A

Supplements to the Agent-Based Model study of urban community gardens

A.1 ODD model description

A.1.1 Model overview

Purpose

The purpose of this agent-based model is to study the evolution of volunteer participation over time in urban community gardens, in different institutional contexts (internal rules).

State variables and scales

The model consists of the following concepts:

- Agents - initiators, gardeners and potential gardeners of the community garden. Initiators set up the garden and accept to participate a certain amount of times, regardless of their motivation.
- Individual strategies
  - contributing: the agents decide to participate (as gardener) based on behavioural beliefs (individual level, see Table A.1) and normative beliefs (social pressure, in our case called social norm);
  - taking yield: a gardener chooses an amount of garden yield to take;
  - violating a rule: a gardener can violate a garden rule with a certain probability.

- Institutions - The gardeners are bound to follow institutions, which in our case are coded based on Ostrom's Design Principles (Table A.2).
- Outcomes - Agents expect various forms of gratification from participating in urban community gardens. The outcomes are in line with the motivations explained in Appendix. They are measured, for each experiment, in terms of positive expectation of yield, social cohesion and trust. We also measure the gardening duration, which is defined by the simulation tick at which the collective action stopped.

The model contains several state variables and parameters, either characterizing the agents or the system (Tables A.2, A.3, A.4).

The model runs for a single experimental site over a maximal time of 600 ticks, which corresponds to 6 years.

beliefs	**practical need**	**label**
Social cohesion/development	Social ties	cohesion
Enhancing cultural practices	Interaction	social
Consuming fresh food	Yield	yield
Saving/making money	Yield	yield
Enjoying nature	Time on the garden	enjoyinggarden
Enhancing spiritual practices	Time on the garden	enjoyinggarden
Environmental sustainability	Contributing to the garden	sustainability
Education	New knowledge	education
Land accessibility	Ideal of garden being accessible	landavailability
Improving health	Time on the garden or yield	yield / enjoyinggarden
Uncomfortable conditions (negative)	Bad weather or bad conditions	conditions
Too much work (negative)	Too many tasks	toomuchwork

Table A.1 – Individual beliefs and their labels

Design principle	Assigned Institutional variable	Type variable	Description implementation
garden boundaries*	*DPplotboundaries*	true/false	boundaries around gardens influence the probability for yield to be stolen, probabilities are indicated by garden
garden boundaries monitoring garden boundaries	*DPprobabilitysanctioning*	floating point $\in [0.1, 0.9]$	determines the probability that a rule violation is sanctioned
garden boundaries	*DPfee*	floating point $\in [0, 0.9]$	determines the fee to join gardening (0.9 is maximal)
collective-choice arrangements	*DPglobalprobabilityruleviolation*	floating point $\in [0.1, 0.9]$	determines the initial probability of rule violation of a volunteer
proportional equivalence benefits/costs	*DPMaxTakingMoreThanShare*	floating point $\in [1, 5]$	determines the max value of the range from which volunteers randomly choose their desired amount of yield
graduated sanctions	*DPgraduatedsanctions*	boolean true/false	determines whether graduated sanctions are active or not
conflict-resolution mechanisms	*DPconflictharm*	floating point $\in [0, 100]$	determines the extent to which a conflict harms trust

* the potential effect of fences diminishing belief in land availability is not taken into account

Table A.2 – Ostrom Design Principles in the model

state variable	**definition**
Lifetime	first moment there is 1 or no volunteer on the garden
Trust	sum of *gardeners*' trust after every tick / total visits. Trust is defined as good encounters / total encounters.
Cohesion	Sum of *gardeners*' cohesion belief after every tick / total visits. Cohesion is defined by the rate of *gardeners* in the group with whom a *gardener* has a tie.
Yield	Sum of *gardeners*' yield belief after every tick / total visits. Yield is evaluated positively if the wished amount of yield is received.
Too much work	Sum of *gardeners*' belief for too much work after every tick / total visits. It is evaluated positively if the amount of volunteers is higher than a given threshold.
Amount of visits	Total number of times an agent became gardener
Amount of good encounters	Total number of encounters perceived as positive
Amount of violations	Total number of unsanctioned violations seen
Amount of own sanctions	Amount of sanctions an agent received.
Total encounters	Amount of encounters an agent has experienced.

Table A.3 – Overview of the state variables

parameter	definition
Cohesion belief strength	Ratio of gardeners with a high belief strength for cohesion.
Conditions belief strength	Ratio of gardeners with a high belief strength for comfortable conditions.
Education belief strength	Ratio of gardeners with a high belief strength for education.
Enjoying garden belief strength	Ratio of gardeners with a high belief strength for enjoying gardening.
Sustainability belief strength	Ratio of gardeners with a high belief strength for environmental sustainability.
Land availability belief strength	Ratio of gardeners with a high belief strength for land accessibility.
Social belief strength	Ratio of gardeners with a high belief strength for social interaction.
Too-Much-Work belief strength	Ratio of gardeners with a high belief strength for too much work.
Yield belief strength	Ratio of gardeners with a high belief strength for yield.
Contributing Threshold	Threshold above which the intention value is high enough for a *potential gardener* to become *gardener*
NoAccessSessions	Amount of sessions an agent cannot join gardening when suspended.
MaxAmountTellingOffAfterSuspension	Maximum amount a volunteer is told off after being suspended, before having denied access to the garden permanently.
Membershipduration	Amount of gardening sessions a membership lasts.
MinAmountOfTellingOff	Minimum amount of times a volunteer is told off before being suspended.
MaxAmountOfTellingOff	Maximum amount a volunteer can get told off before being suspended
BalanceAttitudeSocialNorm	The weight of the social norm over individual beliefs (see Behavioural Intention formula below).
ChanceYieldAvailability	Probability that yield is available on a gardening session.
ChanceYieldStolenWhenBoundaries	Probability that yield gets stolen when it is available, when there are boundaries around the garden.
VolunteersToFullySee	Number of other gardeners a gardener can see and evaluate
AmountOfTasks	Amount of tasks necessary to properly maintain the garden
Initiators	Amount of initiators the garden started with.
InitiatorCommittedTime	Amount of time initiators commit.
Conflict time	Periodic time of conflict.

Table A.4 – Overview of the parameters

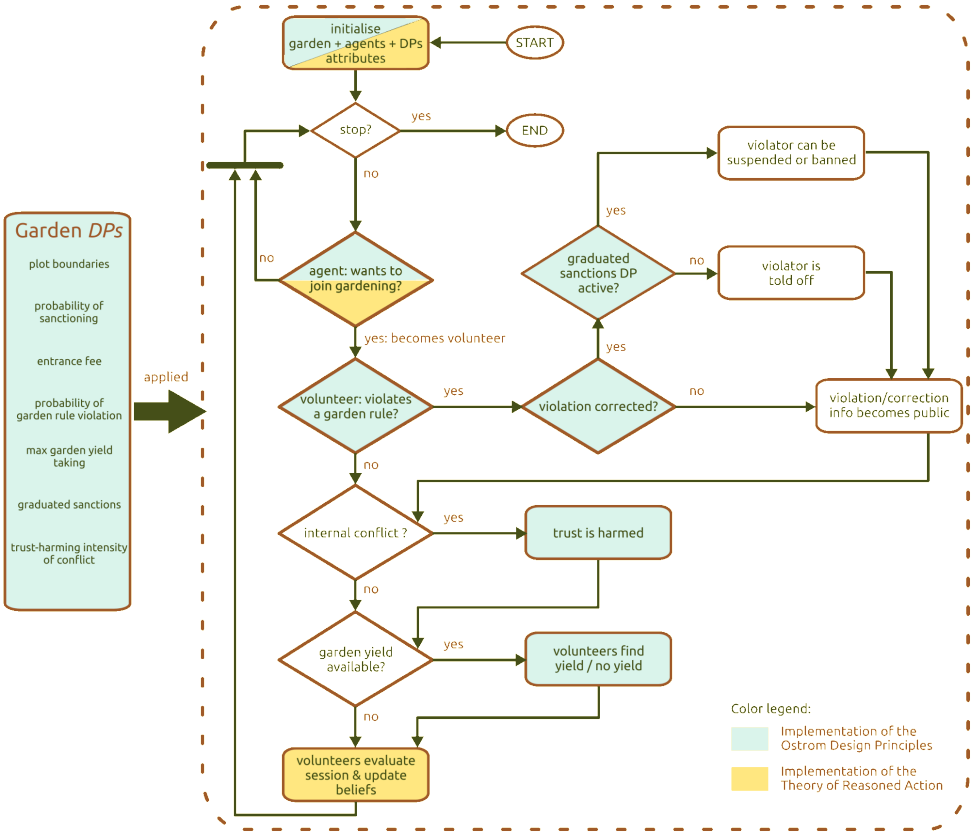

Figure A.1 – Narrative model of the urban gardening case with applied Design Principles(translated into Institutional variables from Table A.2)

Process Overview and Scheduling

The simulation model consists of two general processes which are depicted in Figure A.1.

1. Agents participate to the gardening when their intention is higher than the contributing threshold (see subsection Individual Decision Making). The *initiators* participate for a certain time no matter their motivation.

2. Participants, i.e. *gardeners*, contribute by spending time in the garden. If yield is available, they can take a fair share of it or not, in which case they violate a rule, with a set probability. A violation can be sanctioned, the probability for which depends on the institutions set. The sanction may affect the agent's rights to come back at the next round. The number of sanctioned violations are counted and influence the participating agents' belief evaluation values. If yield is not available, the agent's yield belief evaluation value is updated. Conflicts regarding rules arise periodically: according to how conflict-resolution mechanisms are implemented, this may result in a more or less severe perception

of bad encounters. At the end of the round, the actions and outcomes are assessed by the agents: their belief evaluations and probability of violating a rule are hence updated ; the same goes for the attributes of the community and biophysical conditions of the system.

A.1.2 Design concepts

Theoretical and Empirical Background

We build our model with the overall structure of the Institutional Analysis and Design (IAD) framework (Figure **??**, article body): external variables (Biophysical conditions, Attributes of Community and Rules-in-Use) determine the Action situations taken by the agents ; the resulting Interactions and their Outcomes are evaluated to update the external variables and the actions taken. In our case the Biophysical Conditions and Attributes of the community boxes are initially defined thanks to structured interviews in our case-study and to the database of urban community gardens. The Rules-in-Use box derives from Ostrom's Design Principles, adapted and simplified as visible in Table A.2.

For each agent, taking action is evaluated with the formalisation of behaviour dynamics defined in the Theory of Reasoned Action (Figure **??**, article body): a resulting behaviour depends both on attitudes and subjective norms (see next subsection).

Individual Decision-Making and Sensing

Based on the TRA, we can formulate the behavioural intention as follows:

$$BI = (A_B)W_1 + (SN)W_2$$

with
BI Behavioural Intention
A_B Attitude towards performing the behaviour
W_1 Empirically derived weight (see 4.11)
SN Subjective norm related to performing the behaviour
W_2 Empirically derived weight

The attitude can be calculated by the sum of the belief strength and belief evaluation:

$$A_B = \sum_{i=1}^{n} b_i e_i$$

with
b_i Belief strength, or the certainty to which the belief is held
e_i Belief evaluation, the extent to which the attribute is judged to be positive or negative
n Number of beliefs considered

The social norm is calculated in a similar way:

$$SN = \sum_{i=1}^{n} b_i m_i$$

with
b_i Normative belief strength, or perceived expectation of salient others
m_i Motivation to comply with the perceived expectation of others.
n Number of normative beliefs considered

The evaluation of the willingness to participate in community urban gardening is therefore the combination of the functions above:

$$\begin{aligned} Intention \quad = \quad & ((b_{cohesion} * e_{cohesion}) + (b_{social} * e_{social}) + (b_{yield} * e_{yield}) + (b_{education} * e_{education}) \\ & +(b_{landavailability} * e_{landavailability}) + (b_{enjoyinggarden} * e_{enjoyinggarden}) \\ & +(b_{sustainability} * e_{sustainability}) - (b_{conditions} * e_{conditions}) \\ & -(b_{toomuchwork} * e_{toomuchwork})) * W_1 \\ & +(b_{needcontribution} * m_{needcontribution}) * W_2 \end{aligned}$$

with
b_x Belief strength for x
e_x Belief evaluation for x
W_1 The weight of the attitudes
W_2 The weight of the social norm

The belief evaluation only impacts the overall behavioural intention if the related belief strength is higher than 0. In other words, a *gardener* for example not volunteering for the purpose of receiving yield, would not see its motivation decrease when no yield is available.

The belief strengths are characteristics of the agents, and range between 0 and 1. They are derived from the survey data in Germany. For example, 80 % join in order to take some garden products, therefore 80 % of the agents generated are given a high value for the corresponding belief strength, between 0.5 and 1. The evaluations also range between 0 and 1. An agent decides to go gardening when the intention is higher than a set decision threshold called *ContributingThreshold*. An agent either decides to contribute, and thus becomes a *gardener*, or not to contribute, and becomes or remains a *Potential gardener*. *Gardeners* proceed to the next action situations, while *Potential gardeners* can make the choice to contribute again on the next decision opportunity. This is summarised in Figure A.2. The value of this parameter is found by performing a sensitivity analysis with all design principles active and then inactive (see results section).

The weights W_1 and W_2 relate to each other as follows. Each element $b_i m_i$ from the previous formulas has a maximal value of 1. We have 7 positively counted

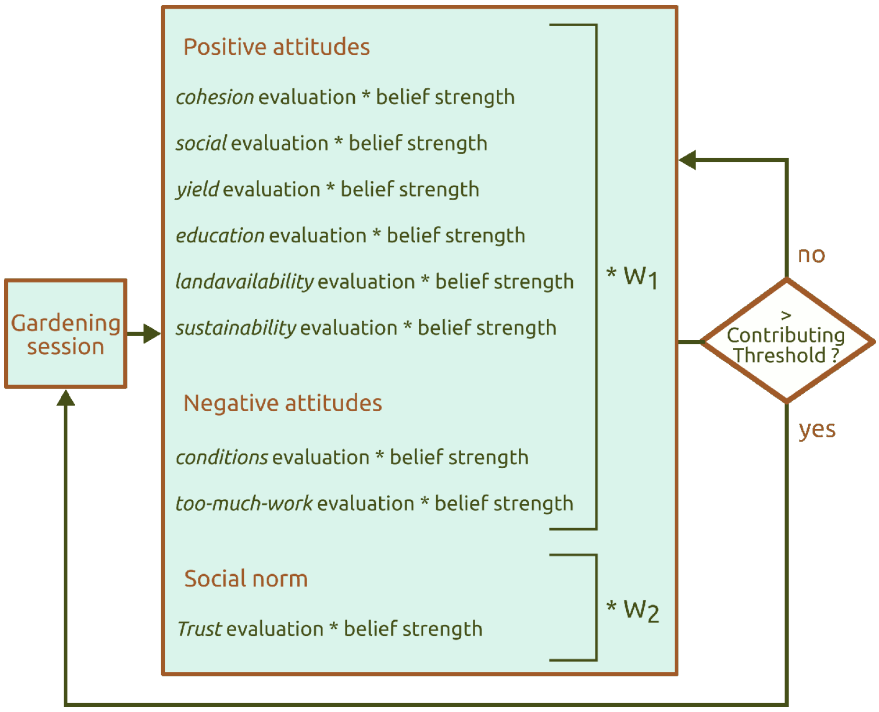

Figure A.2 – Evaluation of the behavioural intention to contribute

attitudes and 1 social norm, which gives us a maximum total value of our intention formula equal to 8. The weights ratio is therefore:

$$7 * W_1 + 1 * W_2 = 8$$

$$W_1 = \frac{8 - W_2}{7}$$

The range of values for W_2 is determined through sensitivity analysis around the ratio W_2/W_1, based on the study of Eves, Hoppé and McLaren, 2003. This behavioural study is built on the Theory of Planned Behaviour, which is similar to the Theory of Reasoned Action but with the additional component of perceived behavioural control. They determined the weight of attitudes subjective norm by asking 250 people how likely they would perform certain leisure activities in the near future with several scales of 7 possible answers, and how frequently they engaged in such activities in the previous month. The authors thus calculate a numerical value for attitudes and subjective norm. They thus found a values of 5.11 and 5.08, respectively for W_2 and W_1, in the case of participation in team-sports. Gardening is also a collective activity, and we consider a range for W_2 comprised between 0.5 and 4 in order to explore the implications of higher weights of subjective norm. This gives a ratio W_2/W_1 ranging from 0.47 to 7.

Each agent can assess the behaviour of a certain number of other agents (whether they violated a rule, during contribution on a gardening session). This is parameterised by $VolunteerToFullySee$.

Learning

At the end of each volunteering session, *gardeners* evaluate their beliefs according to what happened in the garden. The values of belief evaluation e_x for all beliefs are therefore updated individually for each *gardener*, with the formula below.

$$e_{belief} = \frac{\sum_{i=1}^{n} e_{belief,gardeningSession_i}}{AmountOfVisits}$$

with:

$e_{belief,gardeningSession_i}$	The evaluation of a belief on gardening session i
$AmountOfVisits$	The number of times that an agent chose to become a *gardener*

- Yield – When the *gardener* receives a fair share of yield, the belief is evaluated positively. When the gardener does not receive a fair share of yield while it should, the belief is evaluated negatively.
- Social development or cohesion – It is assessed by the density of interpersonal relationships in a group (Friedkin, 2004).

$$CurrentCohesion = \frac{PresentTies}{N_{gardeners}}$$

with:

$PresentTies$	Amount of relationships an individual has with the other present *gardeners*
$N_{gardeners}$	Number of *gardeners* present

- Some beliefs are always evaluated positively: enjoy gardening, environmental sustainability, cultural practices (requiring at least one other participant on the garden) and land accessibility, when there are no fences.
- Education – Learning happens on the garden (Duchemin, Wegmuller and Legault, 2009; Saldivar-Tanaka and Krasny, 2004). Following the concept of learning curves, the more an individual learns, the more time and effort it takes to gain more expertise. Therefore, we assume the belief for education starts at 1, and then exponentially decays until 0. The maximum amount of visits after which an agent's belief for education is 0, is an input parameter. Each agent randomly gets assigned a value between 0 and that input parameter.
- Too-much-work – More tasks require more people. We use a parameter, specific to the garden: the amount of gardeners necessary on a session to sufficiently maintain the garden. Only below this threshold is the session evaluated negatively.

- Uncomfortable conditions – We use a fixed percentage of days with uncomfortable conditions, as provided by the garden leaders of Vredestuin (Netherlands). At the beginning of each session, the agents are given a random number between 0 and 100. If this number is below the percentage above, the conditions are bad and $e_{conditions}$ has the value 1. Otherwise, it has the value 0.

- Social norm / need of contribution – This evaluation is based on trust and indirect reciprocity. Indirect reciprocity is the belief strength for trust, and gets assigned the highest value, 1. Trust is updated per *gardener* each round, and becomes the belief evaluation. A gardener can either collaborate or defect during an encounter. Trustworthiness of the group is assessed across encounters with all *gardeners*. We assume that the reputation of the group directly impacts the individual's trust.

$$Reputation = \frac{p}{n}$$

with:

p	number of cooperative actions (encounters with someone who is not seen violating a rule or in a bad conflict)
n	number of encounters with others in total

- Probability of rule violation – Seeing others violating rules increases one's probability of violating rules (Ostrom, 2005; Anderies, Janssen and Schlager, 2016). The initial value of $ProbabilityRuleviolation$ is determined by the set value of $DPglobalprobabilityruleviolation$ (Table A.2).

$$ProbabilityRuleviolation = \frac{AmountOfSeenViolationsWithoutSanctions}{TotalEncounters}$$

with:

$ProbabilityRuleviolation$	probability for an agent to violate a rule during gardening
$AmountOfSeenViolationsWithoutSanctions$	amount of violations without sanctions an agent saw
$TotalEncounters$	total encounters an agent experienced

Our assumptions are summarised in Appendix A.2 (Table A.9).

Interaction and Collective

Interactions only occur between the *gardeners* agents, the time of the gardening session. This is open to agents that show a sufficiently high intention to participate (see above), and that are not suspended because of rule violations and the way in which the institutions are implemented (Ostrom Design Principles).

Heterogeneity

Agents are heterogeneous with respect to their belief strengths and homogeneous with respect to all other parameters.

A.1.3 Details

The model has been built in Netlogo. The code to replicate our model is stored on the CoMSES Computational Model Library under the following url : [link updated after that this ODD is added to the repository]

Implementation Details

Open NetLogo software. Go to File>Open... [select urbgarden.nlogo]. Select Tools > BehaviorSpace. Choose experiment [ExpFinal] and click Run.

Initialisation

The model starts with giving fixed belief strengths values to agents, according to the general characteristics of an urban community gardening community. All agents start with a belief evaluation of 1 (maximum) for education, land availability, enjoying gardening, sustainability and reciprocity (or trust). They start with a belief evaluation of 0 (minimum) for cohesion. Belief evaluation values evolve over time, with the learning processes described above.

A.2 Additional data

Motivations	Justification
Social development	The activities of gardening foster a social environment that enhances the activity itself by providing participants with a social network that becomes important particularly when they are feeling isolated (Duchemin, Wegmuller and Legault, 2009).
Social cohesion	People feel connected to each other (Kam and Needham, 2003); participants form relationships with one another and offer mutual help, which does not occur in individual gardening systems (Veen et al., 2016)
Consuming fresh food	It depends on the stage of the garden, biophysical variables but also on the active institutions and the participants' behaviour (Duchemin, Wegmuller and Legault, 2009); it is a possible source of conflict when it comes to (fair) yield taking (Butler, 2013; Charles, 2012) or even stolen yield from non-participants (Ruggeri, Mazzocchi and Corsi, 2016)
Saving/making money	Eating or selling own garden production is a current practice (Guitart, Pickering and Byrne, 2012; Patel, 1991).
Improving health	Improving a diet, increased exercise and involvement in nature (Guitart, Pickering and Byrne, 2012)
Enjoying nature	This point is debatable when it comes to man-made gardens ; however, this belief is intended as the well-being provided by being outdoor (Rogge, Theesfeld and Strassner, 2018).
Education	Specific education about gardening (Drake and Lawson, 2015) or more general: science, nutrition and environmental education (Guitart, Pickering and Byrne, 2012) ; indirect social education can also be gained by simply participating (Duchemin, Wegmuller and Legault, 2009)
Enhancing cultural practices	Cultural practices are broadly defined as the knowledge of 'what to do, when and where', and how to interact within a particular culture; in the urban gardening context, this can be translated to integration, particularly for foreign immigrants; in our work, this belief is satisfied by the presence of others in the garden (Rogge, Theesfeld and Strassner, 2018).
Increasing land accessibility	This belief reflects the very common issue of claim to the urban public space, when its accessibility is reduced due to land developments and privatisations (Huron, 2015; Williams, 2018). Urban community gardens also add the idea of increasing the share of green spaces in the city (Schmelzkopf, 2002). This belief can be diminished by the presence of group or garden boundaries (Milburn and Vail, 2010).
Environmental sustainability	Green spaces highly contribute to urban sustainability, such as microclimate regulation, water runoff, pollution mitigation, water filtering or biodiversity (Colding and Barthel, 2013, (Wolch, Byrne and Newell, 2014), to which community gardening practices (permaculture, organic farming or conventional) contribute. However, few studies, such as Rogge, Theesfeld and Strassner, 2018 have actually evaluated this impact. We translate this belief as the participants' belief of acting positively towards the environment.
Enhancing spiritual practice	This relates to the connection to nature achieved through gardening; it acts as meditation, a way to release tensions and developing spirituality (Kingsley, Townsend and Henderson-Wilson, 2009), and engaging in more caring connections with other people (Okvat and Zautra, 2011).
Social norm	Trust in contributing to the community, which is higher when other users are reciprocating (Chalise, 2015), more likely occurs in smaller groups (Poteete and Ostrom, 2004). Reciprocity can be measured in two ways: as a norm in the group and as a variable between two agents. Because we are looking at the relation of an individual with the group, reciprocity as a norm is more applicable. The higher this societal reciprocity, the more one expects all agents to reciprocate (Mui, 2002); the group's overall reputation is an important factor when deciding whether or not to contribute at the individual level.
Amount of work	It is the amount of activities leading to a desired quality ; *gardeners* leave if maintaining the garden requires more effort than they expected (Chalise, 2015), which can happen when there are not enough gardeners.
Uncomfortable conditions	We consider here physical conditions, such as bad weather, limiting the willingness to participate (Vercauteren et al., 2013; Drake and Lawson, 2015). Other conditions, such as the feeling of not being welcome, are not considered in this work.

Table A.5 – Motivations for urban community gardening, drivers of the beliefs variables of the Theory of Reasoned Action in our model

Question	Gandhi Tuin	Vredestuin
Are there plot boundaries?	Yes	No
Are there group boundaries?	No	No
When a membership structure is active, people can try the garden 3 times before they have to become a member	/	/
Are there rules towards balanced benefits/costs?	no	no
Are decisions taken collectively?	yes	no *
Are there conflict-resolution mechanisms?	yes, but poorly executed	no, but no conflicts arose yet
How often does a large conflict, which could harm the volunteer's trust in a collaborative community, occur?	150 to 200 sessions	/
Without effective conflict resolution mechanisms in place, what is the probability for such a large conflict to harm the trust of an individual volunteer ?	1/2	1/4
Is there monitoring in place?	no	no
Are there graduated sanctions?	yes	no
What is the probability that someone is punished (told off) when violating a rule?	between 0.25 and 0.6	/
Is your initiative officially recognised and allowed?	yes	yes
How many other volunteers can a volunteer assess the contribution of during a gardening session?	3-4	3-4
What is the chance for an individual to violate a rule during a session (such as not tidying the kitchen, or bringing a dog)?	1/30	1/30
What is the minimal amount of volunteers necessary for proper maintenance of garden?	10	10
How many core members are there?	4	20-25
What is the size of the volunteer pool?	>1000	>1000
What is the fraction of sessions with uncomfortable conditions?	1/4	1/4
What is the fraction of sessions with available yield?	1	1
What is the fraction of sessions when yield gets stolen while there are no boundaries around the garden?	/	1/100
After how much time does a volunteer stop learning in the garden?	/	1.5 year

Table A.6 – Field questions to the garden leaders (Netherlands cases)

IAD component	Output variables	Input parameters	Data source
biophysical conditions	product availability	chance of uncomfortable conditions chance of available product	Gandhi Tuin
community attributes		beliefs types number of initiators pool of potential volunteers beliefs strength (all agents) chance of bonding with others age of initiative (maximum) interaction rate	German database, Gandhi Tuin, Vredestuin, literature, case-study
rules-in-use *		Ostrom Design Principles (adapted)	literature, Gandhi Tuin, Vredestuin
action situations		tasks	Gandhi Tuin
outcomes	beliefs evaluation social ties good encounters gardening duration	conflict rate	Gandhi Tuin

* quantitative values are only used during validation

Table A.7 – Data sources

Belief label	Proportion of gardeners concerned (%)
social	30
cohesion	90
yield	60
enjoyinggarden	80
sustainability	60
education	50
landavailability	30
conditions	60
toomuchwork	20

Table A.8 – Motivations for community gardening, from the social sustainability survey (German database)

Assumption	Comment
The impression of being helpful in the garden increases the behavioural intention to contribute as well	
Initiators usually stay committed to maintaining the garden longer than regular volunteers	
Gardeners only negatively evaluate yield taking when their fair share of yield is unavailable	
Enjoy gardening, environmental sustainability, cultural practices (requiring at least 1 other participant on the garden) and land accessibility (when no garden boundaries) are always evaluated positively	
After 100 to 400 sessions, educational purpose is not a relevant attitude anymore	Varying range
Agents can be told off 2 to 40 times before being suspended	
An agent is suspended for 5 to 20 sessions	No cases with suspensions were noted in the examples from Germany
After having been suspended, an agent can be told off 2 to 10 times before being denied access	
A conflict can harm trust up to a 100 times worse than seeing someone violate a rule	
Taking too much yield means taking up to 5 times the fair amount	5 could be too much
The probability for rule violation during gardening is between 0.01 and 0.9	Varying range
When violating a rule, the probability of being sanctioned is between 0.01 and 0.9	Varying range
Membership can last 13 to 52 weeks	
The perception of Too-much-work is a barrier to participation	Confirmed by (Chalise, 2015)

Table A.9 – Additional model assumptions