SAM4SN (Spread of Awareness Model for Social Norms) ODD

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1. PURPOSE

The model simulates the micro-behaviors of individuals about the consumption of a limited resource. The *overall goal* is to observe at a macro-level how *a social norm emerges* about sustainability or unsustainability.
The system simulates how awareness spreads in a community of agents, how the dynamic of such awareness impacts on individual reduction goals and on resource consumption, how the availability of smart metering functions can impact on such mechanisms. The awareness of individual agents is defined by the influence of influent agents in the surrounding, by a general perception of environmental aptitude of the community, by a social reinforcement about the concordance of individual and collective consumption trends when social norms became true.
There is an overall reduction objective that the system can reach or not. The reaching of such objective corresponds to a sustainable consumption or, in short, to sustainability.
The *agents* are households. Agents don't move and their position is always the same. This choice of non mobile agent is driven by the consideration that agents are sharing the infrastructure where are available the smart metering functions, that are a part of the infrastructure where households live.
Such smart metering functions are:

- In home metering;
- Individual feedback about the individual own consumption of the limited resource;
- Information about green leaders and their low consumption profile, that are taken as reference;
- Personalized advice for consumption reduction.

The *resource* which consumption has to be reduced is **energy**, but could be water as well. Such resource is available on the model system scale without limitation. It has to be reduced for environmental sustainability related issues, but is perceived by agents without availability limitation. The size of the community is such that overuse does not lead to market price increasing. That means the people detracting environmental issue with an unaware environmental behavior have not price mechanism to counter their overconsumption.
Green people, i.e. people with high awareness, can decide to limit their privacy rights about own consumption information and accept to share with the community their own consumption data. Such voluntary mechanism of "privacy versus reputation" is an emerging trend in green communities, where to become a *green opinion leader* is a goal to reach (Griskevicius et al., 2010; Wesley Shultz et al., 2007). Awareness is a feature of each agent. It changes by interaction with neighbors in a given radius, by influence of a green aptitude of a community and by a mechanism of social reinforce. In other words awareness changes by local interactions and by a global social influences.
Each agent belongs to a type, according to his awareness level. Because the typing defines the consumption patterns and the potential reduction patterns, the awareness spread leads to behavioral changes of agents in resource consumption. When the above mentioned smart metering functions empower agents allowing them the ability to measure the critical resource, to have an individual feedback about his own consumptions, to have a comparison with other agents and giving him suggestions about resource consumption reduction, the consumption patterns changes.
The system identifies both individual consumption trends (i.e. reduction versus increment) and overall consumption trend.
The agents know the global trend about the resource consumption. When their behaviors are concordant with the general consumption trends the agents "reinforce" their beliefs and such social reinforcement in round changes their awareness. By changing awareness an agent can change the type he belongs to and such type determines new consumption/reduction patterns.
An empirical definition of social norm widely used in the research area of global environmental challenge (Kinzig et al., 2013) said that when enough people or certain people adopt these norms, there can be a tipping point (Levin et al., 1998; Gladwell, 2000) such that the proenvironment norms become widely shared and environmentally friendly behaviors become pervasive.
This tipping point may be as low as 10% of the population, if the minority is "consistent and inflexible" in its beliefs (Xie et al., 2011).

According with the above mentioned researches we define a *tipping point for a social norm* when the number of committed agents (actives and evangelists or blinds, i.e. the most aware and influent agents) adopting a behavior is at least the 10% of the population, their consumption trend is concordant with the overall consumption trend and the number of agents with concordant reinforcement is greater than the number of agents with concordant reinforcement of opposite sign.
When a global reduction goal is someway established (it can be a reduction program played by a local government or an information campaign) the system reaches such a goal several runs after such the tipping point is defined. We can say that a social norm toward sustainability emerges and we call it sustainability social norm. The ABM aims to study the relationship between the tipping point for a sustainability social norm and the goal reaching.
The smart metering functions empowers agents with measuring, individual feedback, comparison with others and availability of practical suggestions about green behaviors. Such smart functions play a role toward sustainable behaviors. If they are made available in already sustainable contexts they short the time needed to reach the reduction goal.
When they are introduced in a not sustainable context, they can contribute to change the trend of collective behaviors and to allow the emergence of a sustainable behavior.

2. ENTITIES, STATE VARIABLE AND SCALE

2.1 ENTITIES

The entities of the models (i.e. the agents) are people involved in the consumption of one limited or critical resource. Each agent is a household. There are five types of entity: blinds, indifferents, spectators, actives, and evangelists.

- Blind agents have negative environmental behaviors. As detractors of the need to prevent an overuse of the resource, their environmental sustainability goals are negative. Their consumption increases and they are mocking other green agents (i.e. actives or evangelists). Their awareness level is very low and they have significant negative influence on neighbors. They represent a constraint against the reaching of tipping points. Usually they don't increase enough their awareness to change type. They became more aware only if a significant part of their neighborhood is green and if social norms became really significant. They are responsive only to negative social reinforcement. Their consumption patterns are independent of the smart metering functions that empower others types of agents. They are quasi-committed agents.

- Indifferent agents are neutral about the environmental sustainability goal. They usually compose the larger group in the initial situation. Their consumptions are constants, with only some possible small reduction under very specific conditions, i.e. when they are supplied with combination of smart metering functions. They don't have influence on neighbors, but are influenced by them. They are responsive to positive or negative social reinforcement.

- Spectator agents are quite stable in their behavior, but are open to listen and to observe their neighbor's behaviors. Under some combinations of smart metering functions they can have reduction goal. They do not have influence on their neighbors, but are influenced by them. They are responsive to positive or negative social reinforcement.

- Active agents are green people, engaged into reduction of resource consumption. They have a significant positive influence on neighbors. They allow other people to look at their own data in order to show beneficial behavior results and to share reduction goal with others. They are responsive to positive social reinforcement. They are quasi-committed agents.

- Evangelist agents are green activists that, in addition to active agents, are able to supply new resource into the system by producing the resource, for example when they produce renewable energy at a local scale with solar panels. They are prosumers. They have a strong influence on neighbors, but are not influenced by them. Their awareness never decreases: an evangelist is forever. They are responsive to positive social reinforcement. They are committed agents.

The agents belong to one and only one type at time. Each type of agent has a shape and a color, as described below in Table 1:

TYPE OF AGENT	SHAPE	COLOR
Blind	Cross	Red
Indifferent	Triangle	Brown
Spectator	Square	Yellow
Active	Pentagon	Green
Evangelist	Circle	Blue

Table 1 - shape and colors of agent types

2.1.1 PARAMETERS

Main parameters of the ABM are:

- The maximum number of each type of agent.
- The radius of influence of neighbors in awareness spread.
- The threshold to type shift.
- The reduction-goal coefficient of every type of agent.
- The reduction rate for every type of agent.
- The parameters to set the sustainability social norms.
- The influence parameters for the social reinforcements.

In Appendix the complete list of parameters.

2.2 STATE VARIABLES

Within the agent-based component, the ABM has two hierarchical levels: agents, representing households, and subclasses of agent with different environmental aptitude and behaviors.
Micro behaviors of different agent types have been described in section 2.1.
State variables of the agents include the location of the agent and the availability of smart metering functions in such a location.
Each agent belongs to a type, according with his awareness level. Agent can be or not be supplied by smart functions of metering.
Each agent has a goal about the limited or critical resource to be reduced or optimized. Each agent reaches his individual goal at a given rate.
Evangelists and actives compose a green cluster. The green fraction is the ratio of green agent and the whole number of agents.

2.2.1 Globals variables

Each run the number of agents belonging to a type can change, while total number of agents is constant. Main global variables are:

- the current number of blinds
- the current number of indifferents
- the current number of spectators
- the current number of actives
- the current number of evangelists
- the resource consumption
- the resource production
- the resource use level
- *the delta-resource, i.e. the relative variation of the resource*
- *a "sustainability" tipping point*
- *a "unsustainability" tipping point*
- *the green fraction, i.e. the percentage of active and evangelist over the whole population*

2.2.2 Agent variables

A state variable of agents is the `awareness`, a cardinal numerical quantity.
Other agent variables are:

- `own resource consumption`
- `resource reduction goal`,
- `own resource production`

Different types of agent have different awareness; such awareness is a continuous variable, as showed in Figure 20.
Other agent variables are:

- `old-own-resource-consumption`
- `delta-individual-consumption`
- `social reinforcement`
- `metering`
- `feedback`
- `comparison`
- `suggestion`

Another feature an agent is his green competition index that is the rate with an agent try to reaches the reference consumption of the agent with the minimal consumption inside the overall system (see section 7.3.3 Fig.6).

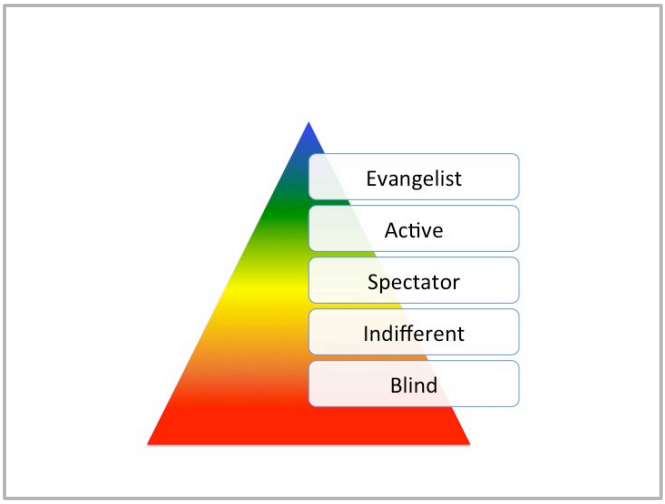

Figure 1 – Agent types and awareness levels

2.3 TEMPORAL EXTENT

The time unit is the tick. One time step corresponds to a day and the time horizon is *of one-two years at maximum* (no limits have been setup).

2.4 SPATIAL DIMENSION

The community is composed of agents. On a patch, representing the location (address) of one household, there can be one and only one agent. The maximum number of agents is smaller than the maximum number of patches. The dimension of the world is a square of 33 x 33 cells. Only one agent can occupy each cell. The maximum number of the agents is 800.
The spatial extent could be a portion of a city or of a geographic area where smart metering functions are all (or a subset) available is the modeled world.
In a real application case of SAM4SN model, the household positions would be given as input data, as well as the enabling smart metering functions.
The only random variable that is used is to assign the initial position of the agents.

3. PROCESS OVERVIEW AND SCHEDULING

3.1 PROCESS

The main procedure calls several sub-procedures:

- **Update of awareness**
- **Update of types**
- **Update of reduction goals**
- **Update of consumption**
- **Social Reinforcement**

When reduction goal is achieved the system stops.
Each agent looks around himself to verify how many neighbors and of what type there are in the given radius. According to specific conditions he changes his awareness level. The rules to update awareness are different for each agent types, as described in detail in section 7.1.
Awareness is modified on the basis of influence of neighbors in a given radius, as described in section 7.1. **The radius of influence is 2**, for an overall spatial dimension of 33x33 cells. The most influent agents, the evangelists, have a double influence radius, i.e. 4.
The awareness is affected also by a perception of the overall "pro environment" aptitude. For some types of agents - spectators and actives - also a given fraction of green neighbors on the whole population can increase awareness. This represents a kind of general community based social pressure that leads to an additional increase of awareness.
We can say that if the 30% of the whole population is composed by green agents (i.e. active or evangelist) this light-green percentage will increase the awareness of a spectator, while "to be impressive for active" agents such green percentage must be stronger, i.e. the 80% of the whole population (see 7.1 for details).
For blind agents, which are strongly against changing their position of negation about environmental issues, only very green neighbors can change their awareness and only if no other blind agents are on the neighbors.
The awareness depends also from the social pressure by a parameter that measures the *reinforcement* that an agent receive from the comparison between his own consumption trend and the overall one; when such trend is concordant the agent is reinforced in his believes and desire. Such reinforcement impact on awareness. When the individual behavior tends toward a sustainable consumption and the overall trend is the same or better the reinforcement is positive and the awareness increases.
After the *upgrade of awareness* of each agent, when agent awareness is beyond a given threshold the system *updates* the membership of the agents to a type. Each agent has an own consumption pattern. Such pattern depends on the type of agent and on the availability of smart metering functions. Such smart metering function are the enablers to make agents able to measure the resource that he consumes, to have feedback on his individual consumption, to compare his own consumption with other agents, namely the agent with the lowest consumption that will act as a reference, and some suggestion to reduce his own consumption.
Such abilities correspond to general abilities that can be enabled by ICT-based smart metering functions, but that can be enabled also otherwise. For example a behavior change program can enable them by the help of people acting as supporter or testimonial.
Each type of agent has a reduction goal that drives the consumption pattern, as described below in section 7.3 from (7) to (19).
In general the own resource consumption of each agent is given by the difference of the previous consumption less the reduction goal, as described in (1).
The reduction goal depends also on the smart metering function of "metering" and of "comparison" (see from (7) to (11) and Figure 3).
Each type of agent has a different consumption patterns and such consumption is updated on the basis of the individual reduction goal. Both are updated each run.
The overall consumption is evaluated on the basis of the individual consumption and also on the resource production. Production of the resource is given by individual household renewable energy production.

3.2 SCHEDULING

In the main procedure the state variables are assigned a new value when the new value is stored until all agents have executed the process, and then all are updated at once (synchronous updating). Time is simply represented by using time steps: assuming that time moves forward in chunks. When the overall reduction goal (as given by the user) is achieved, the system stops.

4. DESIGN CONCEPTS

4.1 BASIC PRINCIPLES

The behavioral changes needed to reach the overall goal of reducing the consumption of a resource are driven by the awareness of agents involved in. Such agent awareness can change interacting with neighbors. The awareness level defines the own resource consumption of the types of agent.
Special agents, so-called "blinds", are not genuine about environmental issues; when they are neighbors of another agent they have a negative effect and can decrease the awareness of the neighbors. The hypothesis underlying the model is that awareness spread process depends on direct interaction of each agent with immediate neighbors. Only spectator and active agents are influenced also by a global perception on how many green agents are in the world and this has a kind of social influence on aware agents, further increasing their awareness level.
Agents interact between them by proximity. According to the number and the type of neighbors in a given radius each agent changes his awareness. When the awareness reaches a given value (threshold), the agent changes the type he belongs to. There are several thresholds. The main hypothesis of this model is that the influence of neighbors depends on their type and for each type the awareness changes are different. The threshold to change the type to belong is different from each agent type. Greener agents have a higher threshold to shift to a more aware type, but they never decrease their awareness and their awareness increase faster than in other less green agents. There is a kind of cascade effect, limited only by the influence sphere of the agents.

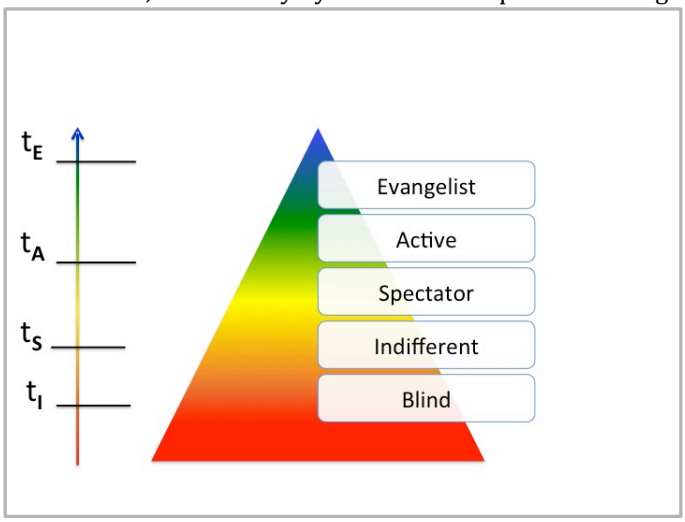

Figure 2 – Multiple Thresholds

Threshold values to switch from one type to another are:

$t_{Indifferent}$ = 8 (the threshold from blind to indifferent)
$t_{Spectator}$ = 16 (the threshold from indifferent to spectator)
t_{Active} = 100 (the threshold from spectator to active)
$t_{Evangelist}$= 2000 (the threshold from active to evangelist)

As described in Chapter 6, each type of agent has different awareness as well consumption reduction patterns.
Examples have been supplied in Table 1 of electricity saving actions that can be performed by five types of agents. Evangelist agents are activists and are also able to addict new resources into the systems. In the case of energy they are energy *prosumers*.
The own resource consumption (orc_i) of each agent depends on the type of agents and on tits reduction goal.
In general at time t is given by:

$$(1)\ \mathbf{orc_{i(t)} = orc_{i(t-1)} - rg_{i(t)} * W_i} \qquad \text{with i: \{blind,indifferent,spectator,active,evangelist \}}$$

The own resource consumption (orc_i) of each agent is the difference between the previous resource consumption and the individual reduction goal, multiplied by the speed to reach it.
The availability of smart metering functions allows several possible scenarios.
The reduction goal (rg_i) is different for type of agent and depends on the availability of the smart metering function of the feature of agents to perform metering and comparison.

Such reduction goal is reached with a given rate W_i that depends on the smart metering functions of individual feedback and suggestions.
The proposed ABM aims to relate such consumption pattern to the availability of specific functions of smart metering systems. A basic assumption is that consumption behaviors are driven by awareness, but there are some empowering factors, like the availability of smart metering functions.
Availability of smart metering function enables the agent to know the own consumption of the resource and to identify an individual reduction goal.
If such metering function is coupled with the feedback function, the reduction goals are faster to reach.
The simultaneous availability of metering and comparison functions enables agents to identify which is the more "green resource consumer" and to set their own reduction goal to a shared goal that is given by the minimum consumption in the community, according a competition index (see Section 7.3.3 and Figure 4 for details).
When metering, feedback and tips & tricks functions are available all together, the rate to reach the reduction goal is the highest.
There is a social reinforcement function depending on the comparison between the global trend of consumption and the individual trend of consumption. When the relative global trend is concordant and higher in absolute value than the individual one, the reinforcement variable is set to 1 when both are negative (i.e. a reduction is the trend) or is set to -1 when both are negative (i.e. an increase of consumption is the trend)(see par.7.5 for details).
Awareness depends on such reinforce, because its value is added to the awareness level. When the global trend and the individual one are of reduction, and the first is higher than the second in absolute value, the awareness increases.
When the global trend and the individual one are of increase, and the first is higher than the second in absolute value, the awareness decreases.

4.2 EMERGENCE

Sustainable or unsustainable scenarios of consumption emerge on the basis of initial conditions about number of types of agent and smart metering functions set up. Some initial scenario configurations lead to decrease resource consumption, i.e. to invert the initial trends.
A Sustainability social norm can emerge. When it emerges usually is persistent.
The overall reduction goal is reached some runs after the sustainability social norm is established.
Empowering the agents with function of metering, individual feedback, comparison with other agents and suggestion to improve its behavior allow to reaches the reduction goal.

4.3 INTERACTION

There is a direct interaction by neighbors and by the global percentage of green agents.
The belonging drives the communication to a given breed, because the (implicit) assumption is that awareness level is related to a similar communication level, able to involve neighbors (more aware agents are more communicative).

4.4 STOCHASTICITY

The initial position of each agent is choose randomly, under the only condition of only one turtle per patch: each agent represents an household.

5. INITIALISATION

The initial state of the model world, i.e. at time t = 0, depends parameters that are supplied by user-interface: the number of agents of each type, the available metering functions, the global resource consumption value, and the overall reduction goal value.

5.1 USER DEFINED VALUES

The initialization values supplied by the user are the following state variables:

- The initial numbers of different types of agents (range is between 0 and maximum value) are supplied by a slider on the Interface:

- `N-blind`
- `N-indifferent`
- `N-spectator`
- `N-active`
- `N-Evangelist`

The maximum number of agents is different by type:

Max number of Blinds = 50
Max number of Indifferent = 300
Max number of Spectators = 300
Max number of active = 200
Max number of evangelist = 50

The total number of agents is constant and is given by the sum of the number of different types**.** *The total number of agents is a bit smaller than the total number of patches of the world.* Most influent agents, i.e. blinds and evangelists, are in general less than other types of agent. Are also supplied by the sliders on the Interface:

- The `Initial global resource consumption` (its value is between 0 and 50000).

- The `overall reduction goal` is expressed in percentage (Its value is between 0 and 100).

- The available smart metering functions are setup by switchers. User defines which combination of metering function is available, by a mix of ON-OFF functions:

- `metering-availability`
- `individual-feedback`
- `neighbor-comparison`
- `Tips&Tricks`

- The `seed` parameter is supplied by the user. It is assigned to the random-seed function (used to allocate agents on free cells in the initialization phase)

- `Sustainability-tipping-point` and `unsustainability-tipping-point` are set up to false.

5.2 AGENT CREATION AND INITIALIZATION

Shapes and colors of each type of agent are set up according to Table 1.

Agents of the different types are created. They are randomly allocated on a cell: the `seed` value is used to find a position. When this cell is not empty, the system looks for another cell and so on.
On each cell there can be only one agent and the agents do not move around.

The `initial awareness values` of the agents are different for each type and correspond to the minimum value of the type.
The minimum awareness level is:

Blind =0
Indifferent = 8
Spectators = 16
Active =100
Evangelist = 2000

- The `initial own resource consumption` (i.e. the initial individual consumption of the limited resource) is different by type. It is evaluated on the basis of the idea that an agent of type *i* consumes C_i times more than an evangelist agent – the most aware and less consuming type of agent - where C_i:

C_{active} = 1.1

$C_{spectator}$ = 1.2
$C_{indifferent}$ = 1.3
C_{blind} = 1.4

This assumption corresponds to a consumption of a blind agent of 40% more than an evangelist, and so on.
To assign an initial value to iorc we need to multiply such coefficient for the elementary unit of consumption. An elementary unit of consumption (euc) is defined, on the basis of the Initial global resource consumption (*Igrc*) value, as:

(2) $euc = \frac{Igrc}{\sum_i (N_i * C_i)}$

with i: $\{blind, indifferent, spectator, active, evangelist\}$

The initial-own-resource-consumption ($iorc_i$) for the different types of agents is given by:

(3) $iorc_i = euc * C_i$

- The `individual reduction goal` of each types is set to 0:

(4) $rg_i = 0$

- The `own resource consumption` is set to the initial-individual-resource-consumption.
- The `reinforce` agent variable is set to 0.
- The `individual resource production` is an attribute of evangelist agents. It is setup to the 1% of his initial-own-resource-consumption.
- The agent variables related to the empowering of agents by enabling the ability of metering, feedback, comparison and suggestion are setup according to user choice about smart metering function availability.
  - `Metering` is set to TRUE if metering-availability is switched ON
  - `Feedback` is set to TRUE if individual-feedback is switched ON
  - `Comparison` is set to TRUE if neighbor-comparison is switched ON
  - `Suggestion` is set to TRUE Tips&Tricks is switched ON

6. INPUT DATA

At the current prototyping stage the model does not use input from external sources[1]. In further developments and use of the model on real cases such data will be features of the specific infrastructure of a specific geographic area.

7. SUBMODELS

7.1 UPDATE OF AWARENESS

At each run the awareness of the agents is updated according to the neighbors influence. The awareness diffusion mechanism is driven by the principle that the more influential neighbors are those at the two boundary of awareness scale: evangelist and active (at the top) and blind (at the bottom). We call evangelist and active agents "green agents".
The awareness changes each run, as a variation of the previous run.
For each type *i* of agents (i.e.: blind, indifferent, spectator, active and evangelist) the awareness at a given time t is given by:

(5) $a_{it} = a_{i(t-1)} + \Delta a_i$

$a_{i0} = k_{i0}$

where, for every *i*:

(6) $\Delta a_i = \alpha_i v_{gr} + \varepsilon_i v_e + \beta_i v_b + \gamma_i n_{gr30} + \delta_i n_{gr80} + sr_i$

and

α_i= awareness **local** increment coefficient1 (for agent of type *i)*

[1] Real smart metering availability for a given geographic area will be supplied as system input.

ε_i =awareness **local** increment coefficient2 (for agent of type *i)*
β_i= awareness **local** decrement coefficient (for agent of type *i)*
Υ_i= awareness **global** light-green increment coefficient (for agent of type *i)*
δ_i =awareness **global** strong-green increment coefficient (for agent of type *i)*

	$i = blind$	$i = indifferent$	$i = spectator$	$i = active$
α_i	1	1	1	0
ε_i	0	0	0	2
β_i	-2	-1	-1	0
γ_i	0	0	1	0
δ_i	0	0	0	1

Table 2 – Awareness local and global coefficients for type of agents

The first two terms are related to local influence mechanisms, while the third and fourth are related to an overall influence mechanism. The fifth term is related to reinforcement in belief of the agent.
Evangelists are top-level environmentally aware agents, and their awareness cannot decrease; they never became a less aware type of agent. So is meaningless to further increase the awareness of an evangelist agent. Evangelists are the most influent agents and their influence radius is double than the other type of agents.
Referring to (6) v_{gr}, v_e v_b, $n_{gr30\text{-}80}$, n_{gr80} are dummy variables:

*v_{gr} = 1 if there is at least one active agent in the influence radius or an evangelist in influence radius * 2*
*v_e = 1 if there is at least one evangelist agent in influence radius * 2*
v_b = 1 if there is at least one blind in the influence radius
n_{gr30} =1 if the percentage of green agents(i.e. active or evangelist) is more than 30% of the whole population
n_{gr80}= 1 if the percentage of green agents is more than 80% of the whole population

k_{i0} is the setup value of awareness and is a constant for each type of agents (5):

	$i = blind$	$i = indifferent$	$i = spectator$	$i = active$	$i = evangelist$
k_{i0}	0	8	16	100	2000

Table 3 – Set up constants for type of agents

Third and fourth terms depend on the green agentset.
Green agentset is composed by active and evangelist agents. When its value is more than 30% of the whole population, spectator awareness increases, under a light global influence represented by the "light green" coefficient. When the green agentset is composed by more than 80% of the whole population, active awareness increases, under a strong global influence, represented by the "strong green" coefficient.
The term *sr* in expression (6) is the social reinforcement of the agent about his individual behavior and depends on the comparison between the global resource consumption and its own consumption trend; r can be +1, 0 or -1 (see section 7.7.5). It affects awareness level.

7.2 UPTADE OF TYPES

An agent changes his type when his awareness passes a given threshold (see Fig. 2).

7.3 REDUCTION GOALS

As observed in (1) the individual reduction goal varies according to agent type.
For blind agents is independent from the availability of any facilitating conditions, because blind agents want to increase its consumption despite any evidence of need to reduce the resource consumption.

(7) $\mathbf{rg_{blind} = iorc_{blind} * K_{blind}}$

where K_{blind}= -0.01.

The reduction goal is negative. The blind agents increase of 1% of its initial-consumption (iorc) the own consumption.
For the other types of agents the individual reduction goal depends of the availability of two smart metering functions:

- `metering-availability`
- `neighbor-comparison`

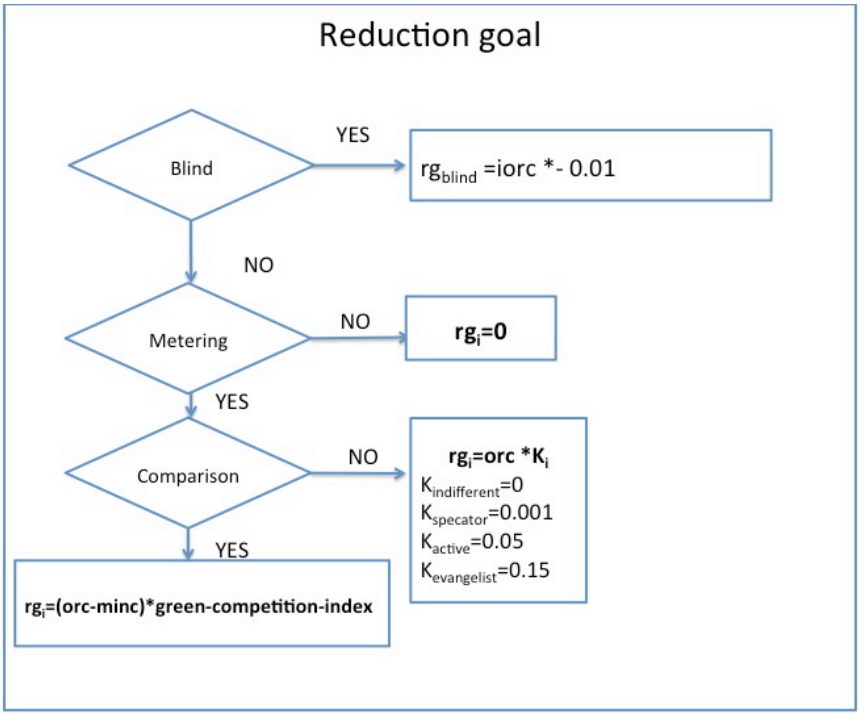

Figure 3 - Reduction goals of agents

7.3.1 No metering

If no metering function is available, the reduction goal is zero and the consumption is constant for every type of agent, apart blind agents that increases their consumption (see above).

(8) $rg_i = 0$
(9) $\mathbf{orc_{i(t)} = orc_{i(t-1)}}$

7.3.2 Metering

When the metering function is available the reduction goal (rg) at time t is a given percentage of the individual own resource consumption at t-1 ($orc_{i(t-1)}$).

(10) $\mathbf{rg_i = orc_{i(t-1)} * K_i}$

where K_i is a consumption modification coefficient., depending on agent type:

$K_{evangelist} = 0.15$
$K_{active} = 0.05$
$K_{spectator} = 0.001$
$K_{indifferent} = 0$

7.3.3 Comparison

When the function of comparison with neighbors is available, agents know the consumption of less consuming agents and then they set their own reduction goal on the basis of the minimum consumption of other agents.

(11) $\mathbf{rg_{i(t)} = (orc_{i(t-1)} - min\_cons_{t-1}) * green\text{-}competition\text{-}index}$

The reduction goal depends on the minimum known consumption and is given by the difference between the previous consumption of the agent and the reference consumption of another agent that has the minimal consumption (min_cons_{t-1},). Such difference is multiplied by a competition index.
The minimal consumption of agents is given by the consumption of a green agent which consumption is the minimal in the whole systems.
In the model when the smart metering function called neighbor-comparison is set to ON, all agents have as the feature of comparison set to TRUE.
The basic idea behind is that in real situation green agents accept **to relax their privacy constraint about individual consumption for social reputation**. For sake of simplicity, all agent consumptions are available to identify the minimal consumption among agents.
The green-competition-index gives a weight of the aptitude of an agent to emulate the less consuming agents. It is depending on the awareness of the agent, and is defined for indifferent, spectators and evangelist, but not for blinds, as:

(12) $\boldsymbol{green - competiton - index = 1 - \frac{1}{awareness - 8}}$

(13) $\boldsymbol{green - competiton - index = 0}$ **if awareness < 8**

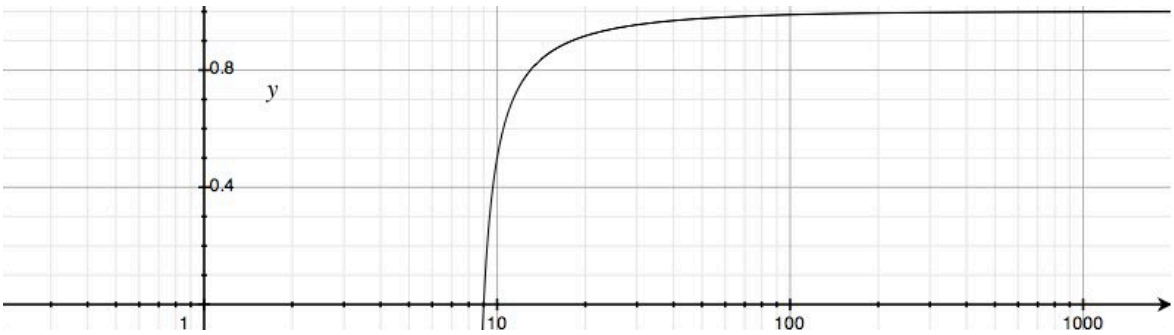

Figure 4 - Green competition index

For blind agents, i.e. with awareness <8, green-competition-index=0
Green competition index is small for low aware agents and increases for more aware agents till reaching the value of 1 for evangelists.

(14) $\mathbf{rg_{i(t)} = (orc_{i(t-1)} - min\_cons_{t-1}) * green\text{-}competition\text{-}index}$

7.4 INDIVIDUAL RESOURCE CONSUMPTION

The own resource consumption depends on the reduction goal. It is computed as the difference between the previous tick resource consumption and the individual reduction goal that has to be reached with a given rate W_i

(15) $\mathbf{orc_{i(t)} = orc_{i(t-1)} - rg_{i(t)} * W_i}$

The blind agent has a negative reduction goal (see (7) and Fig. 3).

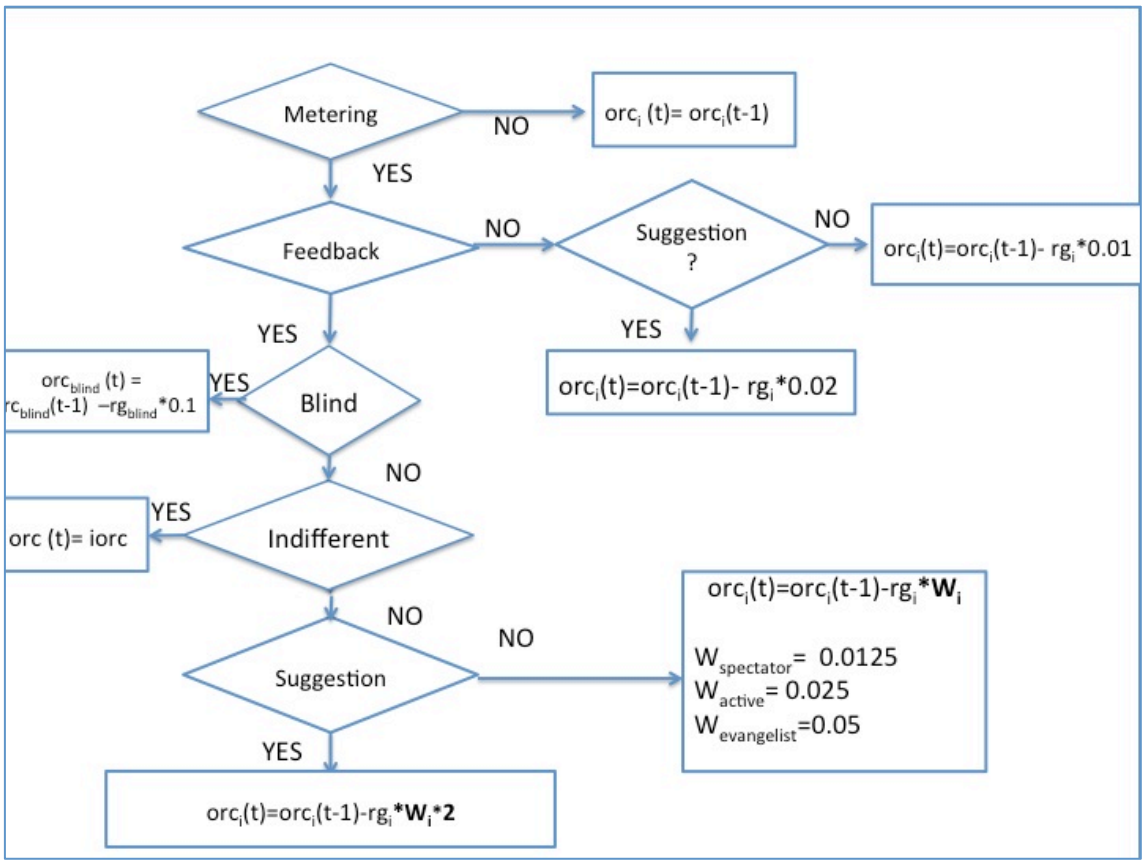

Figure 5 – Own resource consumption of an agent

The rate to reach the reduction goal depends of the availability of three smart metering functions:

- `metering-availability`
- `individual-feedback`
- `Tips&Tricks`

7.4.1 No Metering

When no metering functions are available the own resource consumption is the same of the previous run:

(16) $\mathbf{orc_{i(t)} = orc_{i(t-1)}}$

7.4.2 Only metering

The own resource consumption is given by the old own resource consumption less the reduction goal by the rate to reach it, as shown in above. When metering function but not feedback and not suggestion functions are available, $\mathbf{W_i}$ is the same for every types and is :$\mathbf{W_i = cost = 1/100}$.

(17) $\mathbf{orc_{i(t)} = orc_{i(t-1)} - rg_{i(t)} * 0.01}$

7.4.3 Only metering and feedback

If metering and feedback but not suggestion functions are available, the reduction goal is the same of (17), but the rate to reach such goal depends on the type of the agent.

(18) $\mathbf{orc_{i(t)} = orc_{i(t-1)} - rg_{i(t)} * W_i}$

$W_{evangelist} = 0.05$
$W_{active} = 0.025$

$W_{spectator} = 0.0125$
$W_{indifferent} = 0$
$W_{blind} = 0.1$

7.4.4 Tips& tricks

When there is the availability of the Tips& tricks function, the households is supplied by personalized suggestion about possible improvement in his behavior.
If both metering and Tips& tricks smart functions are supplied, the rate to reach the individual goal doubles.

(19) $\mathbf{orc_{i(t)} = orc_{i(t-1)} - rg_{i(t)} * W_i * 2}$

7.4.5 Resource production

The only type of agent able to produce resource in addition to consume it is the evangelist.

(20) $\mathbf{orp_{evangelist} = orc_{evangelist} * 0.02}$

The evangelist produces the 2% of his consumption.
The overall resource production is the sum of all resources produced by evangelists.

7.4.6 Global Resource use

The Global resource use is given by the difference between overall consumption and overall production.

7.5 SOCIAL REINFORCEMENT

Social Reinforcement is a variable of each agent. Reinforcement relies on the comparison between the global trend of resource use (Δr) and the individual trend ($\mathbf{\Delta_i c}$) of consumption, as below described.

7.5.1 Global resource use trend

Global-resource-use (GRU) is given by the difference between Global resource Consumption and Global Resource production:

(21) GRU=GRC-GRP

The overall delta of resource use at time t is:

(22) $\Delta R = GRU_t - GRU_{t-1}$

The global resource use trend is given by the relative delta of resource use:

(23) $\mathbf{\Delta r = (GRU_t - GRU_{t-1}) / GRU_t}$

7.5.2 Individual resource consumption trend

The individual resource consumption trend is given by:

(24) $\mathbf{\Delta ic = (orc_t - orc_{t-1}) - orp_t / orc_t}$

where:
$\mathbf{orc_t}$ is the own-resource-consumption at time t
$\mathbf{orp_t}$ is the own-resource-production at time t (orp_t different from 0 only for evangelists).

7.5.3 Agent social reinforcement

The default value of social reinforcement is set to zero.
When the relative global trend (Δr) is concordant and higher in absolute value than the individual one (**Δic**) the social reinforcement (*r*) variable change for some type of agents.
When both are negative (i.e. the reduction is the trend, both at a global and individual level) the social reinforcement (sr) is set to 1 for active agents.

(25) **Δr <0 and Δic <0 → sr =1**

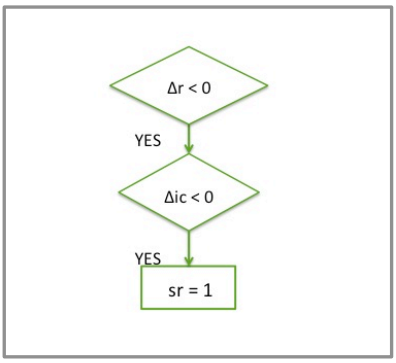

Figure 6 – Social reinforcement of active agent

The same conditions for evangelist agents with also the condition that the relative overall reduction is greater than the relative individual one:

(26) **Δr <0 and Δic <0 and |Δr| > |Δic| → sr =1**

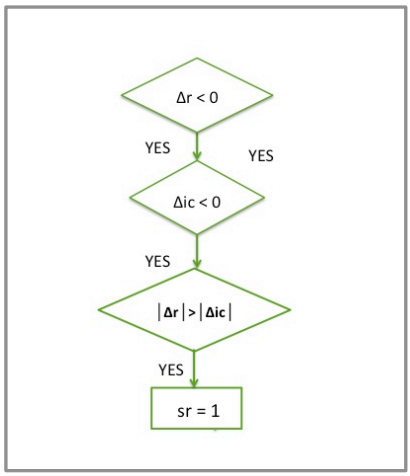

Figure 7 – Social reinforcement of evangelist agent

For indifferent and spectator agents the condition for the positive reinforcement are the same, but they can have also a negative reinforcement. When the trend is of increasing, both at a global and individual level, the social reinforcement is set to -1 for indifferent and spectator agents.

(27) **Δr >0 and Δic >0 and |Δr| > |Δic| → r=-1**

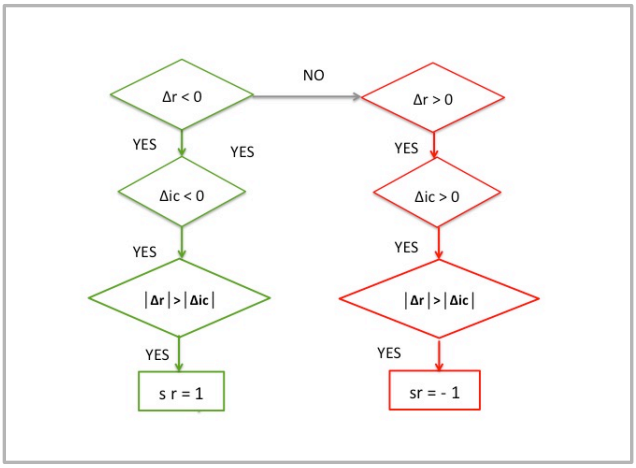

Figure 8 – Social reinforcement of spectator and indifferent agents

Blind agents can have only negative reinforcement.

(28) **Δr <0 and Δic <0 → r =1**

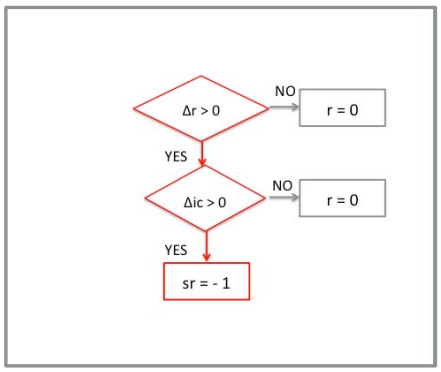

Figure 9 - Social reinforcement of blind agent

In details looking at the social reinforcement for the different types of agent, we can see that the reinforcement appear under certain conditions, that are different by types.

The only agent with the social reinforcement put to zero is the blind, to avoid overestimate his negative effect on reaching the tipping point for sustainability.

Other agents are maintaining their previous social reinforcement and change it only when the above described condition happens. This choice is driven by the need of representing a feeling of the agent about the consumption trend, with some "inertia" and not as a real time value at all.

7.5.4 Social reinforcement and awareness

Awareness depends on such social reinforcement, because its value is added to the awareness level. When the global trend and the individual one are of reduction, and the first is higher than the second in absolute value, the awareness increases.

When the global trend and the individual one are of increase, and the first is higher than the second in absolute value, the awareness decreases.

(29) $\Delta a_i = \alpha_i v_{gr} + \varepsilon_i v_e + \beta_i v_b + \gamma_i n_{gr30} + \delta_i n_{gr80} + sr_i$

7.6 TIPPING POINTS

We are looking for two social norms: sustainability and unsustainability social norms. A sustainability social norm is somehow announced by the reaching of a tipping point. It emerges when a given percentage of committed agents has a consumption trend that is concordant with the overall one. By default the tipping points are set to false. The tipping point toward sustainability is reached when the relative number of green agents with a negative delta individual consumption is greater than the 10% of the total number of agents. In addition the total number of green agents with a positive reinforcement must be greater than the total number of unaware agents with a negative reinforce.

$$\frac{\textbf{Number of actives \&evangelists with } \Delta ic < 0}{\textbf{Total number of agent}} > 0.1$$

AND $\Delta r<0$

AND **Number of agents with social reinforcement = 1 > Number of agents with social reinforcement = -1**

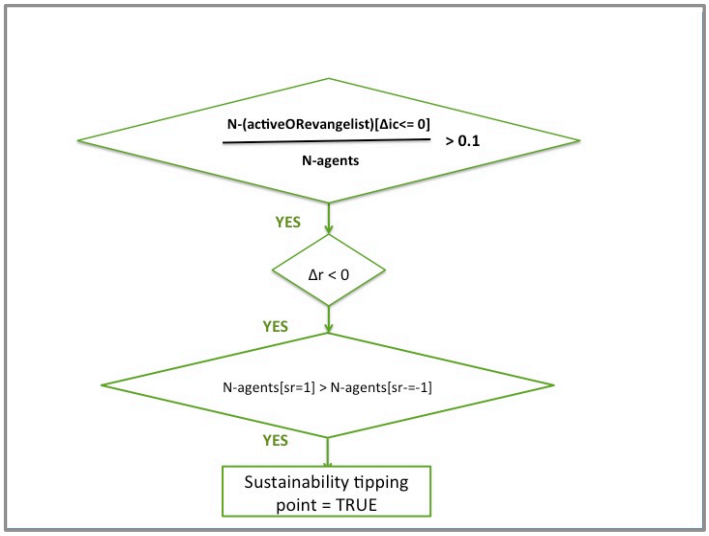

Figure 10 - Sustainability tipping point

An unsustainability tipping point emerges when the relative number of blinds with a positive delta individual consumption is more than the 10% of the total number of agents and the total number of blind agents with a negative reinforce is greater than the total number of green agents with a positive reinforce.

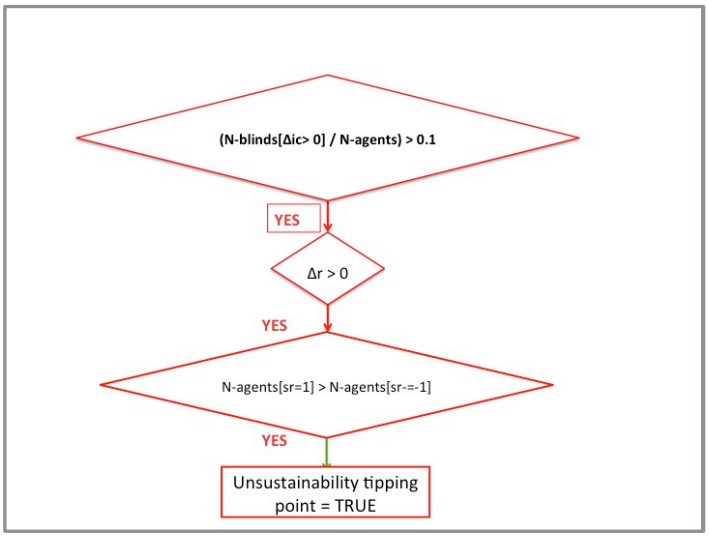

Figure 11– Unsustainability tipping point

$$\frac{\textbf{Number of blinds with } \Delta ic > 0}{\textbf{Total number of agent}} \textbf{ > 0.1}$$

AND $\Delta r>0$
AND **(Number of agents with social reinforcement = -1) > (Number of agents with social reinforcement = 1)**

7.7 UPDATE OF OVERALL RESOURCE USE

The value of previous run is saved.
After that each individual consumption is updated as below described, the global resource consumption is evaluated as well the global resource production. The overall resource use is given by the difference between the overall resource consumption and the overall resource production.
When the global resource use is smaller than the difference between the initial resource use and the absolute overall reduction goal the model stops.

APPENDIX: List of parameters

Parameters	Reference formula	Notation in ODD	Values
General			
Max-N-blinds			50
Max-N-indifferents			300
Max-N-spectators			300
Max-N-actives			200
Max-N-evangelists			50
In-radius			2
Sustainability Tipping point	Percentage of active or evangelists agents on the whole population		10%
Unsustainability Tipping point	Percentage of blind agents on the whole population		10%
Max-reduction-goal			100
Max-initial-global-resource-consumption			50000
Relative Initial Consumption (referred to evangelist agent consumption)	$iorc_i = C_i * euc$		
Blind		C_{blind}	1.4
Indifferent		$C_{indifferent}$	1.3
Spectator		$C_{spectator}$	1.2
Active		C_{active}	1.1
Initial reduction goal	rgi(t=0)	0	
Initial resource consumption	$orc_i(t=0)$	iorci	
Social reinforcement	reinforce(t=0)	0	
AGENT AWARENESS			
Initial awareness			
Blind			0
Indifferent			8
Spectator			16
Active			100
Evangelist			2000
Awareness thresholds			
Blind- indifferent			8
Indifferent- spectator			16
Spectator- active			32
Active-evangelist			2000
Awareness increment			
Local influence	$\alpha_i v_{gr} + \varepsilon_i v_e + \beta_i v_b$		
α_i= awareness **local** increment coefficient1		α_i	
Blind			1
Indifferent			1
Spectator			1
Active			0
ε_i =awareness **local** increment coefficient2		ε_i	

Blind			0
Indifferent			0
Spectator			0
Active			2
β_i= awareness **local** decrement coefficient		β_i	
Blind			-2
Indifferent			-1
Spectator			-1
Active			0
Global influence	$\gamma_i n_{gr30}+\delta_i n_{gr80}$		
light green percentage of green agent on the whole population	n_{gr30}		30%
strong green percentage of green agent on the whole population	n_{gr80}		80%
global light-green increment coefficient	γ_i		
Blind			0
Indifferent			0
Spectator			1
Active			0
global strong-green increment coefficient	δ_i		
Blind			0
Indifferent			0
Spectator			0
Active			1
REDUCTION GOAL	$rg_i = orc_i(t-1) * K_i$		
REDUCTION GOAL Coefficient	$\mathbf{K_i}$		
Blind			-0.01
With Metering			
Indifferent			0
Spectator			0.001
Active			0.005
Evangelist			0.15
INDIVIDUAL CONSUMPTION	$\mathbf{orc_i(t) = orc_i(t-1) - rg_i(t) * W_i}$		
Rate to reach the reduction goal	$\mathbf{W_i}$		
Blind			0.1
With only Metering			
Indifferent, Spectator, Active, Evangelist			0.01
With only Metering & Suggestion			
Indifferent, Spectator, Active, Evangelist			0.02
With only Metering &Feedback			
Indifferent			
Spectator			
Active			
Evangelist			
With Suggestion			
Indifferent, Spectator, Active, Evangelist			$\mathbf{W_i * 2}$
Resource production			

Blind, Indifferent, Spectator, Active			0
Evangelist	$\mathbf{orp_{evangelist} = orc_{evangelist} * 0.02}$		

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