Household Recycling Behaviour in Suburban Beijing

An agent-based modelling approach

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SPM9555 Agent Based Modelling of Complex Adaptive Systems

Preface

This research is conducted by 4 graduate students, as part of the course *SPM9555 Agent-based Modelling of Complex Adaptive Systems*, as given by Dr. ir. Igor Nikolic at the faculty of Technology, Policy and Management, which is part of the Delft University of Technology.

For this research, the students have applied the modelling steps for an agent based model, as provided by Van Dam, Nicolic and Lukszo (2013).

We thank the University of Beijing and Dr. Tong Xin for providing us with this interesting research topic and giving us valuable feedback throughout the research process.

We also like to thank Dr. ir. Jan Kwakkel for his help with applying the EMA Workbench, and mostly Dr. ir. Igor Nicolic for his advice and supportive feedback throughout the research process.

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STEP 1: Problem Formulation and Actor Identification

The first step of the iterative cycle for an agent-based model focusses on the formulation of the problem and the identification of actors. First, the problem is addressed by stating the main lack of insight, the current observed behaviour, the desired behaviour, and the cause of this difference. Thereafter, the client and the other actors involved are described and analysed. This step ends by describing our role in this project.

What the stated problem is

The case that is considered in this research is waste management in Beijing, more specifically the recycling behaviour of households in a suburban village, north of Beijing. In a world with a growing need for sustainable development, recycling is just one of many attempts to decrease our environmental impact. Looking at the waste management hierarchy (United Nations Environment Programme, 2013), prevention of waste is the most favoured action to manage waste, whereas disposal is the least favoured one. Somewhere in between, and logically more favoured than disposal, is the option of recycling waste. In this way, waste can be treated and materials can be used again. Essential for an effective recycling programme is the participation of households. Households produce waste and are able to separate this waste into recyclable- and non-recyclable waste. The recyclates then go to the recycling factories.

This research attempts to analyse and experiment with the system currently in place, in order to improve the household participation rate. The problem of this current system consists of a lack of insight for the problem owner, and a difference between the observed and desired situation.

The lack of insight that is addressed in this research is the poor understanding of what the most important contributing factors are towards a household's decision on the recycling of waste. Contributors are factors that a household takes into account when making a decision. The observed situation that currently emerges is that only 40% recycles of 500 households who participate in the programme, which is about 200 households. The desired situation is that at least half of all 10.000 households participate, thus a difference of 4.800 households. The difference between the current and desired situation is caused by insufficient interventions to influence the recycling behaviour of households. Interventions are ways of influencing the households, by intervening in the system. Referring to the lack of insight, knowing the most important contributors can help to use targeted interventions with which the participation rate can be increased.

The owner of the problem

This topic is provided by dr. Tong Xin from the University of Beijing, who performs research on household waste management in Beijing. They have set up a programme in which 500 households are considered, and tried several ways to influence these households' recycling behaviour. Examples of interventions are a marketing campaign on the streets, and providing valuable coupons for recycled waste. Thus, the university is considered to be our client. However, the actual problem owner for this topic is the Chinese government, while they're concerned with public tasks, including sustainable waste management. This research must therefore focus on the ways in which governmental levels can influence the households.

What actors are of influence for the analysis

Besides the client and the problem owner, there are several other relevant parties. Probably the most relevant group consists of more than 10.000 households living in the suburban village north of Beijing. This actor desires minimal effort and maximal result, but there are also other factors that influence its recycling behaviour. The rationale behind that behaviour is important to understand, while all households together directly determine the participation rate. Another relevant group consists of the waste collectors. By going door-to-door they collect valuable waste in order to sell this to recycling companies. Their transportation capacity of waste is an important part of the recycling system, making it more attractive for households to participate. A last relevant group consists of the recycling companies. They receive or buy valuable recyclates in order to process them into reusable materials.

What the goals and tasks of the research team are

Our goal is to perform research on this topic in collaboration with Dr. Tong Xin from the University of Beijing. Our role in this research is that of the modeller, thereby analysing the system, translating this into a model, and drawing conclusions based on the results. This document functions as our final report on the research performed. Hopefully this report can contribute to further research on this topic.

STEP 2: System Identification and Decomposition

The second step of performing an agent-based analysis of a socio-technical system consists of the system identification and decomposition. This comes down to deciding what is inside and outside the system we analyse. The system overview presents the relevant agents, their states and properties, and their actions and interactions. It's a first attempt at decomposing the whole complex system. Thereafter, the environment describes what is outside our system. Another important part of this step is to select and explain a theory that decides on the household recycling behaviour. Finally, the time frame is discussed in which this research analyses the system.

System overview

Most socio-technical systems are so large and complex that they can only be interpreted by simplifying and assuming the system (Van Dam et al, 2013). This also applies to our case, so this part presents our interpretation of the system. Two subjects are dealt with: the system structure and the actors within that system. The information in this part is based on a client interview, own interpretations, and further feedback on that.

Structure

The structure of the system covers two main themes: the neighbourhoods in the village, and the waste management system. First, the village roughly consists of three neighbourhoods, all with their own type of households. In the north east, there is a neighbourhood of original local residents. They lived in the village from before it was urbanized by the government. There are strong social interactions between the households in this area. These households will be called the *local residents*. In the north west, there is a neighbourhood with mostly staff from the nearby university. These households have a higher income and are highly educated. These households will be called the *university staff*. Lastly, in the south there is a neighbourhood which is composed of independent buyers, as these houses are open to the general market. There is a more differentiated population living in these parts of the village. These households will be called the *independent residents*. The result is a village consisting of three interesting neighbourhoods, each with its own characteristic households.

The system related to the central theme of this research, is the waste management system, particular for recyclates (view figure 1). Each household creates waste, for which it has roughly two options: landfill or recycling. To get some sense: of all municipal solid waste 90% goes to landfill, while approximately 25% is recyclable (Zhen-shan et al, 2009). In the considered Chinese village, there are two ways of recycling: using containers or collectors. Containers are situated at certain locations throughout the village, and requires people to bring their recyclable waste to the containers themselves. In return, households may receive valuable coupons. Collectors are people who go door-to-door to collect or buy valuable recyclates. In turn, they sell these recyclates to the recycling companies. Besides a formal collection system, recyclates are also collected informally. Even though the informal recycling activities encompasses serious health and environmental issues, they are necessary to deal with household waste in fast urbanization (Tong et al, 2015).

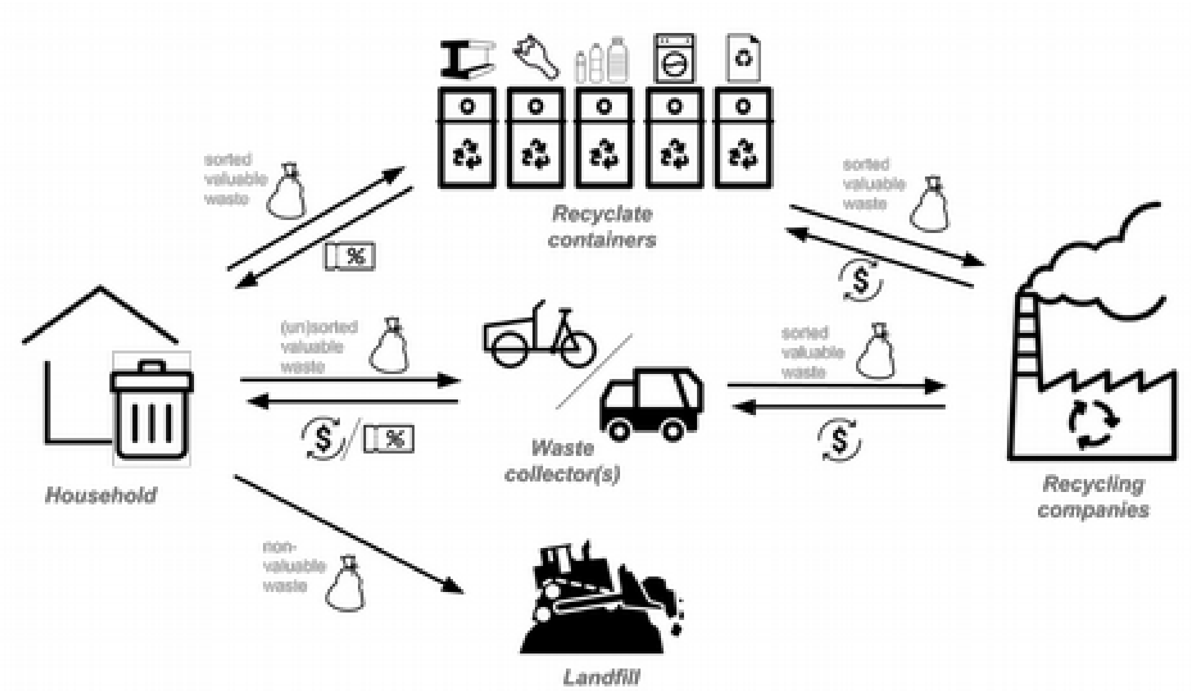

Figure 1: Overview of waste management system

Agents

The agents that will be part of our model, are households. The recycling decision of households is our main topic of interest. This behaviour is not significantly influenced by other actors, but merely by other households. However, the government or other actors may influence the environment of the households, which may influence their decision.
All households have:

- A household size: the number of people in a household
- A neighbourhood: each household is situated in one of the three neighbourhoods
- A level of education
- A determined amount of income
- Environmental awareness: the degree of awareness about the environment
- Knowledge of recycling: the knowledge on the recycling possibilities in the village
- An amount of recyclable waste
- A recycling intention: each household intents to recycle or not to recycle
- A recycling behaviour: each household shows a certain recycling behaviour
- Available time for recycling: spare time is sufficient or insufficient
- Distance to the container: the distance to the closest recycling container
- Available space for recycling: storage space is sufficient or insufficient
- A willingness to change: the degree to which a household is willing to change its current behaviour
- A social network: a list of households that a household interacts with
- Direct neighbours: the adjacent neighbours of a household
- Friends: other households in the village that are part of the social network

All households do activities like:

- Create recyclable waste
- Process recyclable waste via landfill, collectors, or containers
- Interact with their social network

Description of the environment

Besides the agents as described before, there are other elements that are part of the model: the environment. Everything that is not influenced by the agents, but does influence them forms the environment of the model. This research explores the ways in which the households are influenced by possible interventions. Those interventions are part of the environment, and can be divided into four categories: the amount and location of containers, the available recycling methods, economic incentives, and provision of information.

An important factor for households when it comes to recycling, is the distance towards the nearest recycling container. The closer a container is situated, the more convenient it is for a household to recycle its waste (Chu et al., 2013). Therefore, the amount and location of the containers is part of the environment. The second intervention category is the availability of recycling methods. As described before, there are two possibilities to recycle: via collectors or containers. If only one of these methods would be available, households are limited in their choice. The decision for this choice partially depends on a third intervention: the economic incentives. Both recycling methods can offer a certain remuneration in turn for the recyclates. In this way, the environment can increase the attractiveness of recycling. A last category consists of information provision. Every household possesses two kinds of knowledge: environmental awareness and recycling knowledge. Both can be increased by providing information, for example via TV commercials, flyers, or information points. So, the model environment can make households more aware of the environment or of the recycling possibilities.

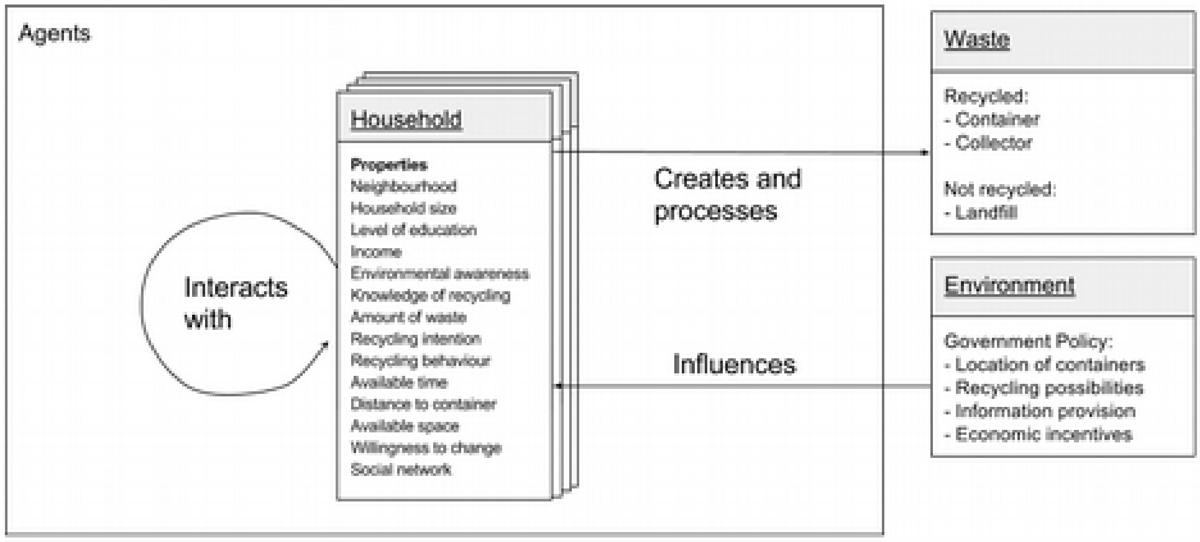

Figure 2: Overview of household properties, actions, and the environment

Behaviour of agents

An inevitable part of every agent-based model is to assess the way in which agents make decisions. This leads to visible behaviour, which in turn is experimented with. For this research, a decision-making theory must be applied to deal with the way in which households choose what to do with their recyclable waste. As suggested by the client, three partly overlapping theories will be applied: theory of reasoned action, theory of perceived behaviour, and theory of perceived behaviour in combination with situational factors. These theories assume individuals make systematic, rational decisions based on the information available to them (Jager, 2000). A decision, or recycling behaviour, follows from the intention, which is created by several components, as can be seen in figure 3. Which components are applied, depends on the applicable behaviour theory. As it is unknown how households exactly make their decisions, all three theories will be used in this research.

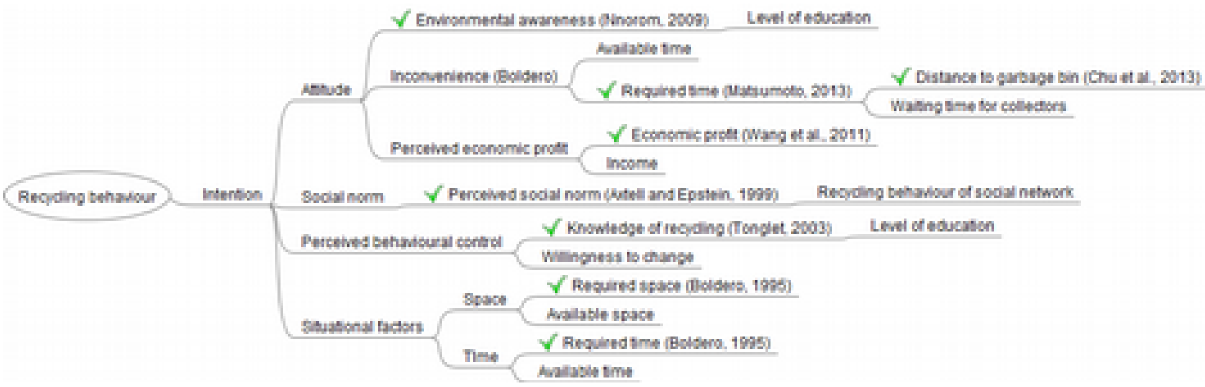

Figure 3: Mindmap of the behaviour theories

The theory of reasoned action (Fishbein and Ajzen, 1975) consists of two independent components: the attitude towards the behaviour, and the subjective norm. Together they form the intention of an individual, or in this case, a household. The attitude is an individual's evaluation of using an opportunity, which can be positive or negative. This means that a household evaluates the use of a recycling method. An important aspect of attitude is to evaluate the economic benefit of recycling. As researched by Wang et al (2011), the economic benefit has a vital impact on the preference of recycling style for residents in Beijing. The relative importance of this benefit is assumed to depend on the income of a household. Economic benefit from recycling is considered to be more valuable to lower-income households. A second aspect of attitude is the convenience of recycling, mentioned by amongst others Wang et al (2011), Matsumoto (2013), and Boldero (1995). In essence, this is the effort needed to recycle, which depends on the time required to recycle. The time required is based on the distance towards the nearest container, or the time a household must wait for collectors to come by. Again, an assumption is made that a household compares this time with its available time. For example, one can imagine that recycling is more convenient if a household has a lot of spare time. The third and final aspect of attitude is the environmental awareness, which also plays a role in the attitude of a household towards recycling. Literature seems to disagree on this topic (Wang et al, 2011), but here it is assumed that environmental awareness has a direct, positive effect on attitude, as is showed by Nnorom (2009). We assume that the awareness is not completely random, but based on the level of education.

Next to attitude the social or subjective norm is another component of the behaviour theories. This basically is (a perception of) the way in which society behaves. Axtell and Epstein (2001) determine the social norm based on a social network, consisting of several other agents. The social norm is based on the behaviour of this social network, and thus is a perceived social norm, while a household is not aware of everyone's behaviour. Social norm and attitude together form the intention within the theory of reasoned action. As an extension, the theory of planned behaviour adds perceived behavioural control (Jager, 2000). This component is the degree of which a household thinks it has control over its behaviour to recycle. Normally, this would be determined by asking households how much control they feel they have over their behaviour. For instance, Tonglet et al (2004), asked their respondents questions about their knowledge of recycling and the possibilities in their neighbourhood. As there is no data available for this topic, we use the knowledge of recycling as a determinant. We assume this knowledge is, just as environmental awareness, based on the level of education. In addition, the willingness to change is assumed to also determine the perceived behavioural control. It can be seen as the degree of which households are prepared to use their control in order to adjust their intention.

On the topic of recycling, some research added situational factors to improve the behaviour theories described above (Tonglet, 2003; Boldero, 1995). The two main factors identified are time and space, which can be seen as constraints. If a household (thinks it) does not have enough time or space to recycle, it will not recycle. To determine this, the required time and space have to be compared with the available time.

Time frame

The time frame of this model is 1000 ticks, in which one tick corresponds with one day. Therefore, each model run covers approximately 3 years. In this way, the households create waste every day, and they are able to recycle it every day. Furthermore, we assume an equilibrium will certainly be reached within the 1000 ticks. If the model shows no equilibrium, the 1000 ticks will provide enough information on the dynamics of the behaviour. Overall, 1000 ticks will assumably be long enough to provide useful information on the agent behaviour over time.

STEP 3: Concept Formalisation

Software Data Structures for states and properties

The variables that will be used in the model are identified in the previous step. The way these properties will be set up in the model will be described in this step. The setup of a property exists of determining property types, values and units. The set up can be found in table 1. The values of the properties with an asterisk are based on data provided by the client. This is highly aggregated data from the Beijing Statistic Yearbook in 2014. The values of all other properties are set up between 0 and 1, to make them comparable, or reasonable assumptions based on own insight.

Table 1: Setup of properties for each household

Property	**Type**	**Values**	**Unit**
A household size*	integer	{2, 3}	people
A neighbourhood*	string	{university staff, local residents, independent residents}	-
A level of education*	string	{low, medium, high}	-
An income*	integer	between 40.000 and 210.000	Yuan
Environmental awareness	integer	between 0,15 and 1	-
Knowledge of recycling	integer	between 0,15 and 1	-
An initial amount of waste	integer	between 0 and 9	kg
Waste generation	integer	between 1 and 5	kg/day
Waste limit	integer	10	kg
A recycling intention	string	{container, collector, landfill}	-
A recycling behaviour	string	{container, collector, landfill}	-
Available time for recycling	integer	between 0,9 and 1	-
Distance to the closest container	integer	between 0 and 1	-
Waiting time for collector	integer	between 0 and 1	-
Available space for recycling	integer	between 0,8 and 1	-
A willingness to change	integer	between 0 and 1	-
A social network	list of lists	Direct neighbours + Friends	-
Direct neighbours	list	{neighbour1, neighbour2, …, neighbour8}	-
Friends	list	between 1 and 14 {friend1, …}	-

STEP 4: Model Formalisation

Step 4 translates the concepts identified in the previous steps into a storyline for the agent-based model. In plain language, all events that will become part of our model are described in chronological order. It's a useful tool to communicate the model to the client and improve it based on feedback.

Model narrative

This narrative has three distinctive model components: waste generation, social interactions, and recycling behaviour. The choice whether to recycle or not is determined by a household using a certain rationale, or decision making theory. Before the model is executed (during setup) the theory selection has to be made, so every household makes use of one specific rationale during the simulation of the model.

We consider a village north of Beijing, consisting of approximately 10.000 households. Each household has its own characteristics which lead to waste generation, social interaction with neighbours, and recycling behaviour.

At setup, the households are spread across the map and divided into three neighbourhoods:

- University Staff (North-West)
- Local Residents (North-East)
- Independent Residents (South)

Depending on its neighbourhood, each household is attributed with values for the following properties:

- Neighbourhood
- Household size
- Level of education
- Income
- Knowledge of recycling
- Environmental awareness
- Available space
- Available time
- Distance to container
- A willingness to change
- Amount of waste
- Recycling intention
- A social network

A 'behaviour theory' for this model run is selected from the interface and applied:

- *Theory of Reasoned Action* (TRA)
- *Theory of Planned Behaviour* (TPB)
- Theory of Planned Behaviour and Situational Factors (TPB+)

Waste generation

Each day, a household produces recyclable waste. The total amount generated each day is based on three properties:

- Household size: a larger household increases the waste generation (positive causality)
- Income: a higher income increases the consumption of a household and thereby the waste generation (positive causality)
- Level of education: higher educated households have a higher environmental awareness which decreases the waste generation per household (negative causality)

Social interactions

Each week, a household communicates with a certain amount of directly neighbouring households and other friends. The amount and type of friends which is interacted with differs per household. This interaction leads to a certain perception of household recycling behaviour in the village, also called the 'perceived social norm'. Every household thus creates their own social norm on how many households recycle their waste. Along with other variables, this influences their decision whether to recycle or not.

Recycling behaviour

If the 'amount of waste' reaches a determined threshold (the container is full), the household decides whether it will use one of the available options:

i. Deposit the recyclates into a collection <u>container</u> nearby
ii. Sell or give the recyclates to a 'door-to-door' <u>collector</u>
iii. Throw recyclates away together with other household waste to a <u>landfill</u>

Options i and ii are both recycling methods, while iii is the disposal of recyclates. The choice for one of these options is based on the 'intention' of that household. This relation is not a one-to-one relation, while in practice many households won't adapt their behaviour when their intention changes. So, at the moment the 'amount of waste' reaches the threshold, the intention at that moment might become the behaviour. This intention is determined by a combination of factors, given by the selected 'theory of behaviour':

- TRA states that the personal 'attitude' towards a decision and the 'social norm' together influence the 'intention' to perform certain behaviour
- TPB adds 'perceived behavioural control' to the TRA
- TPB+ adds situational factors, which can be considered an extra evaluation of the situation, before deciding on intention. Situational factors are the space for storing waste at home and the time needed for recycling.

To determine the intention, first a determination of the best applicable method for the particular household will be made. Only if the household intends to recycle, the preferable recycling method will become its intention. This will be determined according to a decision tree, which is depicted in figure 4 and explained below. For TRA and TPB, this results in a preference for using the container or the collector.

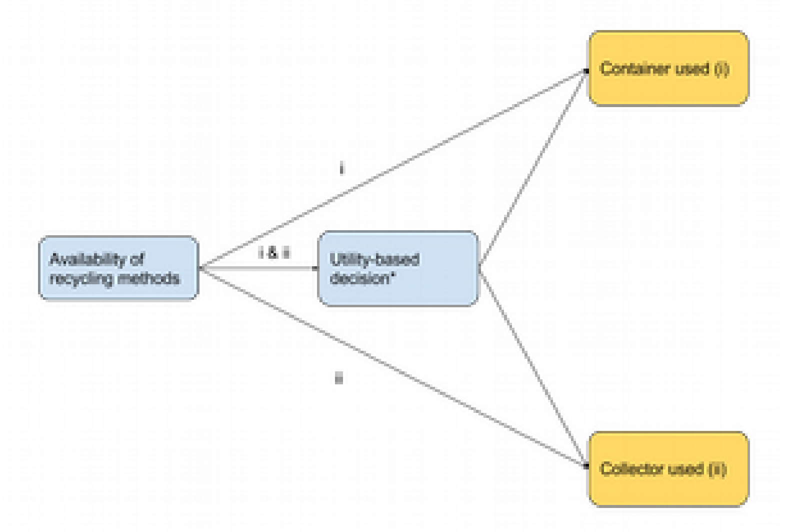

Figure 4: Decision Tree for TRA and TPB

A household checks which methods are available, while our model must contain at least one recycling possibility (if recycling is not possible, everyone must dispose their waste, so a model would be unnecessary). If only one method is available, this method will be the outcome of the decision tree and input for the intention calculation. When both methods are available, the household will calculate the 'utility' for both methods, based on the required time and 'economic incentives' provided by the methods. The method with the highest utility will be chosen (i or ii).

If situational factors are applicable, with TPB+, certain hard constraints become part of the household rationale. These constraints are then part of the decision tree and landfill becomes another possible outcome. In figure 5 can be seen that in this case, more steps are part of the decision tree before deciding on its preference.

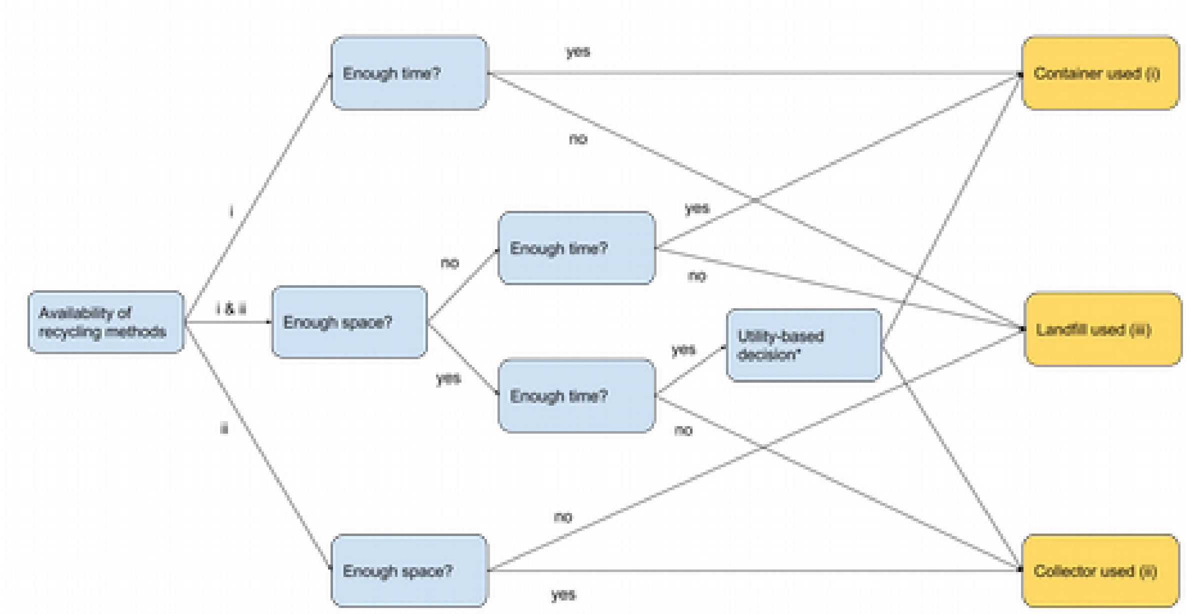

Figure 5: Decision Tree for TPB+

Again, the first step is to check what the available recycling methods are. If the recycling container is the only option, it must be checked if the household thinks it has enough time to recycle its waste via the container. This is done by comparing the required time (based on distance to container) with the available time. If a household decides it has sufficient time, the container is input for the intention calculation. If time is insufficient, it will dispose its waste to the landfill. In case of a collector as only recycling option, space becomes the determining factor, while a household must store its waste until it's collected. When both methods are available, it must be checked if there is enough space and enough time. If both positive, a utility calculation again provides a preference as input for the intention calculation.

The next step in the line of reasoning is to calculate the intention, which can be to recycle or not to recycle. If this intention is to recycle, the intention is the method that was output from the decision tree. If the intention is not to recycle, the recyclates will be disposed to landfill. Furthermore, while not all intentions result in behaviour, only in 70% of the cases a recycling intention results in recycling behaviour. View figure 6 for an overview of this procedure.

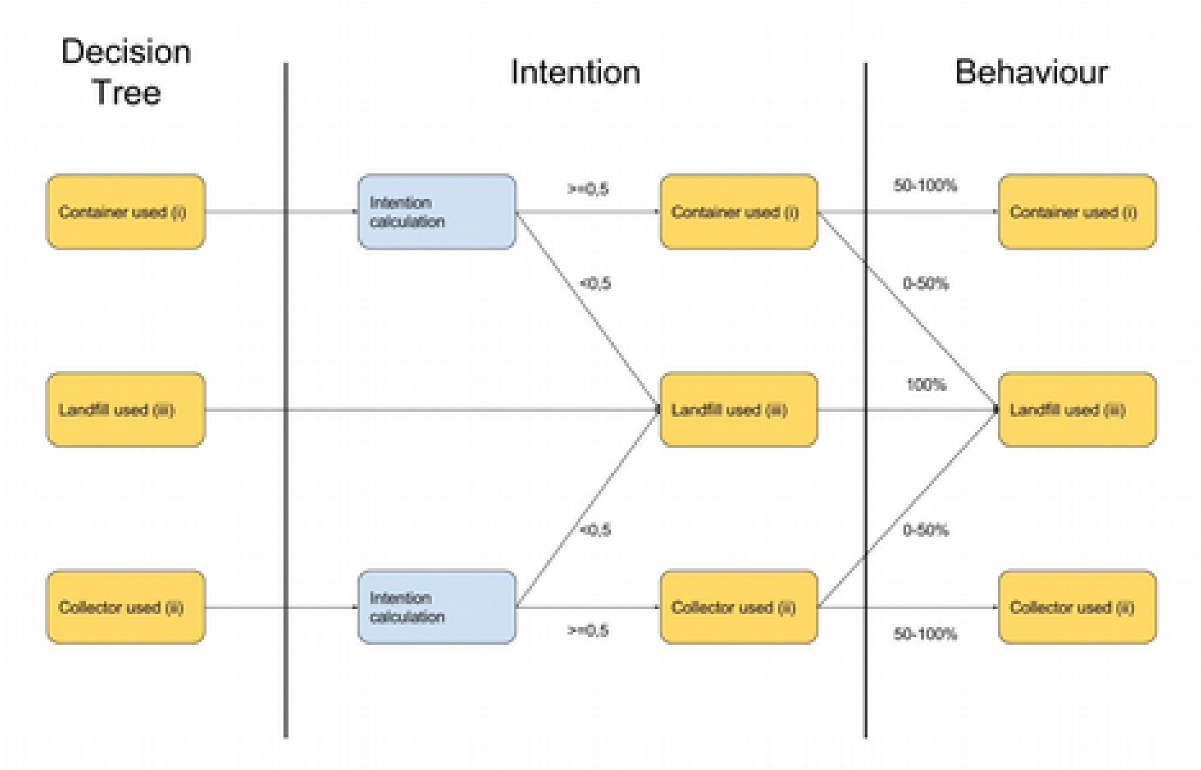

Figure 6: From Decision Tree to Behaviour

The main part of deciding on recycling behaviour, is the calculation of the intention. Basically, there are two ways: with the theory of reasoned action (TRA) or with the theory of planned behaviour (TPB). The situational factors from TPB+ are only applied in the decision tree, so the intention calculation of TPB+ is the same as in TPB.

TRA bases the decision on attitude and the social norm:

- Attitude is the result of environmental awareness, the perceived economic profit, and convenience
    - Environmental awareness is determined by the level of education of the household. The higher the level of education, the higher the environmental awareness.

    - The perceived economic profit is calculated by comparing the profit of recycling (in terms of money) with the income. The higher the profit and the lower the income, the higher the perceived economic profit will be.
    - The convenience is based on the distance to the nearest recycling container. The higher the distance, the lower the convenience.
- The social norm is the number of households that recycle compared to the total number of households in a household's social network

TPB adds the behavioural control to the rationale above:

- The perceived behavioural control is based on the knowledge of recycling and the willingness to change
    - The knowledge of recycling is determined by the level of education, just as the environmental awareness.
    - The willingness to change is not based on any other variable, thus is a completely randomized factor.

All these variables have a value between 0 and 1, where values above 0,5 have a positive influence on recycling. Combining these variables, and optionally assigning weights to them, results in a value for each household. As can be seen in figure 6, if this value is lower than 0,5 the household will dispose its recyclable waste along with other household waste. If equal or higher than 0,5 the household's intention is to use the recycling method from the decision tree. In case of landfill as result of the decision tree, the intention doesn't need to be calculated, as the behaviour is already decided upon.

STEP 5: Software Implementation

Modelling environment (Netlogo)

The software tool that is used for building this model is Netlogo. Netlogo is a tool for building agent based models. Since civilians have an influence on each other, an agent based model is the best way to perform this research. Social interaction is one of the main components in our model, in which civilians influence each other by persuading others with their visible behaviour.

NetLogo implementation

The implementation of the narrative in the modelling environment consists of two steps: transform the procedures into code and create the interface.

Code

The Netlogo code is based on the narrative that is built in step 4. In this step the different procedures and calculations are theoretically constructed, based on the information available at that moment.

This procedures and calculation in the narrative are transformed into Netlogo code by using the programming language Netlogo supports. In this transformation, no existing constructs are used, everything is built from scratch. The entire code can be found in appendix B.

Interface

Figure 7 shows the interface of the implemented model. On the left-hand side, the model parameters can be adjusted by using the choosers and sliders. The different behaviour theories and the availability of recycling methods can be chosen with the two choosers at the upper left corner. Under these choosers are the sliders of the economic incentives of the collector and container. These can be used to vary the incentives between 0 and 30.
Under the economic sliders is the TransformationIntoBehaviour slider placed. This slider determines the chance that civilians actually do what they intend to do. The last three sliders are the weights of the attitude, social norm and perceived behavioural control.

On the right-hand side are two graphs, the graph of total waste, divided over the different disposal manners (in kg) and the intended participation rate of the different disposal manners (as a percentage of the entire population). Furthermore, there are seven monitors at the right-hand side. These are the total waste, the total waste per disposal manner and the average attitude, social norm and perceived behavioural control of the households in the model.

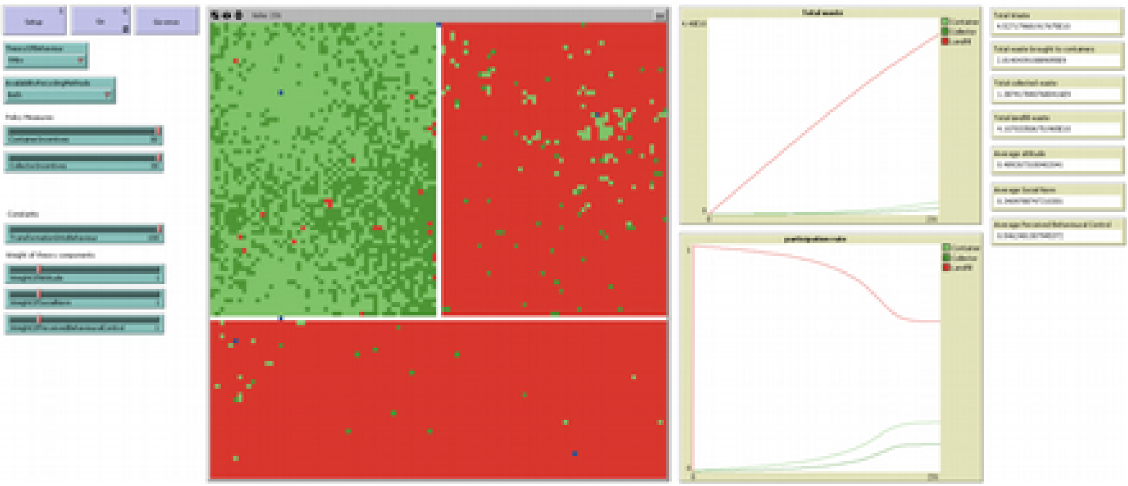

Figure 7:Interface layout of the agent based model in Netlogo

STEP 6: Model Verification

So far, the model is coded, implemented in NetLogo and it is able to do a model run. However, a check must be performed to assess if the model works correctly and according to the narrative: the verification of the model. This step consists of three parts, after which can be concluded that the model implementation is verified. First, the individual agent behaviour is tracked during simulation and checked for the inputs, states, and outputs. The second part verifies the model interactions in a minimal setup. The last verification is the testing of the entire model, using a series of tests.

The model verification was a success, making the model ready for the experimentation phase. The steps of the verification and outcome of each test can be found in appendix C.

STEP 7: Experimentation

After having verified that the model is correctly coded into Netlogo, the model is ready for the experimentation phase. In this chapter the experimental design, the experimental setup and the execution is elaborated upon.

Experimental Modelling Approach

In the model, various uncertainties, both structural and parametric, are present. To explore the impact of these uncertainties on the predicted participation rate of the modelled recycling program, an experimental modelling approach is used (Kwakkel et al, 2013). Using the EMA Workbench python package, an ensemble of parametric sets as input for the simulation runs is generated. Using this method, the impact of the various uncertainties on the recycling rate of the households is systematically explored.

The output of the model can be used for scenario discovery. This method aims at identifying combinations of input parameters that are strongly predictive for specific model outcomes. In this specific case, the parameters that are most important for generating outcomes where recycling is broadly adopted or not can be clustered and analysed. This is useful to determine which mechanisms are interesting to be the subject of further research.

Generating sets of scenarios
The scenarios are generated using Latin Hypercube Sampling. This ensures that the whole uncertainty space is explored.

Time
Each computational experiment will simulate 1000 ticks. As each tick represents one day in the model, the whole simulation run will simulate almost 3 years.

Experiment setup

In this chapter the experiment setup will be described.

Uncertain Parameters
The uncertainties explored during the experiment, are shown in Table 2.

Table 2: Explored uncertainties in the experimentation phase

Uncertainty	Kind of parameter	Min value	Max value
Weight of Attitude	Real	1	5
Weight of Social Norm	Real	1	5
Weight of perceived behavioural control	Real	1	5

Container Incentives	Real	1	30
Collector Incentives	Real	1	30
Transformation into behaviour	Real	50	100
Theory of behaviour	Categorical	TRA, TPB or TPB+	

Inclusion of probabilistic uncertainty

The EMA workbench does not have a default way of dealing with probabilistic uncertainty yet. Therefore the seed number of the model was added as uncertainty to the experiments. This guaranteed a different seed each run and therefore probabilistic uncertainty was included in the model.

Number of experiments and execution

The model is run 2000 times with different parameters provided by the workbench. More replication would be preferable as there are 7 parameters and probabilistic uncertainty is included. However, 2000 replications was the maximum number that could be reached in the available time. More replication would not make the results any different, only more precise.

STEP 8: Data Analysis

Using the EMA workbench, 2000 experiments with different input parameters were run. In this phase the output of these experiments are analysed. The output of the experiments consists of a time series of the participation rate of the landfill, collector and container for every tick (day) in the model.

Data exploration

To explore the results the different participation rates are plotted over time. Figure 8 shows the amount of households that is not participating in a recycling program. The data shows that in the best case around 60% of the households are participating in a recycling program. In a quarter of the simulations between 25% and 62% of the households are participating after 1000 days. In at least 25% of the experiments nobody is participating in a recycling program after 1000 days. On average over all experiments around 15% is using a recycling program after 1000 days.

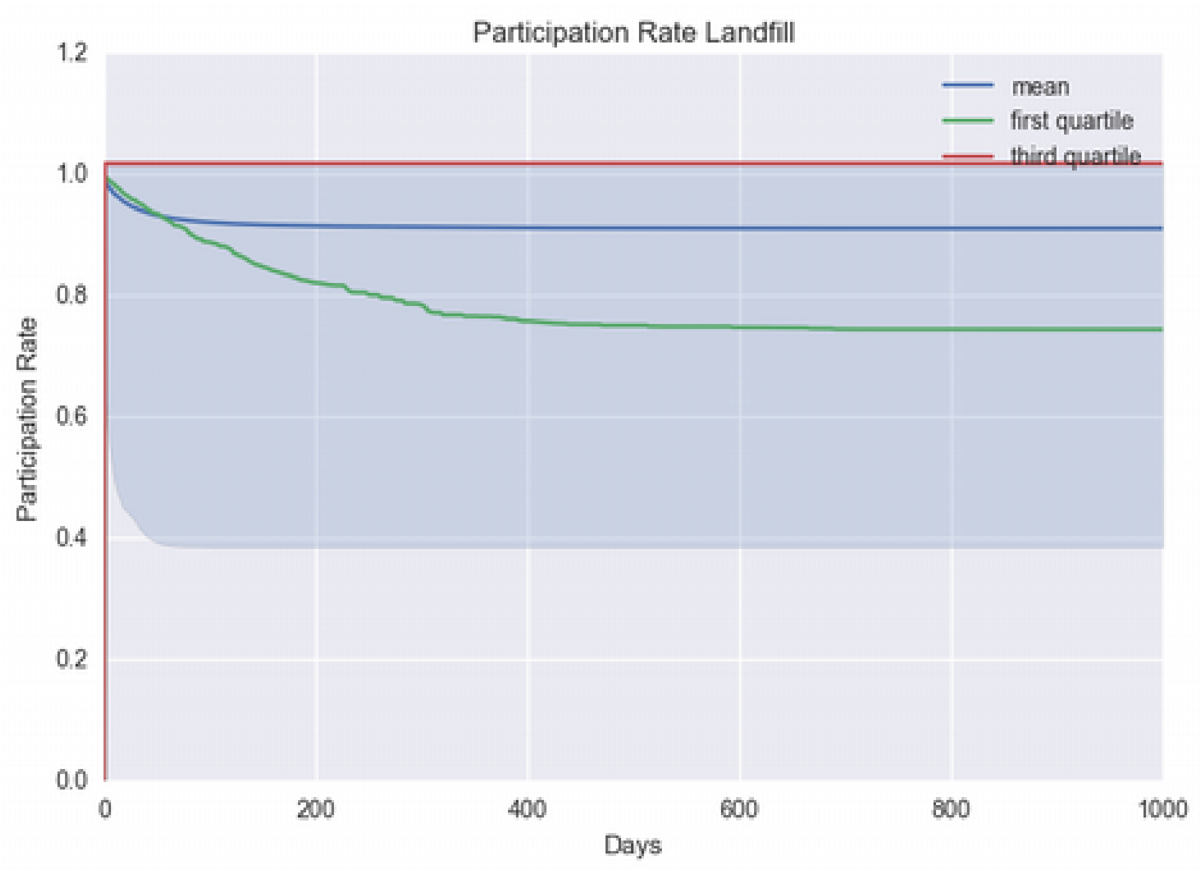

Figure 8: Range of the results of the use of the landfill.

To explore the data further, the result of every 20th experiment is plotted as a line over time. Using only 5% of the executed simulations improves the readability of the visualization and still represent the whole data set. Next to the plotted lines, a violin plot is made which represents the density of the outcomes after 1000 days. It is striking that a lot of the outcomes have a participation rate in the recycling program of less than 10%. It is also notable that there are almost no outcomes between a participation rate of 10% and 25%. There are however a lot of experiments with a participation rate in the recycling program of 25% to 60% percent. The experiment with a low participation rate (< 5%) and high participation rate (>25%) of the recycling methods are most interesting for our research and will be analysed using PRIM in the next paragraph.

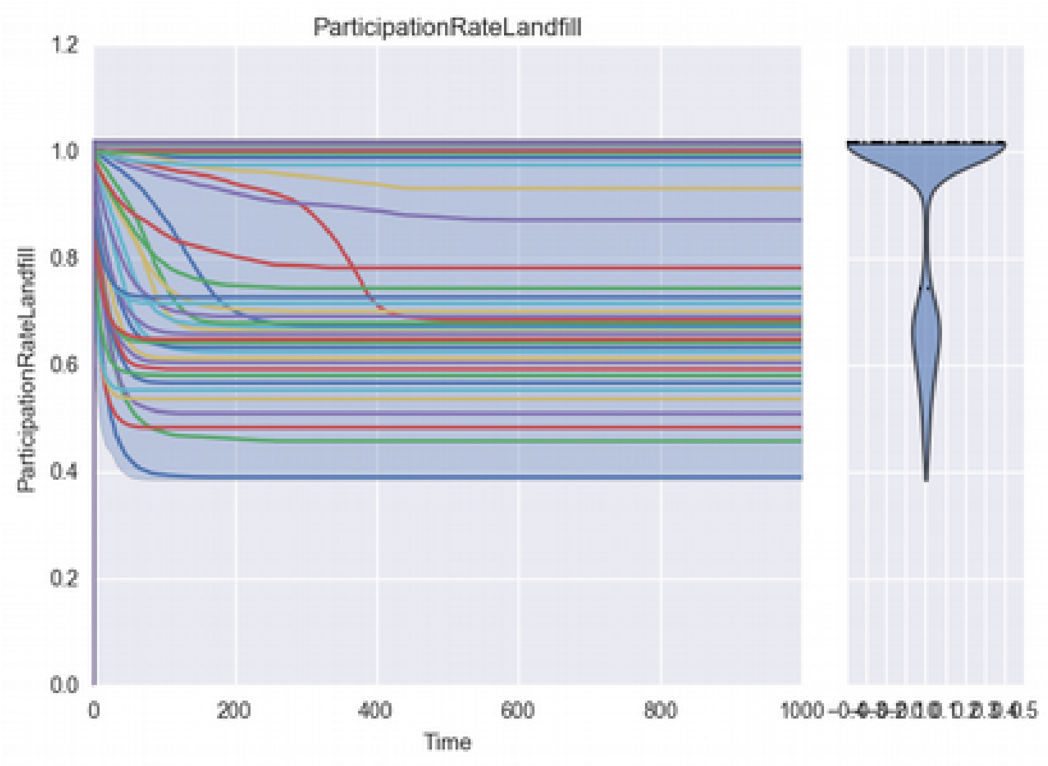

Figure 9: Density of model outcomes in the experiments

Identify and cluster interesting output values

Patient Rule Induction method (PRIM) is the most frequently used algorithm for scenario discovery (Friedman et al, 1999). It aims at finding combinations of values of input parameters which are likely to result in a prespecified range of values for the output variables. These combinations, called subspaces, are described by PRIM in the form of hyper rectangular boxes. Figure 10 explains PRIM visually.

The PRIM algorithm returns multiple boxes which estimate the correct input values for a participation rate of 25+ percent in the recycling programs after 1000 days. These boxes differ from each other in coverage and density. The coverage of a box is the number of points of interest(i.e. Participation rate of 25+ percent in recycling programs) inside the box. With a coverage of 1 all points of interest are inside the box. The density shows how much of the points in the box are of interest and how much are not. A density of 0.4 for example means that 40% of the point inside the box are of interest, but 60% is not. The researcher should make a trade-off between coverage and density to find the best box. The different boxes for a participation rate of 25+ percent in the recycling programs after 1000 days are displayed in figure 11.

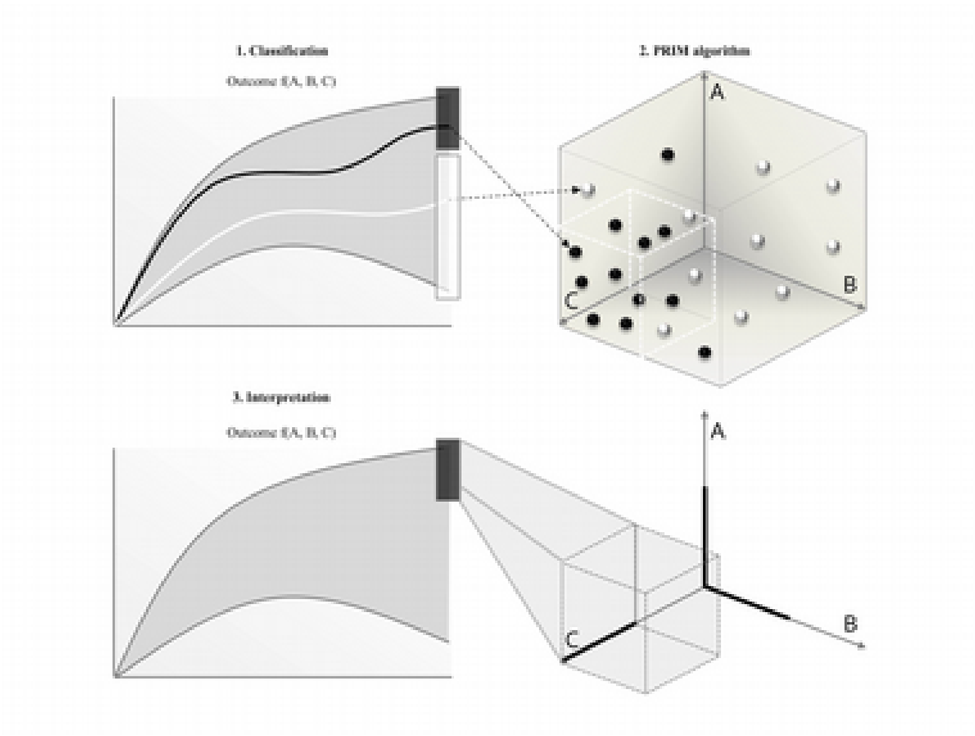

Figure 10: Visual explanation of PRIM (Greeven et al, 2016)

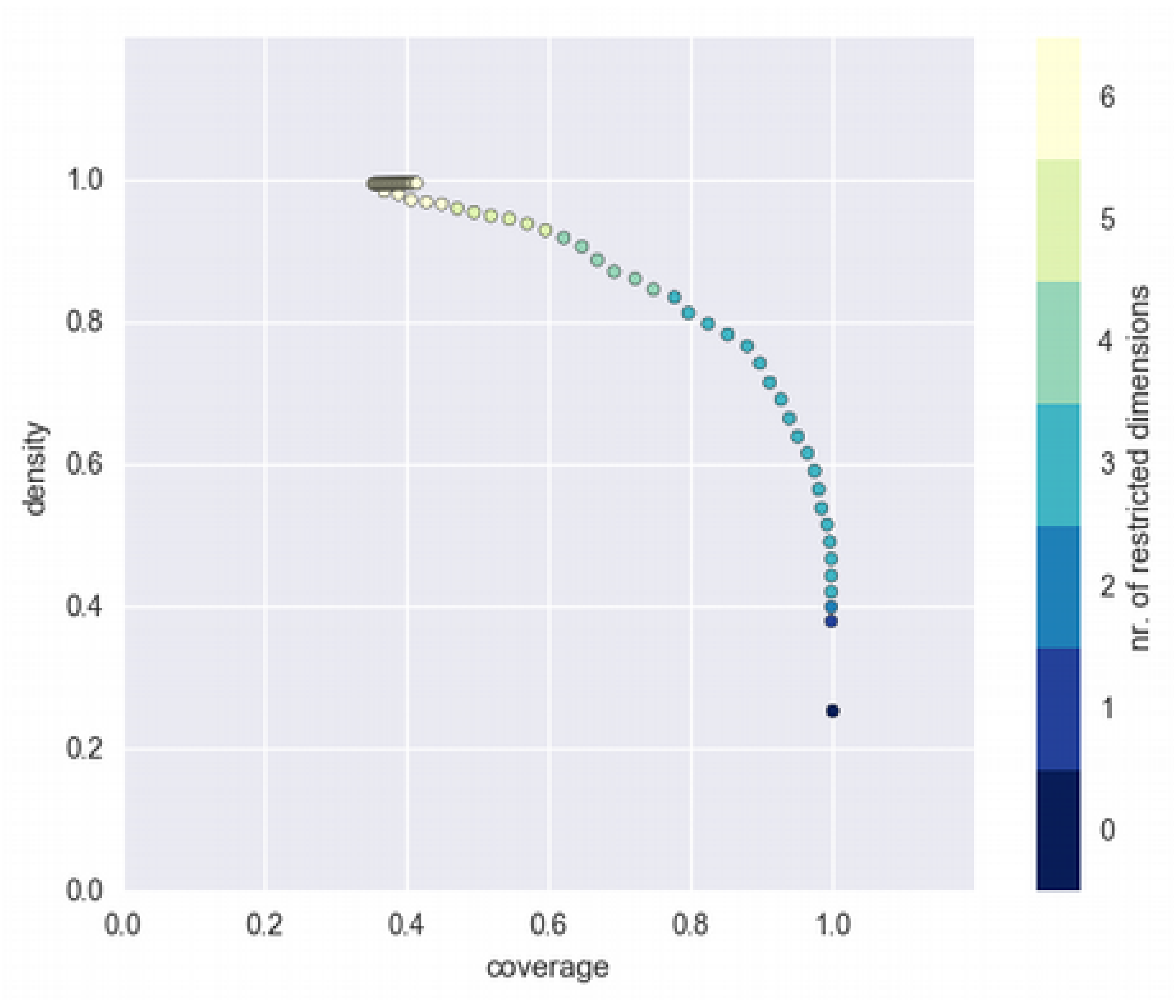

Figure 11: The density and coverage of the different PRIM boxes.

In figure 12 the input range of box 19 is shown. 82.4% of the experiments with an outcome of 25+ percent of the participation rate in the recycling programs had a weight of perceived behavioural control between 2.4 and 5 and a weight of the social norm between 1 and 3.4. The social theory used in these experiments was TPB or TPB +. Furthermore 79.8% of the experiments with input values in this range, resulted in a outcome that 25+ percent of the households participated.

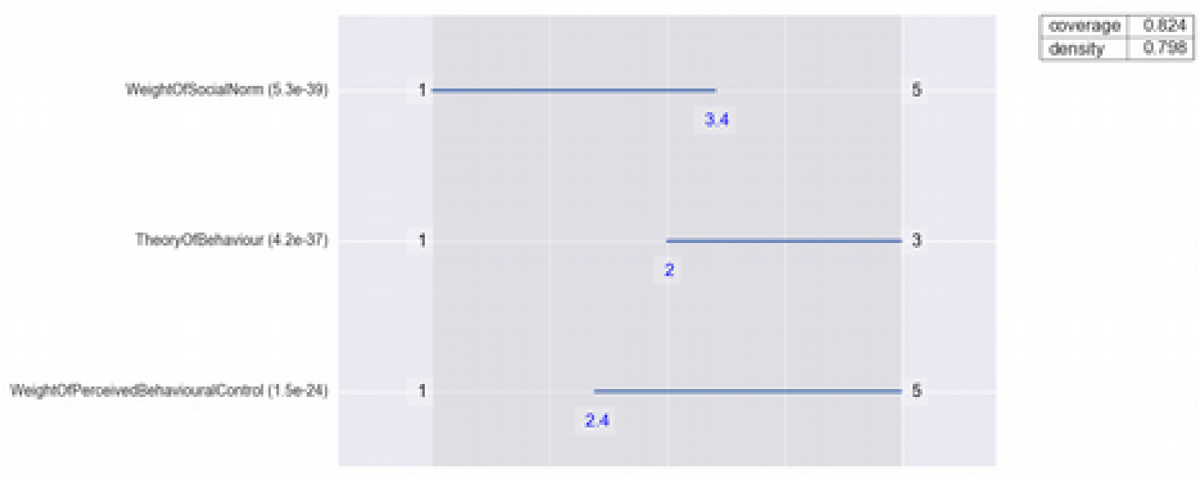

Figure 12: Cluster of experiments where the recycling rate is 25+%

So far, the PRIM algorithm is used for finding the input values for a favourable outcomes. However, it is also very interesting to find the input values for which the outcomes are very unfavourable. Therefore, the PRIM analysis is repeated to find the range of input values which result in a participation rate of less than 5%. The resulting boxes are shown in figure 14.

In figure 13 the results of box 10 are displayed. It covers 82.4% of all experiments with an outcome of the participation rate lower than 5%. 84.4% of all experiments with the weight of the social norm between 2.2 and 5 result in a negative outcome.

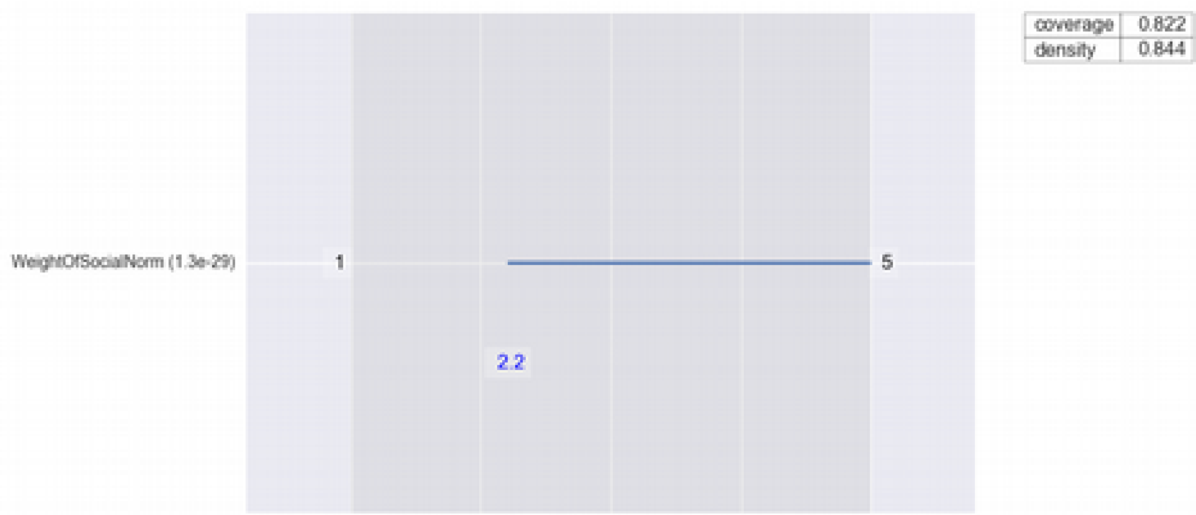

Figure 13: Result of PRIM analysis aimed at participation rate lower than 5%

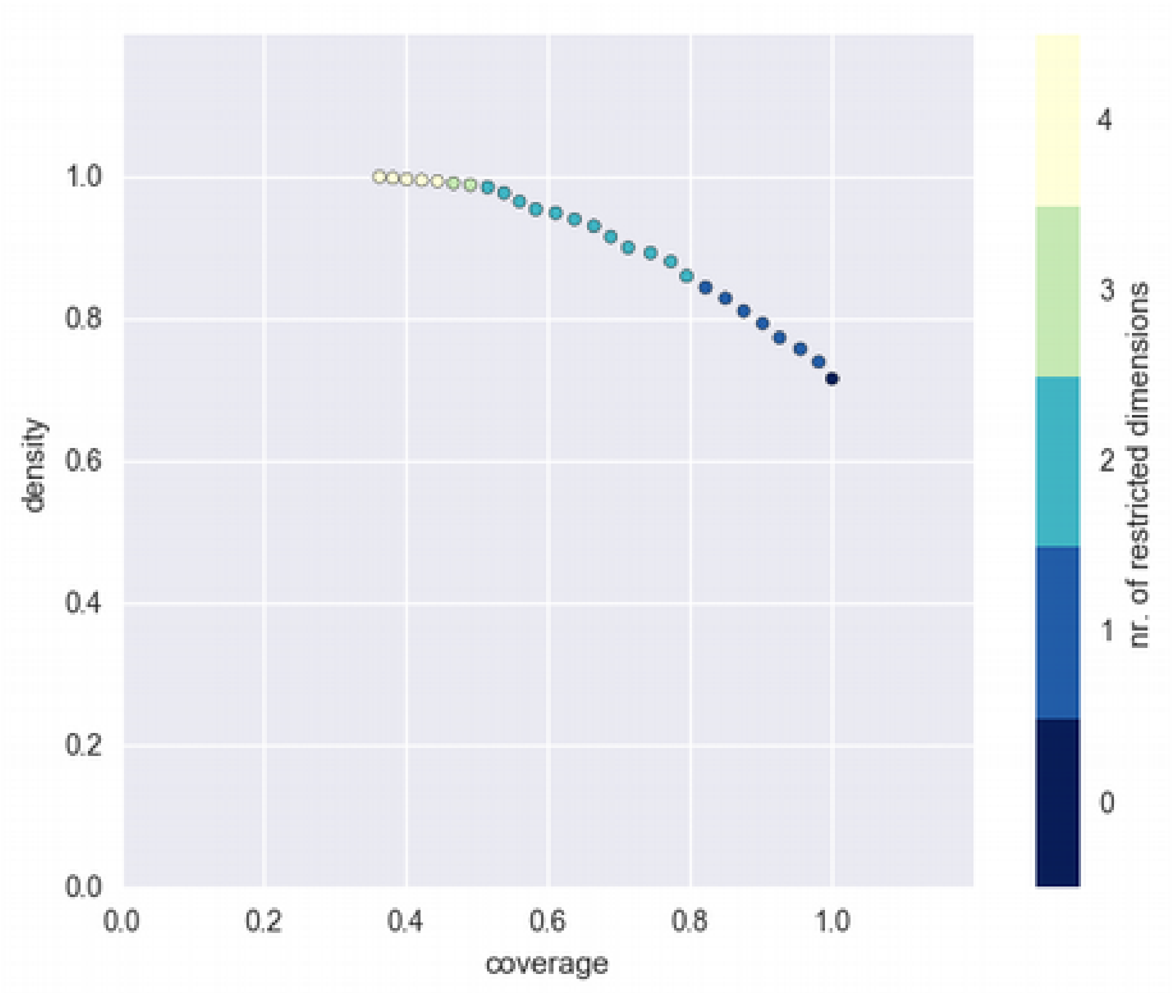

Figure 14: Different boxes generated by PRIM analysis

Interpretation and explanation

The last two subchapters showed interesting results of the model. In this subchapter, the results will be interpreted and explained.

Social norm blocks the adoption of recycling programs.

The results show that a high weight of the social norm is likely to result in a participation rate below 5% after 3 years. The results also shows that a low weight of the social norm makes it likely that the simulation ends up with a high (25+%) participation rate. Therefore, it can be concluded that when the social norm is important in the choice of people, they are less likely to adopt a recycling program when nobody else is using it. When hardly anyone is recycling, the social norm does not change and it keeps blocking participation in a recycling program.

Perceived behavioural control

The presence of perceived behavioural control in the forming of an intention is stimulating for the participation rate in the recycling programs. The results show that when the household form their intention based on the theory of reasoned action, which excludes perceived behavioural control, it is very unlikely that they will adopt a recycling program. Furthermore, a high weight of the perceived behavioural control, makes it more likely that many households will start recycling.

Attitude is not decisive

The results show that the weight of attitude is not a decisive factor whether household will recycle or not. Neither are incentives aimed at improving the attitude. A possible explanation of this is that the attitude towards recycling can only be made a little bit more positive using incentives. Another sub factor like awareness of recycling is much harder to change and hold back the positive effect of incentives.

STEP 9: Model Validation

The aim of this step is to examine if the model is applicable for its domain and corresponds to reality: did the team model the right thing? To do so, two different methods for validation are executed, namely expert validation and literature validation.

Expert validation

The principle of expert validation is that experts look at a model and its results and can give an informed opinion on the model, based on their background, experience and knowledge. The expert that has been consulted in this project is Dr. Tong from the university of Beijing. Her department is performing research on an experiment on recycling behaviour in the area of Huangchao Fanbu Yaoliie. The narrative is set up in collaboration with her staff, to test our understanding of the problem and the related phenomena. In this process the narrative has had many iterations, due to the increase of knowledge of the system and the adjustments of the researchers of the department of Dr. Tong. In the process of these iterations the narrative has been validated.

Literature validation

Another way of supporting and validating a model is by literature. In this project, literature is used in two ways: creating the structure of the model and validating the results.
The backbone of the model is behaviour theory with the theory of reasoned action and theory of planned behaviour in particular. Both theories are compiled of different components that together determine intention. The variables that influence the different components of these theories are found in literature and used to create the structure of the thinking process. With using the different variables to construct the attitude, social norm and perceived behavioural control, the conceptual model is grounded in literature. However, most of these papers conclude that there is a significant relation between two variables (between convenience and attitude for instance). The conclusions are qualitative, while models such as agent based models need quantitative input. The models are based on calculations and decision rules, but the only available data is demographic data. The data on correlations between the variables is lacking.

The second use of literature is comparing the results with previous studies. One of the results of the model is the repressive character of the social norm when there are few people recycling. This claim is supported by the paper of Schultz et al. (2007), in which they describe the destructive power of a social norm. In a research program on the influence of the social norm on energy use, consumers receive feedback on their energy use. This feedback consisted of information whether they used below or above the average energy use. The people who had an energy use below average started to use more. The people that perform better than the norm have the tendency to move towards the norm.

This claim can be related to the model. Households with a positive attitude towards recycling (attitude > 0.5) and a high perceived behavioural control (PBC > 0.5) can still use the landfill when the social norm is not to recycle.

In conclusion, the conceptual model the model is based on is grounded in literature and validated, but the quantitative aspect of the model is mostly based on assumptions. Although there is some support in literature for the conclusions of the model, the quantitative relations and values of the model need more research in order to be able to draw strong conclusions.

STEP 10: Model Use

The last step reflects on the research question, introduced in step 1, using the insights from the research conducted in the steps in between. This chapter presents the main findings,

Main findings

This exploratory modelling study provided many useful insights in the recycling behaviour of Chinese households. These insights cannot be interpreted as predictions of what might happen, but can be used to identify interesting mechanisms in the recycling behaviour of Chinese households and provide interesting topics for further research.

The role of the social norm

When households think as described in the theory of reasoned action, the social norm has a decisive effect on whether an area starts recycling or not. The effect can be both positive and negative. If for some reason, a large share of the households decides to recycle, the social norm can accelerate this trend. On the other hand, if the participation rate is low, the social norm represses recycling. Given the current low participation rate, it would be beneficial if the social norm has less influence on the recycling intention. Based on other contributors, it is more likely that a neighbourhood will adopt a recycling program.

The role of perceived behavioural control

Perceived behavioural control plays a large role in this study. When perceived behavioural control has a high relative weight in comparison with the other components of the intention determination, it is more likely that a household will recycle. This suggests it is interesting to research the role of perceived behavioural control in a neighbourhood when deciding to recycle or not, and to investigate how perceived behavioural control related to recycling behaviour can be influenced in a positive way.

The role of attitude towards recycling

The model shows that the role of attitude in the determination of the recycling behaviour is relatively small. This suggest that policy aimed at improving the attitude of Chinese households might not be as effective as assumed. Thus, interventions such as increasing environmental awareness, convenience of recycling, and economic profit, contribute to recycling to some degree, but main focus should be on social norm and perceived behavioural control. Further field research might provide more insight in the role of attitude and in what way it is influenced by incentives aimed at this factor.

Assumptions for the model

The assumptions made in this research result in limitations in the interpretation of the model. Because of the explorative use of the model, its results should not be considered as a prediction of what will happen. It merely shows what might happen under different circumstances. This provides insights in which dynamics of the system must be further explored in order to understand the system better. Many assumptions have been made to result in the findings above (for full list, see appendix A). Overall, there are four main assumptions. First and foremost, the applied behaviour theories assume that households are rational decision-makers. Second, the lack of data required us to assume values for household characteristics, whereas the available data was highly aggregated. Another assumption is the relation between characteristics and the actual behaviour of households. A last type of assumption is the influence of the social norm. As concluded before, it has a large (positive or negative) impact, because of the way it is modelled. These four main types of assumptions influence the results from this research. It must be stressed that wrong assumptions for one or more of these types may lead to other insights and conclusions.

Further research

During this study, several new topics for further research have been identified.

Gathering more individual data on the properties of households

Households in our model have several personal characteristics, such as level of education, income, household size, level of knowledge etc. These personal characteristics are based on information provided by Dr. Tong and her department, but this information was quite basic. Due to a lack of better data, the distribution of these characteristics was based on this limited data. More comprehensive data will increase the degree of reality of the diversity in the different households.

How is the intention of a household truly formed?

One could only try to predict the participation rate in a recycling program when it is known how the intention of their target group is truly formed. Therefore, it should first be researched which social theory explains the behaviour of their target group best. Then insights should be gathered on the different factors, sub factors and (the weight of) their relations. For example, how is the attitude towards recycling in your target group formed and which factors influence attitude the most? Furthermore, there could be differences in the determination of intention between several groups of households. These differences could be caused by level of income, level of education or household size for instance. If significant differences exist, this could give more information on which interventions could be based.

Intervention possibilities.

In this modelling study incentives were incorporated, aimed at influencing the attitude towards recycling, such as economic incentives. However, the result showed that these incentives were not decisive whether a recycling program would be a success or not. Therefore, it is interesting to examine whether there are other incentives possible which are aimed at increasing the social norm or perceived behavioural control.

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Appendix A - List of assumptions

Table 3: Table with assumptions made during the research process

System
Division of level of education, income, and household size over all households
The village consists of three neighbourhoods
There are only two ways of recycling: Using containers or collectors

Real behaviour
If a household decides on its recycling behaviour once the bag is full, this decision cannot be altered anymore, because the behaviour takes place that day
Social interaction of a household with its social network (agent set) happens once a week. This social interaction comes down to knowing if a household recycles or not.
Households look at the perceived economic profit (profit in relation to their income and required time) instead of absolute economic profit

Behaviour theory
Households maximize their utility in a rational way
The social norm only influences if a household recycles, not how
Situational Factors are space and time
Income has an influence on the perception of economic profit, low-income households therefore valuate economic benefits more
The available time of a household is compared by a household with the required time for recycling, for households with much spare time recycling is not so inconvenient
The environmental awareness is based on the level of education
Knowledge of recycling is based on the level of education
Willingness to change determines the perceived behavioural control, and is a randomly determined factor
Behaviour is determined by either TRA, TPB or TPB+
A household compares the required time and space with the available time and space
Education has a positive effect on awareness
Awareness had a positive effect on attitude
Knowledge has a positive effect on perceived behavioural control

Education has a positive effect on knowledge
Willingness to change has a positive effect on perceived behavioural control
Household size and income have a positive causal relation with waste generation, education has a negative causal relation with waste generation

Modelling choices
Households do not have to separate their waste during the waste collection phase to be able to recycle. All three choices of recycling behaviour are therefore possible at any time and under any circumstance
Awareness is determined by education in a certain way
For the duration of the simulation, no household will move out of the village or neighbourhood and no new households will move in
Social network consists of its eight neighbouring households and 1-14 other households in the village (of which 80% in own neighbourhood and 20% in other neighbourhoods)
The required time for recycling with containers is calculated with the distance to the nearest container, for collectors it is determined randomly, with a range comparable with container required time
Willingness to change is randomly determined between 0 and 1
Households create waste every day and are able to recycle every day.
Every household has the same threshold for the processing of waste (households are recycling when the threshold of 10 is reached)
The social norm is constructed by calculating the percentage of people in your network that are recycling
Willingness to change is an independent random variable

Appendix B – Model Code

This appendix contains the Netlogo code, as composed by the research team. It comprises of two components. First, the setup code is provided, which was loaded into the rest of the code, which is provided second.

Setup code

```
to determine-colors
  set border-color white
  set Container-color green + 1
  set Collector-color green - 1
  set Landfill-color red                                                              ;; set the standard color of the different patches
  set PhysicalContainer-color blue - 1
end

to determine-borders
  ifelse MinimalTesting = false [
    ask patches
      [ if pycor = -15 or ( pxcor = 0 and pycor >= -15 )
        [ set pcolor border-color ]                                                   ;; set the color of the borders
        ]
  ]
  [ ask patches [if pxcor = 0 and (pycor > 0 or pycor < 0) [
      set pcolor border-color]
  ]
  ]


end

to determine-containers
  ifelse MinimalTesting = false [
    ask patch 0 50 [set pcolor PhysicalContainer-color]
    ask patch -35 35 [set pcolor PhysicalContainer-color]
    ask patch 35 30 [set pcolor PhysicalContainer-color]
    ask patch -35 -15 [set pcolor PhysicalContainer-color]
    ask patch -45 -20 [set pcolor PhysicalContainer-color]
    ask patch 30 -45 [set pcolor PhysicalContainer-color]
  ]
  [ask patch 0 0 [set pcolor PhysicalContainer-color]]
end

to determine-patch-sets
  ifelse MinimalTesting = false [
  set AllHouseholds patches with   [ pcolor != border-color and pcolor != PhysicalContainer-color ]                    ;; create patch-set of total
households
  set UniversityStaff patches with [ pycor > -15 and pxcor < 0 and pcolor != PhysicalContainer-color ]                ;; create patch-set of university
housing
  set LocalResidents patches with  [ pycor > -15 and pxcor > 0 and pcolor != PhysicalContainer-color ]                ;; create patch-set of local
households
  set IndependentResidents patches with [ pycor < -15 and pcolor != PhysicalContainer-color ]                         ;; create patch-set of independent
housing
  set Containers patches with [pcolor = PhysicalContainer-color]
  ask patches [
    ifelse pcolor = border-color
      [set zone "border"]
      [ifelse pxcor < 0 and pycor > -15 [
          set zone "university"]
         [ifelse pxcor > 0 and pycor > -15 [
             set zone "local"]
             [set zone "independent"]
         ]
      ]
  ]
  ]
  [set AllHouseholds patches with   [ pcolor != border-color and pcolor != PhysicalContainer-color ]                   ;; create patch-set of total
households
   set UniversityStaff patches with [ pxcor < 0 and pcolor != PhysicalContainer-color ]                               ;; create patch-set of university housing
   set LocalResidents patches with  [ pxcor > 0 and pcolor != PhysicalContainer-color ]                   ;; create patch-set of local households
   set Containers patches with [pcolor = PhysicalContainer-color]
   ask UniversityStaff [set zone "university" ]
   ask LocalResidents [set zone "local"]
   ask patches [
     if pcolor = border-color [
       set zone "border"]
   ]
  ]
```

```
end

to determine-constants
  set WasteTreshold 10
  set MinutesPerHour 60
  set HoursPerWeek 40
  set WeeksPerYear 52
  set BaseIncomeLvl3 50000
  set BaseIncomeLvl2 30000
  set BaseIncomeLvl1 20000
  set BaseLvl3 0.7
  set BaseLvl2 0.3
  set BaseLvl1 0.15
 ifelse MinimalTesting = false [
  set MaxFriends 15]
 [set MaxFriends 3]
  set ChanceOfFriendsInOwnZone 70
end

to determine-initial-waste

  ask AllHouseholds [
    set AmountOfWaste random 10   ]                                   ;; initial stock of waste
end

to determine-EducationLevel
   ask UniversityStaff [
    ifelse random 100 < 90                              ;; 90% of the people in the university housing have an
EducationLevel of 3, which is bachelor or above
      [ set EducationLevel 3 ]
      [ set EducationLevel 2 ] ]                        ;; the remaining 10% has an EducationLevel of 2, which is
high school


  ask LocalResidents [
    let randomvalue random 100
    ifelse randomvalue < 35                             ;; 35% of the people in the local houses has an
EducationLevel of 3, which is bachelor or above
      [ set EducationLevel 3 ]
      [ ifelse randomvalue < 85                         ;; 50% of the people in the local houses has an
EducationLevel of 2, which is high school
        [ set EducationLevel 2 ]                        ;; the remaining 15% of the people in the local houses has an
EducationLevel of 1, which is junior high school or below
        [ set EducationLevel 1 ] ] ]


  if MinimalTesting = false [
  ask IndependentResidents [
    let randomvalue random 100
    ifelse randomvalue < 10                             ;; 10% of the people in the independent households have an
EducationLevel of 3, which is bachelor or above
      [ set EducationLevel 3 ]
      [ ifelse randomvalue < 70                         ;; 60% of the people in the independent households have an
EducationLevel of 2, which is high school
        [ set EducationLevel 2 ]
        [ set EducationLevel 1 ] ] ]                    ;; the remaining 30% has an EducationLevel of 1, which is
junior high school or below
  ]
end

to determine-householdsize
  ask AllHouseholds [
    ifelse EducationLevel = 3                           ;; for the households with EducationLevel 3, bachelor or
higher
      [ ifelse random 100 < 20                          ;; 20% chance of
        [ set householdsize 3 ]                         ;; having a household size of 3
        [ set householdsize 2 ] ]                       ;; and 80% chance of household size 2
      [ ifelse EducationLevel = 2                       ;; for the households with EducationLevel 2, high school
        [ ifelse random 100 < 50                        ;; there is a 50% chance of
          [ set householdsize 3 ]                       ;; having a household size of 3
          [ set householdsize 2 ] ]                     ;; and 50% chance of household size 2
        [ ifelse random 100 < 95                        ;; for the households with EducationLevel 3, junior high there
is a 95% chance of
          [ set householdsize 3 ]                       ;; having a household size of 3
          [ set householdsize 2 ] ] ] ]                 ;; and 5% chance of having a household size 2
end

to determine-income
  ask AllHouseholds [
    ifelse EducationLevel = 3                           ;; for the households with EducationLevel level 3, bachelor
or higher
      [ set income ( BaseIncomeLvl3 + random 20000 ) * householdsize ]          ;; the income is between 50000 and
70000 per member of the household
      [ ifelse EducationLevel = 2                       ;; for the households with EducationLevel level 2, high
school
       [ set income ( BaseIncomeLvl2 + random 20000 ) * householdsize ]         ;; the income is between 30000 and
50000 per member of the household
```

```
      [ set income ( BaseIncomeLvl1 + random 10000 ) * householdsize ] ] ]                    ;; for the households with
EducationLevel level 1, junior high, the income is between 20000 and 30000 per member of the household
end

to determine-RecyclingAwareness
  ask AllHouseholds [
    ifelse EducationLevel = 3                                          ;; for the households with EducationLevel level 3, bachelor
or higher
      [ set RecyclingAwareness BaseLvl3 + ( random 20 / 100 ) ]                   ;; the RecyclingAwareness is between 0.8
and 1
      [ ifelse EducationLevel = 2                                      ;; for the households with EducationLevel level 2, high
school
        [ set RecyclingAwareness BaseLvl2 + ( random 40 / 100 ) ]                 ;; the RecyclingAwareness is between 0.5
and 0.9
        [ set RecyclingAwareness BaseLvl1 + ( random 30 / 100 ) ] ] ]             ;; for the households with education level 1,
junior high, the RecyclingAwareness is between 0.3 and 0.6
end

to determine-AvailableTime                                             ;; in minutes per day
  ask AllHouseholds
   [ set AvailableTime 1 - ( Random 10 / 100 ) ]
end

to determine-AvailableSpace                                            ;; m2 ?
   ask AllHouseholds
   [ set AvailableSpace 1 - ( Random 20 / 100 ) ]
end

to determine-ContainerRequiredTime                                     ;; can be calculated by the distance divided by the
average walking speed (in minutes)
    ask AllHouseholds
   [ set NearestContainer min-one-of Containers [distance myself]
     set ContainerRequiredTime (distance NearestContainer / 40)
     ]
end

to determine-CollectorRequiredTime                                     ;; estimation of how long it takes to put the trash out (in
minutes)
  Ask AllHouseholds
  [ set CollectorRequiredTime ( (10 + Random 90) / 100 ) ]
end

to determine-CollectorRequiredSpace                                    ;; sets the required space for recyclates
    ask AllHouseholds
   [ set CollectorRequiredSpace 1 - ( Random 70 / 100 ) ]
end

to determine-RecyclingKnowledge
  ask AllHouseholds [
    ifelse EducationLevel = 3                                          ;; for the households with EducationLevel level 3, bachelor
or higher
      [ set RecyclingKnowledge BaseLvl3 + ( random 20 / 100 ) ]                   ;; the RecyclingKnowledge is between 0.8
and 1
      [ ifelse EducationLevel = 2                                      ;; for the households with EducationLevel level 2, high
school
        [ set RecyclingKnowledge BaseLvl2 + ( random 40 / 100 ) ]                 ;; the RecyclingKnowledge is between 0.5
and 0.9
        [ set RecyclingKnowledge BaseLvl1 + ( random 30 / 100 ) ] ] ]             ;; for the households with education level 1,
junior high, the RecyclingKnowledge is between 0.3 and 0.6
end

to determine-WillingnessToChange
   ask AllHouseholds [
     set WillingnessToChange (random 99 + 1) / 100
   ]
end

to InitialSociallyInteract
      let Recyclers 0


      foreach SocialNetwork [
        ask ? [
          if Intention > 0 [
            set Recyclers Recyclers + 1]
]
  ]


      set SocialNorm Recyclers / NetworkSize


end

to CreateSocialNetwork
  set SocialNetwork [ ]


  set SocialNetwork lput neighbors with [pcolor != white and pcolor != PhysicalContainer-color] SocialNetwork
```

```
  let Friends random MaxFriends
  let a 0

  while [a < Friends] [

    ifelse random 100 < ChanceOfFriendsInOwnZone [
     set SocialNetwork lput one-of patches with [zone = [zone] of myself and pcolor != PhysicalContainer-color and not (pxcor = [pxcor] of myself
and pycor = [pycor] of myself) ] SocialNetwork
     set SocialNetwork remove-duplicates SocialNetwork]
    [set SocialNetwork lput one-of patches with [zone != [zone] of myself and zone != "border" and pcolor != PhysicalContainer-color]
SocialNetwork]
    set a a + 1
  ]

set Networksize count neighbors with [pcolor != white and pcolor != PhysicalContainer-color] + length SocialNetwork - 1

end

to minimal-test

  resize-world -2 2 -2 2
  set-patch-size 150

  clear-all
  reset-ticks

end
```

Model code

```
__includes ["setup.nls"]

globals [
  AllHouseholds                          ;; agentset for households patches (all patches except borders)
  UniversityStaff                        ;; agentset for university households
  LocalResidents                         ;; agentset for local villager households
  IndependentResidents                   ;; agentset for independent housing
  Containers                             ;; agentset for containers
  border-color                           ;; every color is saved into global to avoid having to change a lot
when colors change
  Container-color
  Collector-color
  Landfill-color
  PhysicalContainer-color
  BroughtToContainer                     ;; is the summation of all waste brought to containers
  CollectedRecyclates                    ;; is the summation of all waste given to collectors
  LandfillWaste                          ;; is the summation of all waste for the landfill
  ParticipationRateContainer
  ParticipationRateCollector
  ParticipationRateLandfill
  WasteTreshold                          ;; when this treshold is exceeded, the waste is disposed
  MinutesPerHour
  HoursPerWeek
  WeeksPerYear
  BaseIncomeLvl3                         ;; the base of the income of education level 3. Randomness
comes on top of this
  BaseIncomeLvl2                         ;; the base of the income of education level 2. Randomness
comes on top of this
  BaseIncomeLvl1                         ;; the base of the income of education level 1. Randomness
comes on top of this
  BaseLvl3                               ;; the base of awareness and recycling knowledge of education level
3. Randomness comes on top of this
  BaseLvl2                               ;; the base of awareness and recycling knowledge of education level
2. Randomness comes on top of this
  BaseLvl1                               ;; the base of awareness and recycling knowledge of education level
1. Randomness comes on top of this
  MaxFriends                             ;; the maximum amount of friends in list social network
  ChanceOfFriendsInOwnZone               ;; the chance that a friend is in your own zone
  ]

patches-own[
  HouseholdSize
  Income
  Zone
  Networksize
  SocialNetwork
  NearestContainer                       ;; the nearest container used to dispose of garbage
  ContainerRequiredTime                  ;; the time a household needs to use a container
  CollectorRequiredTime                  ;; the time a household needs to give recyclates to a collector
  CollectorRequiredSpace                 ;; the space a household needs to store recyclates for
collectors
  AvailableTime                          ;; the amount of time a household is willing/able to spend recycling
  AvailableSpace                         ;; the amount of space a household has to put away recyclate
bags
  AmountOfWaste                          ;; the amount of waste that is currently inside the households
  EducationLevel
  RecyclingAwareness
  RecyclingKnowledge
  WillingnessToChange
  Attitude
  SocialNorm
  PerceivedBehaviouralControl
  Intention                              ;; the intention of households, whether they want to recycle
  RecyclingBehaviour                     ;; the actual behaviour of households, whether they recycle their
waste
  ]

to Setup
  clear-all
  reset-ticks


  random-seed 1


  resize-world -50 50 -50 50
  set-patch-size 7.515


  if MinimalTesting = true [
  minimal-test ]

  determine-colors                       ;; in this procedure, the colors of the border and different patches
is determined, see setup.nls
```

```
  determine-borders                                                    ;; in this procedure, the actual borders are determined, see
setup.nls
  determine-containers
  determine-patch-sets                                                 ;; in this procedure, the patchsets are determined to make it
easier to ask certain groups, see setup.nls
  determine-constants
  determine-initial-waste                                              ;; in this procedure, the initial waste of the households is
determined, see setup.nls
  determine-EducationLevel                                             ;; in this procedure, the EducationLevelal level of the
households is determined, see setup.nls
  determine-HouseholdSize                                              ;; in this procedure, the amount of persons in an household is
determined, see setup.nls
  determine-Income                                                     ;; in this procedure, the income of the households is determined,
see setup.nls
  determine-RecyclingAwareness                                         ;; in this procedure, the environmental
RecyclingAwareness of the households is determined, see setup.nls
  determine-AvailableTime
  determine-AvailableSpace
  determine-ContainerRequiredTime                                      ;; in this procedure, the required time to use a container
for the households is determined, see setup.nls
  determine-CollectorRequiredTime                                      ;; in this procedure, the required time to give recyclates to
a collector for the households is determined, see setup.nls
  determine-CollectorRequiredSpace                                     ;; in this procedure, the required space to store recyclates
for a collector for the households is determined, see setup.nls
  determine-RecyclingKnowledge
  determine-WillingnessToChange



  ask allhouseholds [
    DetermineIntention
    UpdateIntentionColour
    CreateSocialNetwork
    InitialSociallyInteract
  ]


end

to Go
  SociallyInteract                                                     ;; the procedure in which the households interact with eachother to
deterimine social norm
  ProcessWaste                                                         ;; the procedure in which the waste is generated, intention
determined and waste processed
  DeterminePlotGlobals
  tick

  if MinimalTesting = true [
    if ticks = 1000 [
      stop
      ]
  ]
end

to SociallyInteract
  if ticks mod 7 = 1 [                                                 ;; The interaction is once every week
    Ask AllHouseholds [
      let Recyclers 0


      foreach SocialNetwork [
        ask ? [
          if Intention > 0 [
            set Recyclers Recyclers + 1]
]
  ]


      set SocialNorm Recyclers / NetworkSize
    ]
  ]

end


to ProcessWaste
  ask AllHouseholds [
    set AmountOfWaste (                ;; CHECK / VALIDATE !!!!
    AmountOfWaste + ( 0.5 + (( income - 40000 ) / 800000 + ( random 21 / 100 )) * householdsize ) / RecyclingAwareness )     ;; increases the
waste with a constant of 0.5 + a factor between 0 and 0.2 related to income (40000 is 0, 200000 is 0.2) + a random factor between 0 and 0.2,
then multiplies with householdsize and corrects for RecyclingAwareness
    if AmountOfWaste >= WasteTreshold [                                ;; decide whether the bins are full
      DetermineIntention                                               ;; the procedure to decide the intention of households
      UpdateIntentionColour                                            ;; the color of the patches has to be adjusted when the intention
changes
```

```
     DecideBehaviour                                                    ;; the intention has to be transformed into the actual behaviour
     ActOnBehaviour    ]  ]                                             ;; the procedure to actual get rid of the waste
end


to DetermineIntention                                                   ;; in this procedure the used theory detemines what decisiontree
is used to come to a calculation of intention
  if TheoryOfBehaviour = "TRA"   [ DecisionTreeTRA ]
  if TheoryOfBehaviour = "TPB"   [ DecisionTreeTPB ]
  if TheoryOfBehaviour = "TPB+"  [ DecisionTreeTPB+ ]
end

 to DecisionTreeTRA
  if AvailabilityRecyclingMethods = "Both" [ ChoiceTRABoth ]                       ;; Fires if both the container and the collector
methods are available                                                   ;; Decision Tree for TRA
  if AvailabilityRecyclingMethods = "Container" [ IntentionTRAContainer ]          ;; Fires if only the container based method is
available
  if AvailabilityRecyclingMethods = "Collector" [ IntentionTRACollector ]          ;; Fires if only the collector based method is
available
 end

 to ChoiceTRABoth                                                       ;; Intention for TRA behavioural theory and container & collector
methods
 let UtilityContainer ContainerIncentives - ( income / 40 * 52 * 60 ) * ContainerRequiredTime          ;; The utility of the Container Method is
calculated by the worth of using a method, described by subtracting the RequiredTime * average income per minute from the incentives given
(incentives come from sliders)
 let UtilityCollector CollectorIncentives - ( income / 40 * 52 * 60 ) * CollectorRequiredTime          ;; The utility of the Collector Method is
calculated by the worth of using a method, described by subtracting the RequiredTime * average income per minute from the incentives given
(incentives come from sliders)
 Ifelse UtilityContainer > UtilityCollector [ IntentionTRAContainer ] [ IntentionTRACollector ]        ;; The method with the largest utility is
chosen for intention calculation
 end

 to IntentionTRAContainer
  Ifelse ContainerIncentives / ( income / 1000 ) > 1                               ;; Check if containerinventives are more than 1% of the
income
    [ let PerceivedEconomicProfit 1                                                ;; If yes, household wants to get the incentive very much
      let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
       set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]          ;; Attitude is formed by the average of
awareness, Convenience and profit
    [ let PerceivedEconomicProfit ContainerIncentives / ( income / 1000 )          ;; If not bigger, incentives divided by a percent
of the income determines the factor
      let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
       set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]          ;; Attitude is formed by the average of
awareness, Convenience and profit

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm ) / (WeightOfAttitude + WeightOfSocialNorm) > 0.5   ;; Checks if the
average of the factors is above 0.5
  [ set Intention 1 ]                                                   ;; If yes, Containers will be used
  [ set Intention 0 ]                                                   ;; If no, LandFill will be used
 end

 to IntentionTRACollector                                               ;; Intention for TRA behavioural theory and collector method
  Ifelse CollectorIncentives / ( income / 1000 ) > 1                               ;; Check if CollectorIncentives are more than 1% of the
income
    [ let PerceivedEconomicProfit 1                                                ;; If yes, household wants to get the incentive very much
      let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
       set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]          ;; Attitude is formed by the average of
awareness, Convenience and profit
    [ let PerceivedEconomicProfit CollectorIncentives / ( income / 1000 )          ;; If not bigger, incentives divided by a percent
of the income determines the factor
      let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
       set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]          ;; Attitude is formed by the average of
awareness, Convenience and profit

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm ) / (WeightOfAttitude + WeightOfSocialNorm) > 0.5   ;; Checks if the
average of the factors is above 0.5
  [ set Intention 2 ]                                                   ;; If yes, Collector will be used
  [ set Intention 0 ]                                                   ;; If no, LandFill will be used
 end


 to DecisionTreeTPB                                                     ;; Decision Tree for TPB
  ifelse AvailabilityRecyclingMethods = "Both"      [ ChoiceTPBBoth ]              ;; Fires if both the container and the collector
methods are available
    [ifelse AvailabilityRecyclingMethods = "Container" [
        IntentionTPBContainer ]                                         ;; Fires if only the container based method is available
      [ IntentionTPBCollector ]   ]                                     ;; Fires if only the collector based method is available
 end

 to ChoiceTPBBoth                                                       ;; Intention for TPB behavioural theory and container & collector
methods
```

```
  let UtilityContainer (ContainerIncentives - ( income / (MinutesPerHour * HoursPerWeek * WeeksPerYear) ) * ContainerRequiredTime)    ;; The
utility of the Container Method is calculated by the worth of using a method, described by subtracting the RequiredTime * average income per
minute from the incentives given (incentives come from sliders)
  let UtilityCollector (CollectorIncentives - ( income / (MinutesPerHour * HoursPerWeek * WeeksPerYear) ) * CollectorRequiredTime)    ;; The utility
of the Collector Method is calculated by the worth of using a method, described by subtracting the RequiredTime * average income per minute
from the incentives given (incentives come from sliders)
  Ifelse UtilityContainer > UtilityCollector [ IntentionTPBContainer ] [ IntentionTPBCollector ]                  ;; The method with the largest utility is
chosen for intention calculation
 end

 to IntentionTPBContainer                                                                          ;; Intention for TPB behavioural theory and container method
 Ifelse ContainerIncentives / ( income / 1000 ) > 1                                                          ;; Check if containerinventives are more than 1% of the
income
   [ let PerceivedEconomicProfit 1                                                                      ;; If yes, household wants to get the incentive very much
     let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                                          ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                          ;; Attitude is formed by the average of
awareness, Convenience and profit
   [ let PerceivedEconomicProfit ContainerIncentives / ( income / 1000 )                                   ;; If not bigger, incentives divided by a percent
of the income determines the factor
     let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                                          ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                          ;; Attitude is formed by the average of
awareness, Convenience and profit

  set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2                             ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm + WeightOfPerceivedBehaviouralControl * PerceivedBehaviouralControl)
/ (WeightOfAttitude + WeightOfSocialNorm + WeightOfPerceivedBehaviouralControl) > 0.5   ;; Checks if the average of the factors is above 0.5
  [ set Intention 1 ]                                                                   ;; If yes, Containers will be used
  [ set Intention 0 ]                                                                   ;; If no, LandFill will be used
 end

 to IntentionTPBCollector                                                                          ;; Intention for TPB behavioural theory and collector method
  Ifelse CollectorIncentives / ( income / 1000 ) > 1                                                         ;; Check if CollectorIncentives are more than 1% of the
income
   [ let PerceivedEconomicProfit 1                                                                      ;; If yes, household wants to get the incentive very much
     let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                                          ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                          ;; Attitude is formed by the average of
awareness, Convenience and profit
   [ let PerceivedEconomicProfit CollectorIncentives / ( income / 1000 )                                    ;; If not bigger, incentives divided by a percent
of the income determines the factor
     let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                                          ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                          ;; Attitude is formed by the average of
awareness, Convenience and profit

  set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2                             ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm + WeightOfPerceivedBehaviouralControl * PerceivedBehaviouralControl)
/ (WeightOfAttitude + WeightOfSocialNorm + WeightOfPerceivedBehaviouralControl) > 0.5   ;; Checks if the average of the factors is above 0.5
  [ set Intention 2 ]                                                                   ;; If yes, Collector will be used
  [ set Intention 0 ]                                                                   ;; If no, LandFill will be used
 end

 to DecisionTreeTPB+                                                                               ;; Decision Tree for TPB+
  if AvailabilityRecyclingMethods = "Both"      [ ChoiceTPB+Both ]                                           ;; Fires if both the container and the collector
methods are available
  if AvailabilityRecyclingMethods = "Container" [ IntentionTPB+Container ]                                  ;; Fires if only the container based method is
available
  if AvailabilityRecyclingMethods = "Collector" [ IntentionTPB+Collector ]                                  ;; Fires if only the collector based method is
available
 end

 to ChoiceTPB+Both                                                                                 ;; Intention for TPB+ behavioural theory and container &
collector methods
  ifelse CollectorRequiredSpace > AvailableSpace [ IntentionTPB+Container ]                                ;; If there is not enough space for
collectors, intention will be calculated for containers, if there is enough, the time will be checked
   [ ifelse ContainerRequiredTime > AvailableTime [ IntentionTPB+Collector ]                                ;; If there is too much time required for
containers, intention will be calculated for collector use, if there is enough, utility is checked
   [ let UtilityContainer ContainerIncentives - ( income / (MinutesPerHour * HoursPerWeek * WeeksPerYear) ) * ContainerRequiredTime     ;; The
utility of the Container Method is calculated by the worth of using a method, described by subtracting the RequiredTime * average income per
minute from the incentives given (incentives come from sliders)
     let UtilityCollector CollectorIncentives - ( income / (MinutesPerHour * HoursPerWeek * WeeksPerYear) ) * CollectorRequiredTime     ;; The
utility of the Collector Method is calculated by the worth of using a method, described by subtracting the RequiredTime * average income per
minute from the incentives given (incentives come from sliders)
     Ifelse UtilityContainer > UtilityCollector [ IntentionTPB+Container ] [ IntentionTPB+Collector ] ] ]         ;; The method with the largest utility is
chosen for intention calculation
 end

 to IntentionTPB+Container                                                                         ;; Intention for TPB+ behavioural theory and container method
   ifelse ContainerRequiredTime > AvailableTime
     [ Set Intention 0
```

```
        Ifelse ContainerIncentives / ( income / 1000 ) > 1                                    ;; Check if containerinventives are more than 1% of the
income
      [ let PerceivedEconomicProfit 1                                        ;; If yes, household wants to get the incentive very much
        let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit
      [ let PerceivedEconomicProfit ContainerIncentives / ( income / 1000 )                          ;; If not bigger, incentives divided by a percent
of the income determines the factor
        let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit

        set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2   ]                    ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge]


     [ Ifelse ContainerIncentives / ( income / 1000 ) > 1                                    ;; Check if containerinventives are more than 1% of the
income
      [ let PerceivedEconomicProfit 1                                        ;; If yes, household wants to get the incentive very much
        let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit
      [ let PerceivedEconomicProfit ContainerIncentives / ( income / 1000 )                          ;; If not bigger, incentives divided by a percent
of the income determines the factor
        let Convenience 1 - ( ContainerRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit

        set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2                    ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm + WeightOfPerceivedBehaviouralControl * PerceivedBehaviouralControl)
/ (WeightOfAttitude + WeightOfSocialNorm + WeightOfPerceivedBehaviouralControl) > 0.5   ;; Checks if the average of the factors is above 0.5
   [ set Intention 1 ]                                                ;; If yes, Containers will be used
   [ set Intention 0 ]   ]                                            ;; If no, LandFill will be used
 end

 to IntentionTPB+Collector                                            ;; Intention for TPB+ behavioural theory and collector method
   ifelse CollectorRequiredSpace > AvailableSpace
     [ Set Intention 0                                                ;; If there is too much space required for collector use, the waste
will be put in the landfill (intention 0)
       Ifelse CollectorIncentives / ( income / 1000 ) > 1                                    ;; Check if CollectorIncentives are more than 1% of
the income
       [ let PerceivedEconomicProfit 1                                        ;; If yes, household wants to get the incentive very much
         let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit
       [ let PerceivedEconomicProfit CollectorIncentives / ( income / 1000 )                          ;; If not bigger, incentives divided by a
percent of the income determines the factor
         let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
         set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit
       set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2                    ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge
     ]
     [
  Ifelse CollectorIncentives / ( income / 1000 ) > 1                                    ;; Check if CollectorIncentives are more than 1% of the
income
   [ let PerceivedEconomicProfit 1                                        ;; If yes, household wants to get the incentive very much
     let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit
   [ let PerceivedEconomicProfit CollectorIncentives / ( income / 1000 )                          ;; If not bigger, incentives divided by a percent
of the income determines the factor
     let Convenience 1 - ( CollectorRequiredTime / AvailableTime )                        ;; Convenience starts at 1 and is reduced by the
required time divided by the Available Time
      set Attitude ( RecyclingAwareness + PerceivedEconomicProfit + Convenience ) / 3 ]                 ;; Attitude is formed by the average of
awareness, Convenience and profit

  set PerceivedBehaviouralControl ( WillingnessToChange + RecyclingKnowledge ) / 2                    ;; PerceivedBehaviouralControl is
formed by the average of Willingness to change and recycling knowledge

 Ifelse ( WeightOfAttitude * Attitude + WeightOfSocialNorm * SocialNorm + WeightOfPerceivedBehaviouralControl * PerceivedBehaviouralControl)
/ (WeightOfAttitude + WeightOfSocialNorm + WeightOfPerceivedBehaviouralControl) > 0.5   ;; Checks if the average of the factors is above 0.5
  [ set Intention 2 ]                                                ;; If yes, Collector will be used
  [ set Intention 0 ]                                                ;; If no, LandFill will be used
     ]
 end


to UpdateIntentionColour
```

```
  ifelse Intention = 1                                    ;; if recycling intention is recycling,
    [ set pcolor Container-color ]                          ;; then the color of the household should be of Container use
    [ ifelse Intention = 2                                ;; if recycling intention is waiting for collector
       [ set pcolor Collector-color ]                       ;; then the color of the household should be of waiting for
collector
       [ set pcolor Landfill-color ] ]                     ;; Else the color of the household should be of landfill
end


to DecideBehaviour          ;; CHECK FIRST SCENTENCE IN VALIDATION !!!
  ifelse random 100 < TransformationIntoBehaviour                  ;; 70% chance that the intention is tranformed into
the desired behaviour
    [ set RecyclingBehaviour Intention ]                        ;; in this line, the intention = behaviour
    [ ifelse Intention > 0                                ;; if intention is not landfill
        [ set RecyclingBehaviour Intention + 1]                  ;; the behaviour equals intention + 1, they want to recycle
but end up waiting for the collector or collector ends up to landfill
        [ set RecyclingBehaviour 3]  ]                          ;; if intention is landfill, it is going to be landfill, because it can
not be decreased more
end


to ActOnBehaviour
  ifelse RecyclingBehaviour = 1                             ;; when households actually recycle
    [ UseContainers ]                                     ;; they get rid of their waste here
    [ ifelse RecyclingBehaviour = 2                          ;; when households wait for collectors at the door
      [ WaitForCollectors ]                               ;; they get rid of their waste with this procedure
      [ BringToLandfill ] ]                               ;; when households don't want to recycle, they get rid of their waste
with this procedure
end


to UseContainers                                          ;; the procedure of getting rid of the waste by recycling, with the
consequences of this behaviour
  set BroughtToContainer BroughtToContainer + AmountOfWaste
  set AmountOfWaste 0
end

to WaitForCollectors                                      ;; the procedure of getting rid of the waste by waiting for
collectors, with the consequences of this behaviour
  set CollectedRecyclates CollectedRecyclates + AmountOfWaste
  set AmountOfWaste 0
end

to BringToLandfill                                        ;; the procedure of getting rid of the waste by landfill, with the
consequences of this behaviour
  set LandfillWaste LandfillWaste + AmountOfWaste
  set AmountOfWaste 0
end

to DeterminePlotGlobals
  set ParticipationRateContainer (count patches with [Intention = 1]) / count allhouseholds
  set ParticipationRateCollector (count patches with [Intention = 2]) / count allhouseholds
  set ParticipationRateLandfill (count patches with [Intention = 0 and pcolor != PhysicalContainer-color and pcolor != border-color]) / count
allhouseholds
end
```

Appendix C – Model Validation

Recording and tracking agent behaviour

In this first step, an individual agent is tracked during the simulation. Its inputs at setup, its states during the simulation, and its output after the simulation are checked. In this way, it can be verified if the values are logical and intended. The households only execute one decision making process during the simulation, which takes place once the amount of recyclates reaches the threshold and the household must decide what to do with it.

For this verification, one patch or household is tracked. See the input at setup for one of the households in table 4. In this example the recycling awareness and recycling knowledge are the same. However, this is not necessarily the case.

Table 4: Setup of household (-28,29)

Patch (-28,29)	
householdsize	2
income	100.474
zone	"university"
networksize	11
socialnetwork	[(agentset, 8 patches) (patch -16 29)
nearestcontainer	(patch -25 35)
containerrequiredtime	0.33
collectorrequiredtime	0.20
collectorrequiredspace	0.01
availabletime	1
availablespace	0.87
amountofwaste	4
educationlevel	2
recyclingawareness	0.85
recyclingknowledge	0.85
willingnesstochange	0.55
attitude	0.54
socialnorm	0
perceivedbehaviouralcontrol	0.70
intention	0
recyclingbehaviour	0

The initial amount of waste of this household is 4 and this amount develops in the following way:

Tick 1: amount of waste = 5,12
Tick 5: amount of waste = 9,10

In the next tick, the amount of waste will reach the threshold of 10. Therefore, the household will have to make the decision if it will recycle. The *attitude* and *perceivedbehaviouralcontrol* remain the same during the simulation. The *socialnorm* is updated according to the number of recycling households in its *socialnetwork.* This appears to be 0, so the three factors are combined and the *intention* and *recyclingbehaviour* are 0. After this, the *amountofwaste* is set to 0 again, before the household starts generating waste again at the next tick:

Tick 6: amount of waste = 0
Tick 7: amount of waste = 1,21

Interaction testing in minimal model

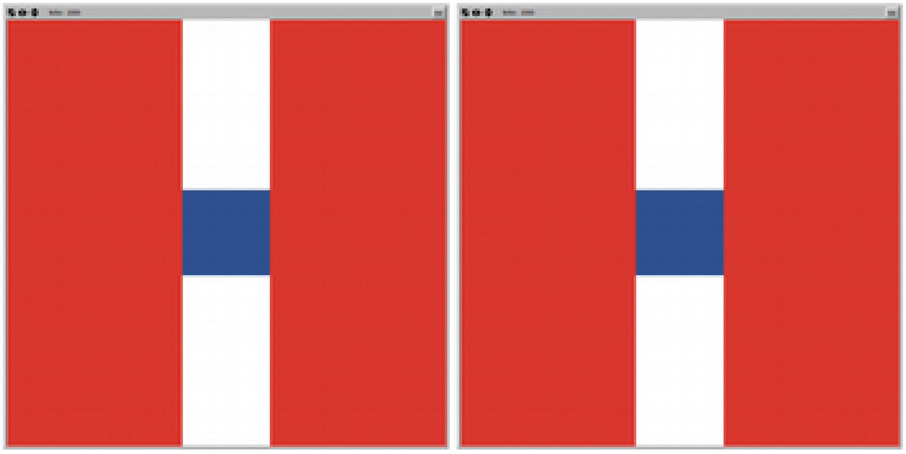
The most minimal model with interaction would be a world with two households. However, the agents in our model are not turtles that walk around, but patches with a fixed location. An important part of the model is the social network of a household, which consists of direct neighbours and friends. Furthermore, aspects such as the distance to the nearest container and the different neighbourhoods are also not possible to include if only two patches are part of the simulation. Therefore, a minimal model is created with several households, two neighbourhoods (university staff and local residents), and one container. This results in a model with twenty-five patches, of which twenty households, four border-patches, and one container.

Theoretical prediction and sanity test

The tests consist of theoretical predictions under five different input-scenarios.

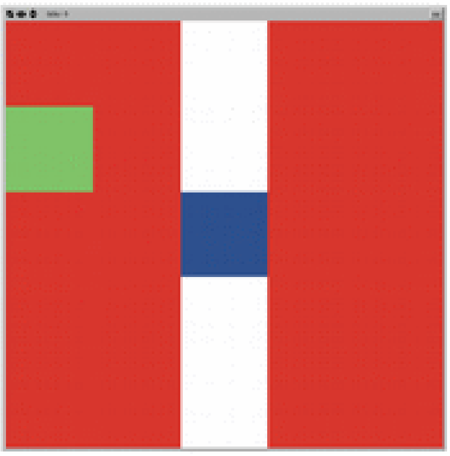
In Test 1, we predict that no single household will decide to recycle its waste, due to the low incentives. As can be seen in the table below, no household recycles its waste and no further surprises were found.

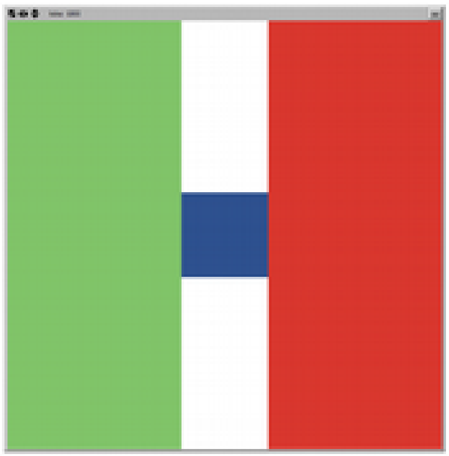
Test 1 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	Households using containers	0
AvailabilityRecyclingMethods	Both	Households using collectors	0
ContainerIncentives	0	Households using landfill	20
CollectorIncentives	0	Total amount of waste	829 677
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	1	Collected recyclates	0
WeightOfSocialNorm	1	Landfill waste	829 677
WeightOfPerceivedBehaviouralControl	1	Average attitude	0.53
		Average social norm	0
		Average pbc	0.57



In Test 2, we predict that some households will use a recycling method. Given that the container is really close in this model, we suspect them to use the container. During this test, we found out that it's possible for households to be part of their own social network, as a friend. In the normal model, the chance of this happening would be very small, in the minimal model however, this is quite likely. After fixing the error, the simulation is performed again. The output of the simulation is as predicted.

Test 2 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	Households using containers	10
AvailabilityRecyclingMethods	Both	Households using collectors	0
ContainerIncentives	30	Households using landfill	10
CollectorIncentives	30	Total amount of waste	829.677
TransformationIntoBehaviour	100	Brought to container	330.483
WeightOfAttitude	1	Collected recyclates	0
WeightOfSocialNorm	1	Landfill waste	499.193
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,62
		Average social norm	0,45
		Average pbc	0,57

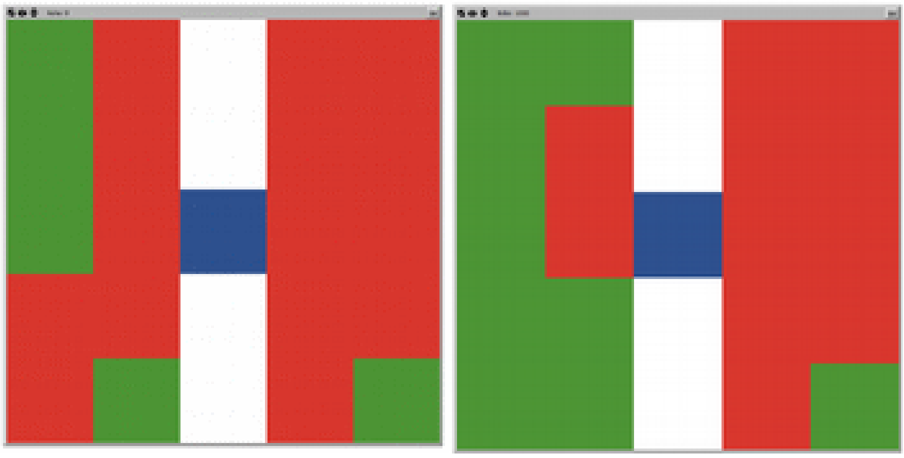




In Test 3, the only available recycling method are the collectors, and the attitude becomes more important. In this way, we predict that some households will make use of the collectors, while attitude becomes higher and more important in the decision.

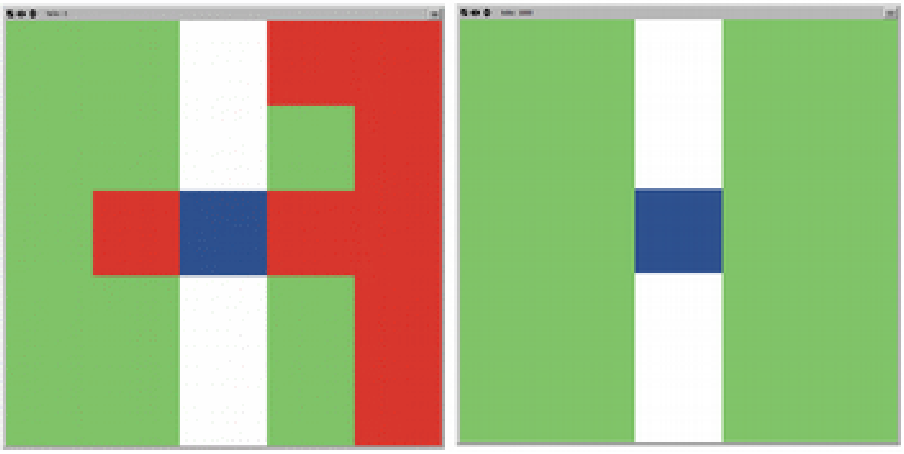
Test 3 (1000 ticks)

Input		*Output*	
TheoryOfBehaviour	TPB+	Households using containers	0
AvailabilityRecyclingMethods	Coll.	Households using collectors	9
ContainerIncentives	30	Households using landfill	11
CollectorIncentives	30	Total amount of waste	829.677
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	3	Collected recyclates	303.742
WeightOfSocialNorm	1	Landfill waste	525.935
WeightOfPerceivedBehaviouralControl	3	Average attitude	0,48
		Average social norm	0,40
		Average pbc	0,57



In Test 4, we applied the TRA as selection theory, kept both incentives high, and significantly increased the weight for attitude. We predict this should result in all households recycling, more specifically, using the containers. After simulation, this was indeed the result. However, the average social norm was only 0,99 instead of 1. When checking the code, a small error was found in counting the size of the social network. After fixing the error, the size of the social network for all households was correct, and the average social norm became 1.

Test 4 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TRA	Households using containers	20
AvailabilityRecyclingMethods	Both	Households using collectors	0
ContainerIncentives	30	Households using landfill	0
CollectorIncentives	30	Total amount of waste	829.677
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	4	Collected recyclates	549
WeightOfSocialNorm	1	Landfill waste	829.128
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,62
		Average social norm	1
		Average pbc	0



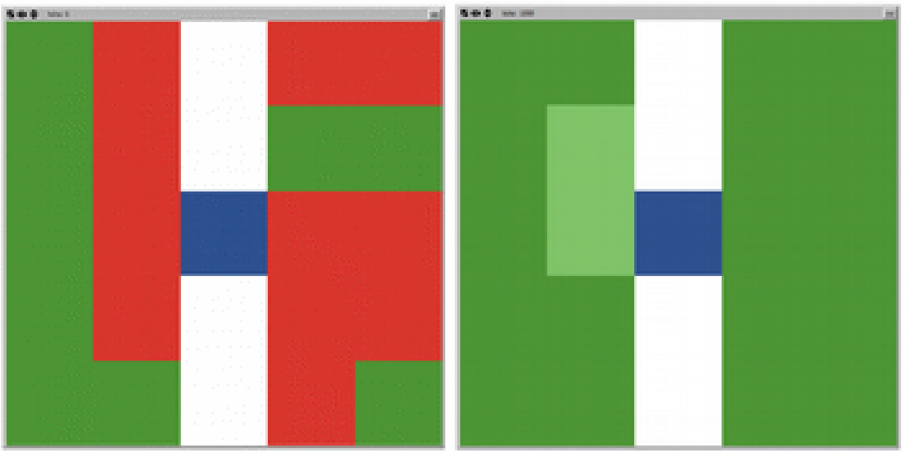
In Test 5, the selection theory is TPB, without container incentives, maximum collector incentives, and the weight for perceived behavioural control is 3. We predict that some households use collectors, but no households use the containers. Surprisingly, no households used collectors in the simulation, which is definitively an error. After fixing the error in the code (misplaced brackets in a calculation), the resulting simulation performs as predicted.

Test 5 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB	Households using containers	0
AvailabilityRecyclingMethods	Both	Households using collectors	11
ContainerIncentives	0	Households using landfill	9
CollectorIncentives	30	Total amount of waste	829.677
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	1	Collected recyclates	363.465
WeightOfSocialNorm	1	Landfill waste	466.212
WeightOfPerceivedBehaviouralControl	3	Average attitude	0,48
		Average social norm	0,52
		Average pbc	0,57

Break the agent tests

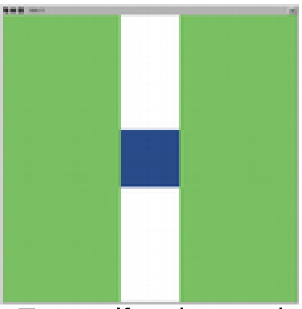
In Test 6, only the collector incentives are increased to the extreme value of 3000. Combined with a slightly increased weight of attitude, this should lead to all households using the collectors. As a result, almost all households choose for recycling via the collectors. However, two households use the containers. After inspection, this can be explained by the space required for using the collectors. Both households have insufficient space to store their recyclates, and instead choose for the containers, even though its incentives are low.

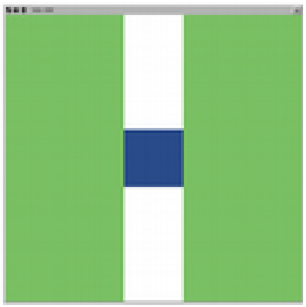
Test 6 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	Households using containers	2
AvailabilityRecyclingMethods	Both	Households using collectors	18
ContainerIncentives	0	Households using landfill	0
CollectorIncentives	3000	Total amount of waste	829.677
TransformationIntoBehaviour	100	Brought to container	73.525
WeightOfAttitude	2	Collected recyclates	755.077
WeightOfSocialNorm	1	Landfill waste	1.075
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,70
		Average social norm	1
		Average pbc	0,57



In this run the only component of the theory of planned behaviour that is used, is the attitude. The other components have a weight of 0. Because of the fact that the only dynamic value in the theory is the social norm, the run is expected to be constant over the course of the 1000 ticks. The beginning is expected to have a high participation rate since the social norm cannot have its negative influence on the recycling behaviour.
When the run is executed, the hypotheses have been confirmed, the initial participation is higher than in other runs, 100% recycles from the beginning, and remains constant.

Test 7 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	Households using containers	20
AvailabilityRecyclingMethods	Both	Households using collectors	0
ContainerIncentives	30	Households using landfill	0
CollectorIncentives	30	Total amount of waste	829677
TransformationIntoBehaviour	100	Brought to container	829677
WeightOfAttitude	1	Collected recyclates	0
WeightOfSocialNorm	0	Landfill waste	0
WeightOfPerceivedBehaviouralControl	0	Average attitude	0,62
		Average social norm	1
		Average pbc	0,57



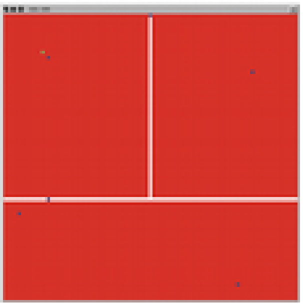
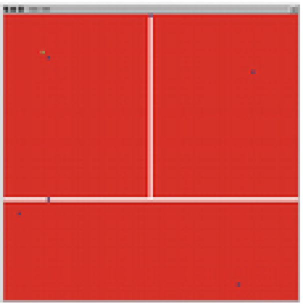
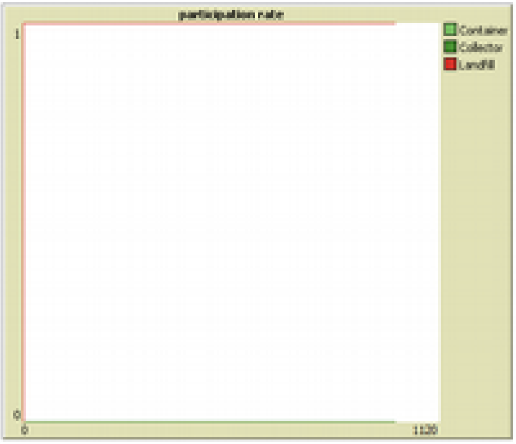


To verify the entire model, four different tests will be executed. The four tests are the theoretical prediction and sanity checks, breaking the agent, variability testing and timeline sanity. Theoretical prediction and sanity checks and breaking the agent have been executed in the minimal model as well. To check whether the model still holds in the large version, these tests are repeated.
The third test is the variability testing. In this test, the randomness and the distribution of the output variables are checked with 100 repetitions to see whether the distribution of the output variables can be explained. If not, this mostly indicates a problem.
The fourth test is the timeline sanity check. In this check a few courses of a model run are checked to see whether the variables develop in a logical way and corresponding to reality. If possible it is desirable to have this checked by experts from practice.

Theoretical prediction and sanity checks

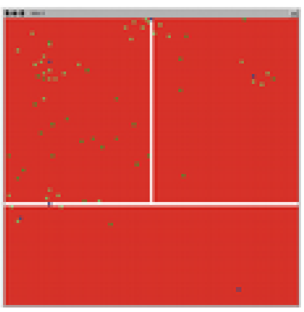
The first test of the theoretical prediction and sanity check is set up as seen in the table below. The model is predicted to have a low participation rate of recycling, since there are no incentives and no social norm to persuade citizens to participate. After the model run only 0.01% of the civilians participate in the recycling project. The hypothesis is correct.

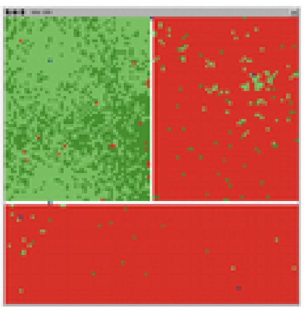
Test 1 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	% Households using containers	0.01%
AvailabilityRecyclingMethods	Both	% Households using collectors	0
ContainerIncentives	0	% Households using landfill	99.99%
CollectorIncentives	0	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	1.07*10^7
WeightOfAttitude	1	Collected recyclates	0
WeightOfSocialNorm	1	Landfill waste	1.96*10^11
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,39
		Average social norm	8*10^-5
		Average pbc	0,55

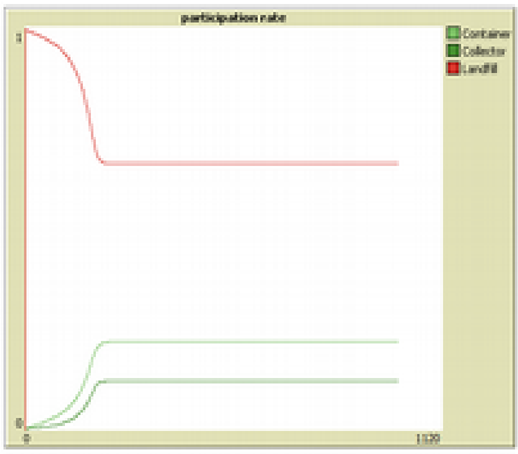




In this test the incentives are increased to persuade the civilians to participate in the project. The hypothesis is that the incentives will have influence on the civilians that have a high knowledge and awareness (the university staff), but not on the other parts of the model. After the model run can be concluded that the incentives have an influence on the model, but not enough to persuade the people who are not very willing from their intrinsic motivation.

Test 2 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	% Households using containers	21.85%
AvailabilityRecyclingMethods	Both	% Households using collectors	12.13%
ContainerIncentives	30	% Households using landfill	66.02%
CollectorIncentives	30	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	2.57*10^10
WeightOfAttitude	1	Collected recyclates	1.38*10^10
WeightOfSocialNorm	1	Landfill waste	1.56*10^11
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,49
		Average social norm	0,34
		Average pbc	0,55

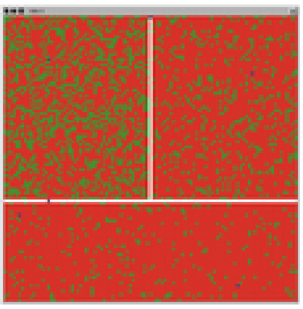
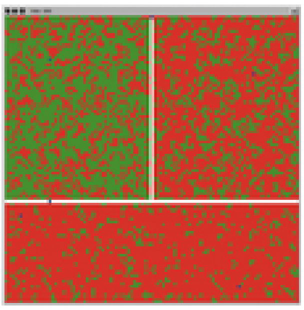






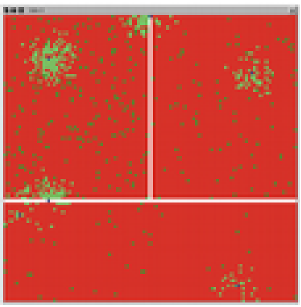
The third test has only one recycling method available, namely the collectors, and gives an alternate weight to attitude and perceived behavioural control, a weight of 3. The hypothesis is that the participation rate will increase in every region, since personal properties are more important than the social norm, which holds the development back. However, where the participation normally grows in a cluster, the development will probably be less clustered in this case.
The model run shows that more people are participating in the beginning of the run and this participation rate grows during the run, but not as much as in previous runs. This can be explained by the fact that the personal characteristics don't change, only the environment. However, the environment influences the recycling decision less in this run. As expected, the participating civilians are less clustered than in previous runs.

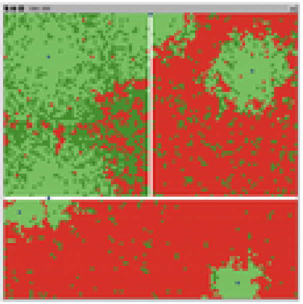
Test 3 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	% Households using containers	0
AvailabilityRecyclingMethods	Coll.	% Households using collectors	35.89%
ContainerIncentives	30	% Households using landfill	64.11%
CollectorIncentives	30	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	3	Collected recyclates	5.10*10^10
WeightOfSocialNorm	1	Landfill waste	1.44*10^11
WeightOfPerceivedBehaviouralControl	3	Average attitude	0,44
		Average social norm	0,36
		Average pbc	0,55

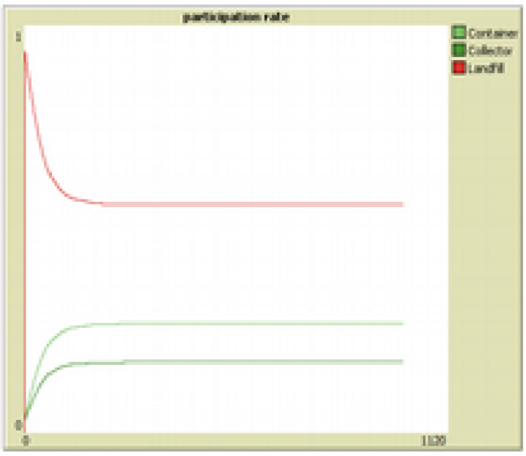




In the fourth run the theory of behaviour is set as TRA, and the weight of attitude in the recycling decision is 4. This means that Perceived behavioural control doesn't apply in this run, since it is not part of the Theory of Reasoned Action.
In this run the participation rate is expected to be high in the university region, since their attitude is higher on average than in the other regions. The participation is expected to be higher around the containers, due to the higher convenience and therefore attitude. After the run can be seen that the participation is higher in the university region than in the other regions and it is clustered around the containers.

Test 4 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TRA	% Households using containers	26.74%
AvailabilityRecyclingMethods	Both	% Households using collectors	17.22%
ContainerIncentives	30	% Households using landfill	56.05%
CollectorIncentives	30	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	3.97*10^10
WeightOfAttitude	4	Collected recyclates	2.28*10^10
WeightOfSocialNorm	1	Landfill waste	1.34*10^11
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,50
		Average social norm	0.44
		Average pbc	0

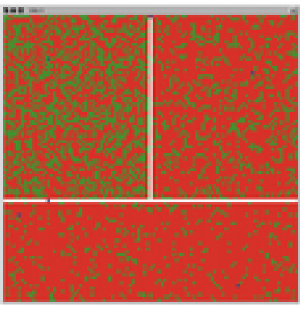


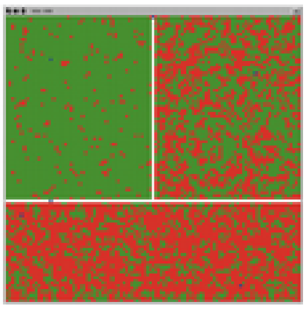


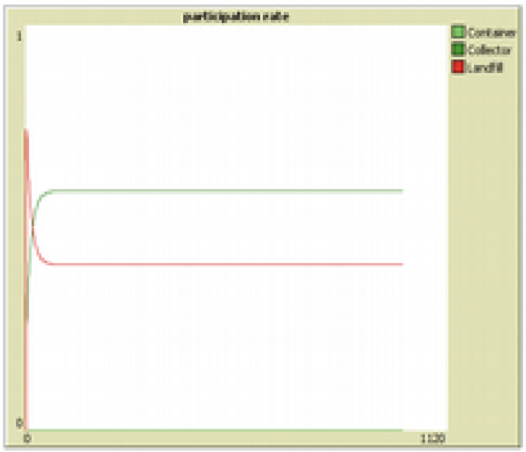


In the fifth run, the Theory of Behaviour is set on Theory of Planned behaviour, without the situational factors (required time and space, which can exclude collecting or container when the required time and space exceed the available time and space). Furthermore, the container incentives are set at 0, while the collector incentives are set at 30. One of the weights has been adjusted, namely the weight of perceived behavioural control, which is set at 3. The run is expected to have more people using the collector than the container for their waste disposal. The run is also expected to have less single civilians that don't participate while their entire group of neighbours does, since this is caused by a lack of time or space.
As can be seen below, all recycling civilians use the collection option, caused by the incentives. However, there are still individual civilians that don't recycle. After examination is discovered that this is caused by a low perceived behavioural control, which has a high weight in this run.

Test 5 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB	% Households using containers	0%
AvailabilityRecyclingMethods	Both	% Households using collectors	59.08%
ContainerIncentives	0	% Households using landfill	40.92%
CollectorIncentives	30	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	0
WeightOfAttitude	1	Collected recyclates	9.32*10^10
WeightOfSocialNorm	1	Landfill waste	1.03*10^11
WeightOfPerceivedBehaviouralControl	3	Average attitude	0,44
		Average social norm	0,59
		Average pbc	0,55







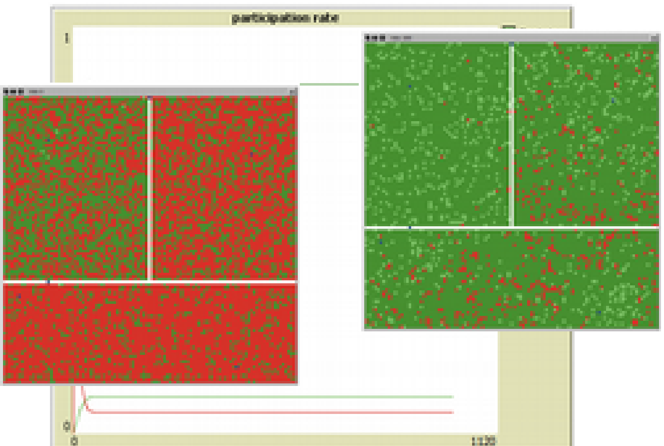
Break the agent tests

In this run, the collector incentives are set very high (3000) to see what the influence of an extreme value is. The container incentives are set at 0 and the weight of attitude (which is influence by economic incentives) is set at 2.

The model is expected to have a high participation rate for collectors. However, there is a built in maximum for the influence of economic incentives. Therefore this is expected to have a high influence, but not as much as needed to have the entire community recycling.

After the run only 5% does not recycle. The economic incentive, combined with a high social norm is not enough for them, since their personal characteristics block this transition. An interesting result is the 9% that does recycling by using a container, while there are no container incentive. The social norm stimulates them to recycle and they do so in the only feasible way for them, the container.

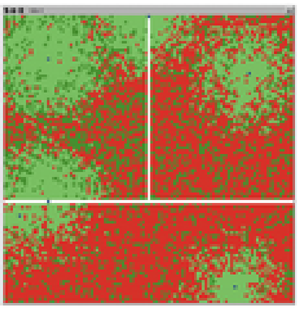
Test 6 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	% Households using containers	8.97%
AvailabilityRecyclingMethods	Both	% Households using collectors	85.88%
ContainerIncentives	0	% Households using landfill	5.14%
CollectorIncentives	3000	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	1.46*10^10
WeightOfAttitude	2	Collected recyclates	1.66*10^11
WeightOfSocialNorm	1	Landfill waste	1.57*10^10
WeightOfPerceivedBehaviouralControl	1	Average attitude	0,63
		Average social norm	0.95
		Average pbc	0,55

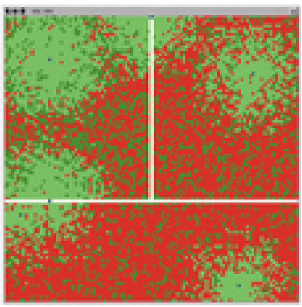


In this run the only component of the theory of planned behaviour that is used, is the attitude. The other components have a weight of 0. Because of the fact that the only

dynamic value in the theory is the social norm, the run is expected to be constant over the course of the 1000 ticks. The beginning is expected to have a higher participation rate since the social norm cannot have its negative influence on the recycling behaviour.
When the run is executed, the hypotheses have been confirmed, the initial participation is higher than in other runs and remains constant.

Test 7 (1000 ticks)			
Input		*Output*	
TheoryOfBehaviour	TPB+	% Households using containers	27.88%
AvailabilityRecyclingMethods	Both	% Households using collectors	21.44%
ContainerIncentives	30	% Households using landfill	50.67%
CollectorIncentives	30	Total amount of waste	1.96*10^11
TransformationIntoBehaviour	100	Brought to container	4.13*10^10
WeightOfAttitude	1	Collected recyclates	3.24*10^10
WeightOfSocialNorm	0	Landfill waste	1.22*10^11
WeightOfPerceivedBehaviouralControl	0	Average attitude	0,49
		Average social norm	0.49
		Average pbc	0,55





Variability testing

The model has several parameters that can be varied during the experimentation. To see what the influence of the parameters is on the important variables of the model, the correlation between the variables is determined. The expected direction of the different relations can be found in table 5. The calculated correlations can be found in table 6. From these correlations can be concluded that the weight of social norm and weight of perceived behavioural control have the most influence on the output variables of the model.
The differences between the expected and calculated correlations are at the influence of the weight of attitude: these relations have not been proven significant. During model runs it looks like the social norm blocks the recycling behaviour. The hypothesis was that a higher weight of other components would overcome this block. However, this hypothesis did not hold, as proven by the insignificant correlations.

Table 5: Expected relation directions

Input\Output	Average attitude	Participation rate landfill	Participation rate collector	Participation rate container
↑ Collector incentives	↑	↓	↑	↓
↑ Container incentives	↑	↓	↓	↑
↑ Weight of attitude	→	↓	↑	↑
↑ Weight of social norm	→	↑	↓	↓
↑ Weight of Perceived behavioural control	→	↓	↑	↑

Table 6: Correlations between input and output variables

Input\Output	Participation rate landfill	Participation rate collector	Participation rate container
Collector incentives	-0.05	0.3	-0.18
Container incentives	-0.12	-0.15	0.27
Weight of attitude	-	-	-
Weight of social norm	0.5	-0.33	-0.35
Weight of Perceived behavioural control	-0.4	0.28	0.25

Timeline sanity

The following figures (figures 15, 16, and 17) are constructed at the following amount of ticks in time: 0, 10, 20, 50, 75, 100, 125, 150, 175, 200, 400, 1000.

In the beginning, not much is changing. Every ten ticks the civilians make a recycling decision, which is preceded by a determination of their intention. The only component of the intention that is dynamic, the social norm, does not change much in the beginning, as it depends on the amount of recyclers. Therefore, the increase in participation rate is small in the first fifty ticks. The civilians that are persuaded to recycle are mostly in the upper left corner, the university region. They have a higher personal attitude and perceived behavioural control, due to their higher education and thus knowledge and awareness. This makes a small change in social norm enough to cause some changes in intention.

When 75 ticks have passed, more and more civilians start to recycle, since the social norm increases. There are even some changes in other regions because some of the civilians in the university region are in their network of friends. The clusters start to grow around the containers, due to the higher convenience these civilians experience, which is a part of the attitude. It takes them the least amount of time to dispose their waste. After 200 ticks almost every civilian in the university region recycles. The last civilians that are willing and able to recycle change between 200 and 400 ticks. The remaining civilians in the university region that make use of the landfill are forced to do so, due to their lack of time and space for the container or collector. This scenario proves the difficulty of persuading civilians who are not in the university region, since only few are recycling. They have a very high personal attitude and perceived behavioural control and do not need the social norm to recycle.

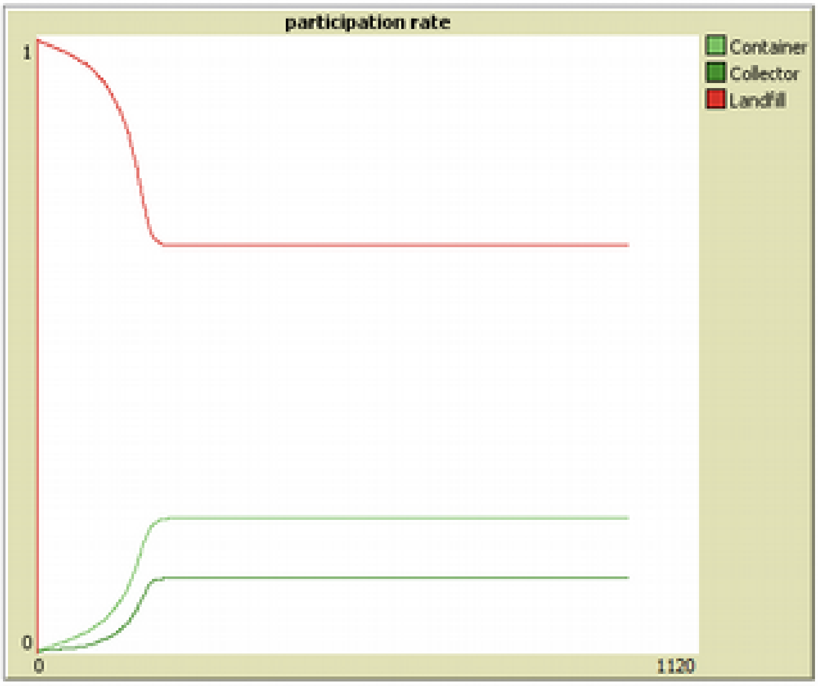


Figure 15: Timeline of simulation

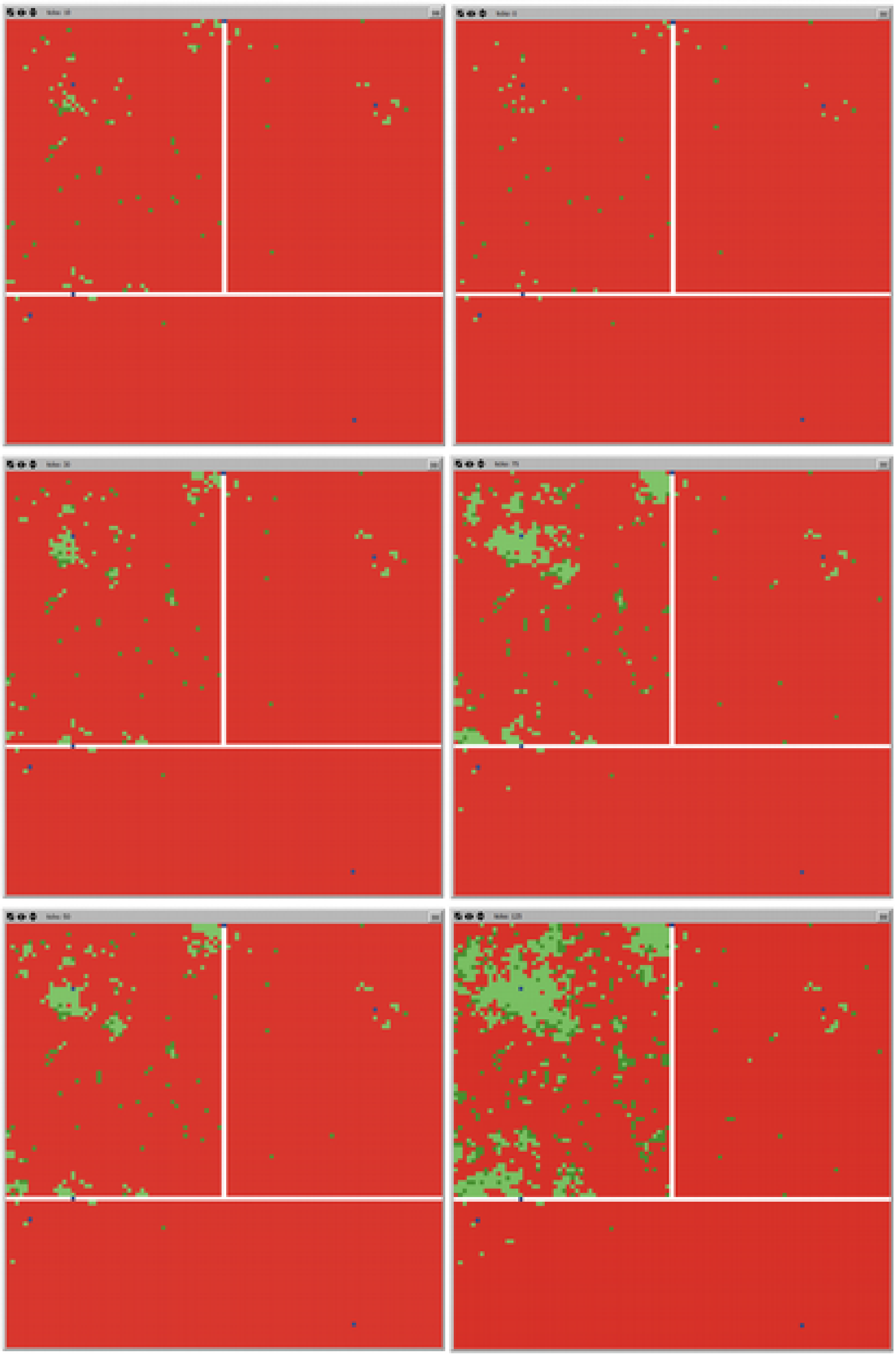


Figure 156: Model view for time ticks 0,10,20,50,75,100 (from left to right, top to bottom)

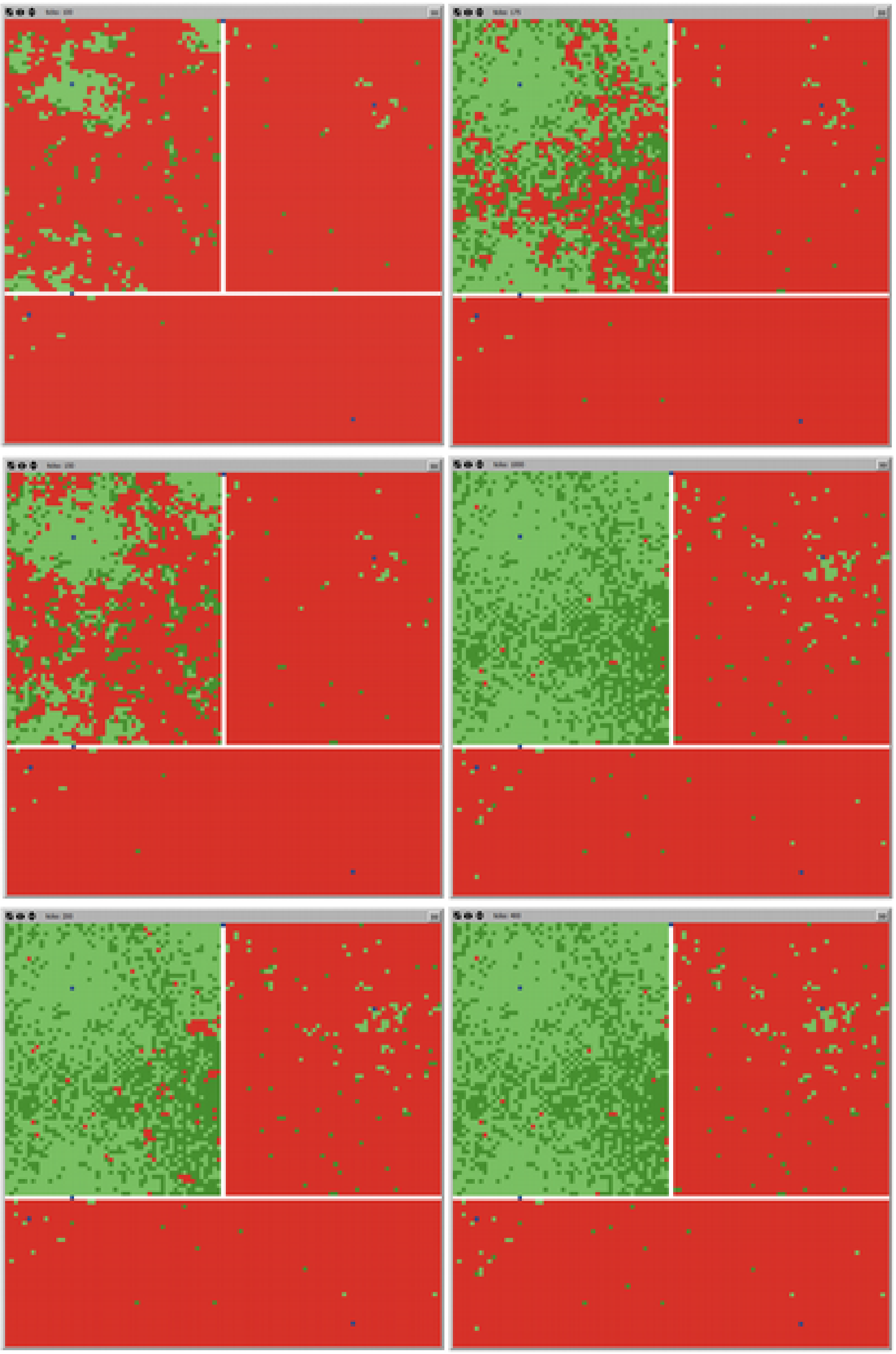


Figure 167: Model view for time ticks 125, 150, 175, 200, 400, 1000 (from left to right, top to bottom)