The assumptions about the replacement rate and lifetime decrease due to reuse used in this research are informative for other

modeling purposes. This is a societal contribution because this increases the effectiveness of these modelling studies. These insights ensure the environmental and market integrity of the industry and reduce the risk of overestimating the environmental impact of reuse.

A more extensive elaboration of the practical and societal recommendations based upon this research can be found in section 10.5.

11.5 RECOMMENDATIONS FOR FUTURE RESEARCH

This study provides insight in the influence of rebound effects and value changes related to textile reuse, using an agent-based modeling approach. Due to time restrictions, several assumptions and simplifications had to be made, as discussed in chapter 10. Therefore, this section presents recommendations on how the research performed could be improved and expanded. Furthermore, during the study, several uncertainties regarding textile reuse and rebound effects became apparent. Therefore, this section also presents recommendations for future rebound and textile reuse studies.

11.5.1 Improving and expanding the research performed

It is suggested to expand the model in order to make it more dynamic. Future research can implement disposal behaviour based on consumer types and consumer values. This will result in an integrated textile reuse system that can be used to test the impact of behavioral change on various disposal options. It is also suggested to include future dynamics be in the model. Such as, changes in the demand for textiles and population growth. This will create more realistic future scenario's. Next to the aforementioned suggestions, social interaction within the model could be expanded. It would be advised to implement thresholds of textile reuse adaptation. Thereby creating realistic diffusion of the level of reused textiles by consumers within the system.

In addition, future research can expand the model by subdividing formal disposal options into separate reuse possibilities. For example, subdividing between second-hand shops, vintage shops and online platforms. In addition, a subdivision between different textile items can be made. Differentiating between, for example, sweaters, bath textiles, and jeans. Also, a subdivision based on quality is suggested. It would be interesting to see what the effects of different textile qualities is on the extent in which reuse can occur. This would provide more knowledge on the effect of textile production and design and reuse possibilities.

With regard to the value changes, it is suggested to design and test interventions related to these value changes. In this research the general value changes are assessed. For future research, it is recommended to design and implement interventions related to the value changes in the modelled system. This is desirable for policy makers who want to deploy interventions because it provides in-depth understanding of the effectiveness of these interventions. The interventions are dynamic and more specific than the tested value changes. For example, the effectiveness of interventions might in- or decrease over time. To recommend policy makers about which intervention should be deployed these insights are crucial.

11.5.2 Textile reuse and rebound

There is still a lot of uncertainty regarding rebound effects, especially related to textile reuse. It would be recommended to conduct research on the rebound effects of different type of textile items. For example, studying whether rebound effects occur differently for bed linen compared to t-shirts. It would also be interesting, to assess the levels of rebound for different types of reuse. This would create possibilities to distinguish between rebound related to informal and formal reuse. Even differences between formal reuse might occur, such as between online platforms and second-hand shops.

Next to different types of rebound, for future research it is suggested to gain more insight on replacement rates, especially in the Netherlands. This will strengthen the modeling studies that are related to reuse rebound effects. In addition, additional research on the amount of lifetime decrease due to reuse should be performed. Currently, there is much disagreement within the literature on how the lifetime of a textile item should be measured. Providing precise values for the decrease in lifetime due to reuse could remove this disagreement as well as the uncertainty regarding the environmental impact due to reuse.

Additional research on consumer behavior is also recommended. Conducting research to assess the actual segmentation related to textile reuse would result in precise consumer segments that reflect reused textile purchases. In addition, knowledge about consumer values related to textile reuse could be improved by performing future research. For example, a survey could be established assessing the consumer purchase intention and willingness to pay for reused textiles. Besides, additional research on social interaction is suggested. To gain more in-depth understanding about the influence of social adaption and the threshold when reusing textile items becomes mainstream.

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A | INTERVIEWS

A.1 HUMAN RESEARCH ETHICS COMMITTEE APPLICATION

All research projects from the TU Delft conducting interviews, need to seek approval from the Human Research Ethics Committee (HREC) before the interviews can be held. The HREC application for this research required three documents:

1. A completed HREC checklist, signed by the first supervisor
2. Data Management plan
3. Completed informed consent form

The HREC checklist contains questions about the research and a risk assessment and mitigation plan on how certain risks are handled. The Data Management plan consists of questions about the collection and reuse of existing data, data quality, data storage, data sharing and data management responsibilities. During the preparation of this plan the data steward from the faculty Technology, Policy and Management has been consulted. The informed consent form is a document specifically established for this research. It contains information about the research objectives, data handling, participation withdrawal and contact details. Each participant has read the form and verbal or oral consent has been received. The created and completed documents are submitted via Labservant from the TU Delft. On February 18th 2022, the application has been approved by the Human Research Ethics Committee

All interviewees are asked for their consent to record and transcript the interviews. Upon request the interviewee can receive the transcript and rectify it if necessary. The interview recordings are only accessible by the researcher and are destroyed after completion of the thesis. The pseudonymized transcripts are available upon request.

A.2 INTERVIEW GUIDE

Nine semi-structured interviews have been conducted. A semi-structured interview means that questions are predefined by means of an interview guide. During the interview however, some questions are skipped and other questions considered important during the interview are asked. The general interview guide has been adapted for each specific interviewee. The interview guide can be divided in the following themes: general, textile reuse system, consumer behaviour, rebound effects, measuring textile reuse and closing. The general interview guide is as follows:

General

- What is your role within [organization]?
- How do your activities relate to textile reuse?
- From a political, economical, social, technological, legal and/or environmental perspective, what do you think is needed to improve reusing textiles?

Textile reuse system

- *Show figure B.1* What do you think of this visualization?
- Within my research resale retail consists of second-hand shops, vintage shops and online platforms. How do you estimate the distribution within resale retail?

Consumer behaviour

- When consumers purchase reused textiles, what factors are involved?
- How would you prioritize these factors?
- Do you think these factors differ within the resale retail options?
- Does the prioritization differ within the resale retail options?

Rebound effects

- To what extent do you think rebound effects influence the impact of textile reuse?
- With what intention do you think consumers buy reused textiles? Does this usually replace a new item?
- If not, why do you think so?
- Are there certain factors or intentions that cause higher or lower rebound effect?
- Do you think rebound effects occur differently per resale retail option?
- Do you think there are other factors that influence the impact of reuse?

Measuring textile reuse

- What do you think are the most important factors for measuring the impact of reuse?
- How do these factors relate to each other?

Closing

- Thank you very much for your participation and valuable contribution
- Do you have any further questions or comments about the interview or the research?
- If I have any questions at a later time, could I contact you by email?

B SYSTEM ANALYSIS

A visualization of the current Dutch textile reuse system is depicted in figure B.1. This visualization is used as a basis for the quantification of the system.

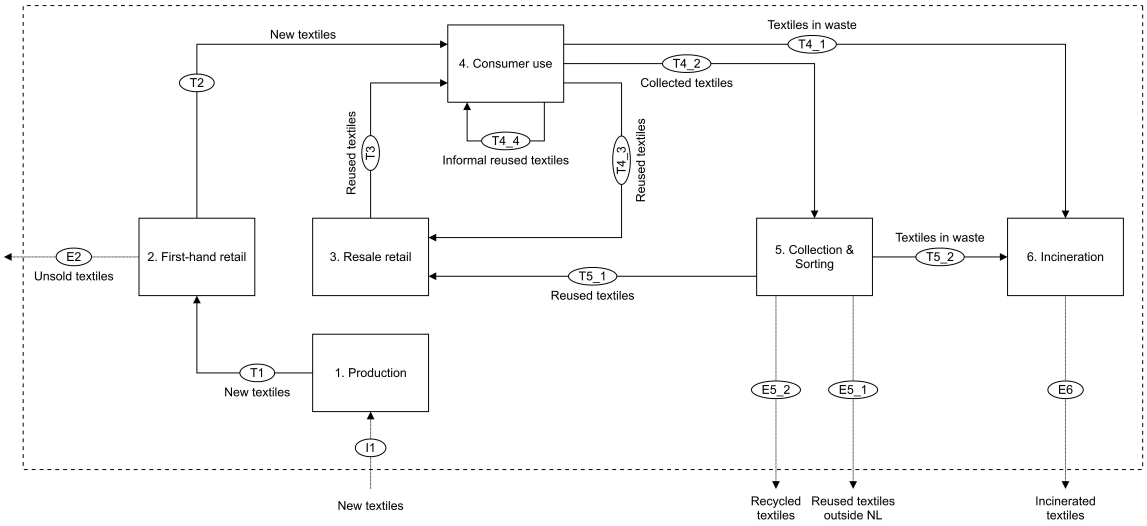

Figure B.1: Visualization of Dutch textile reuse system

B.1 PROCESSES AND FLOWS

A description of each process and flow flow is given in table B.2 and B.1, respectively. Import flows enter and export flows exit the Dutch textile reuse system, they are respectively marked as I and E. All other flows are marked with T.

Table B.1: Process description

Process	Description
1. Production	Production of virgin materials into new textile items
2. First-hand retail	Textile products entering the Netherlands until they reach the consumer
3. Resale retail	Sale of formally reused textiles via resale retailers
4. Consumer use	Consumption and disposal of textiles
5. Collection & Sorting	Collection and sorting of textiles by collectors and sorters
6. Incineration	Burning textiles to produce energy

Table B.2: Flow description

Flow	Description	Source
I1	Textiles imported for production	(Bakker, 2021b)
T1	To the Netherlands imported textiles. No data available about textile production in the Netherlands	(Bakker, 2021b)
E2	Unsold Dutch textiles	(Bakker, 2021b)
T2	Textiles sold by retail sector	(Bakker, 2021b)
T3	Reused textiles that are being sold by second-hand shops, vintage shops and online platforms	Calculated based on inflow
T4_1	Textiles that are thrown away with regular waste and are incinerated	(Hopstaken et al., 2020)
T4_2	Textiles collected via various collectors	(Hopstaken et al., 2020)
T4_3	Reused textiles sold or given, via second-hand shops, vintage shops or resale platforms	(Busi et al., 2016)
T4_4	Reused textiles via direct exchange from consumer to consumer	(Morley et al., 2006)
T5_1	Part of collected textiles that is being sold to the resale retail market	(Hopstaken et al., 2020)
T5_2	Part of collected textiles that are eventually incinerated	(Hopstaken et al., 2020)
E5_1	Part of collected textiles that are reused outside the Netherlands	(Hopstaken et al., 2020)
E5_2	Part of collected textiles that is recycled	(Hopstaken et al., 2020)
E6	Sum of incinerated textiles	Calculated based on inflow

B.2 ASSUMPTIONS

To quantify the textile flows of the system, several assumptions have been made:

- I1 - Because, there is no reliable data production within the Netherlands this market is left out of scope Bakker (2021a).
- I1 - Calculated production is based on im- and export data from (CBS, 2021a). Textile items are segregated based on product type and average weight (Bakker, 2021a).
- T2 - It is assumed that unsold textiles leave the system. In reality these are being stored, donated, sold, fiberized or incinerated (Wijnema, 2016).
- P3 - It is assumed that all reused textiles sold on the resale retail market are obtained through previous Dutch consumers. In reality however, some second-hand and vintage shops also import reused textiles. (Modint, personal communication, 2022)
- T3 - It is assumed that all bought and collected textiles of the resale retail market are sold (Bakker, 2021a).
- T4_3 - Bakker (2021b) reports 19 kton of textiles that are reused, via second-hand shops and vintage shops. This does not include online platforms. Data about online platforms is hard to find, therefore the data from (Bakker, 2021b) is not used.

- T4_3 - Busi et al. (2016) estimated that 17% of disposed textiles are reused through user-to-user channels in Norway. This includes giving clothes away to family and friends, sell them at flea markets or on the internet. This does not include collected reused items that are sold via second-hand shops. It is assumed that this percentage is the same for the Netherlands.

- T4_4 - Morley et al. (2006) states that 100 kton of textiles are given away directly, between family members and friends, without a third party. The same year, the total textile disposal in the UK was 1.956 kton. This means that 5.1% of all textile items are informal reused. It is assumed that this also applies to the Netherlands.

- P5 - It is assumed that the balance difference of 4.2 kton is stockpiled while in reality this difference is due to 1) stockpiling, 2) inaccuracy of the respondents and 3) double counting (Hopstaken et al., 2020).

C ACTOR ANALYSIS

Figure C.1 depicts the enlarged version of the formal chart of the Dutch textile reuse system. Table C.1 gives an overview of the actors involved in the textile reuse system in the Netherlands, including their interests and power. Furthermore, actors specific for the Dutch reuse system are presented in the fourth column of the table.

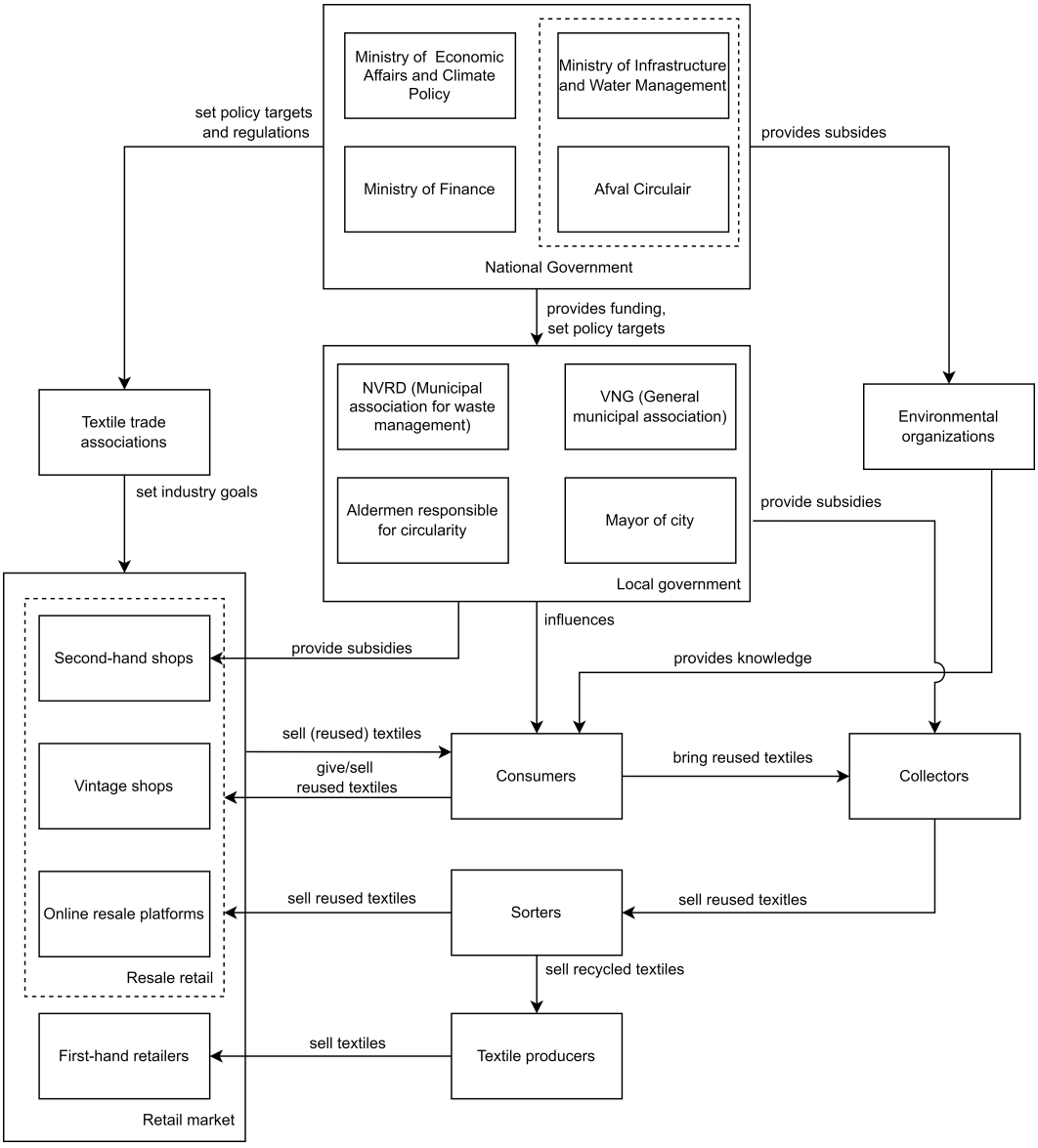

Figure C.1: Formal chart of the Dutch textile reuse system

Table C.1: Power and interest of involved actors

Actor	Interest	Power	Specific Dutch actor
Consumer	Transition towards a reuse system without changing principles and everyday behaviour.	Influence the reuse system by deciding their disposal option and purchase of reused textile items (Bukhari et al., 2018).	
Collectors	Conservation of resources by enabling a second life for textile items (Sympany, 2022). Most collectors are non-profit or charitable.	Operate one of the important reuse streams. No formal power, but power in the form of information, knowledge and skills.	Reshare, Sympany, Curitas, Climpex, Texned
Sorters	Are often part of a specific collector and therefore have the same aim. Separate textiles based on their status and usability to eventually sell them (Wieland Textiles, 2022).	Operate of one of the important reuse streams. No formal power, but power in the form of knowledge and skills.	Circulus Berkel (Reshare), Erdotex (Climpex), Texned, HVC groep
Second-hand shops	Offer the opportunity to buy used textiles. Especially for consumers with less economic resources (Het goed, 2022). Some second-hand shops operate for charitable reasons.	Have an important role in the textile reuse system. Do not hold much power as individuals but can influence powerful parties when united.	Branchevereniging Kringloopbedrijven Nederland, het Goed, Leger des Heils, The Swapshop, Zeeman
Vintage shops	Offer the opportunity to buy unique vintage items (Episode, n.d.). Often operate to make profit, Their impact on the Circular Economy might be lower compared to second-hand shops, because of their less environmental character.	Have an important role in the textile reuse system. Do not hold much power as individuals but can influence powerful parties when united.	Episode
Online resale platforms	Enable consumers to easily buy and sell reused textiles (The Next Closet, n.d.).	Have an important role in the textile reuse system. Are often larger than individual second-hand shops and have therefore more power. Can influence parties with formal power when united.	Vinted, The Next Closet, Marktplaats, OLX
NVRD	The NVRD is the Royal Dutch association for waste management and cleaning. The NVRD is intimately involved in the circular textile reuse system, because reusing textiles positively influences the municipal waste management (NVRD, n.d.).	The NVRD can influence powerful parties. They think along the direction of the Circular Textile policy of the Dutch government (Cirkelwaarde et al., 2020). Together they hold a lot of knowledge and information.	
VNG	The VNG (Vereniging van Nederlandse Gemeenten) represents all municipalities. The VNG provides knowledge and lobby's regarding the circular textile policy.	The VNG can influence powerful parties. They think along the direction of the Circular Textile policy of the Dutch government (Cirkelwaarde et al., 2020). Together they hold a lot of knowledge and information.	
Aldermen responsible for Circularity	Municipalities are aiming for a city without waste and a maximum potential for reuse. Aldermen want to contribute to a circular textile reuse chain (Gemeente Amsterdam, 2021).	The aldermen can steer the reuse system with subsidies, market consultation and tenders towards the preferred direction (Gemeente Amsterdam, 2021). Therefore, they have a lot of formal power.	
Mayor of city	The mayor wants to steer its city to a sustainable and circular one to contribute to the national goal. Has less interest in the issue than the aldermen.	The mayor determines the policy to steer towards the precise circular textile goal. Therefore, the mayor holds a lot of formal power.	
Ministry of Infrastructure and Water Management	Reusing textiles is an important part the mission for a circular textile chain in 2050 (Rijkswaterstaat, n.d.).	The ministry holds a lot of formal power. They can steer parties into the right direction with subsidies and other measures (van Veldhoven, 2020)	
Afval Circulair	Within the ministry of I&W Afval Circulair executes and develops the policy regarding waste and the circular economy.	Afval Circulair provides knowledge about the circular textile sector to the ministry of I&W. Furthermore, they partly decide the policy towards a textile reuse system (Rijkswaterstaat, n.d.). They hold formal power as well as knowledge.	
First-hand retailers	The goal of most retailers is to make profit and continue their business. Retailers are however shifting towards more circular business models.	Retailers do not have a lot of formal power. But have an important position within the textile chain, due to their knowledge and size when united.	
Textile producers	The goal of most textile producers is to make profit and continue their business. Most textile products used within the Netherlands are produced elsewhere in the world. Reusing textiles would eventually lead to a decrease in the market for first-hand textiles.	Producers do not have a lot of formal power. But have an important position within the textile chain, due to their knowledge and size when united.	
Textile trade associations	The aim of textile trade associations is that the Dutch textile sector uses substantial fewer virgin materials in 2025. Discarded textiles can be used longer through reuse (Koppert, van den Brouw, van den Adel, Zeegers, & van Yperen, 2017).	Textile trade associations can influence powerful parties. Have an important role in the execution of the policy set by the government, due to their knowledge.	Modint, Inretail, VGT
Environmental organizations	Inform consumers and other actors about the environmental effects of reuse. Stimulate consumers to discard to enable reuse and buy reused textiles (Milieu Centraal, n.d.)	Hold power in the form of knowledge. Can influence parties through campaigns and lobbies.	Milieu Centraal

D CONSUMER VALUES

In this appendix the approach to determine the importance of the consumer values per consumer segment is explained in more detail. Firstly, an in-depth explanation on the numerical values per consumer value is presented. Secondly, the assumptions made while assigning the values are reported. The determination of the consumer values is based upon the data available in the study of (Gwozdz et al., 2017).

D.1 EXPLANATION NUMERICAL VALUES

Value of price
Gwozdz et al. (2017) reports the level of income and average expenditure per consumer segment. This is shown in figure D.1. Based on these data, the value of price is determined. The premium shopper has the highest value of price and average expenditure, the budget minimalist the lowest. Therefore, the values of price for the premium shopper and budget minimalist are respectively, 0.45 and 0.85 (see section D.2). The income of the casual minimalist and budget shopper are equal. The expenditure of the casual minimalist is however comparable to the expenditure of the budget minimalist. Therefore, the values of price for the casual minimalist and budget shopper are respectively, 0.75 and 0.65.

Value of environment
The value of environment is measured using the environmental apparel consumption (EAC) scale. This scale assesses the frequency of environmental purchase behaviours (Gwozdz et al., 2017). The premium shopper has the highest EAC value (2,6) and the budget minimalist the lowest (2,9). Therefore, the values of environment for the premium shopper and budget minimalist are respectively, 0.3 and 0.6 (see section D.2). The value of the environment for the casual minimalist and budget shopper are equal and are determined to be 0.45.

Value of uniqueness
The value of uniqueness is partly determined based on the apparel acquisition mode of each segment. Gwozdz et al. (2017) identified the following acquisition modes: high street, shopping mall, online shopping, mail order, small boutiques, second-hand, supermarket, and swapping. Small boutiques and swapping are seen as 'unique' acquisition modes. Although second-hand is a unique acquisition mode as well, this mode is omitted because it would bias the determination of reused purchase behaviour of a consumer. As shown in figure D.3, the relative unique acquisition mode is the highest for the premium shopper (15%) and the lowest for the budget minimalist (9%). Therefore, the value of uniqueness for both consumer segments is respectively 0.6 and 0.4 (see section D.2). The unique acquisition modes for the budget shopper (11%) and casual minimalist (13%) fall within this range. The

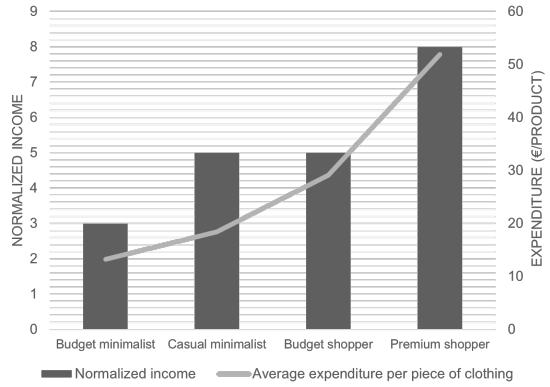

Figure D.1: Income and average clothing expenditure per consumer segment

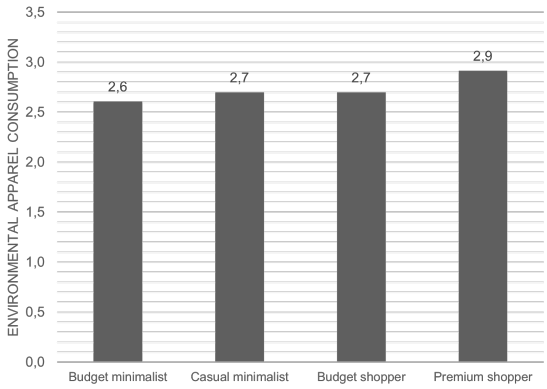

Figure D.2: Environmental apparel scale per consumer segment

apparel acquisition mode does not fully correspond to the value of uniqueness. Therefore, it is assumed that value of uniqueness for both consumer segments is 0.55.

Value of convenience

The value of convenience is determined based on the apparel acquisition mode of each segment. Of the acquisition modes as identified by Gwozdz et al. (2017) online shopping and mail order are identified as 'convenient' acquisition modes. Convenience is the principal motivator for consumers to adopt online purchasing (Jiang et al., 2013). Therefore, the consumer segments with a high share of online purchasing modes will have a high value of convenience. As shown in figure D.4, the budget shopper has the highest share of online purchasing modes (37%) and the budget minimalist the lowest (27%). Therefore, the value of convenience for the budget shopper is 0.7 and 0.4 for the budget minimalist (see section D.2). The online purchasing modes of the casual minimalist (30%) and premium shopper (32%) are slightly higher than those of the budget minimalist. The online apparel acquisition mode does however not fully correspondent to the value of convenience. Therefore, it is assumed that the value of convenience for both consumer segment is 0.55.

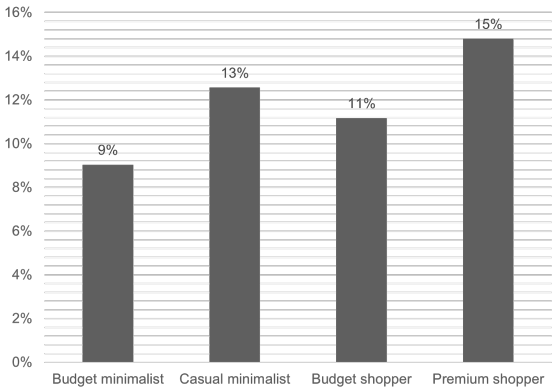

Figure D.3: Unique acquisition modes per consumer segment

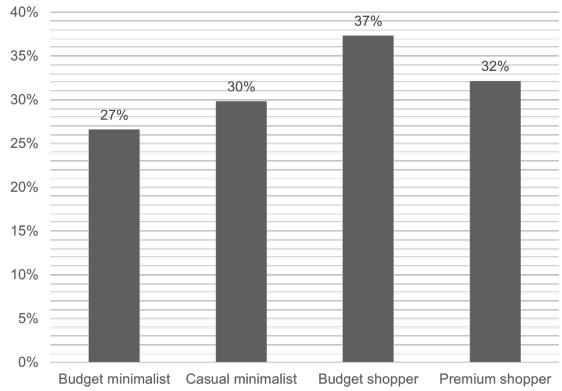

Figure D.4: Online acquisition modes per consumer segment

Value of ownership

The consumer segments of (Gwozdz et al., 2017) do not indicate any differences related to the value of ownership. Therefore, this value exceeds the determination of segments. Presumably, this will not cause problems because the establishment of the consumer segments

is not based upon values related to ownership. The value of ownership scores will however, create extra heterogeneity among consumers within the segments. The scores for the value of ownership are randomly distributed with a mean of 0.4 and a standard deviation of 0.2 (see section D.2).

D.2 ASSUMPTIONS

- Price largely determines reused purchase behaviour (Liang & Xu, 2018). It is assumed, that the bandwidth of the value of price is between 0.45 and 0.85.
- Uniqueness is an important reason to shop reused clothes, but price tends to prevail (Laitala & Klepp, 2018). It is assmued, that the bandwidth of the value of uniqueness is between 0.4 and 0.6.
- Environmental concerns determine reused purchase behaviour. But, price and uniqueness tend to prevail (Geurtsen et al., 2020). Therefore, the bandwidth of the value of environment is between 0.3 and 0.6.
- Convenience is the most important barrier for consumers to adopt reused textiles (Geurtsen et al., 2020). Therefore the bandwidth of the value of convenience is between 0.4 and 0.7.
- Previous ownership is an important barrier for consumers to adopt reused textiles. Convenience however, tends to prevail (Geurtsen et al., 2020; Žurga et al., 2015). Therefore, it is assumed that the value of ownership has a mean of 0.4 and a standard deviation of 0.2.
- Income and average expenditure per clothing item determine the value of price.
- The environmental apparel consumption scale determines the value of environment.
- The apparel acquisition modes 'small boutiques and swapping' partly determine the value of uniqueness. Furthermore, an educated assumption has been made to determine the eventual value of uniqueness.
- The apparel acquisition modes 'online shopping and mail order' partly determine the value of convenience. Furthermore, an educated assumption has been made to determine the eventual value of convenience.
- The value of ownership is independent of the consumer segments.

E FLOW-DIAGRAMS AND BPMN

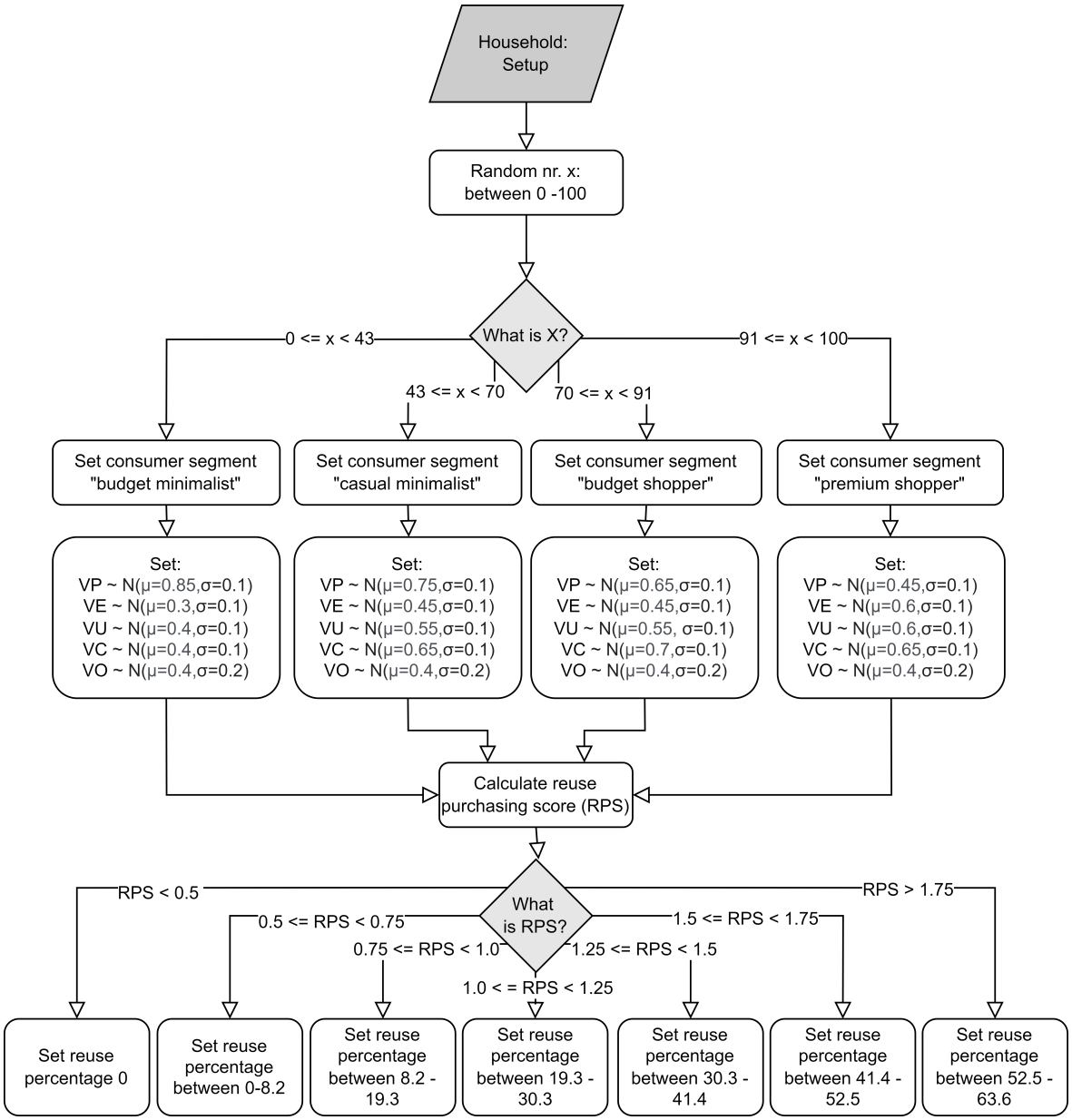

Figure E.1: Flow diagram reuse percentage (enlarged version)

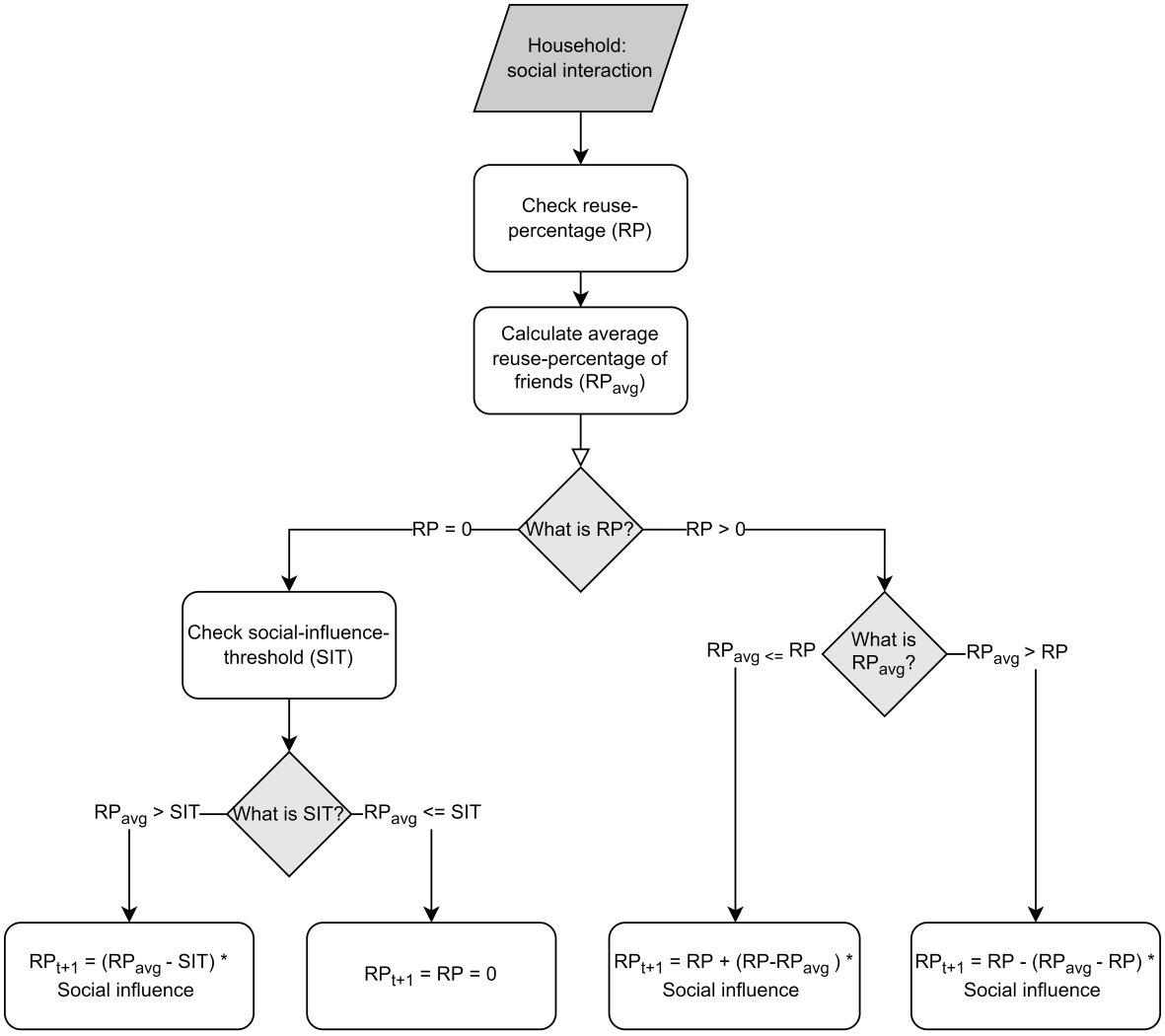

Figure E.2: Flow diagram social influence (enlarged version)

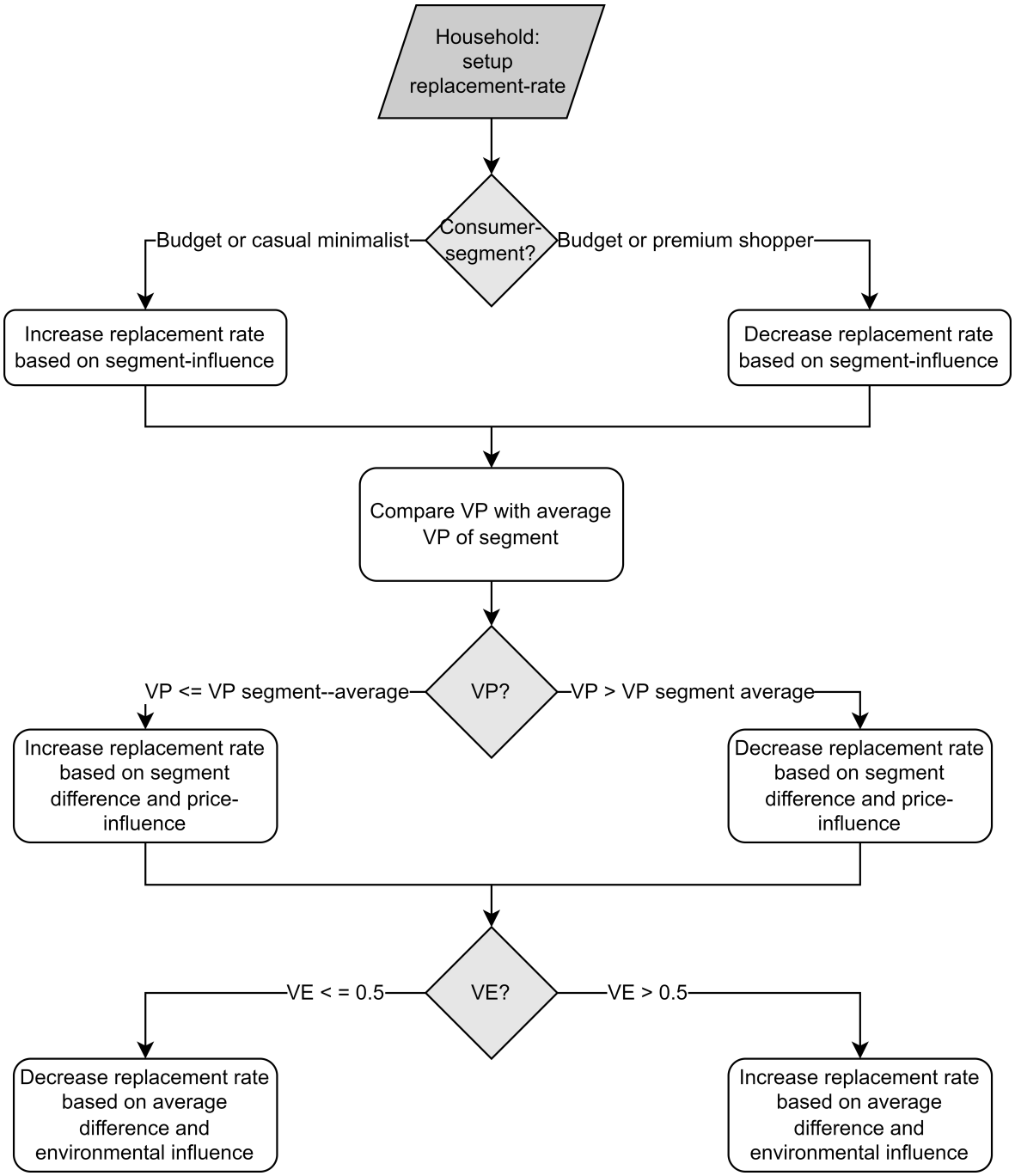

Figure E.3: Flow diagram replacement rate (enlarged version)

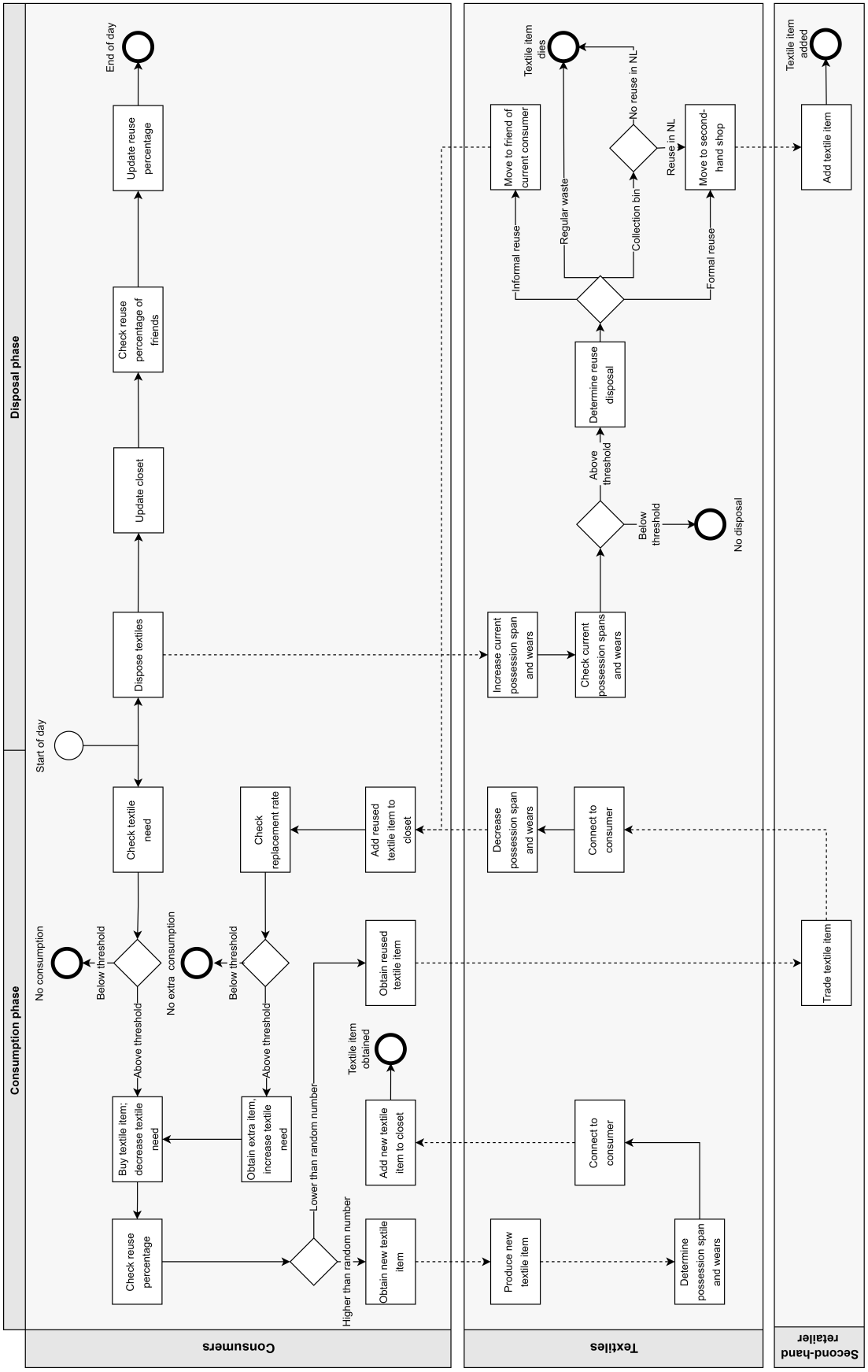

Figure E.4: BPMN-inspired conceptual model (enlarged version)

F MODEL ASSUMPTIONS

F.1 CONSUMER PROPERTIES

- A consumer is part of one of the following consumer segments: budget minimalist, casual minimalist, budget shopper or premium shopper
- The values of price, environment, uniqueness and convenience follow a normal distribution with the average numerical score per consumer segment as mean, and standard deviation 0.1. [1]
- The value of ownership is independent upon the consumer segment and follows a normal distribution with mean 0.4 and standard deviation 0.2.
- Yearly consumed textiles per consumer is based on relative percentual difference of consumer segment and yearly textile consumption parameter.
- The reuse purchasing score of consumers is determined by adding the values of price, environment and uniqueness and substracting the values of convenience and ownership.
- The reuse purchasing score is calculated at the start of the model run and does not change during the run.
- The reuse purchasing score determines the reuse percentage of consumers.
- The reuse purchasing score and reuse percentage of consumers. [2]

F.2 CONSUMER BEHAVIOUR

- The amount of textiles a consumer owns and buys per year is determined based upon the consumer segment.
- All consumers buy at least 10 textile items per year.
- Consumers purchase a textile item if their current textile need exceeds the threshold to buy one item.

1 The numerical values of the five consumer values are based upon the interviews, previous research and own interpretation.

2 This does not fully correspond to the data of (Gwozdz et al., 2017) because the reuse percentage can never go below zero, whereas a normal distribution assumes this can happen.

- The textile disposal options are static and follow the Dutch average based on the quantification identified in chapter 4.
- Informal textiles are only obtained if a friend discards one of his textile items.
- Informal reused textiles are moved to one of the friends of the previous owner. This is the friend with the greatest current textile need and a percentage of reuse greater than zero.
- If a textile item is worn, this item is worn all day.
- If a consumer has less than four textile items, the consumer buys an additional item.
- Consumers within a certain radius of a consumer are friends of this consumer. These friends constitute the social network of the consumer.
- Every consumer has at least one friend.
- The difference between the average reuse percentage of friends of the consumer and the own reuse percentage of the consumer, determines if and how much the percentage reuse increases or decreases.
- The strength of the social influence can be varied by means of a slider.
- If the percentage of reuse of the consumer is zero, the percentage of reuse only increases if the average percentage of reuse of the friends is greater than a certain threshold.

F.3 TEXTILES

- No differentiation between textile items has been made.
- At the start of the model run, every textile item is already worn and has an increased lifespan.
- At the start of the model, all reused textiles have had 1 previous owner.
- The possession wears is dependent upon the possession span of the textile item.
- There are fewer textiles in the system than in reality. The 'model-scale' chooser indicates how much less textiles a consumer owns in the model than in reality. A 'model scale' of 0.1 means that 10 textile items in reality represent 1 textile item in the model.
- At the beginning of the model run, resale retailers start with several reused items, allowing consumers to buy reused textiles from the beginning.
- The textile items in possession by resale retailers, acquire a new owner if a consumer decides to purchase a reused textile item.

- When the current possession span or wears is greater than the predefined possession span and wears, the textile item is disposed of by the current owner.
- If incineration or recycling is chosen as disposal option, the textile item dies and leaves the modelled system
- Reused textiles cannot be reused again. After the possession span of the second owner, the reused textile item is incinerated.

F.4 REBOUND EFFECTS

- The possession span and possession wears of the textile item decreases every time the item changes owners.
- The replacement rate determines if the purchase of a reused textile item leads to the purchase of an additional item
- The replacement rate depends on the consumer segment, value of price and value of environment.
- Consumer segments with low textile expenditures have a lower replacement rate than consumers with high textile expenditures.
- Consumers with a relatively high value of price compared to consumers within their consumer segment have a lower replacement rate.
- The average value of price is fixed on the initial values for all consumer segments. As a result, the replacement rate is reduced when the price increases.
- Consumers with a high value of environment have a higher replacement rate compared to consumers with a low value of environment.
- The magnitude of the in- or decrease of the replacement rate based upon the consumer segment, value of price and value of environment can be varied by means of a slider.
- Rebound effects related to the income effect, directly lead to additional textile purchases. [3]

F.5 EXPERIMENTATION

- The run stops when consumers can no longer wear textiles. This means that if there are fewer textiles than the amount of consumers times the amount of textiles a consumer wears daily, the model run stops.
- An increase in reuse applies to all consumers by the same percentage.

3 In reality, the extra savings from low-priced reused textiles can also be spent on other products or services.

- In the scenario with 100% reuse, the replacement rate leads to the purchase of an additional reused textile item, rather than a new item. [4]

- An increase in the value of price, leads to a decrease in the replacement rate relative to the average value of price of the consumer segment. [5]

4 Otherwise the 100% reuse scenario would still consists of new consumed items, which would bias the results

5 The replacement rate is determined based upon the relative value of price compared to other consumers within the consumer segment. Without this assumption an increase in the value of price would not lead to a decrease in the replacement rate, which seems unrealistic.

G PARAMETRIZATION

Table G.1 presents an overview of the initial values of all parameters of the model. When no value could be found via desk research or interviews, assumptions have been made. These assumptions are not a wild guess, but are chosen because they fit the other model parameters, are inspired based upon previous modelling studies or are an own interpretation of the researcher.

Table G.1: Chosen model parameters and values

Category	Parameter	Value	Source
Model	Number-consumers	100	Assumption
	Initial-number-resale-retailers	3	Assumption
	Model-scale	0.1	Assumption
Consumer	Budget minimalist	43%	Gwozdz et al. (2017)
	Casual minimalist	27%	Gwozdz et al. (2017)
	Budget shopper	21%	Gwozdz et al. (2017)
	Premium shopper	9%	Gwozdz et al. (2017)
	Personal values	0-1	Chapter 5
	Yearly-textile-consumption-avg	35	Maldini et al. (2017)
	Daily-textile-wears	3	Assumption
Textiles	Initial-number-textiles	130	Maldini et al. (2017)
	Possession-span-average	5.2	Klepp et al. (2019)
	Possession-span-stdev	2	Assumption
	Possession-wears-average	76	Klepp et al. (2019)
	Regular-waste-disposal	49%	Chapter 4
	Collection-bin-disposal	39%	Chapter 4
	Formal-reuse	9%	Chapter 4
	Informal-reuse	5%	Chapter 4
	Max-times-reuse	1	Assumption
Rebound effects	Lifetime-decrease-reuse	30%	ThredUP (2019), WRAP (2017) and Farrant et al. (2010)
	Initial-replacement-rate	70%	Farrant et al. (2010)
	Segment-influence	5%	Assumption
	Price-influence	5%	Assumption
	Environmental-influence	5%	Assumption
Social interaction	Social-influence-radius	10	Assumption
	Social-influence-threshold	5%	Assumption
	Social-influence	0.5	Assumption

H VERIFICATION

During and after the development of the model, several verification steps have been executed. These steps are based upon the paper of van Dam et al. (2013) and entail code code walk-through, recording and tracking of agent behaviour, interaction testing limited to minimal model and multi-agent testing. The execution of the verification steps is explained in this appendix.

H.1 CODE WALK-THROUGH

For this verification process the programmed code is walked through, to check if no mistakes have been made and the code does what it should be doing according to the conceptual model. The model interface was used to check whether the implemented code resulted in the preferred model behaviour. An example is shown in figures H.1 and H.2. Within the code, social interaction is programmed. However, while only seeing the code it is not fully certain if consumers indeed calculate the average reuse percentage of their friends. In the command center from the model interface this was checked. Therefore, it could be concluded that the consumers indeed calculated the average reuse percentage of their friends.

```
to social-interaction
  ask consumers [
    set avg-reuse-percentage-friends ( mean [reuse-percentage] of friends )
```

Figure H.1: Code walk through verification

```
Command Center
observer> show mean [avg-reuse-percentage-friends] of consumers
observer: 10.521961326892706
observer>
```

Figure H.2: Command center verification

H.2 RECORDING AND TRACKING OF AGENT BEHAVIOUR

To make a distinction between reused and non-reused textiles they have been assigned, respectively the colours yellow and red. This makes it easy to see at a glance, what approximately the amount of reused textiles is. Furthermore, this ensures that the textiles can be visually tracked. For all entity types this has often been done during the development of the model. By doing this, the properties of the agents can be monitored and it can be measured if they change as they should.

An example of recording and tracking of agent behaviour is shown in figure H.3. This figure shows three snapshots of a consumer within the agent-based model over time. The figures depict that the closet size of the consumer changes over time: from 160, to 110 and 130. This indicates that the consumer has bought and disposed of clothing during this time period. Furthermore, the percentage of reused textiles has changed. This is due to social interaction of the consumer with his friends. In this particular case, the average reuse

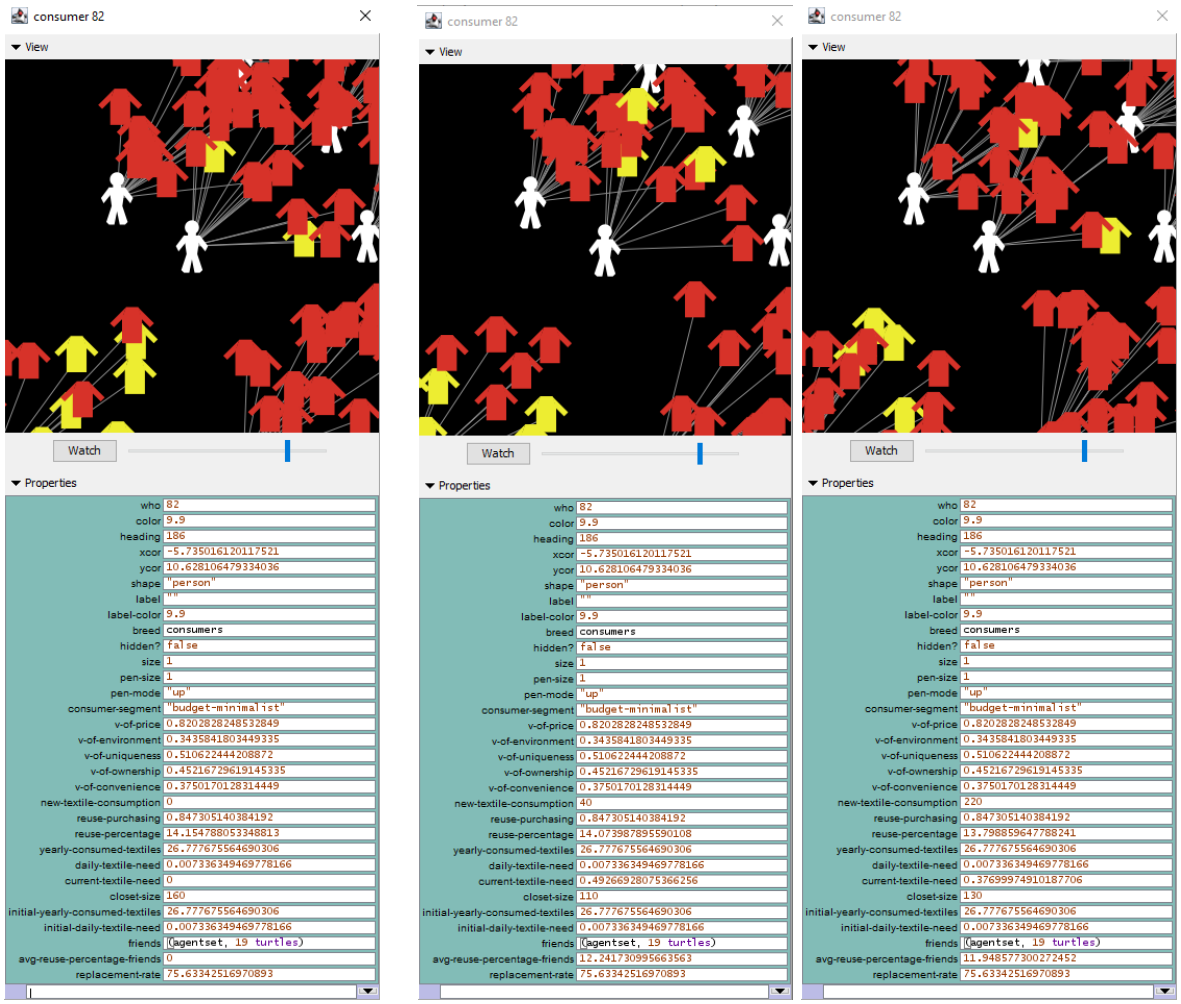

Figure H.3: Tracking consumer 82 over time (from left to right: year 0, 2 and 30)

percentage of the friends is lower than the percentage of the consumer itself resulting in a decrease in the percentage reused textile purchases.

H.3 INTERACTION TESTING LIMITED TO MINIMAL MODEL

In this verification step, the model is run with only one consumer and just a few textiles. During this step, it is examined if the consumer behaviour occurs as shaped in the conceptual model. During the first attempt, several errors occurred because a single consumer could not dispose his textile items informally. This was the case, because there where no other consumers available to give the item to. To solve this, the code is adapted and several lines have been added. Because, of this informal reuse can only occur with enough consumers.

H.4 MULTI-AGENT TESTING

In this step, the model is verified with the initial parametrization. In the user interface, the graphs show the behaviour of the agents. When looking at the graphs while the model runs, it can be monitored to see if the model behaves as expected. Multiple runs have been

performed, to check whether the behaviour occurs consistently. In addition, all parameter settings have been varied. Under some parameter settings, model runs resulted in a run-time error; this is, an integrated verification procedure of Netlogo. If an error occurred, a new feature has been programmed to improve the model and prevent the error from happening. It should be noted that these errors do not always occur. Therefore, the model is run multiple times under different parameter settings to check whether it is robust.

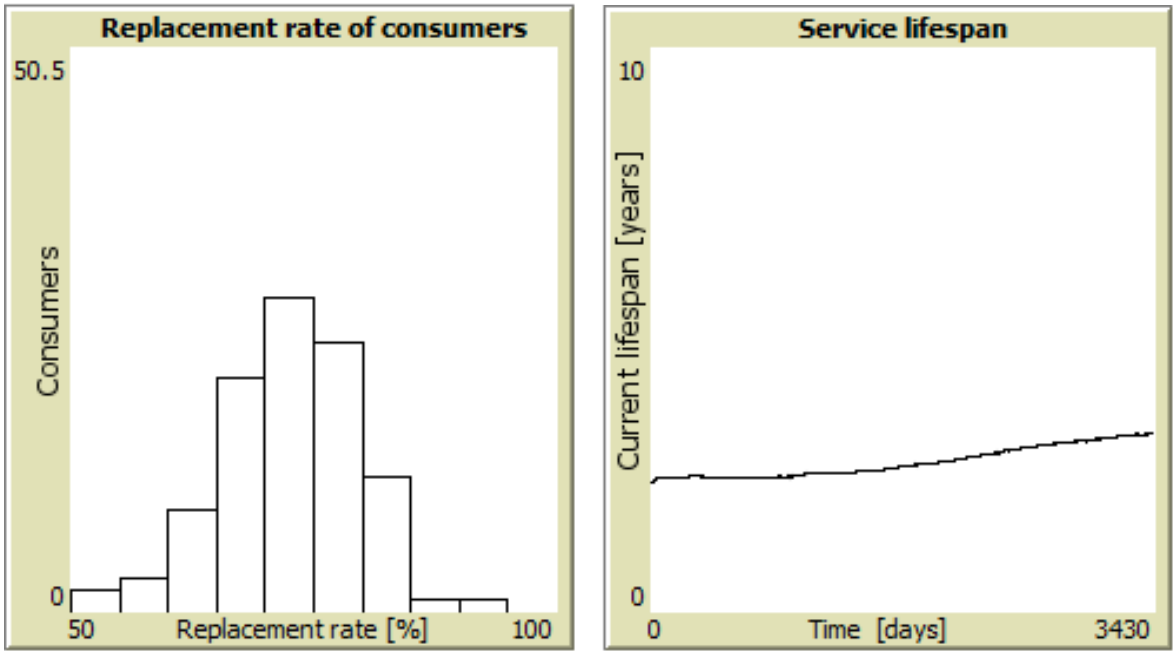

Figure H.4: Graphs in user interface

I INTERVENTIONS

For this research, several interventions have been investigated that guide behavioural change. These interventions target one of the consumer values that determine reuse purchasing behaviour. The interventions are based upon the research of Geurtsen et al. (2020) that researched environmental clothing behaviour, by order of the Ministry of Infrastructure and Water Management. In addition they proposed several interventions to stimulate environmental clothing behaviour. Several of these interventions, including the consumer value they influence and the type of instrument, are presented in table I.1. Of course, there are many more interventions that increase the lifetime of textile items and reduce the consumption of new materials. However, this study focuses on consumer behaviour regarding the consumption of reused textiles. Therefore, only interventions that meet these criteria are presented in the table below.

Table I.1: Interventions

Consumer value	Examples	Communication	Regulatory	Financial
Price	Reduce tax on reused textiles			X
	Subsidising reused textiles			X
	Increase the price of textiles with a high environmental impact			X
Environmental	Communication campaign	X		
	Environmental labels on textile items	X		
Convenience	Increase availability of reused items within city center		X	
	Increase availability of reused textile items within regular shops		X	

J MODEL RESULTS

J.1 GENERAL MODEL BEHAVIOUR

J.1.1 Base case

Figures J.1, J.2 J.3 J.4 and J.5 show the outputs of the KPI's in the Basecase. In the Basecase the model is run 50 times. The line graphs on the left-hand side show the results of the KPI's over time, with a 95% confidence interval. Interestingly, several linegraphs show fluctuating behaviour (reused textiles, service lifespan and owners), while others (new-textile consumption and textile wears) do not. The fluctuating KPI's are the result of emergent behaviour. These are dependent upon the relation between entities within the model. However, the other KPI's, new consumption and textile wears are stable. The consumption of new textile items does not change during the model and is determined by the initial parameterization. The number of textile wears is always overruled by the service lifespan of textile items. Therefore, this variable does not show fluctuating results during the model run.

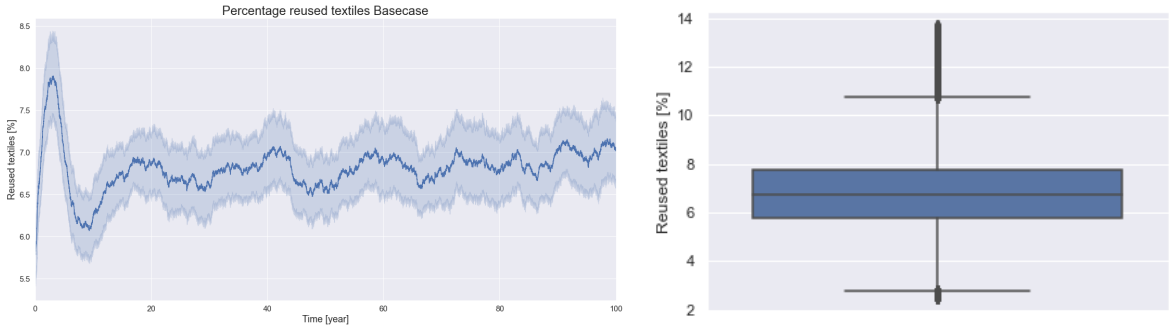

Figure J.1: Percentage reused textiles base case

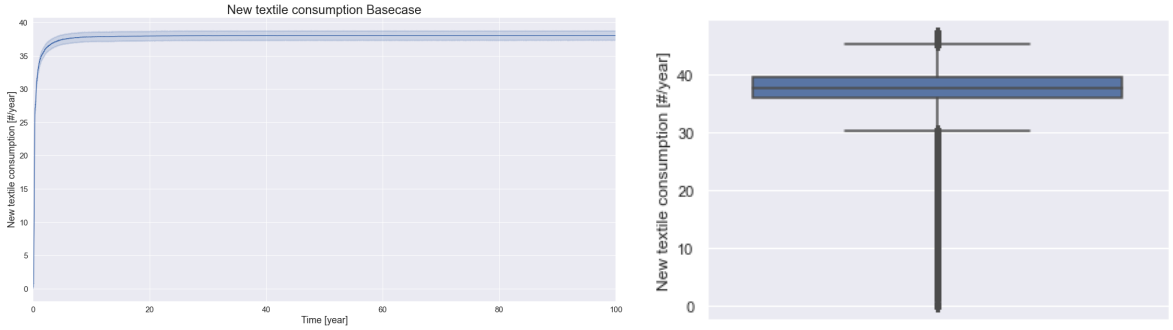

Figure J.2: New textile consumption base case

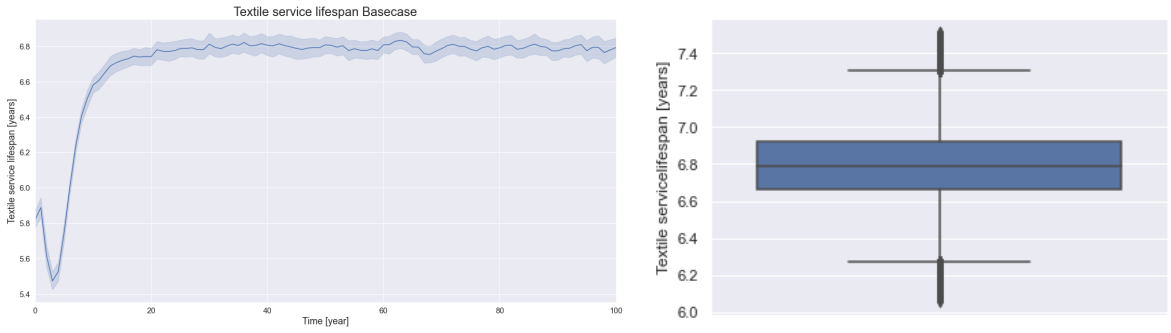

Figure J.3: Service lifespan textiles base case

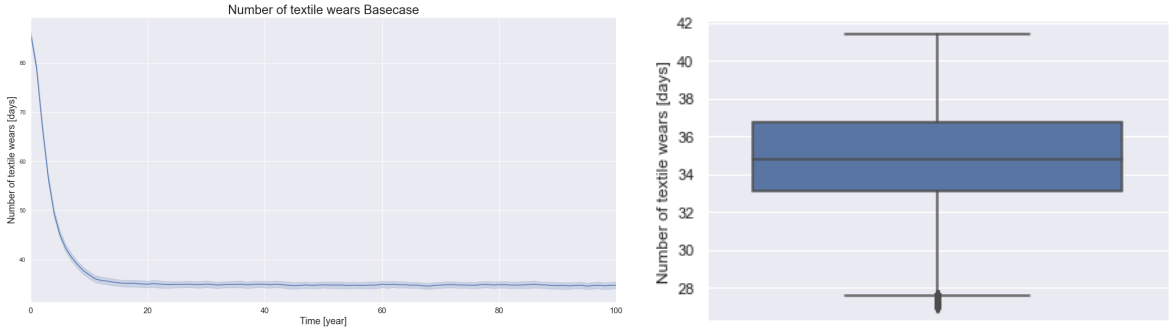

Figure J.4: Number of textile wears base case

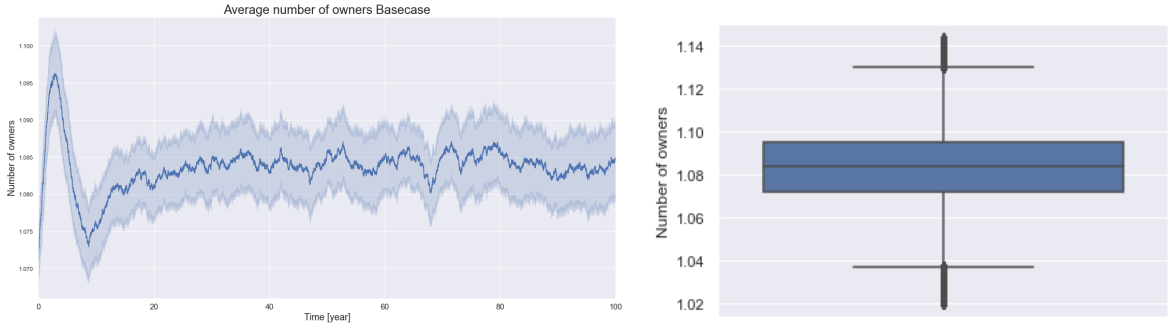

Figure J.5: Number of owners base case

J.1.2 Reuse variation

Because the 100% reuse scenario shows contrasting behaviour compared to the other scenarios, the results are discussed separately.

With the 100% reuse scenario

Figure J.6 and J.7 show the outputs of the KPI's with different variations of reuse. With a reuse percentage of 100% the model run stops on average after 7 years. This creates unexpected outcomes of the service lifespan and amount of wears, because the model is still in run-up time. Therefore, no reliable results about the KPI's in the 100% reuse scenario can be given. Except, that the scenario is not viable.

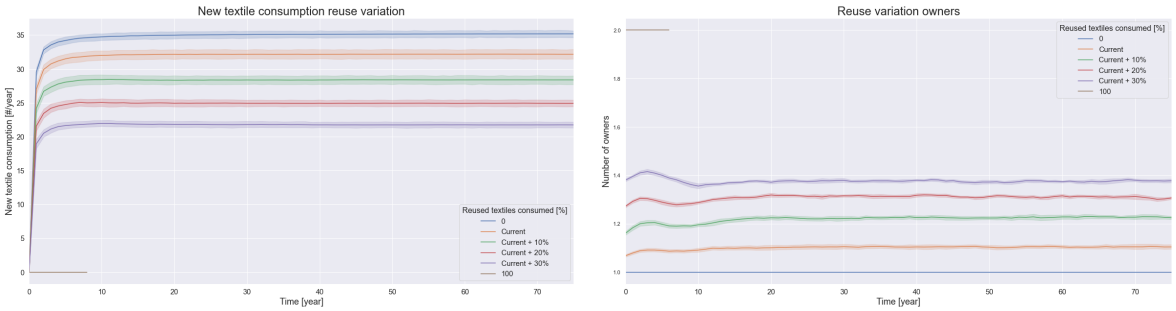

Figure J.6: New textile consumption and amount of owners reuse variation

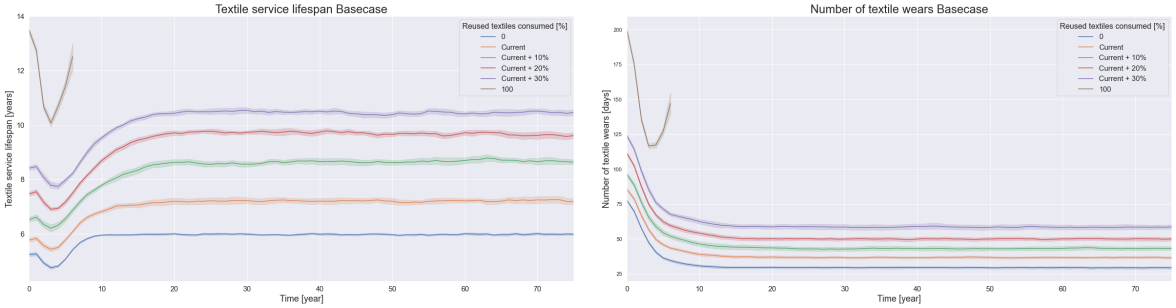

Figure J.7: Service lifespan and amount of wears reuse variation

Without the 100% reuse scenario

Figure J.8, J.9, J.10, J.11 and J.12 show the effect of an increase in reuse on the Key Performance Indicators. They show that an increase in reuse leads to a reduction in the consumption of new textiles and an increase in the service lifespan, number of wears and owners of textile items.

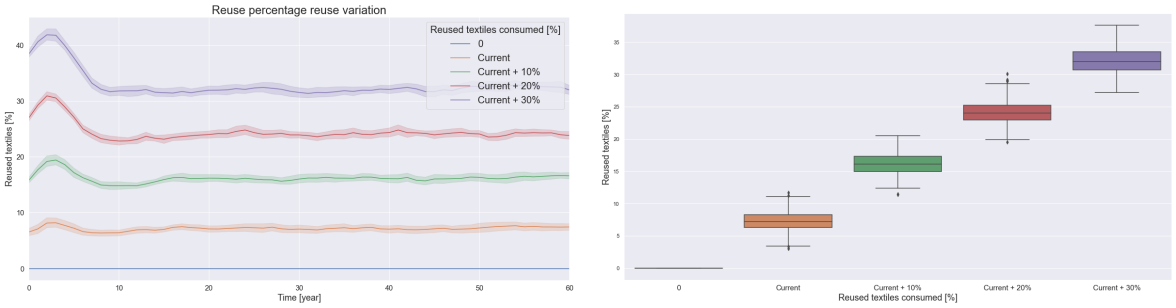

Figure J.8: Percentage reused textiles reuse variation

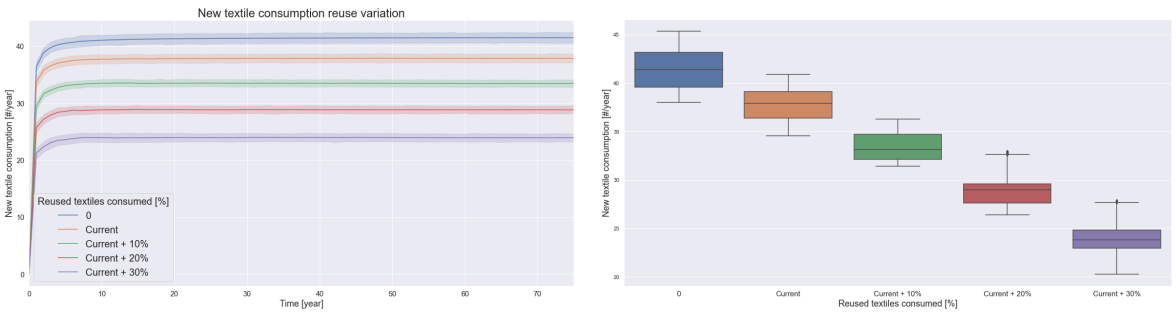

Figure J.9: New textile consumption reuse variation

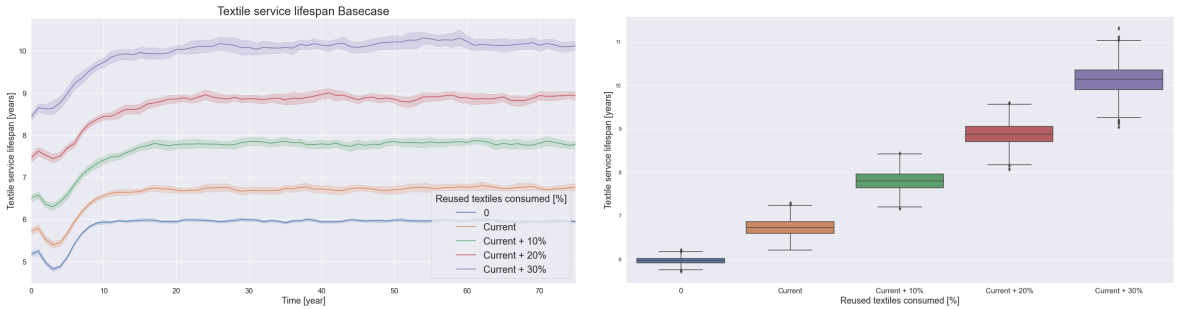

Figure J.10: Service lifespan textiles reuse variation

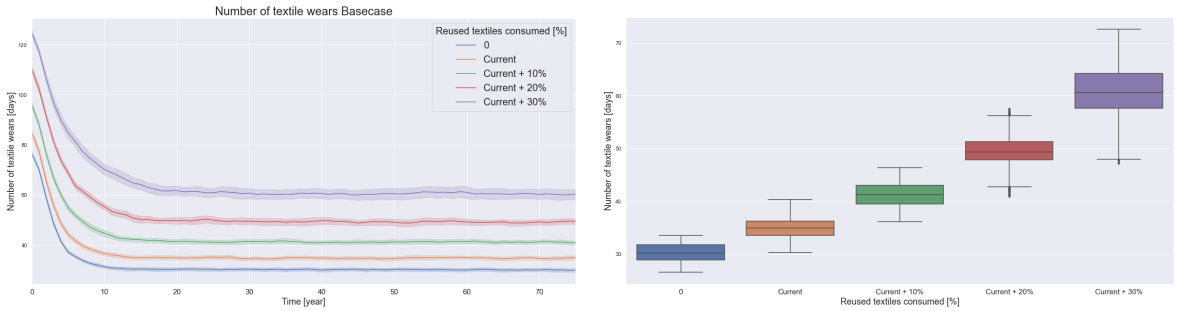

Figure J.11: Number of textile wears reuse variation

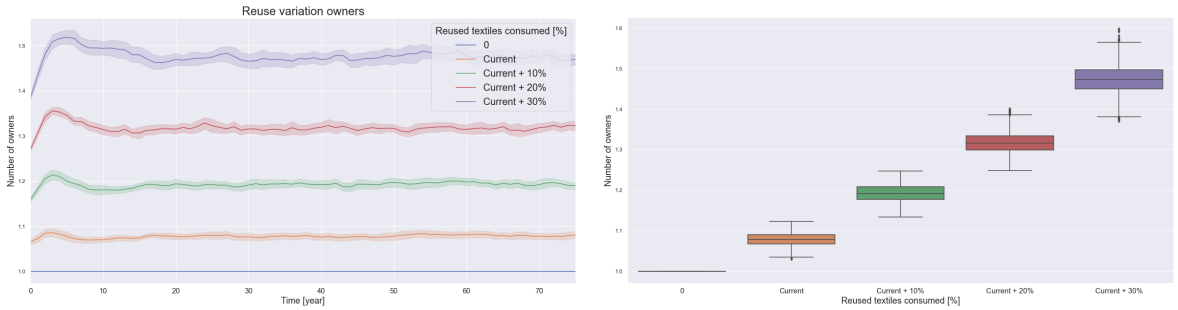

Figure J.12: Number of owners reuse variation

J.2 VALUE ANALYSIS

J.2.1 Price increase

Figures J.13, J.14 and J.15 show the effect of an increase in the value of price on the service lifespan, amount of wears and number of owners. The figures show that an increase in the value of price leads to a notable increase in the three variables.

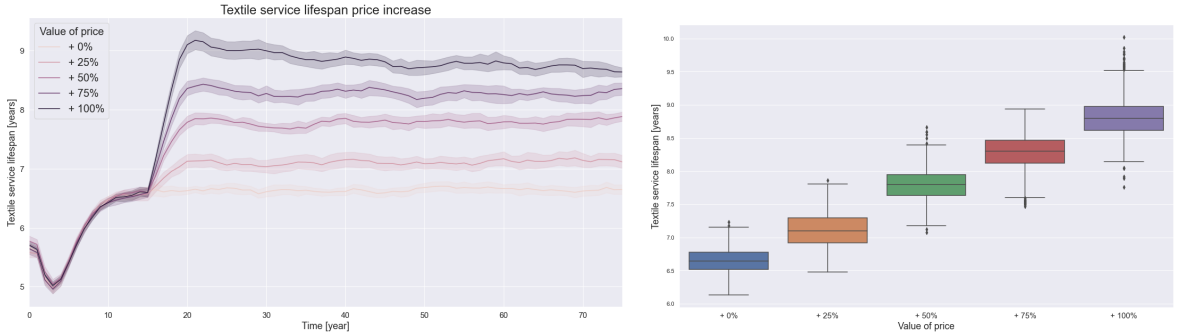

Figure J.13: Service lifespan price increase

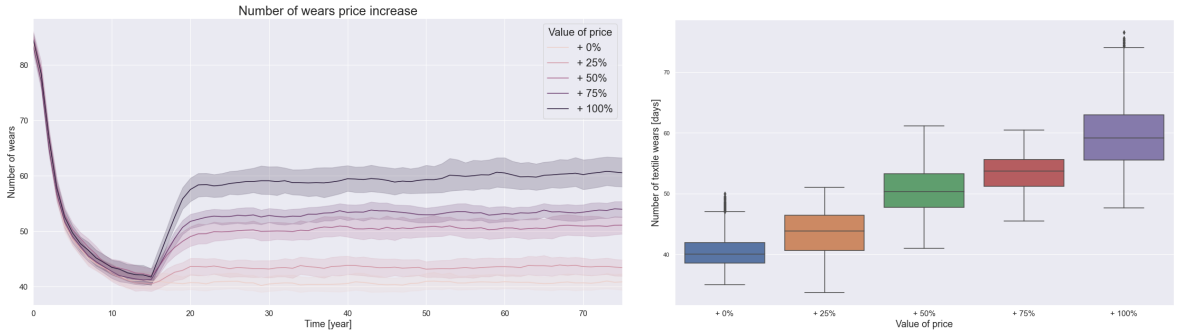

Figure J.14: Number of textile of wears price increase

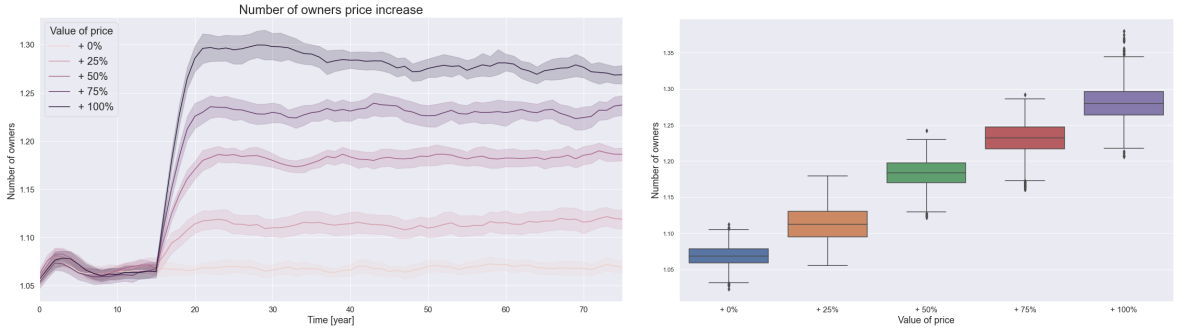

Figure J.15: Number of owners price increase

J.2.2 Environment increase

Figures J.16, J.17 and J.18 show the effect of an increase in the value of environment on the service lifespan, amount of wears and number of owners. The figures show that an increase in the value of environment leads to a notable increase in the three variables.

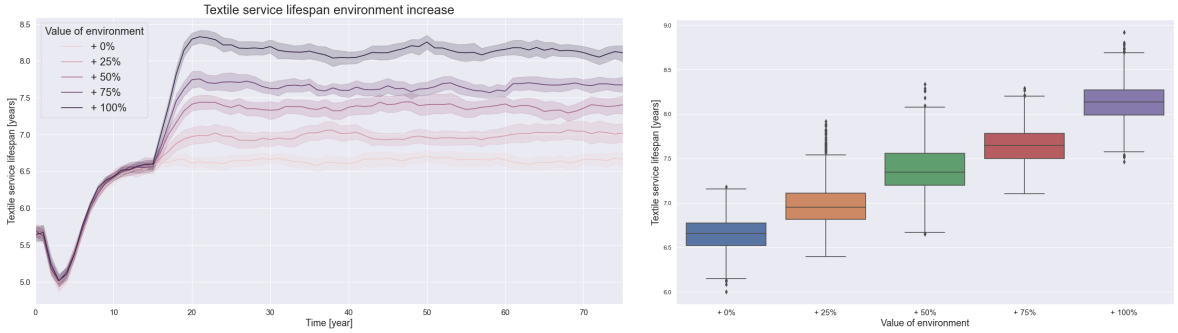

Figure J.16: Service lifespan environment increase

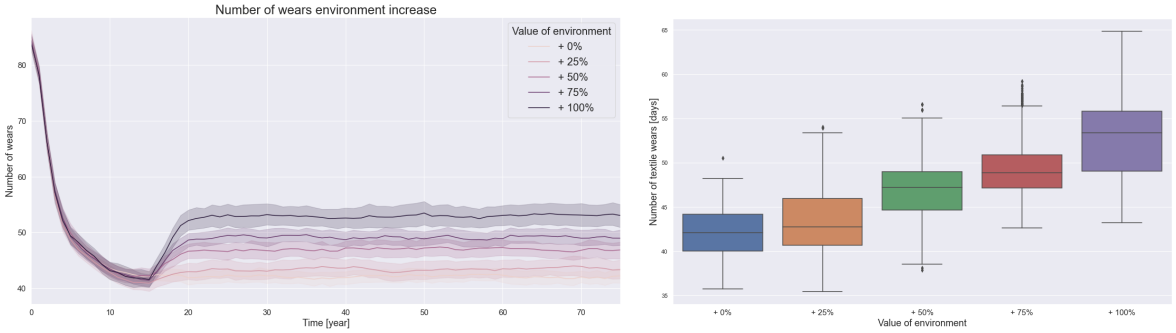

Figure J.17: Number of textile wears environment increase

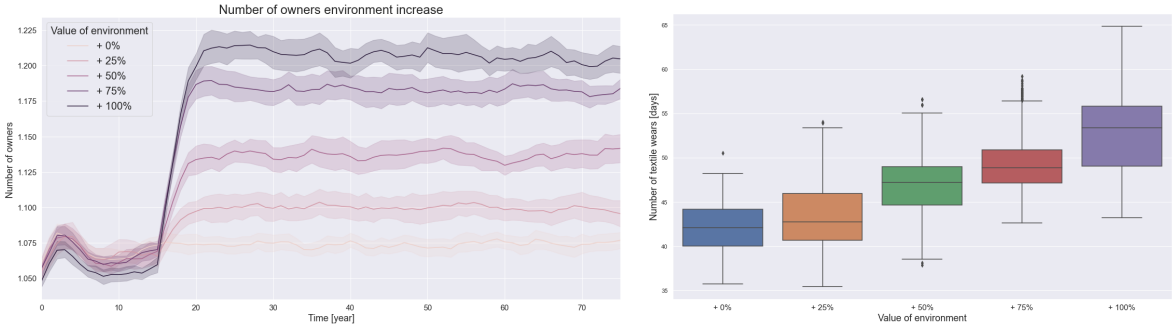

Figure J.18: Number of owners environment increase

J.2.3 Convenience increase

Figures J.19, J.20 and J.21 show the effect of a decrease in the importance of the value of convenience on the service lifespan, amount of wears and number of owners. The figures indicate that an increase in the value of convenience leads to a notable increase in the three variables.

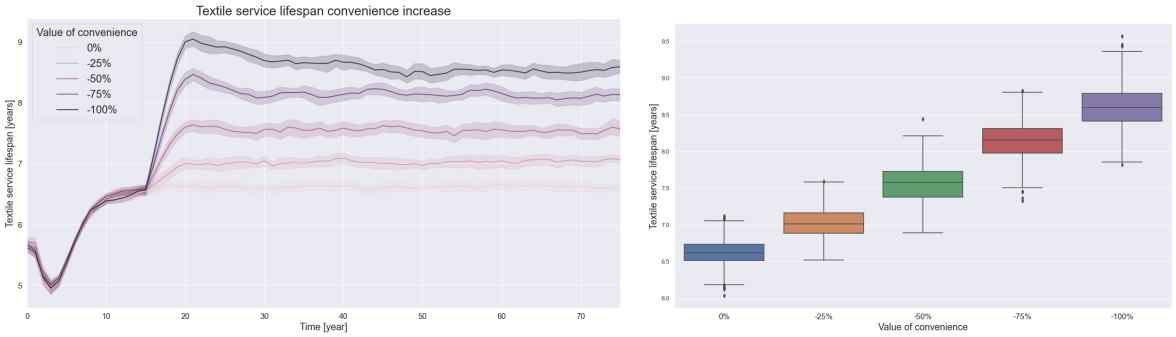

Figure J.19: Service lifespan convenience increase

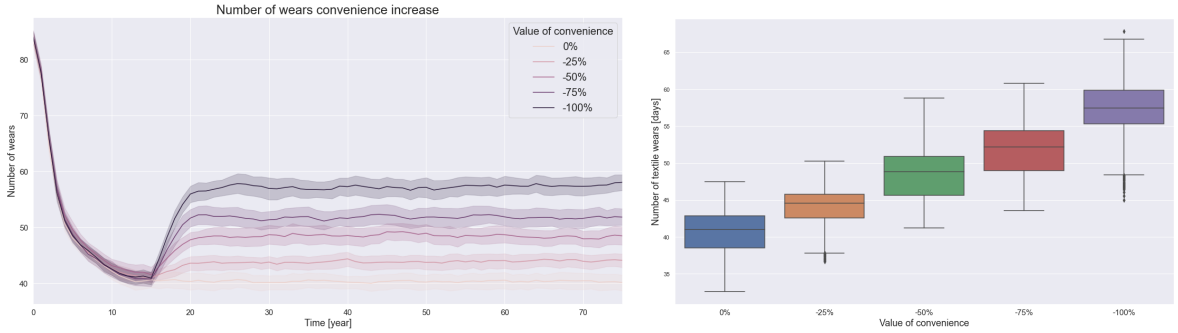

Figure J.20: Number of textile wears convenience increase

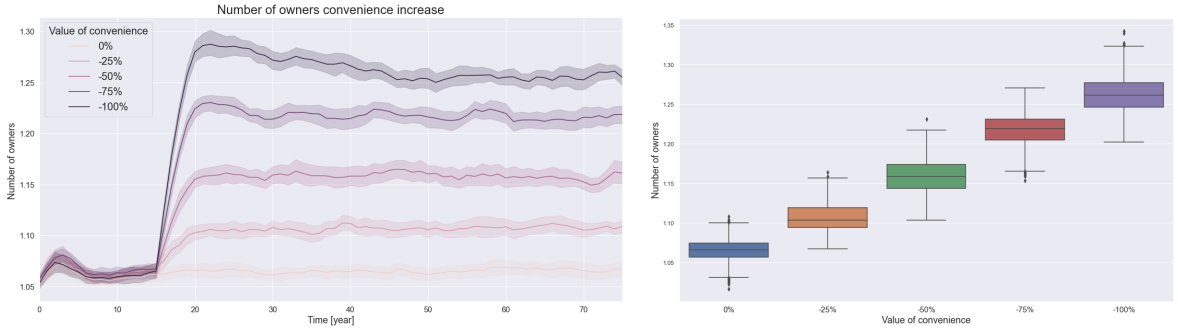

Figure J.21: Number of owners convenience increase

Value combination

Figures J.22, J.23 and J.24 show the difference between the effect of the value of price, environment and convenience on the service lifespan, amount of wears and number of owners.

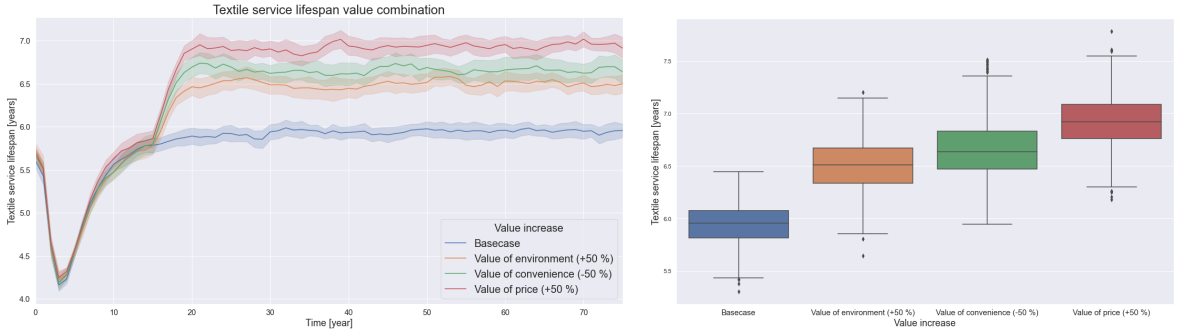

Figure J.22: Service lifespan value combination

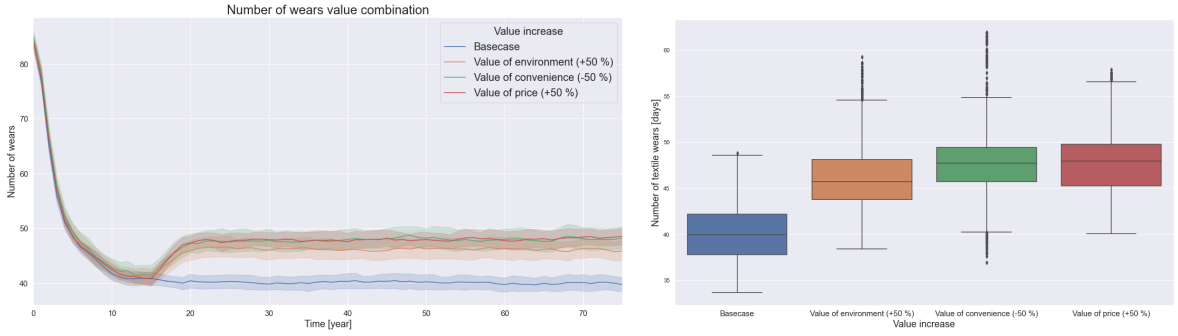

Figure J.23: Number of wears value combination

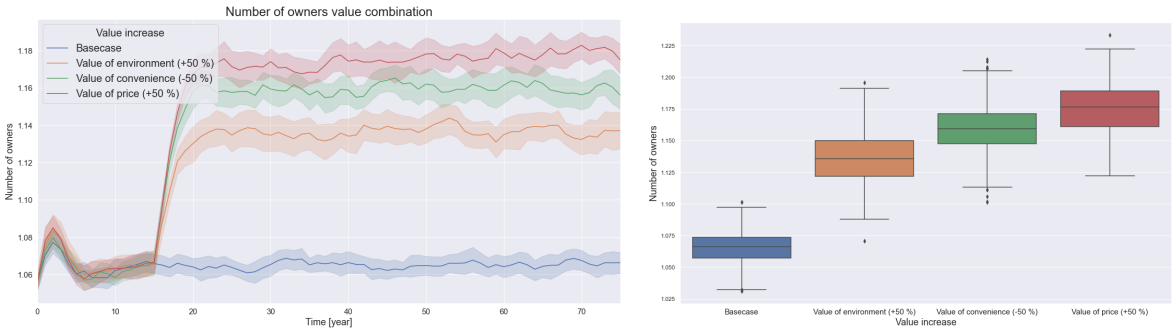

Figure J.24: Number of owners value combination

J.2.4 Value combination with only high values

Figure J.25 shows the effect of value changes if only consumers are targeted who perceive the value as important.

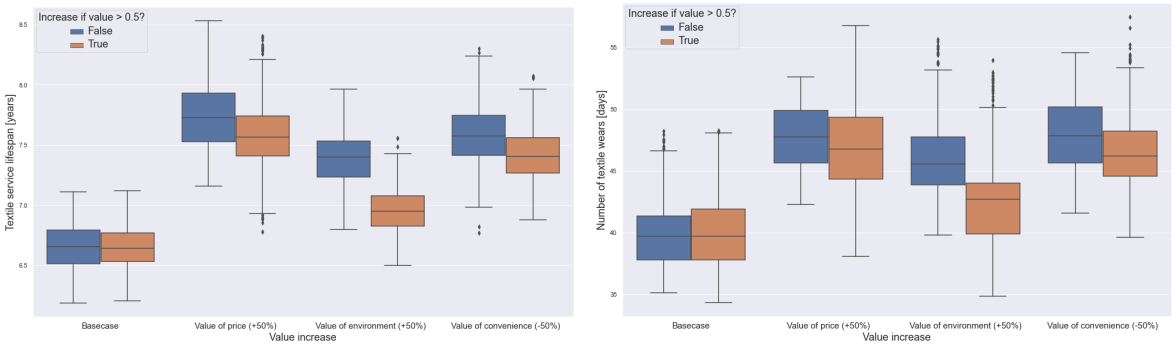

Figure J.25: Boxplot service lifespan and number of wears value combination high values

K VALIDATION

K.1 SENSITIVITY ANALYSIS

A sensitivity analysis consists of changing the values of internal and input parameters of the model to determine the effect upon the model behaviour (van Dam et al., 2013). The parameter change should lead to the same relationships in the model as in the real system. For the sensitivity analysis, several parameters have been adapted. The analysed parameters for the sensitivity analysis are shown in table K.1.

Table K.1: Input settings for sensitivity analysis

Parameter	Initial value	Sensitivity values
Consumer segment distribution	Based on Gwozdz et al. (2017)	Based on Gwozdz et al. (2017) Equal distribution (all 25%)
Social influence factor	0.5	0.25 0.5 0.75 1.0
Lifetime decrease reuse	30	0 25 50 75 100
Initial replacement rate	70	0 25 50 75 100

K.1.1 Consumer segment distribution

The ratio between consumer segments in the model is initially based upon Gwozdz et al. (2017). According to their research the distribution of the budget minimalist, casual minimalist, budget shopper and premium shopper is respectively 43%, 27%, 21% and 9%. However, in the Netherlands this ratio might be different. Therefore, the sensitivity of the consumer segment distribution has been analysed. Figure K.1 shows the total reused textiles for the two distributions. The results show that the amount of reused textiles differs for the two distributions. This shows that the model is sensitive to variations in the consumer segments. This is the case, because each consumer segment has different reuse percentages and purchase behaviour.

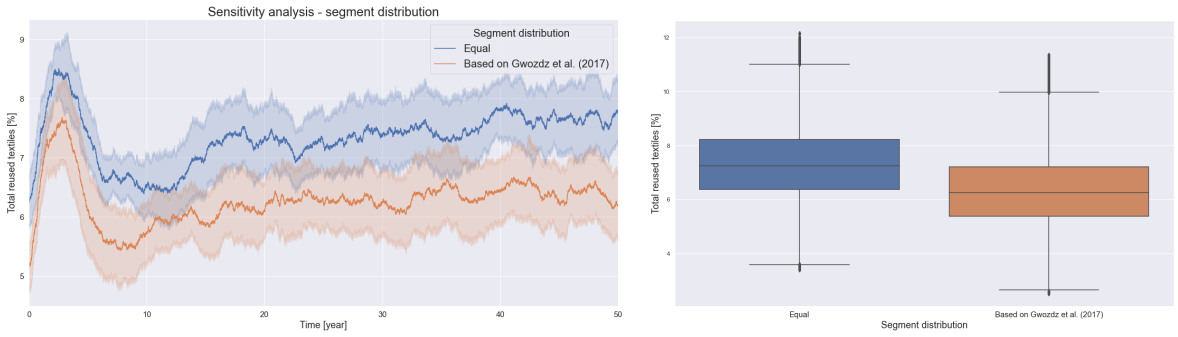

Figure K.1: Total reused textiles sensitivity analysis consumer distribution

K.1.2 Social influence factor

The social influence factor determines how much a consumer is influenced by their social network. In other words, a comparatively high social influence factor results in a high in- or decrease of the percentage reused textiles of the consumer, due to their social network. The results in figure K.2 show a very small correlation between the total amount of reused textiles and the social influence factor. The total reused textiles increases in most cases with an increase in the social influence factor. However, this does not apply for a social influence factor of 0.75. Probably because the effect is so small, it is balanced out in some cases by randomness. This indicates that the choice of the social influence factor has a minor impact on the model results.

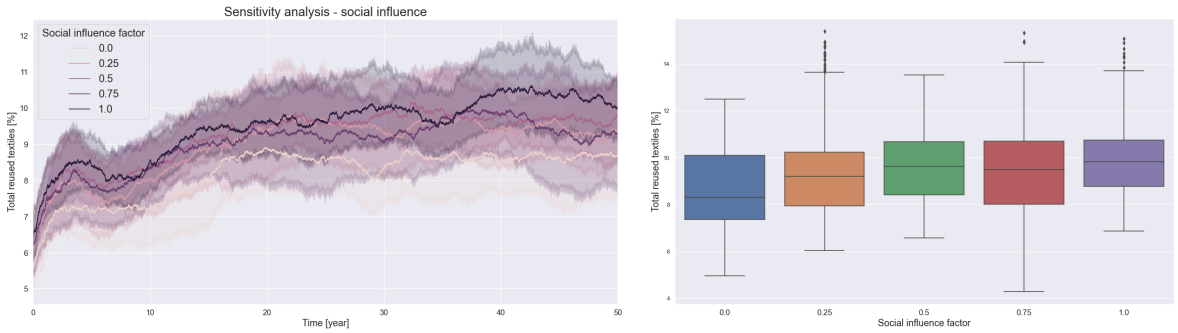

Figure K.2: Total reused textiles sensitivity analysis social influence

K.1.3 Rebound - lifetime decrease

The lifetime decrease variable represents one of the main rebound assumptions in this research. When a textile item is reused, the possession span of the second owner decreases compared to the possession span of the first owners. After all, the item is worn already and therefore the quality of the textile item is degraded. In this research, the decrease in lifespan when a textile item is reused is 30 %. The choice of this variable is highly uncertain. ThredUP (2019) presume in their study that 30% of the lifetime of a textile is completed when a textile item is reused. WRAP (2017) however argues that a lifespan decrease of 50% seems reasonable when a textile item is reused. Farrant et al. (2010) even assumed that reused clothes are worn as long as new clothes. This indicates that there is currently no uniformity in the choice of this value.

The results in figure K.3 show a direct relationship with the lifetime decrease and the total reused textiles. This is most likely to be explained by the decrease in service lifespan due to the lifetime decrease factor as shown in figure K.6. Because textile items remain within the system for a smaller time period, the average amount of reused textiles decreases. This leads to a decrease in the percentage of textile items within the system, as shown in figure K.3. Interestingly, there is almost no effect on the number of textile wears per textile item, as shown in figure K.6. This shows again that the time a textile item remains within the system is mainly determined by the possession span of the textile item, not the amount of possession wears.

The sensitivity analysis shows that the choice of the value for the lifetime decrease influences the results considerably. This is an important insight, as the choice of value is uncertain. This should be taken into account when interpreting the results, and will be further discussed in chapter 10.

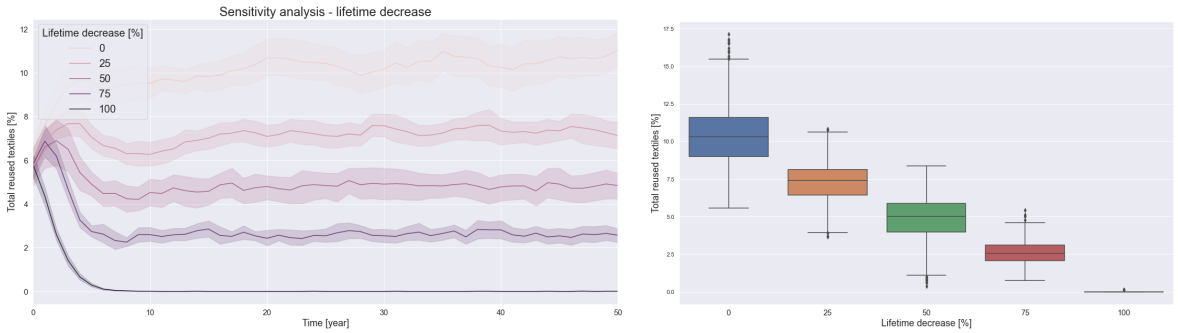

Figure K.3: Total reused textiles sensitivity analysis lifetime decrease

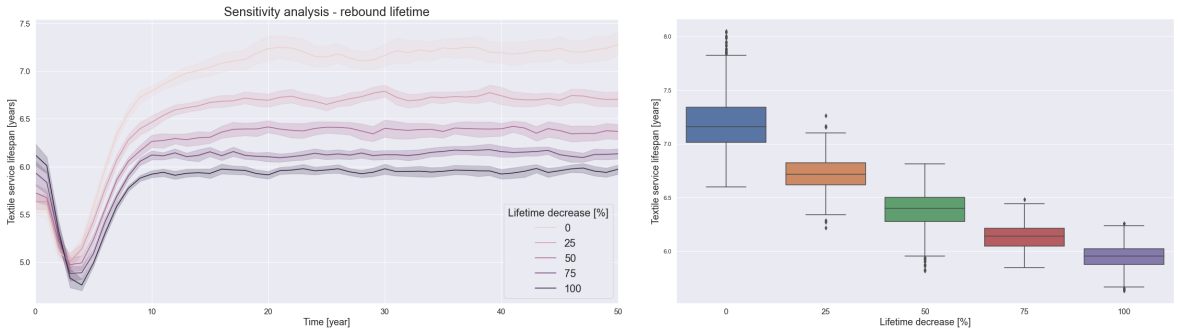

Figure K.4: Service lifespan sensitivity analysis lifetime decrease

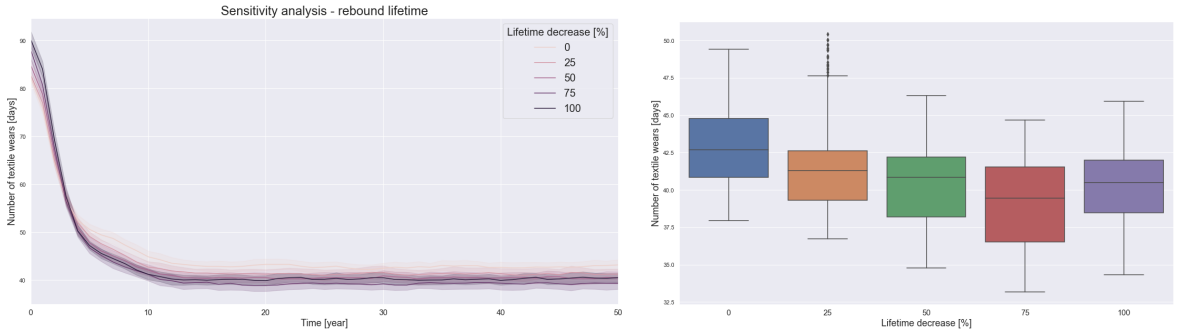

Figure K.5: Number of textile wears sensitivity analysis lifetime decrease

K.1.4 Rebound - replacement rate

The replacement rate represents, next to the lifetime decrease variable, the main rebound assumption in this research. Based on the values and segment of the consumer, the replacement rate is determined. The replacement rate indicates the chance that the purchase of a reused item leads to the purchase of an additional textile item. The results in figure K.6 shows almost no relation between the replacement rate and the consumption of new textile items. Only a replacement rate of 100% leads to a small but notable difference in newly consumed textile items. However, this difference could also be explained because of randomness within the model. Possibly, the level of reuse within the system is not enough to notice the reduction in new textiles consumed. The small reduction is likely to be canceled out due to randomness.

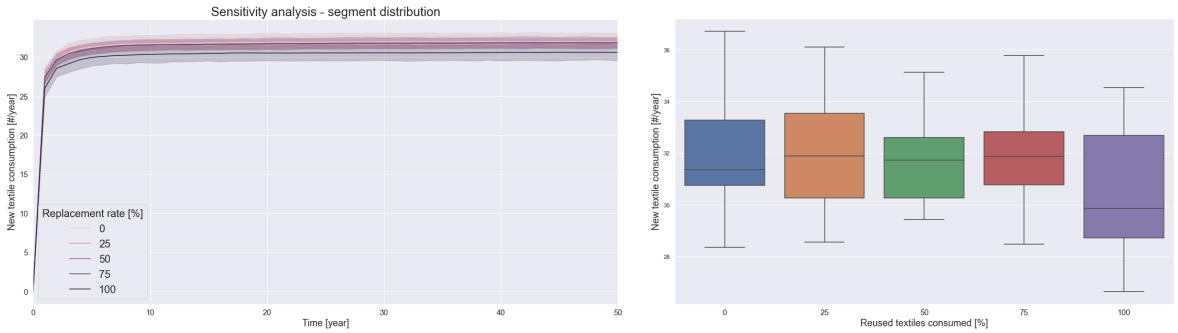

Figure K.6: New consumption sensitivity analysis replacement

K.1.5 Maximum reuse

A critical assumption during this research is that all textile items can be reused only once. This assumption is added to prevent unrealistic behaviour in the 100% reuse scenario. During the expert validation, the experts argued that this assumption does not always apply. Therefore, the sensitivity of this assumption is checked in this validation step.

Current scenario

The results in figure K.7 show that changing the amount of times a textile item can be reused has no effect on the total percentage of reused textiles in the current situation. In addition, figure K.8 also shows no relationship between the service lifespan and the amount of times a textile item can be reused.

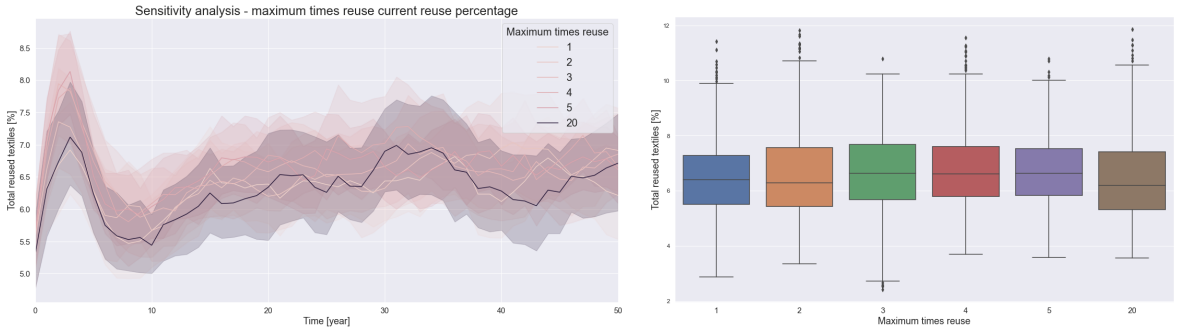

Figure K.7: Total reused textiles current scenario - sensitivity analysis maximum reuse

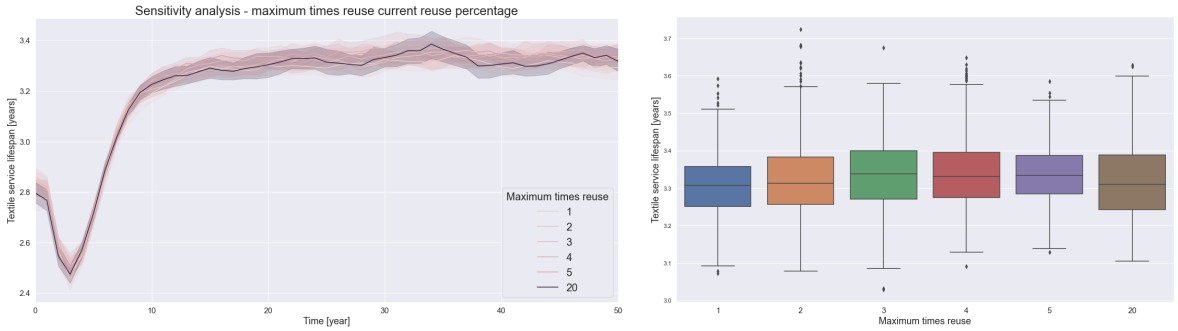

Figure K.8: Service lifespan current scenario - sensitivity analysis maximum reuse

30% textile reuse increase

The results in figure K.9 show that in the 30% increase scenario there is no notable difference between the percentage reused textiles with the different parameter settings. However, the service lifespan of the textile item in figure K.9 does change. The parameter setting with

max one time reuse shows contrasting behaviour in comparison with the higher settings. This indicates, that at higher percentages of reuse the assumption causes the service lifespan to be decreased. The effect is not very big, but still this will be reflected upon in chapter 10.

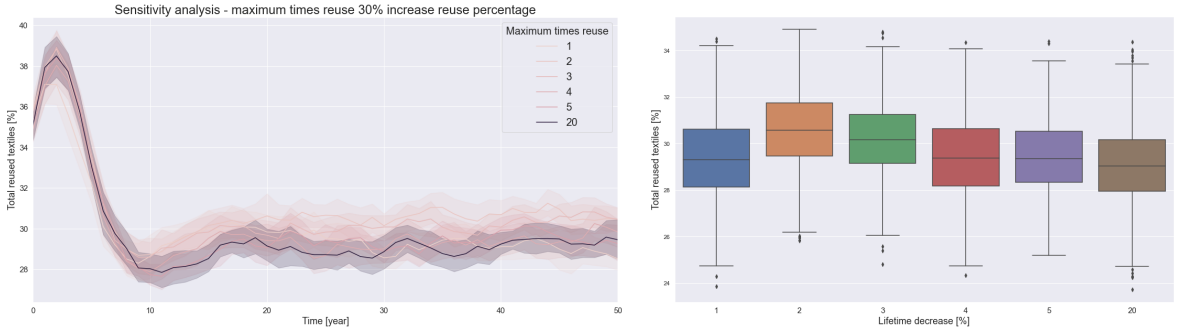

Figure K.9: Total reused textiles increased reuse scenario - sensitivity analysis maximum reuse

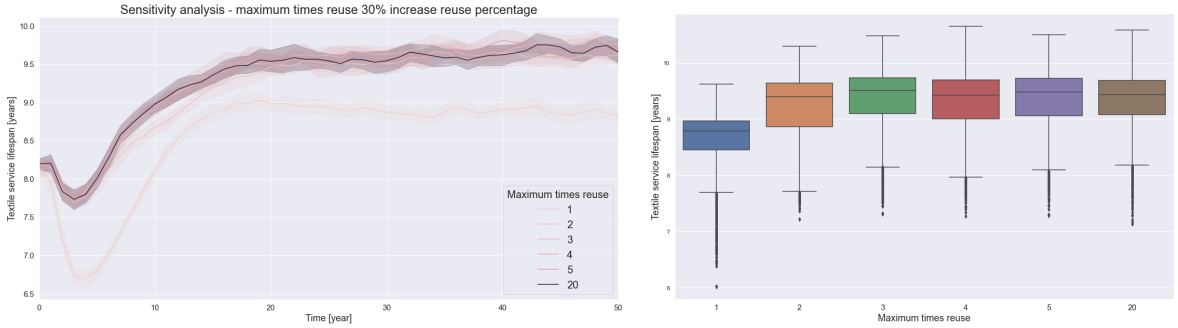

Figure K.10: Service lifespan increased reuse scenario - sensitivity analysis maximum reuse

K.2 LITERATURE COMPARISON

Validation can be performed by studying the literature (van Dam et al., 2013). Similar conclusions drawn from theoretical research and non agent-based models increase the confidence in the model outcomes. For this validation step, the total percentage reused textiles in the system has been analysed in comparison with literature.

The percentage of formal and informal reused textiles are based upon the quantification of the Dutch textile reuse system as identified in chapter 4. This resulted in a percentage of 8% for formal reused textiles and 5% for informal reused textiles. Because of this, the total amount of reused textiles is expected to be 13%. However, the model results showed an average percentage of reused textiles in the system of 7.8%. This can be explained because of rebound effects, as reused textiles are degraded earlier (substitution effect) and might lead to the consumption of new textile items (income effect). Maldini et al. (2017) and de Wagenaar et al. (2022) also estimated the amount of reused textiles in the wardrobes of consumers.

Maldini et al. (2017) studied the amount of clothing in the Dutch wardrobes in 2017. Their wardrobe information is based on a small, non-representative sample of respondents. However, their study is the only one that measured the amount of clothing items in Dutch wardrobes and therefore their results are used as an indication. Maldini et al. (2017) estimated that 6% of the items in possession of Dutch owners are reused. This percentage is

slightly lower than the results of the model outcome. This might be the case, because the data from Maldini et al. (2017) is from 2017. The reused market has been growing over the past years and for this research the most recent retrievable data has been used. This might explain the lower percentage of reused textiles of Maldini et al. (2017).

The study of de Wagenaar et al. (2022) explored the international consumers' wardrobe in 2021. They found that on average 17% of the total wardrobe consists of reused items. This percentage is much higher than the results of the model run. This difference can be explained in two main ways. Firstly, because the study of de Wagenaar et al. (2022) incorporates international data. Therefore, not only are high-income countries assessed, but also low-income countries are included. This could result in a higher percentage of reused textiles, as a lot of textile items from high-income countries are reused in low-income countries. Secondly, the respondents of the survey of de Wagenaar et al. (2022) have decided to follow the Circular Fashion MOOC, and therefore based on their interests could already be consuming more reused textiles than average consumers would. These reasons might explain the higher percentage of reused textiles of Maldini et al. (2017).

K.3 EXPERT VALIDATION

Two separate sessions with in total three experts have been conducted for this validation step. The aim of an expert validation session is to systematically review the model assumptions, mechanisms, and outcomes (van Dam et al., 2013). Both sessions consisted of a general introduction, the research approach, and the most important assumptions. Finally, the results were presented. Throughout the session, there was room for discussion and the experts reflected on all the research elements. There were no conclusions presented to prevent bias in the answer of the experts.

K.3.1 Expert session 1

This session was performed with two employees from Rebel. The first expert, has a lot of knowledge regarding the textile industry and performed many projects related to a circular textile industry. The second expert, has a lot of knowledge about agent-based models and what outcomes these models should have.

Physical and social lifespan
The experts argued that it is important to make a clear distinction between physical lifespan and social lifespan. Within the results, it is not incorporated what the physical lifespan is, because it is very hard to measure whether someone disposes of their textile items because they do not want to wear them any longer or whether the textile item is really broken. The experts argued that this might influence the final results and that this therefore should be considered when interpreting the outcomes. Therefore, this will be further discussed in chapter 10.

Imperfect substitution
The experts argued that the assumption that the lifetime of a textile item is reduced, every time it is reused, does not always apply. For reused textiles it might often be the case that the first owner has possessed the item, for a shorter time period than the second owner. An item that you bought, but do not wear often is more likely to be reused than an item that

you wear for a very long period of time. However, the experts agreed that in general you may not say that a reused textile item can last twice longer than a new item. The sensitivity of this assumption is measured in section K.1.

100% reuse
The 100% reuse scenario is rather short. The assumption that textile items can not be reused more than once, is not always applicable. To simplify the model, this assumption is understandable. The sensitivity of this assumption is measured in section K.1.

Informal and formal reuse
For the environmental impacts it depends whether a textile item is reused formally or informally. In addition, even within formal reuse, there are many environmental impacts related to reuse activities. Therefore, it is also important to reflect upon the difference between formal and informal reuse. This will be further discussed in chapter 10.

Rebound experiment
The Key Performance Indicators show a consumption of new textile items over time. This is however for a time period of 100 years, not fully realistic. Because, the population keeps on growing, textile items are consumed more and the reuse market is growing. Therefore, an increase in new consumption is expected. This will be reflected upon in chapter 10.

K.3.2 Expert session 2

This session was performed with one sustainability expert from the textile trade association 'Modint'. An interview with this expert was already previously conducted, in the begin phase of this research. The expert has a lot of understanding of reuse within the textile industry, helps with making policies and then translating these policies into actions for textile companies.

Consumer segments
Very interesting that you segmented the consumers. There is never 'one type' of consumer, so very good that you made a distinction between those types. I really like the way you did this and am very curious about the research you used for the segmentation.

Textile lifespan
I rather speak of useful life instead of lifespan. So important that you make a distinction between social and physical lifespan and also mention this when interpreting the results. In addition, good that you also incorporate the amount of wears. Conceptualization based upon possession span is rather interesting.

Percentage reuse
8% of consumed reused textile items, seems a lot to me. In the Netherlands only 2% is reused via collection bins. However, if items in second-hand shops and Vinted are incorporated than it could be true. The uncertainty of these percentages will be reflected upon in chapter 10.

Reuse variation
Te reduction of new due to reuse is clear. However, the reduction seems a lot. Maybe good to reflect on this. In addition, it would be nice to couple the increase in reuse to the

decrease in new consumption. Large reduction in new, might also be the case due to the social interaction effect.

Rebound
Looks good, could definitely be the case. Interesting that you were able to quantify and visualize these effects.

Value increase
Increasing the value, means to increase the purchase decision, based upon price. The fact that an increase in the value of price, is more effective than an increase in the value of environment seems logical. Eventually people base their purchase decision mainly because of the price of an item.