An Agent-Based Modelling Study on Reuse, Rebound Effects and Value Change in Textiles

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Abstract. Addressing the textile industry's increasing environmental impact requires a greater emphasis on textile reuse, which in turn necessitates behavioural change. However, it is currently unknown which changes in consumer values determine textile reuse consumption the most, while rebound effects that counter these effects may occur. Reuse lowers the impact of textile consumption, but may also cause higher levels of consumption, reducing its environmental gain. This study provides an in-depth analysis of textile reuse rebound effects using Agent-Based Modelling, while acknowledging consumer value heterogeneity. Results show that, even if rebound effects occur, textile reuse still leads to a decrease in the consumption of new textile items, reducing virgin material use and its environmental impact. Reuse also leads to an increase in the lifespan of textile items and the number of times a textile item is worn.

Keywords: Circular Economy · Circular Consumption · Reuse · Textile · Clothing · Agent-based Modelling · Social Simulation

1 Introduction

In the past 15 years, the production of clothing has globally doubled, and the average number of times clothing is worn has decreased by 36% [1]. From an environmental perspective, this is worrying because currently, almost 6-10% of global greenhouse gas emissions originate from the textile industry [2, 3].

The textile industry is now the fourth largest contributing industry to the impact on the environment and climate change in the European Union [4]. Circular economy strategies, such as textile reuse, are essential to overcome this challenge. Therefore, the Dutch government has set ambitious targets for significant growth in textile reuse in the next decade. [20] Achieving these goals requires behavioural change among consumers, yet it remains unclear which shifts in consumer values are most effective in driving reuse of textiles [5].

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Prior research has shown that reusing textiles carries the risk of not replacing primary production or slowing consumption cycles [6]. So-called rebound effects may appear when increases in textile consumption efficiency are offset by increased levels of textile consumption [7]. Researchers, industry experts, and policymakers do not or hardly account for rebound effects, thereby overestimating the environmental benefits of reuse. Moreover, existing literature indicates a lack of knowledge about the underlying assumptions and the causes and mechanisms underlying these rebound effects [8–10].

1.1 Research Gap and Research Question

Research on consumer behaviour and textile consumption increases and several studies have reported on the effects of reuse [6, 11–13]. However, quantitative research examining consumer behaviour on the rebound effects of textile reuse is mostly absent. Moreover, research on textile reuse within the Netherlands is very limited, just as on the circular economy rebound [6, 8], including on reuse and the textile industry. Furthermore, more attention should be paid to the choices and preferences of different groups of consumers. Buying, using, and disposing of textiles entail a complicated socio-cognitive process driven by diverse personal values [6, 13]. So, reuse strategies will not achieve their full potential if they do not consider the heterogeneity of consumers [6]. For instance, Polizzi di Sorrentino et al [14] argue that, especially for rebound effects, incorporating consumer behaviour is essential. However, there are currently no simulation studies that study behavioural change towards increased textile reuse, incorporating heterogeneous consumers.

To address the research gap above, this study aims to increase our understanding of textile reuse rebound effects through model-based research 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 can enhance textile reuse in the Netherlands, given possible rebound effects?*

The research question is addressed using data from existing literature in combination with nine semi-structured interviews, as input to develop an agent-based model. This enables the effects of reuse and corresponding rebound effects to be quantitatively investigated. Subsequently, the model was applied 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, an increased number of textile wears, and a decrease in the number of newly purchased textile items. This study focuses on textiles, reuse, and rebound effects. Textiles in this study include both clothing and home textiles, the latter also known as bed, bath, and kitchen textiles (BBK), which are sold, used, and disposed of in the Netherlands. This study defines reuse as the (re)use of the original product function (e.g., clothing reused as apparel to cover the body). Rebound effects in textile reuse may occur, meaning that reuse activities, which lower the impacts of textile consumption, also cause higher levels of consumption, reducing their environmental benefits [6, 7] due to lower prices or lower quality.

2 Research Design and Methodology

In this study, a bottom-up agent-based modelling (ABM) approach is used in combination with desk study, literature analysis, and expert consultation. The study uses data from existing literature and nine semi-structured interviews as input to develop an agent-based model. The interviews were used to gain insight into the current textile reuse system, the relations between stakeholders, textile purchase and disposal behaviour, and the influence of rebound effects. The interviewees were able to verify the information found during the desk research and supplement it with information from their industry experience or research.

Our approach is motivated as follows. Firstly, the literature argues that quantitative models are needed to study rebound effects in a real-world context [8], while Font Vivanco et al. [10] argue that for this purpose, ABM is an appropriate tool. Secondly, ABM is highly suitable for modelling complex adaptive socio-technical systems [15]. The Dutch textile reuse industry can be seen as such a system in which 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 [16]. Thirdly, an agent-based model is capable of simulating individual agent behaviour and identifying emerging patterns of behaviour [17]. Lastly, agent-based models are suitable for testing consumer value changes [18].

In order to build the agent-based model, the processes and flows within the system are identified and quantified (see Fig. 1). This quantification [18] shows that consumers obtain reused (13%) or new textile items (87%). These reused textile items can be reused formally (66%) or informally (34%). Formal reuse occurs if the reused textiles are obtained via a third party, while informal reuse occurs if this occurs from consumer to consumer. So, the base case mirrors the Dutch textile reuse system, as shown in Fig. 1.

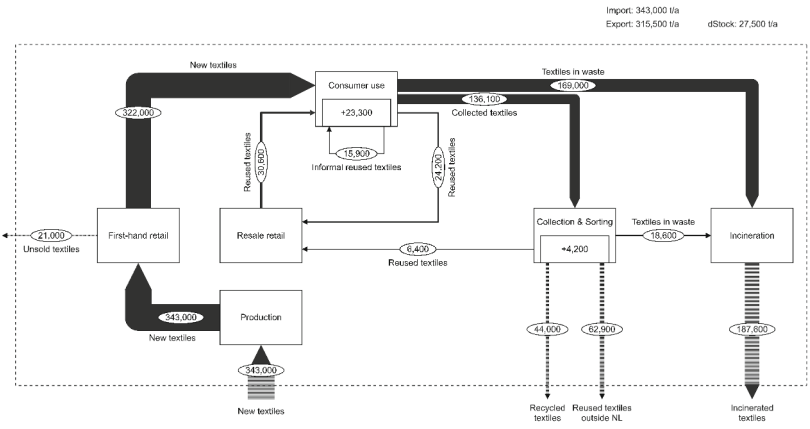

Fig. 1. Quantification of the Dutch textile reuse system, in tonnes in 2018 [18].

Based on the flows within the Dutch textile reuse system, an agent-based model was developed in NetLogo. The model code is available at GitHub, see https://github.com/Brittzandbergen/textile-reuse-thesis. The model interface, as shown in Fig. 2, includes

sliders to adjust parameters (e.g., rebound factors, consumer value changes) and monitors the outputs (e.g., the percentage of reused textiles and new consumption). The model logic is shown in Fig. 3, using the Business Process Model Notation (BPMN). The base case mirrored the Dutch textile reuse system, as shown in Fig. 1.

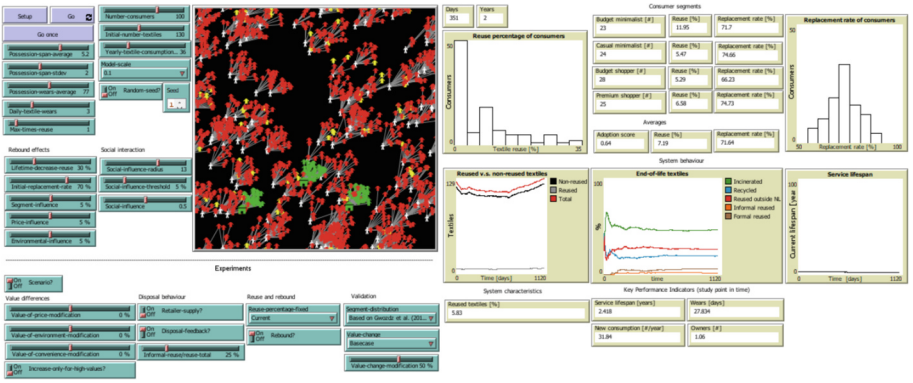

Fig. 2. NetLogo interface

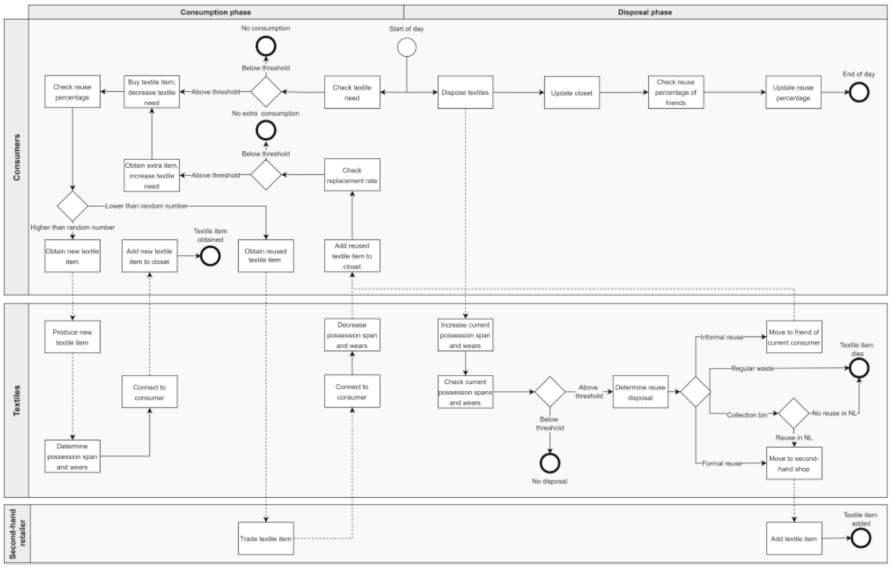

Fig. 3. Conceptual model

To allow for consumer heterogeneity, four consumer segments and five consumer values are incorporated. The consumer segments are derived from [19] as follows: (1) budget minimalist, (2) casual minimalist, (3) budget shopper, and (4) premium shopper.

The values of (i) price, (ii) environment, and (iii) convenience are drivers, while the values of (iv) ownership and (v) convenience are barriers to purchase reused textiles. These consumer values are based on a literature review [18] and quantified for each consumer segment [19], resulting in reuse percentages for each consumer segment. Figure 4 shows how values and social interaction influence the re-use percentage (RP). In the model, every consumer is part of a consumer segment. Depending on the consumer segment, consumers have values that determine their reuse percentage. Consumers also have a social network that influences their reuse percentage. The number of textiles a consumer owns is determined based on the consumer segment and reflects the size of the consumer's closet. The replacement rate differs per consumer and is dependent on their consumer segment, value of price, and value of environment.

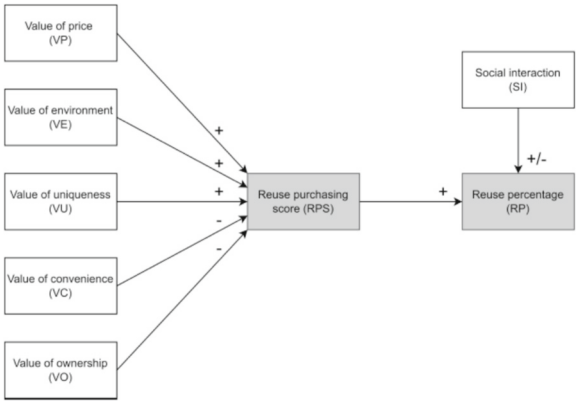

Fig. 4. How values and social interaction influence the re-use percentage (RP).

According to several scholars, the textile reuse behaviour of consumers is influenced by the behaviour of their social network. The model integrates social interaction by simulating a dynamic social network where each consumer is connected to friends, reflecting social influence. Based on the difference between an individual's current reuse percentage and the average percentage of friends, their own reuse behaviour changes accordingly, with larger discrepancies resulting in a greater change. A social influence factor modulates the strength of these interactions, enabling varying levels of the influence of friends. Additionally, resistance to adopting reused textiles is modelled through a threshold that requires a minimal percentage of reuse of the friends before the reuse percentage increases. This captures the complexity of behavioural mechanisms by simulating how individual decisions ripple through the social network, creating emergent patterns that reflect the collective dynamics of textile reuse adoption.

Rebound effects are incorporated in the model through the substitution effect and the income effect, as follows:

(1) **The substitution effect.** Reused textiles are good substitutes for new textiles, but of a slightly lower quality due to usage. Therefore, the lifetime of a textile item in the possession of an owner decreases every time the item is reused.

(2) **The income effect.** Cost savings due to low-priced reused textiles are partly 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, the value of price, and the value of the environment of the consumer.

Table 1 shows the experimental setup, how values were changed, and the number of scenarios. The model was used to run two types of experiments, with a total of 54 scenarios. The first experiment provided a more in-depth understanding of the performance of reuse on the Key Performance Indicators and the occurrence of rebound effects. The second experiment shed more light on the effectiveness of different value changes.

Table 1. Experimental set-up, value change, and number of scenarios

Category	Experiment	Parameters	Value change	Number of scenarios
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	Random-seed	Fixed	5
	high values	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	Random-seed	Fixed	16
	difference	Segment-distribution	4 consumer segments	
		Value of price	+50%	
		Value of environment	+50%	
		Value of convenience	-50%	

Verification of the model was carried out following the steps proposed by van Dam et al. [15], which include code walk-throughs, recording and tracking agent behaviour,

interaction testing, and multi-agent testing. Validation consisted of a sensitivity analysis, a literature comparison, and an expert validation. It was found that the most important variables were found to be sensitive, the percentage of reused textiles is within the bandwidth presented in the literature, and experts agreed on the most important outcomes.

3 Results

Figure 5 shows an increase in re-use and possible rebounds in new and re-used textiles. 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. Increased reuse also leads to an increase in the lifespan of textile items and the number of times a textile item is worn.

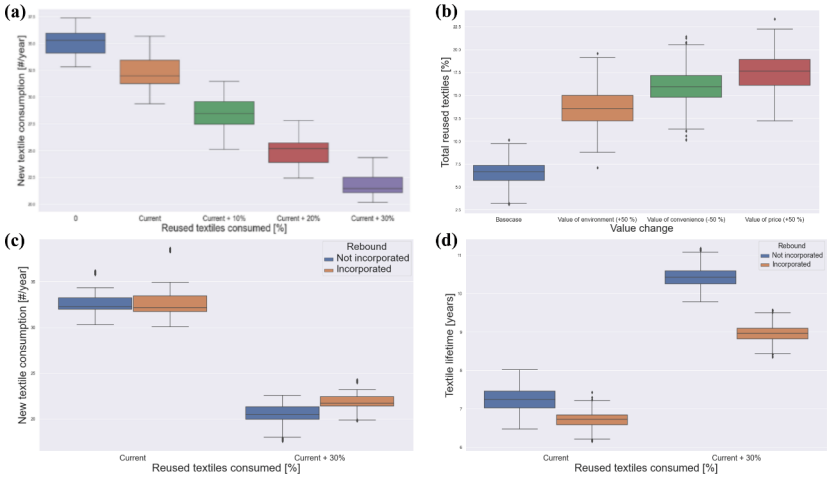

Fig. 5. Boxplots for (a) reuse reducing new textiles consumed (%); (b) value change increasing reuse; (c) rebound in new textiles consumed; (d) rebound reducing lifetime.

In addition, textile reuse also leads to an increase in the number of owners of a textile item. This is relevant because transferring a textile item from one consumer to another generally requires additional activities having some 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 number of textile items in possession by consumers in the Netherlands
2. The increase in the lifetime and number of wears of textile items due to reuse
3. The decrease in new textile items due to reuse.

The first and second effects are relevant at 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 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.

4 Conclusion and Recommendations

The research shows 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. Thus, less virgin input is needed to create textiles. Despite these beneficial results, 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 current and higher levels of reuse. For the current level of reuse, rebound effects occur in two ways. Firstly, not incorporating rebound effects leads to an overestimation of the number 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. For higher levels of reuse, a third rebound effect becomes apparent; not incorporating rebound effects leads to an overestimation of the reduction in purchased new textile items.

Behavioural change is thus required to enhance textile reuse. Despite the fact that each individual consumer reacts differently to a value change, the overall order of efficacy of this adjustment is: price, convenience, and finally, 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.

This study provides recommendations for policymakers, industry experts, and environmental modellers. Policymakers should focus on price incentives and convenience improvements while addressing perverse incentives that lead to rebound effects, such as reused items that lead to additional sales instead of cannibalising the existing market. Environmental modellers are advised to incorporate rebound effects using replacement rates and lifespan factors. By addressing consumer heterogeneity and rebound dynamics, this study contributes valuable insights for advancing sustainable textile practices in the Netherlands.

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