SMARTEES: Deliverable 7.3 (Report)

SMARTEES simulation implementations

December 2020

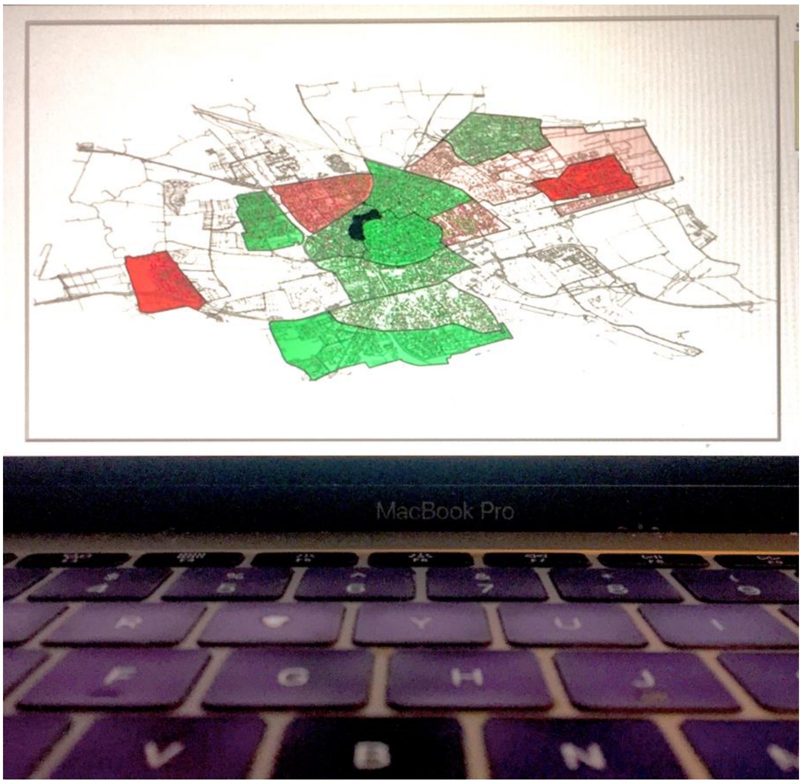

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Table of Contents

Executive summary

This deliverable shows it can be done: computer-simulating the essential behavioural dynamics of different processes of social innovation. Adopting a new technology or changing a common practice is often the talk-of-the-town, generating a lot of interaction in local communities. The social dynamics that arise come with the sharing and valuation of different sorts of information, where networks and norms often play an important role in the success or failure of innovations. As authors, we are happy to have succeeded in implementing a series of simulation models that are capable of reproducing such social dynamics for a number of selected cases. Using the HUMAT integrated framework (see for a description Antosz et al. 2019) a series of models have been coded that simulate the social innovation processes for the SMARTEES' cases. In these artificial societies, representing a large city or small island population, the simulated people can develop and change their opinions; they can be more or less sensitive to norms and the expertise of others, and they can grow social networks to communicate with one another.

Different cases

The cases of local social innovation related to energy that were selected within SMARTEES differ on a number of relevant issues, having implications for the social dynamics that emerge. For example, voting for the closing of a park for car traffic, as in the Groningen Noorderplantsoen case, involves no financial investment of the citizens, is easy to understand, the closing can in principle be reversed easily, and results in changing the practices and experiences of a significant group of citizens. Signing up for a heat-network, as in the Aberdeen case, however, often requires financial investment of citizens in advance, may be difficult to understand in terms of technology and return on investment, is practically irreversible and does not significantly improve the comfort of your home. While joining a heat network in Aberdeen, improving a flat building in Stockholm, or implementing a city block in Vitoria-Gasteiz can involve relatively small groups of people, other cases involve entire cities, such as closing a street in Zürich. The selection of simulated cases gives a good impression of how far we have come towards a generally applicable modelling approach that will be used for policy experimentation in the final stage of the SMARTEES project.

Implementation in HUMAT

The general applicability of the modelling approach in SMARTEES stems from using the HUMAT framework. This integrated theoretical framework serves as a backbone for implementing and comparing different cases. The models being developed using HUMAT provide better theoretical insight into the behavioural dynamics in our cases, allowing for policy experiments in the final stage of the SMARTEES project. This capability of systematically exploring the growth or emergence of societal processes fits into the new type of social science, which Epstein (2006) calls generative social science. The essence of generative social science is captured in the quote "If you didn't grow it, you didn't explain its emergence". This corroborates with the development of a dynamic theory of social psychology (Nowak et al. 2013). The HUMAT framework adds to this new social science by integrating a series of relevant theoretically grounded phenomena in a computational structure, allowing for the modelling of different social innovation cases. The suitable level of detail and theoretical integration in a specific case model depends very much on the characteristics of the respective cases. These define what factors are critical to code in a specific model, a decision that has been supported by the fieldwork of the other work packages. The specific implementation of a case also depends on the availability of data for the different cases, and whether these data are qualitative or quantitative. HUMAT offers a system-thinking-based scheme that causally connects different processes. Therefore, ideas and code that have been developed in one case to model a particular process, could easily be implemented in other case models, and simplified where needed.

Data for calibration - a mixed method approach

A key challenge in the modelling of cases is representing the real population as an artificial society. Choices had to be made on how many agents, and how many different types of agents, are needed to represent the population with sufficient realism. Many different data-sets and data-types have been collected by the other work packages, also using the HUMAT framework as a guide for identifying relevant variables in the different cases. This provided input for calibrating the agent characteristics. For some variables, such as socio-economic data, often quantitative data can be found in databases. These databases may be more or less easily accessible due to format and language, and the translation into values for a community of simulated agents requires a good and consistent framework. For the valid calibration of other variables sometimes more qualitative data have to be used, such as interviews with the people involved and media archives. This demonstrates that the HUMAT framework supports a mixed-method approach in parameterising variables. Whereas mixed method approaches are valuable in developing a wider picture and more confidence in research findings (e.g., O'Cathain & Thomas 2006), adding agent-based modeling to the methods mix provided an opportunity for a much deeper integration of analysed materials. Therefore, the case simulations together showcase an example of a holistic integrated mixed-method design (Caracelli & Greene 1997). The design allows for simultaneous integration of methods, because the agent-based modelling serves as a conceptual and formal platform for merging findings from other methods and data collection techniques. Using a variety of data, the case models were calibrated with respect to (1) motives/needs of the residents, which were activated by the social innovation, (2) geo-socio-demographic characteristics of the resident population, (3) social networks of residents, (4) presence and behavioural tactics of critical nodes and (5) timeline of particular relevant events.

The implemented case models

Key to this deliverable are the implemented simulation models of the selected cases. These are coded models that can run on computers. These models also serve as an input for the sandbox tool. Having cases that differ on key attributes, such as required investments and changing behavioural practices, supports the development of a dashboard for this sandbox tool for selecting cases that match the situation that a user is interested in.

The models are coded in NetLogo, and can be explored by running them on your computer. NetLogo (Wilensky 1999) is a platform widely used to build agent-based models. It allows for the construction of an artificial population of interacting agents. Especially because of the possibilities to (1) implement a series of basic behaviour rules for perception, interaction and behaviour in the agents, (2) parameterise these agents using empirical data to represent the diversity in this artificial population, and (3) grow networks of interacting agents, including influencers (media). The models we have developed in NetLogo are available as computer code. Models however need to be explained in plain language to make it clear what variables are in them, how they are related, and what assumptions are being made using data and theory. To have a standard description of the models, and systematically run through the goals, variables and processes that are addressed with the model implementation, the ODD protocol (Grimm et al. 2010) serves as a standard practice in the field of social simulation. Hence, in the following sections of this report you will find a systematic description of the models that explain what has been implemented. These ODD protocols are essential in understanding the operation of the respective case models if you run them on your computer.

List of abbreviations

ABM	Agent-based model
CSV	Comma Separated Values
PST	Policy Sandbox Tool
SBL	SandBox Language
SI	Social innovation

1 Case study cluster 1: Holistic, shared and persistent mobility plans

1.1 Overview

1.1.1 Purpose and patterns

Purpose of the model is to study the process of accepting a new mobility plan in local communities, by:

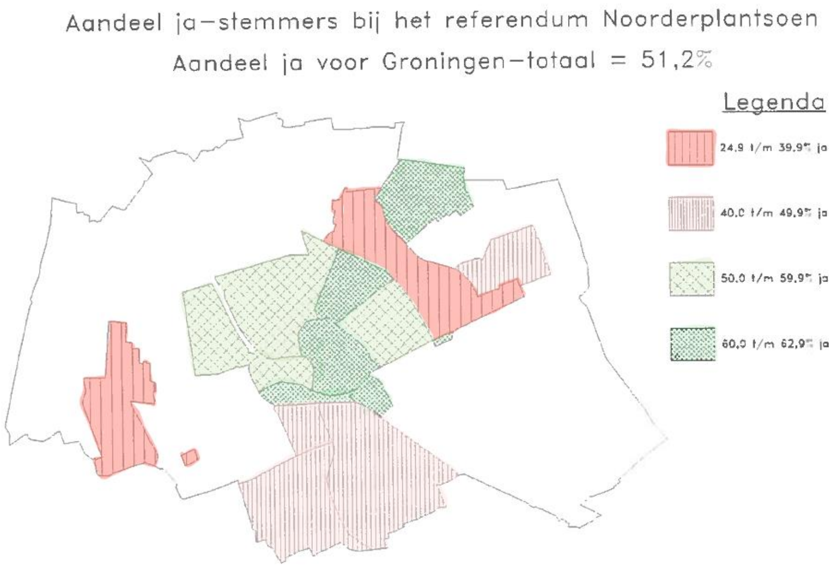
1. Computationally replicating the successful case in Groningen, and subsequently
2. Simulating alternative counterfactual scenarios to explore to which extent the effects of public policies are dependent on certain contextual and policy characteristics.

The main purpose of the Groningen agent-based model is narrower, compared to the aim of investigating the entire Groningen case study. Groningen's overall "Holistic, shared and persistent mobility plans" social innovation is based on a strong critical orientation against the goal of creating a "car-friendly city", which in the 1970's was widely seen as a symbol of progress. Rather, it is oriented towards an alternative model of mobility based on a reduced use of the car, also for improving the air quality and reducing noise pollution (Caiati et al. 2019). This innovation was realized in Groningen and in Zürich over a 50-year period of consistent and focused public policies and interventions. The Zürich model has the same mechanics as the Groningen model, but is calibrated to Zürich data available for 2000. The models will differ with respect to important social actors and their strategies that will be defined during, and implemented after stakeholder workshops.

The agent-based model focuses on diffusion of acceptance of a new organization of traffic in the city's main artery connecting the east to the west - the Noorderplantsoen park. In 1994, Groningers voted in the first Dutch referendum, deciding if the park will become car-free.

The model will be evaluated positively if it is able to correctly reproduce the pattern of voting results by city district under a scenario representing the history of the case (Figure 1.1).

Figure 1.1 Voting results in the 1994 Noorderplantsoen referendum. Source: Gemeente Groningen (1994).



1.1.2 Entities, state variables, and scales

Typical nodes/agents present in the model are residents of the city of Groningen. Individual residents have a set of *needs* that includes the motives of:

- Children's safety in the park (experiential need),
- Shopping convenience (experiential need),
- Transport convenience (experiential need),
- Park activities (experiential need)
- Social need,
- Environmental values.

Moreover, Groningers have a set of beliefs (cognitions) about how the car-free and car-full park satisfy those needs. For example, a resident might believe that the car-free park will be safer for children in the neighbourhood of the park than the car-full park (+1 value of *satisfaction from social innovation* and -1 value of *satisfaction from a car-full park of the children's safety in the park motive*), and that it will be more environmentally friendly (+1 value of *satisfaction from social innovation* and -1 value of *satisfaction from a car-full park* of *the environmental values*). Agents residing on the virtual version of Groningen differ with respect to the degree to which these needs are important to them, and with respect to beliefs about how satisfying it is to have a car-free park and how satisfying it would be to allow through traffic in Noorderplantsoen. Residents also have their individual *cognitive dissonance tolerance threshold*, which if exceeded by the preferred alternative, requires them to take action to reduce it. Moreover, residents are characterised by gender, age group, education and main economic activity and resident district. All residents are inhabiting buildings in the NetLogo world (701 by 401 patches) fitted to the map of Groningen city.

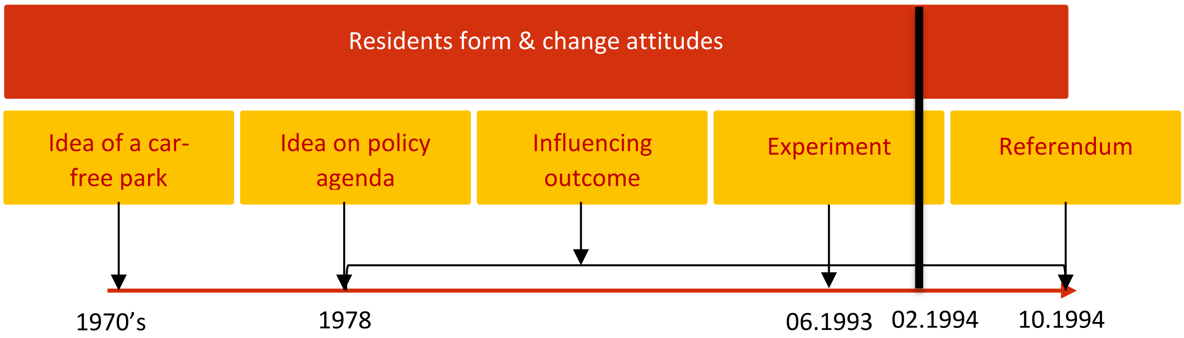
One time step of the model is an abstract unit and represents the trigger for discrete events (For a more detailed meaning of each tick please see Figure 1.3).

1.1.3 Process overview and scheduling

The model is developed to represent the process of residents deciding whether to have through traffic in the Noorderplantsoen park. For the past sixty years, the local government in Groningen has been actively prioritising cyclists and pedestrians in the city traffic. The start of the transitional process in the traffic system was marked by the implementation of the Traffic Circulation Plan in 1977. The determination of the city's Mayor, Jacques Wallage, and the King's Commissioner, Max van den Berg, allowed for restricting car traffic in the city centre and creating space for cyclists and pedestrians. The idea of excluding cars from the Noorderplantsoen park, which was built on the site of the castle wall in the 19th century and is situated to the north of the inner city, originated from residents of Noorderplantsoenbuurt (i.e., a city district located next to the park). They put forward this idea in the process of the neighbourhood restoration project early in the 1970s (Tsubohara 2007). In 1978, the PvdA political party (Partij van de Arbeid, Labour Party) integrated the idea into its election programme (Municipal Programme 78-82) and traffic policy. This started a long negotiation process with interested stakeholders, described in great detail by Tsubohara (2007). The opposition initially came from the shopkeepers from the Shopping Centre Paddepoel, located north of the park. Due to Jacques Wallage's (of the PvdA party) dedication to participatory planning, the negotiations started in 1978. While the leading politicians changed, the decision-making process over the through traffic in the park lasted for approximately fifteen years.
A milestone was reached after the 1990 municipal elections, when PvdA lost the majority in the Municipal executive (College van burgemeester en wethouders) and started sharing the traffic

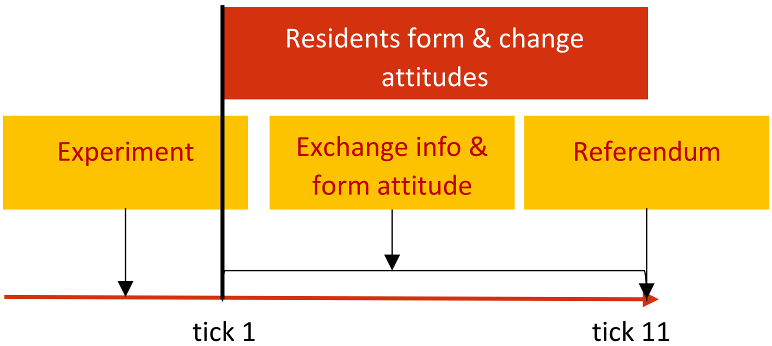
planning responsibility with two other parties: CDA (Christen-Democratisch Appèl, Christian-Democratic party) and D66 (Democraten 66, Democrats 66). It was the decided that the Leliesingel road running through the park was to be closed for cars on a temporary basis. The experimental closure started on the 2nd of June 1993. If traffic nuisance emerged, the road was to be open for car traffic. If not, the "neighbourhood park" with no through traffic would become permanent reality. On the 16th of February 1994, a decision was made to listen to Groningen residents and hold a referendum on the matter on the 5th of October that year. History of the Groningen's Noorderplantsoen park's case study is represented graphically in Figure 1.2.

Figure 1.2 History of the Groningen Noorderplantsoen case study.



The agent-based simulation starts with the idea of the referendum on a car-free park (Figure 1.3), when Groningen residents exchange information with alters in their social networks (*Submodel Information exchange*). In steps 1 through 10 of the model run, on the basis of acquired knowledge, those residents assess how satisfied they would be if the park was open for cars, compared to how satisfied they currently are with the experimental closure (*Submodel Attitude formation*). In step 11, a referendum takes place, when motivated individuals cast their votes *Submodel referendum*).

Figure 1.3 Process overview of the Groningen case study agent-based model.



For the time being, the Groningen agent-based model does not contain counterfactual lobbying scenarios to be simulated. The final decision on scenarios will be made together with the stakeholders during a dedicated workshop. Analysis of the case study and information collected during the first stakeholder workshop suggest the following possible lobbying strategies of critical nodes (i.e., promoters, supporters, opponents of the social innovation and the local media):

- *Submodel Resident meeting,*
- *Submodel Door to door,*
- *Sumbodel Send a letter,*
- *Submodel Media propaganda.*

1.2 Design concepts

1.2.1 Basic Principles

The HUMAT integrated framework was used to model the process of attitude formation among the residents of the Groningen city, who were making a decision about allowing through traffic in the Noorderplantsoen park. Assumptions underlying the HUMAT architecture are based on a number of social theories and empirical studies that provided information about the process of forming and changing attitudes. The social part of the architecture deals with exchanging information about the subject of the attitude (e.g., the SI) in social networks:

- When does an individual ask for advice about SI? – theories of motivated action (Harmon-Jones, Harmon-Jones 2002);
- When does an individual try to convince others to his/her point of view? – theories of motivated action (Harmon-Jones, Harmon-Jones 2002);
- How much does an individual value advice from others? – source persuasion studies (Hovland, Janis, & Kelley, 1953; Hovland & Weiss 1951; Kelman & Hovland 1953; McGinnies & Ward 1980; Pornpitakpan 2004).

The cognitive part of the architecture deals with a fundamental question of how attitudes are formed:

- How does SI suit an individual's particular situation? - needs theories (Maslow 1954; Max-Neef 1992; Kenrick, Griskevicius, Neuberg & Schaller, 2010);
- From the perspective of the individual, does SI have pros and cons? – cognitive consistency theories (Festinger 1954; Harmon-Jones, Harmon-Jones 2002);
- Did the individual try SI before? What were the results? - role of direct experiences in memory formation (Fazio, Zanna 1981; Fazio, Powell, & Herr, 1983; Fazio & Zanna, 1978a, 1978b; Fazio et al. 1982);

1.2.2 Emergence

Emergent outputs of the agent-based model are aggregates of the characteristics of individual residents of Groningen city (popularity of the car-free park stance, perceived satisfaction from the two traffic organization ideas). For more details, please see section *Observation*.

1.2.3 Objectives

Every virtual Groningen resident chooses whether to vote to allow or ban through car traffic in the Noorderplantsoen park. Knowledge of HUMATS is represented as cognitions (Festinger 1954, p. 3) - beliefs about how satisfying each alternative will be for the relevant needs/motives of the individual. Satisfaction of the traffic organization (either allowing or banning car traffic in the park) is a cumulative satisfaction/dissatisfaction of needs/motives weighed by importance of each of those needs/motives. Residents only change their opinion if they received information significantly changing their knowledge about how (dis)satisfying both alternative ideas on traffic organization are. The chosen alternative maximizes the individual’s overall level of satisfaction with respect to the needs/motives that drive the resident’s behaviour and minimizes the level of experienced cognitive dissonance (described in detail in *Attitude formation submodel*).

1.2.4 Interaction

The process of attitude formation is supplemented by information exchange between agents. Every Groningen resident is equipped with episodic memory and can actively initialize information exchange with alters in his/her ego network (for details related to social networks please see *Initiation of social networks* section). Information exchange is implemented as a dissonance reduction technique used by the agents. Therefore, it is only activated when a Groningen resident does not find a clearly more satisfying preference for through traffic in the park, and both alternatives seem similarly dissonant (both a car-free park and a presence of cars have pros and cons). Depending on satisfaction of the social need, information exchange can take two forms: signalling and inquiring (described in detail in *Information exchange submodel*).

If the slightly preferred option does not have enough popularity, ego signals to his/her most gullible alter with an opposite preference and tries to convince them to change their mind. Sufficient popularity is obtained when ego's social need is satisfied. Groningen residents differ with respect to the importance of the social need i.e., to what extent an individual wants to follow the norms set by his/her neighbours. In the Groningen ABM satisfaction of the social need is only calculated on the basis of all social networks. Therefore, the need is sufficiently satisfied only when a fraction of ego's alters equal (or exceeding) the importance of social need has the same preference for through traffic in the Noorderplansoen park. As a result, agents with low importance of social need are individualistically-minded and do not give into social pressure easily. Agents with high importance of social need only feel satisfied when they belong to a neighbourhood of like-minded people.

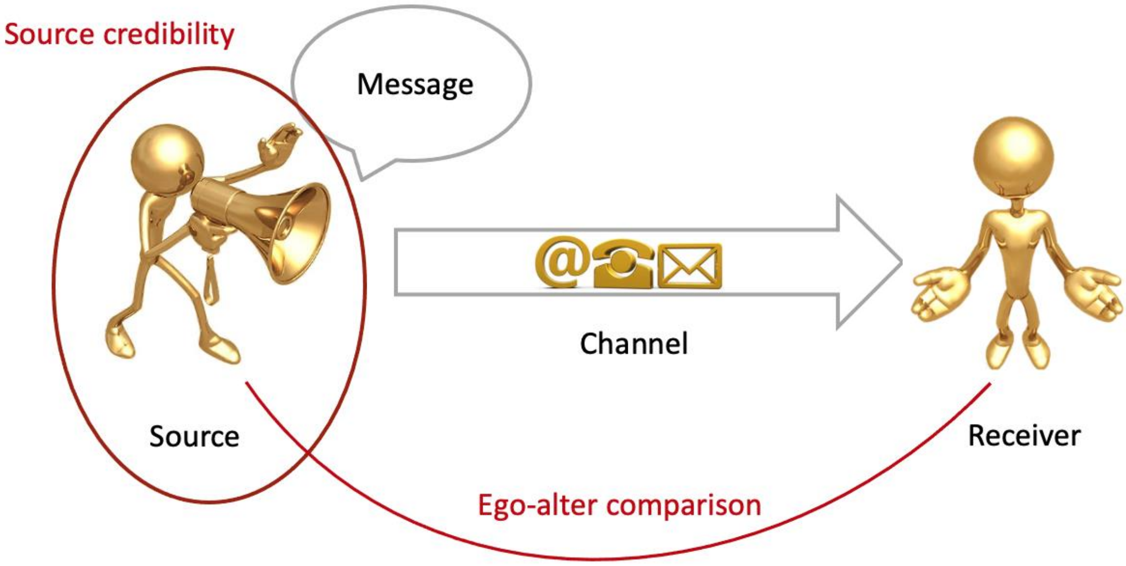
The extent to which the alter will be influenced by a signalling ego depends on the ego's persuasiveness level in the eyes of the alter. Persuasiveness of a typical node in the Samsø ABM depends on the result of ego-alter comparison:

(1) ego-alter similarity with respect to needs/motives - to what extent is the source of information like me (the receiver)? and
(2) ego-alter aspiration level - to what extent do I (the receiver) want to be (perceived) like the source of information?

Similarity between the source and the recipient was found to increase persuasiveness – individuals model behaviours of those with whom they identify (Bandura 2002). Initially, investigated similarity characteristics included demographic variables, such as age, place of birth, ethnicity (Gillespie 1981; Eagly & Himmelfarb 1978; Feldman 1984; Maccoby & Wilson 1957). Later studies emphasised that perceived similarity refers to the extent to which an individual believes a portrayal seems to realistically reflect his or her own experiences (Austin & Meili, 1994). Subsequent studies that explored dimensions of similarity found traits such as intelligence or maturity as important (Andsager et al. 2006). In the Groningen ABM, socio-demographic characteristics of agents determine the existence of links in various types of social networks (described in detail in *Initialization of social networks*). Therefore, they influence information exchange by limiting who the recipient of the message can be. However, persuasiveness of the source of the message per se is determined by ego and alter's similarity with respect to needs/motives driving the decision regarding implemented heating system. Consequently, if the source of the message (e.g., a signalling ego) is a young mother who finds children safety in the park very important, she will be perceived as more persuasive to an alter who also values children safety highly compared to a source who does not consider it an important factor in their decision making (e.g. a childless student).

Moreover, individuals also mimic behaviours of others, because they want to be (or be perceived) like them. Such aspirational characteristics usually refer to socio-economic status (Maccoby & Wilson 1957). In the Groningen ABM, education level was implemented as a proxy for the socio-economic status of agents.

Figure 1.4 Persuasiveness of the source in HUMAT's information exchange.



If the strategy of signalling is not suitable to decrease the dissonance experienced by an agent, he/she chooses to inquire about the slightly preferred heating method. When inquiring, Groningen residents can ask any alter from all types of networks for advice. Moreover, when asking for advice, ego chooses the most persuasive of the alters in his/her social network. For more details on information exchange strategies and persuasiveness of agents, please see *Information exchange* submodel.

1.2.5 Stochasticity

Stochasticity is present in the Groningen ABM during:

- network formation – agents distributed randomly over a square when links are created based on proximity,
- agent location - agents are assigned randomly to households in the district,
- command execution - order of executing commands by agents is random.

1.2.6 Collectives

Virtual Groningen residents are connected via three types of social networks:

- friends,
- co-workers,
- neighbours.

The social networks in the Groningen ABM display characteristics actual social networks are known to possess i.e., they: are limited in size, vary in size between individuals, are strongly homophilic, and exhibit high clustering. To fulfil these requirements, initiation of network topography (described in detail in *Initialization of social networks*) was based on the idea of using social circles described by Hamill and Gilbert (2009).

1.2.7 Observation

Outputs of the Groningen ABM include:

- Popularity of the car-free Noorderplantsoen park and presence of through traffic:
    - N and % of individuals initially preferring a car-free park (step 1);
    - N and % of individuals finally preferring a car-free park (step 11);
    - N and % of individuals voting for a car-free park (step 11);
    - Difference between the initial and final preferences in N and % of individuals;
    - Difference between the final preference and the vote in N and % of individuals;
    - N and % of individuals who have changed their mind at least once;
    - average number of times individuals have changed their mind;
- Satisfactions from the car-free Noorderplantsoen park and presence of through traffic:
    - Average initial satisfaction from the car-free Noorderplantsoen park and presence of through traffic (step 1);
    - Average final satisfaction from the car-free Noorderplantsoen park and presence of through traffic (step 11);
    - Average voters' satisfaction from the car-free Noorderplantsoen park and presence of through traffic (step 11);
    - Difference between the initial and final average satisfactions from the car-free Noorderplantsoen park and presence of through traffic;
    - Difference between the initial and voters' average satisfactions from the car-free Noorderplantsoen park and presence of through traffic;
    - Difference between the final and voters' average satisfactions from the car-free Noorderplantsoen park and presence of through traffic.

1.3 Details

1.3.1 Initialization

The Groningen ABM was calibrated to the Groningen case with respect to (1) timeline of particular relevant events (please see *Process overview and scheduling* for details), (2) geo-socio-demographic characteristics of the resident population, (3) motives/needs of the residents, which were activated by the social innovation, and (4) social networks of residents. Before the final simulations of the model, another dimension of calibration will be added i.e., presence and behavioural tactics of critical nodes. Those behavioural tactics will represent factual and counterfactual policy scenarios.

1.3.1.1 Initialization of population

For the purpose of the agent-based model calibration, a population of Groningen from 1994 was recreated on the basis of available statistical data. The population is representing the actual population of the Island with respect to:

- size of the population (scale of 1:10);
- gender (2 categories: M, F);
- age (3 categories: 18-24, 25-64, 65+);
- education level (3 categories: short, medium, long);
- main economic activity (4 categories: student, employee, not working, retired);
- 13 Groningen districts,

and all the known dependencies between these characteristics. As a result, every agent in the model belongs to one of 936 homogenous groups i.e., intersections of the five socio-demographic characteristics. All the groups comprise a fraction of the modelled population that matches the actual fraction of Groningen residents in 1994 with a particular set of socio-demographic characteristics. As a result, there is no stochasticity in the model in this respect.

Whenever information on dependencies between the characteristics were not available in existing data, assumptions about probable dependencies were implemented (e.g., no retirees in the 18-24 age group) prior to model calibration.

Original data used for population recreation was retrieved from the Statistical yearbook 1999 and Gemeente Groningen's report from the referendum. The following information from the statistical yearbook 1999 was used:

- For socio-demographic characteristics:
  - 2.1 Bevolking naar leeftijd op 1 januari, p.6
  - 2.1.a Bevolking naar leeftijdsgroepen en geslacht op 1 januari 1995 en 1999, p.7
  - 2.11 Opleidingsniveau in procenten per GSB-wijk, 1996 en 1998, p. 14
  - 5.3 Aantal bezette arbeidsplaatsen naar arbeidsduur en geslacht, p. 46
  - 5.8 Opleidingsniveau van de beroepsbevolking, p. 48
  - 6.1 Niet-werkende werkzoekenden (NWW) in de gemeente Groningen op 1 april, p. 52
  - 6.1.1 Niet-werkende werkzoekenden (NWW) per leeftijdsgroep op 1 april in absolute aantallen, p. 52
  - 6.1.3 Niet-werkende werkzoekenden (NWW) naar opleidingsniveau op 1 april in procenten, p. 52
  - 6.1.4 Niet-werkende werkzoekenden (NWW) naar geslacht op 1 april in procenten van de mannelijke, c.q. de vrouwelijke beroepsbevolking, p. 54
  - 6.1.7 Niet-werkende werkzoekenden als percentage van de beroepsbevolking per GSB-wijk op 1 april 1996 – 1998, p. 54
  - 7.2.1 Procentuele verdeling van het aantal uitkeringsgerechtigden wegens arbeidsongeschiktheid naar bevolkingsgroep per ultimo, p. 61
  - 7.2.2 Procentuele verdeling van het aantal uitkeringsgerechtigden wegens arbeidsongeschiktheid naar leeftijdsgroep en geslacht per ultimo, p. 62
  - 7.3.5 Bron van inkomen en gemiddeld inkomen per sociaal economische categorie, Groningen en Nederland, 1994 en 1996, p. 70
  - Aantal studenten woonachtig in de stad en buiten de stad (Unidentified document downloaded from: https://decentrale.regelgeving.overheid.nl/cvdr/images/Groningen%20(Gr)/i177658.pdf)
- For household data:
  - 2.7 Huishoudenssamenstelling op 1 januari, p. 12
  - 2.8 Huishoudens met inwonende kinderen op 1 januari, p. 12
  - 2.9 Leeftijd van alleenwonenden in zelfstandige woningen, p. 14.

After retrieval, data was aggregated into meaningful categories with respect to:

- age,
- education level:
  - lower level - Lager(beroeps)onderwijs;
  - middle level - MAVO, HAVO, VWO, MBO;
  - higher - HBO,WO.
- Groningen's administrative districts - standardization of Groningen's administrative districts was necessary because the data in the Statistical Yearbook and the data from the Gemeente

Groningen's report on the 1994 referendum used two different district classifications. In order to standardize the data, all polling locations recorded in the referendum report were geolocated on the map of Groningen and assigned to districts classification used in the Statistical yearbook.

1.3.1.2 Initialization of motives

Identification of relevant motives, estimation of the motive importances for various socio-demographic groups and satisfaction of motives by car-free park and by presence of through traffic in the park were estimated on the basis of available secondary materials and information from in-depth interviews conducted with key stakeholders from Groningen. The details of calibrating motives related to how the social innovation satisfies experiential needs and values (motives 1-4 and 6) at initialization of the ABM can be found in Table 1.1. At the start of the simulation, Groningen residents already have experiences with the social innovation due to experimental closure of the Noorderplantsoen park. This information is subject to exchange in social networks. Importance of social need (motive 5) at model initialization is distributed normally with a mean of 0,5 and sd of 0.14, truncated between values 0 and 1. Satisfaction of the social need is negative if the fraction of neighbours in ego's network, who choose the same heating system as ego, is below the importance of social need of the ego.

Table 1.1 Calibration to experiential needs and values of Groningen residents at model initialization.

Need	Importance of the need is …	Categories of the related characteristic	Formulas for each category of the related characteristic	Satisfaction from a car-free park	Satisfaction from through traffic in the park
Motive 1: children's safety in the park	increasing with decreasing distance from park + age group 25-64, 65+ + gender (stronger among females)		I = e^-x, where x is the distance from the park. This is the average for women in age group of 25-64.		
		18-24 F	Importance motive 1 (kids safety) = I - 9% * I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		18-24 M	Importance motive 1 (kids safety) = I - 12% * I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		25-64 F	Importance motive 1 (kids safety) = I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		25-64 M	Importance motive 1 (kids safety) = I - 3% * I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		65+ F	Importance motive 1 (kids safety) = I - 3% * I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		65+ M	Importance motive 1 (kids safety) = I - 6% * I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
Motive 2: shopping convenience	increasing with decreasing distance from Paddepoel shopping centre +		I = e^-x, where x is the distance from the shopping centre. This is the average for age group 65+		

	stronger in age group 65+				
		18-24	Importance motive 2 (shopping convenience) = I - 6% * I +/- random-float 10% of I; max 1, min 0	95% -, 5% +	95% +, 5% -
		25-64	Importance motive 2 (shopping convenience) = I - 3% * I +/- random-float 10% of I; max 1, min 0	95% -, 5% +	95% +, 5% -
		65+	Importance motive 2 (shopping convenience) = I +/- random-float 10% of I; max 1, min 0	95% -, 5% +	95% +, 5% -
Motive 3: transport convenience	increasing with increasing distance from park + different satisfaction direction for students		I = e ^ x, where x is the distance from the park.		
		students	Importance motive 3 (transport convenience) = I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		non-students	Importance motive 3 (transport convenience) = I +/- random-float 10% of I; max 1, min 0	95% -, 5% +	95% +, 5% -
Motive 4: park activities	increasing with decreasing distance from park	I = e^-x, where x is the distance from the park. Different adjustment than for motive 1.	Importance motive 4 (park activities) = I +/- random-float 10% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
Motive 6: environmental awareness	increasing with education		I = 0,5		
		higher	Importance motive 5 (environment) = I +/- random-float 50% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		middle	Importance motive 5 (environment) = I - 0,1 +/- random-float 50% of I; max 1, min 0	95% +, 5% -	95% -, 5% +
		lower	Importance motive 5 (environment) = I - 0,2 +/- random-float 50% of I; max 1, min 0	95% +, 5% -	95% -, 5% +

1.3.1.3 Initialization of social networks

Main characteristics of social networks implemented in the Groningen ABM are presented in Table 1.2. The details of network initiation are described below.

Table 1.2 Main characteristics of networks in the Groningen ABM by type.

Network type	Homophily	Fraction of agents who follow heterophily rules	Average number of alters in an ego network (d)
friends	Age, education	3%	5
co-workers	Education, disposable income	1%	5
neighbours	Household location	NA	5 +/- 2[1]

[1] The maximum number of neighbours in ego's network. Please see *Neighbourhood networks* description below for more details.

Friends and co-workers networks

Agents are randomly distributed over a square of size 120 by 120 patches and create links of a given type to all agents in a pre-defined radius *r*:

$$r = \sqrt{\frac{\frac{d}{\pi}}{\frac{n}{s^2}}}, \qquad \text{(Equation 1.1).}$$

Size of that radius depends on the ratio between:

- $\frac{d}{\pi}$, where *d* is the targeted average number of alters in an ego network, and
- $\frac{n}{s^2}$ - density of agents from a given homophilic group per square patch, *n* – number of agents in a group divided by area of the square the group is occupying. Length of the side of the square (*s*) equals 120 patches.

To avoid perfect homophily, a mixing parameter is introduced. The parameter designates the percentage of agents from a given homogenous group (as defined by the homophily characteristics present in a given network, e.g., agents with lower education in the age group of 18-24) who are networked to another group instead.

Neighbours network

In the case of neighbourhood network, the homophily criterion is the household location. Out of all households in the radius of 5, ego creates neighbour links with a maximum of 5 (+/- 2) neighbours. The maximum number of neighbours is set for each Groningen resident individually. If the number of neighbours in radius of 5 patches:

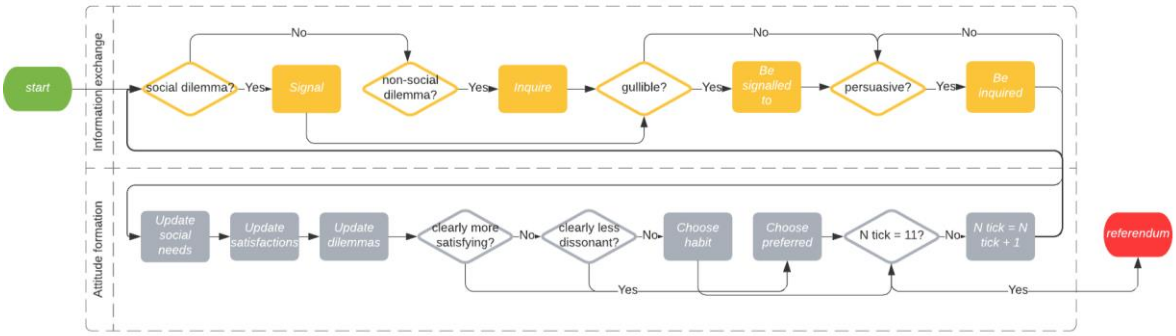
- exceeds the maximum number of neighbours ego should have, ego links to the maximum number of neighbours that live closest to it;
- is less than the maximum number of neighbours ego should have, ego links to the neighbours it has (without creating double links to the neighbours that already connected to ego);
- quals 0, i.e. ego has no neighbours in the defined radius, ego links to the neighbour that lives closest.

Following these rules, all Groningen residents have at least one neighbour in their neighbours network.

1.3.2 Submodels

The main submodel in the Groningen ABM is the HUMAT architecture. The architecture and its role in agent-based modeling in the SMARTEES project was extensively described elsewhere (Antosz et al. 2019), therefore here only the details relevant for the Groningen ABM will be presented (Figure 1.5). The architecture consists of two main processes: (1) attitude formation, and (2) information exchange in the social networks.

Figure 1.5 The process of attitude formation of Groningen residents.



1.3.2.1 Attitude formation (steps 1-10)

If a resident is satisfied with the current heating system, he/she behaves habitually (Simon 1976). However, introducing an innovative alternative may distort those habits. Every Onsbjerg resident evaluates both alternative heating systems on two dimensions: (1) expected satisfaction and (2) psychological comfort (i.e., low level of cognitive dissonance).

Expected satisfaction from an alternative is assessed with respect to six motives ($m \in \{m_1, \dots, m_6\}$) belonging to three groups:

- Children's safety in the park (**experiential** need, e_1),
- Shopping convenience (experiential need - e_2),
- Transport convenience (experiential need - e_3)
- Park activities (experiential need - e_4),
- **Social** need (s),
- Environmental **values** (v_1),

according to Equation 1.2:

$$S_{i,j}^{p,t_n} = \frac{\sum_{m=1}^{6} I_{m,j}^{t_n} S_{i,m,j}^{p,t_n}}{6} =$$

$$= \frac{I_{e1,j}^{t_n} S_{i,e1,j}^{p,t_n} + I_{e2,j}^{t_n} S_{i,e2,j}^{p,t_n} + I_{e3,j}^{t_n} S_{i,e3,j}^{p,t_n} + I_{e4,j}^{t_n} S_{i,e4,j}^{p,t_n} + I_{s,j}^{t_n} S_{i,s,j}^{p,t_n} + I_{v1,j}^{t_n} S_{i,v1,j}^{p,t_n}}{6}, \qquad (\textit{Equation 1.2})$$

where

$I_{m,j}^{t_n}$ - importance of motive m for resident j at time t_n ($\in \langle 0,1\rangle$) - a personality trait that is not dependent on a particular behavioural alternative i.

$S_{i,m,j}^{p,t_n}$ - expected satisfaction from behavioural alternative i with respect to motive m for resident j at time t_n ($\in \{-1, 1\}$).

Residents are heterogeneous with respect to how important each motive is and how satisfying they perceive both alternatives to be with respect to each motive. For details on how importances and satisfactions of motives are related to socio-demographic characteristics of individuals, please see *Initialization of motives*.

As presented in Equation 1.2, evaluations of different motives ($I_{m,j}^{t_n}\, S_{i,m,j}^{p,t_n}$) are summed up to compose an overall satisfaction score of a behavioral alternative. It is consistent with the principles of the Theory of Planned Behaviour (Ajzen, 1991), where cognitions can be envisaged as a multiplication of the strength of a belief or attribute (i.e., the individual difference of motive importance) and the satisfaction of that attribute.

Once a Groningen resident assesses the satisfaction level of both available behavioural alternatives (i.e., car-free park and through traffic in the park), they choose the clearly more satisfying one. If both options seem similarly satisfying (within the value of 0,2 i.e., 10% of the range of theoretical values of satisfaction), the resident further explores alternatives with respect to the amount of cognitive dissonance each one evokes.

Evaluation of a behavioural alternative i with respect to motive m, i.e.:

$$E_{i,k,j}^{t_n} \;=\; I_{k,j}^{t_n}\, S_{i,k,j}^{p,t_n}, \qquad (\textit{Equation 1.3})$$

can be perceived by resident j at time t_n as:

- Dissatisfying (i.e., $I_{k,j}^{t_n}\, S_{i,k,j}^{p,t_n} \in < -1; 0)$),
- Neutral (i.e., $I_{k,j}^{t_n}\, S_{i,k,j}^{p,t_n} = 0$),
- Satisfying (i.e., $I_{k,j}^{t_n}\, S_{i,k,j}^{p,t_n} \in\; (0; 1 >$).

In other words, residents of Groningen experience dissonance between cognitions when a behavioural alternative is perceived to have pros (be satisfying) and cons (be dissatisfying) at the same time. For example, psychological tension occurs when a resident is in the process of making a decision and activates the following two beliefs:

- "my children like playing in the park and I want them to be safe" – car-free park's positive evaluation of the need of children's safety - an argument to vote for the car-free park, and
- "I like to be able to reach my work on the other side of the city with a car" – car-free park's negative evaluation of transport comfort motive - an argument to prefer the presence of through traffic in the park.

Amount of dissonance that a behavioural alternative i evokes in resident j at time t_n ($D_{i,j}^{t_n}$) is quantifiable as follows:

$$D_{i,j}^{t_n} = \frac{2d}{d+c}, \qquad (\textit{Equation 1.4})$$

where:

d - dissonant cognitions ($min(\sum\; satisfying\; E_{i,k,j}, \sum\; dissatisfying\; E_{i,k,j})$),

c - consonant cognitions ($max(\sum\; satisfying\; E_{i,k,j}, \sum\; dissatisfying\; E_{i,k,j}$).

Cognitive dissonance is a motivational force for a change in knowledge (Festinger 1954) or behaviour (Harmon-Jones, Harmon-Jones 2002). Occurrence of cognitive dissonance leads to a psychologically unpleasant state of facing a dilemma. There are two types of such dilemmas. A **social dilemma** occurs when the alternative i yields satisfaction of any of the experiential needs or values AND dissatisfaction of social needs. It corresponds to a situation where, for example, the resident is convinced that new district heating has a sufficient number of pros, but at the same time he/she feels secluded with this opinion, because not enough neighbours want to join the new heating network. To resolve a strong social dilemma, the resident **signals** to his/her neighbours to try to convince them to join the district heating network (for details please see the *Signalling* section of the *Information exchange submodel*). A **non-social dilemma** occurs in any other instance of cognitive dissonance. For example, the resident is convinced that new district heating is popular enough with other neighbours, but in his/her personal opinion has a sufficient number of cons (e.g., requires building an ugly heating plant next door (negatively evaluated aesthetics value), which will be very smelly (negatively evaluated high air quality experiential need)). To resolve a strong non-social dilemma, the resident **inquires** with other alters in his/her ego network to find more arguments for the preferred alternative (for details please see the *Inquiring* section of the *Information exchange submodel*).

Harmon-Jones and Harmon-Jones (2002), in their action-based model of dissonance, hypothesise that the reason for discomfort caused by dissonant cognitions comes from the fact that inconsistent cognitions have the potential of interfering with effective action. Cognitions serve as guides for behaviour, so when cognitions are in conflict, behaviour will be impeded (Harmon-Jones & Harmon-Jones 2018, p. 74). Brehm's motivation intensity theory proposes that people manage their resources following a conservation principle (Brehm et al. 1983; Brehm & Self 1989). Therefore, effort required to execute a behaviour will only be exerted (1) to the extent that it is needed and (2) only when its expenditure is justified (return on the effort is expected). Most often dissonant cognitions are being suppressed or ignored as an effective dissonance reduction strategy (McGrath 2017). Therefore, in HUMAT architecture used in the Groningen agent-based model, dissonance needs to be actively resolved so that behaviour can occur only when it exceeds the individual's tolerance threshold (T). As a consequence, at time t_n a behavioural alternative i evokes a certain fraction of above-tolerance-threshold non-dissonance in resident j:

$$F_{i,j}^{t_n} = 1 - \frac{D_{i,j}^{t_n} - T_j}{1 - T_j}, \qquad \text{(\textit{Equation 1.5})}$$

IF $F_{i,j}^{t_n} > 1$, $F_{i,j}^{t_n} = 1$.

If both alternatives are perceived as similarly dissonant (within 0,1 i.e., 10% of theoretical range of subjective dissonance perception), Groningen resident chooses the alternative that was chosen in the previous time step. If a previous decision is unavailable (at initiation of the model), a random decision is made.

1.3.2.2 Information exchange (steps 1-10)

If the resident is hesitant about the chosen alternative, dissonance resolution strategies are employed only to confirm the decision (signalling and inquiring).

Signalling

When signalling, Groningen residents try to find an alter who would be easiest to convince to change their opinion. Three factors play a role when making a decision. Ego inquires first with alters who:

- have not been inquired with yet,

- choose a different behaviour, and
- are the most gullible.

Inquiring

When inquiring, Groningen residents try to preserve their cognitions and activate a search that maximises the probability of receiving information that fits their slightly preferred alternative. Three factors play a role when making a decision. Ego inquires first with alters who:

- have not been inquired with yet,
- choose the same behaviour, and
- are the most persuasive.

Once the most suitable alter is chosen for information exchange, the degree to which inquiring/signalled to ego is influenced depends on persuasiveness of the inquired to/signalling alter. Persuasiveness of a typical node in the Groningen ABM depends on the result of comparing ego-alter similarity with respect to needs/motives and relative ego-alter aspiration level. The calculation is need/motive similarity is performed for each need/motive for both behavioural alternatives as follows:

$$0.4(1 - abs\left(I_{m,e}^{t_n} - I_{m,a}^{t_n}\right)), \qquad (\text{Equation 1.6})$$

where

$I_{m,e}^{t_n}$- importance of motive m for ego,

$I_{m,a}^{t_n}$ - importance of motive m for alter.

Calculation of the relative aspiration level is based on socio-economic status (SES):

$$O.4 + SES_e - SES_a$$

SES_e- socio-economic status of ego,

SES_a- socio-economic status of alter.

If relative aspiration level < 0, then it is set to no influence (i.e., value of 0).

When Groningen residents influence each other, they affect the perception of importance of a need/motive they are discussing. The degree of similarity between interacting agents multiplied by the relative aspiration between them is therefore applied as a weighing factor to calculate the new importance of the need/motive for both agents. The maximum value of similarity and aspiration are set at 0,4. As a result, e.g., when two agents find similar motives similarly important, they influence each other to a maximum of 40%. The new value of importance is calculated as 60% of the old importance of the influenced agent and 40% of the old importance of the influencing agents. If interacting agents do not find the same needs important (i.e., evaluation of a need is positive for one and negative for the other), the influencing agent does not affect the influenced agent.

1.3.2.3 Referendum (step 11)

Only the motivated residents of the city vote in the referendum where they express their preference for traffic organization in the Noorderplantsoen park. To be considered sufficiently motivated, wither the sum of motive importances has to exceed 1,09 or a single motive has to be important enough (> 0.89).

2 Case study cluster 2: Island renaissance based on renewable energy production

For the island renaissance based on renewable energy production case study cluster, we describe the agent-based model that has been developed to simulate the Samsø island (Denmark). The other main reference case in SMARTEES in this case study cluster is based in El Hierro (Spain), for which a separate model is developed. Two models are significantly different, reflecting the variability of the two cases. In the El Hierro case, contrary to Samsø, the social innovation was primarily top-down. The purpose of the model is to study the acceptability of the expansion of the Renewable El Hierro project, once the citizens have experienced the first phase of the project. Moreover, the El Hierro agent-based model is very similar to the Vitoria Gasteiz agent-based model (see section 4) with respect to design and contents, with small variations to account for differences in data sources, entities and actors involved in the model and their policy strategies.

2.1 Overview

2.1.1 Purpose and patterns

Purpose of the model is to study the process of diffusion of renewable energy production in local communities, by:

3. Computationally replicating the successful case in Samsø, and subsequently
4. Simulating alternative counterfactual scenarios to explore to which extent the effects of public policies are dependent on certain contextual and policy characteristics.

The main purpose of the Samsø agent-based model is narrower, compared to the aim of investigating the entire Samsø case study. Samsø's overall "Island renaissance based on renewable energy production" social innovation is based on the mobilization of the citizens of the island to achieve energy independence through renewable and energy efficiency measures as means to overcome the factors that put the community itself in danger and revive island communities. The strategy was characterized by an intensive (and progressive) mobilization of the citizens for achieving energy independence through renewable energy and the improvement of energy efficiency with a significant role played by all the societal actors in the design, co-development/co-creation and implementation of the initiative.

The agent-based model focuses on mobilizing residents of the Samsø town of Onsbjerg to participate in a district heating network project implemented in their neighbourhood. This was one example of district heating implemented on the island, along the Nordby-Maarup and Ballen-Brundby cases. The main elements of characteristics of the heat network project, also characteristic for the entire social innovation (Caiati et al. 2019), and reflected in the agent-based model include:

- A bottom-up approach, driven by a small number of active members of the local community building an alliance with expert organization of Samsø Energy Academy (Energiakademiet),
- Progressive character of the consensus building through negotiation and dialogue to overcome conflicts and resistance,
- Credible and transparent communication (e.g., open minutes from the meetings and open budget documents),
- Resident co-ownership of the district heating infrastructure and the related economic gains,

- Energy Academy's capitalization on the experience (and lessons learned) through the set-up of three district heating networks in different parts of the Island.

The model will be evaluated positively if it is able to correctly reproduce the pattern of households willing to join the district heating network under a scenario representing the history of the case. Available historical data show the following dynamic of the district heating's popularity among Onsbjerg household residents (Table 2.1)[1].

Table 2.1 Dynamics of popularity of the district heating network among Onsbjerg residents.

date	joining	not joining	unknown decision
20.02.2001[2] (initial interest)	31	10	NA
15.03.2001[3] (initial interest)	59	44	20
15.05.2002[4] (pre-construction)	63	NA	NA
11.2002[5] (ongoing-construction)	69	NA	NA

2.1.2 Entities, state variables, and scales

Typical nodes/agents present in the model are residents of the Samsø island, divided into two groups. Residents of the Onsbjerg district where the heat network is installed, and residents of other districts. Individual residents have a set of *needs* that includes the motives of:

- Affordability (experiential need),
- High air quality (experiential need),
- Safety (experiential need)
- Renovation inconvenience (experiential need),
- Social need,
- Ecological values,
- Islander identity (value),
- Aesthetics (value).

Moreover, Islanders have a set of beliefs (cognitions) about how their current heating system and the new district heating satisfies those needs. For example, a resident might believe that the new district heating will be more affordable than the old system (+1 value of *satisfaction from social innovation* and -1 value of *satisfaction from old system of the affordability need*), and that it will be less polluting for the air (+1 value of *satisfaction from social innovation* and -1 value of *satisfaction from old system* of *the high air quality need*). Agents residing on the virtual version of the Samsø island differ with respect to the degree to which these needs are important to them, and with respect to beliefs about how satisfying it is to continue to use the default heating mode and how satisfying it will be to switch to the district heating network. Residents also have their individual *cognitive dissonance tolerance threshold*, which if exceeded by the preferred alternative, requires them to take action to reduce it. Moreover, residents are characterised by gender, age group, education and income levels. Individual residents form households. All resident agents living in their houses are placed in the NetLogo world

[1] The numbers do not include 8 commercial businesses.

[2] Source: Minutes from the 11th meeting of the working group; 140952 scanned document.

[3] Source: 140952 scanned document.

[4] Source: Samsø weekend newspaper from 15.05.2002.

[5] Source: 2002 Onsbjerg district heating factsheet

fitted to the map of Samsø island. Onsbjerg residents live in their houses located in the Onsbjerg district.

Critical nodes/agents include:

- **Promoters** of the social innovation:
  - a small group of active community members (e.g., Onsbjerg district heating working group)
- **Supporters** of the social innovation:
  - Samsø Energy Academy
  - Expert working with the Energy Academy
- **Opponents** of the social innovation; depending on the heat network implementation, those were:
  - A local plumber (Nordby-Maarup case),
  - A local priest (Onsbjerg case)
  - NRGi energy company (Ballen-Brundby case)
- **Media**.

One time step of the model is an abstract unit and represents the trigger for discrete events (For a more detailed meaning of each tick please see Figure 2.2).

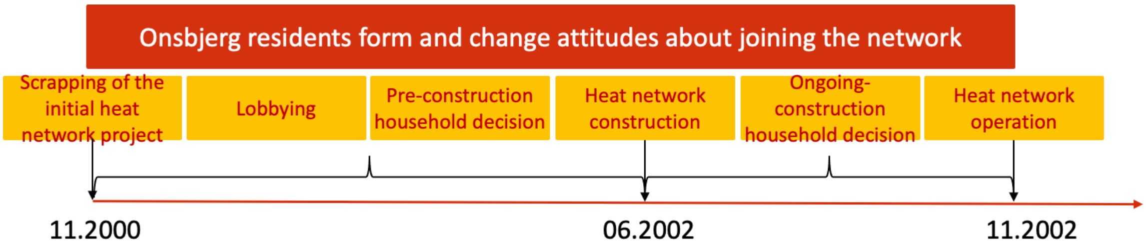
2.1.3 Process overview and scheduling

The model is developed to represent the process of residents deciding whether to join the district heating network in Onsbjerg. The idea for the district heating network in Onsbjerg originated with the 1997 Renewable Energy master plan submitted to the Danish Ministry of Energy (PlanEnergi & Samsø Energiakademi 2007). The plan envisioned creating four district heating networks, including “pearls on a string” - a plant for 530 homes located in seven villages Sælvig/Onsbjerg/Tanderup/Pillemark/Hårdmark/Kolby/Kolby Kaas stretched over a 10 km distance. Due to lack of sufficient investment, the plan was officially abandoned by the Samsø municipality on the 7th of November 2000. Knowing that two local farmers and entrepreneurs, who farmed large tracts of land on contract, produced vegetables near the village and run a construction company - the Kremmer Jensen brothers, would be interested in building the heating plant on one of their properties (DBDH 2002), Onsbjerg residents disappointed with the municipality’s decision met on the 23rd of November 2000 to discuss further options (letter from the Onsbjerg district heating working group to Naturklagenævnet from the 1st of October 2001). Six driven and active community members formed the Onsbjerg district heating working group. The group met regularly over a period of 13 months, between October 2000 and October 2001 (altogether 14 meetings were held) to plan detailed actions and lobby for the social innovation among other Onsbjerg residents. The new project only applied to Onsbjerg residents (a total of 123 households and 8 commercial businesses), and the piping was significantly shortened in comparison to the original plan, to approx. 3 km (VEO 2002). As it turns out, the construction started in June 2002 with only 63 households joining in. However, once the installation became certain and the level of approbation for the social innovation in the neighbourhood became explicitly visible, another 6 households joined in on the project. Such a decision was also financially reasonable for two reasons. One, electricity in the network was guaranteed to be among the cheapest on the island[6]. Two,

[6] *The board of the Onsbjerg district heating system consists of five members from ’Kremmer Jensen ApS’, two members selected by the consumers and one island council member. Changes in heat prices have to be approved by the municipal council* (PlanEnergi & Samsø Energiakademi 2007, p. 12)

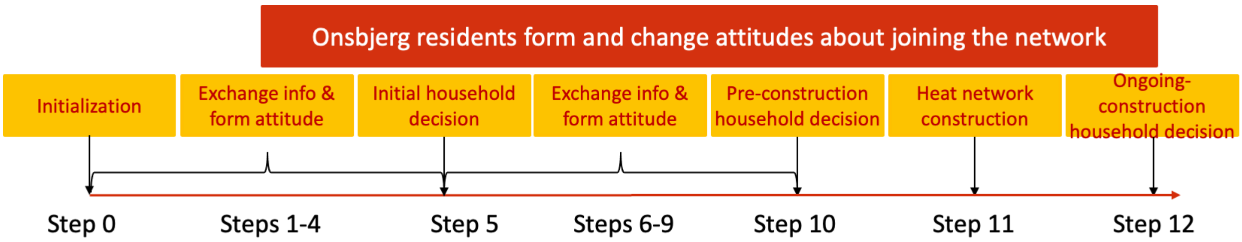
connecting to the heating network for a symbolic 100 DKK (approx. 15 Euro), covering removal of old equipment and installation of the new heating system, was only possible if the construction of the network did not pass the decision-maker's dwelling. Once the piping passed the building, joining costs rose to 300 Euro (VEO 2002). History of the Onsbjerg district heating case study is represented graphically in Figure 2.1.

Figure 2.1 History of the Onsbjerg district heating case study.



The agent-based simulation starts with the idea of the Onsbjerg district heating network project (Figure 2.2). In steps 1-4 and 6-9, uncertain Onsbjerg residents exchange information with alters in their social networks (*Submodel Information exchange*). Subsequently, on the basis of acquired knowledge, those residents assess how satisfied they would be if they joined the network, compared to how satisfied they are with their current heating system (*Submodel Attitude formation*). In step 5 and step 10 of the model run, a discussion between adult household members takes place to reach an agreement on the official household stance on the social innovation (*Submodel household decision*). In step 11 the household has the opportunity to sign up to the heat network, and the construction of the network begins (*Submodel Heat network construction*). At this stage the decision of the household becomes observable for other residents of Onsbjerg. In the 12th and final step, the household inhabitants have their last chance to reconsider under social pressure and join the district heating network at a low cost (*Submodel Attitude formation, Submodel household decision*).

Figure 2.2 Process overview of the Samsø case study agent-based model.



For the time being, the Samsø agent-based model does not contain counterfactual lobbying scenarios to be simulated. The final decision on scenarios will be made together with the stakeholders during a dedicated workshop. Analysis of the case study and information collected during the first stakeholder workshop suggest the following possible lobbying strategies of critical nodes (i.e., promoters, supporters, opponents of the social innovation and the local media):

- *Submodel Resident meeting,*
- *Submodel Door to door,*
- *Sumbodel Send a letter,*
- *Submodel Media propaganda,*
- *Submodel Form coalition,*
- *Submodel Convince opponent.*

2.2 Design concepts

2.2.1 Basic Principles

The HUMAT integrated framework was used to model the process of attitude formation among the residents of the Samsø island, who were making a decision about participating in the district heating network project implemented in their neighbourhood. Assumptions underlying the HUMAT architecture are based on a number of social theories and empirical studies that provided information about the process of forming and changing attitudes. The social part of the architecture deals with exchanging information about the subject of the attitude (e.g., a social innovation (SI)) in social networks:

- When does an individual ask for advice about SI? – theories of motivated action (Harmon-Jones, Harmon-Jones 2002);
- When does an individual try to convince others to his/her point of view? – theories of motivated action (Harmon-Jones, Harmon-Jones 2002);
- How much does an individual value advice from others? – source persuasion studies (Hovland, Janis, & Kelley, 1953; Hovland & Weiss 1951; Kelman & Hovland 1953; McGinnies & Ward 1980; Pornpitakpan 2004).

The cognitive part of the architecture deals with a fundamental question of how attitudes are formed:

- How does SI suit an individual's particular situation? - needs theories (Maslow 1954; Max-Neef 1992; Kenrick, Griskevicius, Neuberg & Schaller, 2010);
- From the perspective of the individual, does SI have pros and cons? – cognitive consistency theories (Festinger 1954; Harmon-Jones, Harmon-Jones 2002);
- Did the individual try SI before? What were the results? - role of direct experiences in memory formation (Fazio, Zanna 1981; Fazio, Powell, & Herr, 1983; Fazio & Zanna, 1978a, 1978b; Fazio et al. 1982);

2.2.2 Emergence

Emergent outputs of the agent-based model are aggregates of the characteristics of individual residents of Onsbjerg district (popularity of original heating system and new district heating, perceived satisfaction from those heating systems) and characteristics of households those individuals live in (popularity of the heating systems). For more details, please see section *Observation*.

2.2.3 Objectives

Every virtual Onsbjerg resident chooses whether to join the district heating network or to continue using the current heating system. Knowledge of HUMATS is represented as cognitions (Festinger 1954, p. 3) - beliefs about how satisfying each alternative will be for the relevant needs/motives of the individual. Satisfaction of a method of heating (either original heating system or the new district heating) is a cumulative satisfaction/dissatisfaction of needs/motives weighed by importance of each of those needs/motives. Residents only change their habits in heating if they received information significantly changing their knowledge about how (dis)satisfying both heating systems are. The chosen alternative maximizes the individual's overall level of satisfaction with respect to the needs/motives that drive the resident's behaviour and minimizes the level of experienced cognitive dissonance (described in detail in *Attitude formation submodel*).

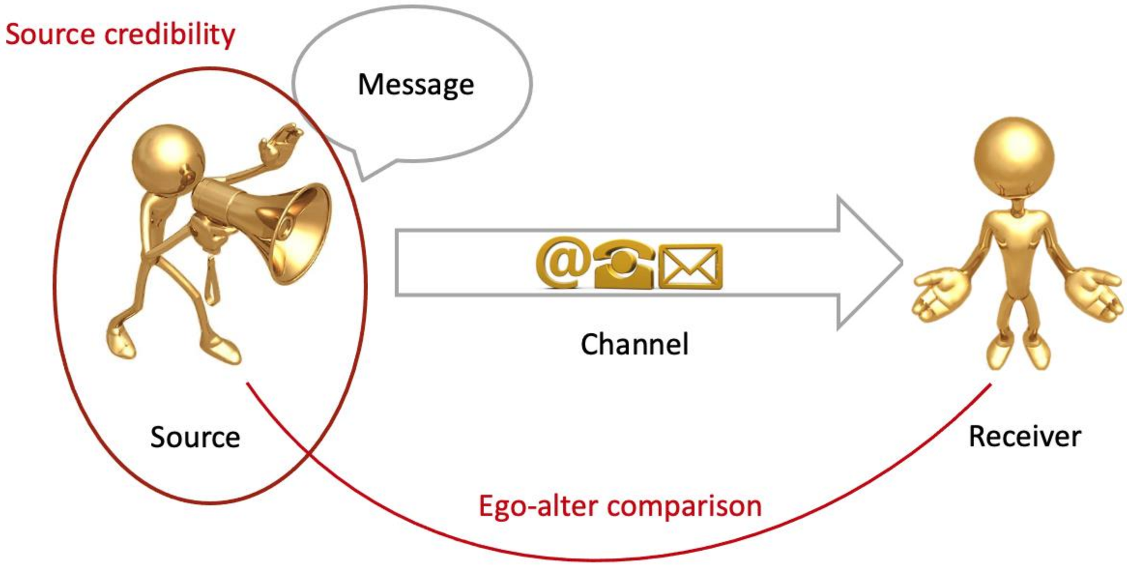
2.2.4 Interaction

The process of attitude formation is supplemented by information exchange between agents. Every Onsbjerg resident is equipped with episodic memory and can actively initialize information exchange with alters in his/her ego network (for details related to social networks please see *Initiation of social networks* section). Information exchange is implemented as a dissonance reduction technique used by the agents. Therefore, it is only activated when an Onsbjerg resident does not find a clearly more satisfying alternative of providing heating, and both alternatives seem similarly dissonant (both heating systems have pros and cons). Depending on satisfaction of the social need, information exchange can take two forms: signalling and inquiring (described in detail in *Information exchange submodel*).

If the slightly preferred heating method does not have enough popularity, ego signals to his/her most gullible alter with an opposite preference for the heating system and tries to convince them to change their mind. Sufficient popularity is obtained when ego's social need is satisfied. Onsbjerg residents differ with respect to the importance of the social need i.e., to what extent an individual wants to follow the norms set by his/her neighbours. In the Samsø ABM satisfaction of the social need is only calculated on the basis of the neighbours network. Therefore, the need is sufficiently satisfied only when a fraction of ego's neighbours equal (or exceeding) the importance of social need chooses the same method of heating. As a result, agents with low importance of social need are individualistically-minded and do not give into social pressure easily. Agents with high importance of social need only feel satisfied when they belong to a neighbourhood of like-minded people.

The extent to which the alter will be influenced by a signalling ego depends on the ego's persuasiveness level in the eyes of the alter (Figure 2.3). Persuasiveness of a typical node in the Samsø ABM depends on the result of comparing ego-alter similarity with respect to needs/motives - to what extent is the source of information like me (the receiver)? Similarity between the source and the recipient was found to increase persuasiveness – individuals model behaviours of those with whom they identify (Bandura 2002). Initially, investigated similarity characteristics included demographic variables, such as age, place of birth, ethnicity (Gillespie 1981; Eagly & Himmelfarb 1978; Feldman 1984; Maccoby & Wilson 1957). Later studies emphasised that perceived similarity refers to the extent to which an individual believes a portrayal seems to realistically reflect his or her own experiences (Austin & Meili, 1994). Later studies that explored dimensions of similarity found traits such as intelligence or maturity as important (Andsager et al. 2006). In the Samsø ABM, socio-demographic characteristics of agents determine the existence of links in various types of social networks (described in detail in *Initialization of social networks*). Therefore, they influence information exchange by limiting who the recipient of the message can be. However, persuasiveness of the source of the message per se is determined by ego and alter's similarity with respect to needs/motives driving the decision regarding the implemented heating system. Consequently, if the source of the message (e.g., a signalling ego) has low disposable income and finds affordability of the heating system very important, he/she will be perceived as more persuasive to an alter who also values affordability highly compared to a source who has a high disposable income and does not regard the cost of heating as an important factor in their decision making.

Figure 2.3 Persuasiveness of the source in HUMAT's information exchange.



Persuasiveness of a critical node in the Samsø agent-based model depends on source credibility:

(1) expertise of the source - the extent to which a speaker is perceived to be capable of making correct assertions (Pornpitakpan 2004), and

(2) trustworthiness of the source - the degree to which an audience perceives the assertions made by a communicator to be ones that the speaker considers valid (Hovland, Janis, & Kelley, 1953).

Initially (from step 1 to step 10 of a model run), the household decision is an invisible behaviour. Therefore, the network of ego's neighbours with whom ego can exchange information about heating methods is relatively small (please see *Initialization of social networks* section for more details). At step 11, as construction of the new district heating starts and the choice becomes visible, ego's neighbours network expands to include all Onsbjerg residents. As a result, peer pressure changes its character from a small-group norm to a more extensive social norm of the district.

If the strategy of signalling is not suitable to decrease the dissonance experienced by an agent, he/she chooses to inquire about the slightly preferred heating method. When inquiring, Onsbjerg residents are not limited to their neighbours networks, and can ask any alter from all types of networks for advice. Moreover, when asking for advice, ego chooses the most persuasive of the alters in his/her social network. For more details on information exchange strategies and persuasiveness of agents, please see *Information exchange* submodel.

In contrast with Onsbjerg residents, the residents of other districts do not make a decision about the heating method. Therefore, even though they hold opinions on the matter of their own preference, they do not actively initiate information exchange. They only share their opinion if asked by an Onsbjerg resident.

2.2.5 Stochasticity

Stochasticity is present in the Samsø ABM during:

- network formation – agents distributed randomly over a square when links are created based on proximity,
- agent location - agents are assigned randomly to households in the district,
- command execution - order of executing commands by agents is random.

2.2.6 Collectives

Virtual Samsø residents are connected via three types of social networks:

- friends,
- co-workers,
- neighbours.

The social networks in the Samsø ABM display characteristics actual social networks are known to possess i.e., they: are limited in size, vary in size between individuals, are strongly homophilic, and exhibit high clustering. To fulfil these requirements, initiation of network topography (described in detail in *Initialization of social networks*) was based on the idea of using social circles described by Hamill and Gilbert (2009).

2.2.7 Observation

Outputs of the Samsø agent-based model include:

- Popularity of the original heating system and the new district heating on individual level:
    - N and % of individuals initially willing to join the heat network (step 5);
    - N and % of individuals joining the heat network at the early stage (pre-construction, step 10);
    - N and % of individuals joining the heat network at a late stage (ongoing construction, step 12);
    - Difference between the initial willingness and early-stage in N and % of individuals;
    - Difference between the initial willingness and late-stage inN and % of individuals;
    - Difference between the early-stage and late-stage in N and % of individuals;
    - N and % of individuals who have changed their mind at least once;
    - average number of times individuals have changed their mind;
- Satisfactions from the original heating system and the new district heating:
    - Average satisfaction from the original heating system and the new district heating (step 5);
    - Early-stage satisfaction from the original heating system and the new district heating (pre-construction, step 10);
    - Late-stage satisfaction from the original heating system and the new district heating (ongoing construction, step 12);
    - Difference between the initial and early-stage average satisfactions from the original heating system and the new district heating;
    - Difference between the initial willingness and late-stage average satisfactions from the original heating system and the new district heating;
    - Difference between the early-stage and late-stage average satisfactions from the original heating system and the new district heating;

- Popularity of the original heating system and the new district heating on the household level:
  - N and % of households initially willing to join the heat network (step 5);
  - N and % of households joining the heat network at the early stage (pre-construction, step 10);
  - N and % of households joining the heat network at a late stage (ongoing construction, step 12);
  - Difference between the initial willingness and early-stage in N and % of households;
  - Difference between the initial willingness and late-stage in N and % of households;
  - Difference between the early-stage and late-stage in N and % of households;
  - N and % of households where decision-makers are in agreement.

2.3 Details

2.3.1 Initialization

The Samsø agent-based model was calibrated to the Samsø case with respect to (1) timeline of particular relevant events (please see *3.1.3 Process overview and scheduling* for details), (2) geo-socio-demographic characteristics of the resident population, (3) motives/needs of the residents, which were activated by the social innovation, and (4) social networks of residents. Before the final simulations of the model, another dimension of calibration will be added i.e., presence and behavioural tactics of critical nodes. Those behavioural tactics will represent factual and counterfactual policy scenarios.

2.3.1.1 Initialization of population

For the purpose of the agent-based model calibration, a population of Samsø from 2001 was recreated on the basis of available statistical data. The population is representing the actual population of the Island with respect to:

- size of the population (3 527 individuals/agents);
- gender (2 categories: M, F);
- age (3 categories: 15-24, 25-69, 70+);
- education level (3 categories: short, medium, long);
- individual disposable income (3 categories: low, medium, high),

and all the known dependencies between these characteristics. As a result, every agent in the model belongs to one of 54 homogenous groups i.e., intersections of the four socio-demographic characteristics. All the groups comprise a fraction of the modelled population that matches the actual fraction of Samsø residents in 2001 with a particular set of socio-demographic characteristics. As a result, there is no stochasticity in the model in this respect.

Whenever information on dependencies between the characteristics were not available in existing data, assumptions about probable dependencies were implemented (e.g., high positive correlation between education level and disposable income) prior to model calibration.

Original data used for population recreation was retrieved from two individual statistical tables from Statistics Denmark:

- Statistics Denmark (2020a). HFU1: Educational attainment of the population (15-69 years) by region, ancestry, education, age, and sex. Retrieved 24.11.2020 from https://www.statbank.dk/hfu1;
  - Region: Samsø
  - Ancestry: Total

  - Education: 79 categories
  - Age: 11 categories (15-19, …,64-69)
  - Sex (men, women)
  - Year: 2001
- Statistics Denmark (2020b). INDKP106: Disposable income for people (14 years +) by region, unit, sex, age and income interval. Retrieved 24.11.2020 from https://www.statbank.dk/INDKP106
  - Region: Samsø
  - Unit: Average income for persons in the group (DKK)
  - Sex (men, women)
  - Age: 13 categories (15-19, …,74+)
  - Income interval: 16 categories
  - Year: 2001

After retrieval, data was aggregated into meaningful categories with respect to:

- age,
- education level:
  - short education - education at the basic school 8-10 grade level (in Danish "grundskole"),
  - medium education - education at the upper secondary level (in Danish "almengymnasial uddannelser, erhvervsgymnasial uddannelser, erhvervs uddannelser"),
  - long education - education at all higher education levels (in Danish "korte videregaaende uddannelser, mellemlange videregaaende uddannelser, bachelor, lange videregaaende uddannelser").
- individual annual disposable income (after tax):
  - low income level - 0-74999 DKK,
  - medium income level - 75000-174999 DKK,
  - high income level - 175000 DKK or more.

2.3.1.2. Initialization of motives

Identification of relevant motives, estimation of the motive importances for various socio-demographic groups and satisfaction of motives by the default heating system and the new district heating were estimated by the modellers together with NTNU researchers responsible for investigating the Samsø case on the basis of available secondary materials and information from in-depth interviews conducted with key stakeholders from Samsø. The details of calibrating motives related to how the resident's current heating system satisfies experiential needs and values (motives 1-4 and 6-8) at initialization of the ABM can be found in Table 2.2. At the start of the simulation, Onsbjerg residents do not have perceptions about the social innovation. This information is subject to exchange in social networks. Importance of social need (motive 5) at model initialization is distributed normally with a mean of 0,5 and sd of 0.14, truncated between values 0 and 1. Satisfaction of the social need is negative if the fraction of neighbours in ego's network, who choose the same heating system as ego is below the importance of social need of the ego.

Table 2.2 Calibration to experiential needs and values of Onsbjerg residents at model initialization.

Need	Importance of the need is …	Categories of the related characteristic	Formulas for each category of the related characteristic	Satisfaction from current heating system
Motive 1: Affordability (experiential)	Increasing with decreasing disposable income per household (income_cat)		I = 0,5	
		low	Importance motive 1 (affordability) = I +/- random-float 10% of I; max 1, min 0	95% -, 5% +
		mid	Importance motive 1 (affordability) = I - 0,2 +/- random-float 10% of I; max 1, min 0	95% -, 5% +
		high	Importance motive 1 (affordability) = I - 0,4 +/- random-float 10% of I; max 1, min 0	95% -, 5% +
Motive 2: High air quality (experiential)	random	Satisfaction changes direction depending on proximity of the household to the heating plant (55.847898, 10.566350; Præstegårdsvej 15)	I = 0,3	
			Importance motive 2 (high air quality) = I +/- random-float 50% of I; max 1, min 0	living more than approx. 200 m from the plant: 95% -, 5%+
				living less than approx. 200 m from the plant: 95% +, 5% -
Motive 3: Safety	increasing with increasing age (age_group)		I = 0,3	
		15-24	Importance motive 3 (safety) = I - 0,2 +/- random-float 50% of I; max 1, min 0	95% -, 5% +
		25-69	Importance motive 3 (safety) = I - 0,1 +/- random-float 50% of I; max 1, min 0	95% -, 5% +
		70+	Importance motive 3 (safety) = I +/- random-float 50% of I; max 1, min 0	95% -, 5% +
Motive 4: Renovation inconvenience	increasing with increasing age (age_group)		I = 0,6	

		15-24	Importance motive 4 (renovation inconvenience) = I - 0,2 +/- random-float 50% of I; max 1, min 0	95% +, 5% -
		25-69	Importance motive 4 (renovation inconvenience) = I - 0,1 +/- random-float 50% of I; max 1, min 0	95% +, 5% -
		70+	Importance motive 4 (renovation inconvenience) = I +/- random-float 50% of I; max 1, min 0	95% +, 5% -
Motive 6: Sustainability (decreasing carbon emissions)- value	increasing with increasing education (edu_cat)		I = 0,3	
		long	Importance motive 6 (sustainability) = I +/- random-float 50% of I; max 1, min 0	95% -, 5% +
		medium	Importance motive 6 (sustainability) = I - 0,1 +/- random-float 50% of I; max 1, min 0	95% -, 5% +
		short	Importance motive 6 (sustainability) = I - 0,2 +/- random-float 50% of I; max 1, min 0	95% -, 5% +
Motive 7: Islander pride (value)	random		I = 0,1	
			Importance motive 7 (pride) = I +/- random-float 50% of I; max 1, min 0	95% -, 5% +
Motive 8: Visual aesthetics (experiential need)	increasing with the living closer to the plant; particularly in relation to the church village grounds		I = 0,2	
			Importance motive 8 (visual aesthetics) = I +/- random-float 50% of I; max 1, min 0	living less than approx. 200 m from the plant: 0
				living more than approx. 200 m from the plant: 0

2.3.1.3. Initialization of social networks

Main characteristics of social networks implemented in the Samsø ABM are presented in Table 2.3. The details of network initiation are described below.

Table 2.3 Main characteristics of networks in the Samsø ABM by type.

Network type	Homophily	Fraction of agents who follow heterophily rules	Average number of alters in an ego network (d)
friends	Age, education	3%	5
co-workers	Education, disposable income	1%	5
neighbours	Household location	NA	5 +/- 2[1]

[1] The maximum number of neighbours in ego's network. Please see *Neighbourhood networks* description below for more details.

Friends and co-workers networks

Agents are randomly distributed over a square of size 120 by 120 patches and create links of a given type to all agents in a pre-defined radius *r*:

$$r = \sqrt{\frac{\frac{d}{\pi}}{\frac{n}{s^2}}}, \qquad \text{(Equation 2.1).}$$

Size of that radius depends on the ratio between:

- $\frac{d}{\pi}$, where *d* is the targeted average number of alters in an ego network, and
- $\frac{n}{s^2}$ - density of agents from a given homophilic group per square patch, *n* – number of agents in a group divided by area of the square the group is occupying. Length of the side of the square (*s*) equals 120 patches.

To avoid perfect homophily, a mixing parameter is introduced. The parameter designates the percentage of agents from a given homogenous group (as defined by the homophily characteristics present in a given network, e.g., agents with lower education in the age group of 15-24) who are networked to another group instead.

Neighbours network

In the case of neighbourhood network, the homophily criterion is the household location. Out of all households in the radius of 5, ego creates neighbour links with a maximum of 5 (+/- 2) neighbours living. The maximum number of neighbours is set for each Onsbjerg resident individually. If the number of neighbours in radius of 5 patches:

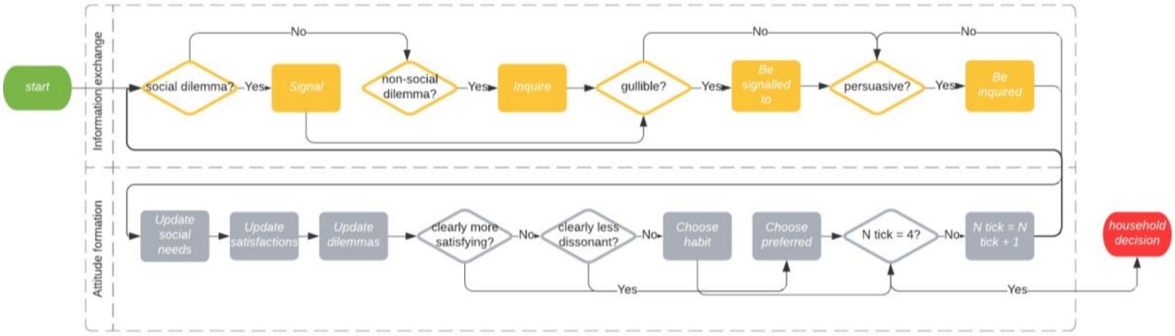
- exceeds the maximum number of neighbours ego should have, ego links to the maximum number of neighbours that live closest to it;
- is less than the maximum number of neighbours ego should have, ego links to the neighbours it has (without creating double links to the neighbours that already connected to ego);
- quals 0, i.e. ego has no neighbours in the defined radius, ego links to the neighbour that lives closest.

Following these rules, all Onsbjerg residents have at least one neighbour in their neighbours network.

2.3.2 Submodels

The main submodel in the Samsø ABM is the HUMAT architecture. The architecture and its role in agent-based modeling in the SMARTEES project was extensively described elsewhere (Antosz et al. 2019), therefore here only the details relevant for the Samsø ABM will be presented (Figure 2.4). The architecture consists of two main processes: (1) attitude formation, and (2) information exchange in the social networks.

Figure 2.4 The process of attitude formation of Onsbjerg residents.



2.3.2.1 Attitude formation (steps 1-9)

If a resident is satisfied with the current heating system, he/she behaves habitually (Simon 1976). However, introducing an innovative alternative may distort those habits. Every Onsbjerg resident evaluates both alternative heating systems on two dimensions: (1) expected satisfaction and (2) psychological comfort (i.e., low level of cognitive dissonance).

Expected satisfaction from an alternative is assessed with respect to eight motives ($mj \in \{m_1, \dots, m_8\}$) belonging to three groups:

- Affordability (**experiential** need, e_1),
- High air quality (experiential need - e_2),
- Safety (experiential need - e_3)
- Renovation inconvenience (experiential need - e_4),
- **Social** need (s),
- Ecological **values** (v_1),
- Islander identity (value - v_2),
- Aesthetics (value - v_3),

according to Equation 2.2:

$$S_{i,j}^{p,t_n} = \frac{\sum_{m=1}^{8} I_{m,j}^{t_n} S_{i,m,j}^{p,t_n}}{8} =$$

$$= \frac{I_{e1,j}^{t_n} S_{i,e1,j}^{p,t_n} + I_{e2,j}^{t_n} S_{i,e2,j}^{p,t_n} + I_{e3,j}^{t_n} S_{i,e3,j}^{p,t_n} + I_{e4,j}^{t_n} S_{i,e4,j}^{p,t_n} + I_{s,j}^{t_n} S_{i,s,j}^{p,t_n} + I_{v1,j}^{t_n} S_{i,v1,j}^{p,t_n} + I_{v2,j}^{t_n} S_{i,v2,j}^{p,t_n} + I_{v3,j}^{t_n} S_{i,v3,j}^{p,t_n}}{8}, \quad (\textit{Equation 2.2})$$

where

$I_{m,j}^{t_n}$ - importance of motive m for resident j at time t_n ($\in$ $(0,1\rangle$) - a personality trait that is not dependent on a particular behavioural alternative i.

$S_{i,m,j}^{p,t_n}$ - expected satisfaction from behavioural alternative i with respect to motive m for resident j at time t_n ($\in \{-1, 1\}$).

Residents are heterogeneous with respect to how important each motive is and how satisfying they perceive both alternatives to be with respect to each motive. For details on how importances and satisfactions of motives are related to socio-demographic characteristics of individuals, please see *Initialization of motives*.

As presented in Equation 2.2, evaluations of different motives ($I_{m,j}^{t_n} \, S_{i,m,j}^{p,t_n}$) are summed up to compose an overall satisfaction score of a behavioral alternative. It is consistent with the principles of the Theory of Planned Behaviour (Ajzen, 1991), where cognitions can be envisaged as a multiplication of the strength of a belief or attribute (i.e., the individual difference of motive importance) and the satisfaction of that attribute.

Once an Onsbjerg resident assesses the satisfaction level of both available behavioural alternatives (i.e., continuing with the current heating method and joining the new district heating network), they choose the clearly more satisfying one. If both options seem similarly satisfying (within the value of 0,2 i.e., 10% of the range of theoretical values of satisfaction), the resident further explores alternatives with respect to the amount of cognitive dissonance each one evokes.

Evaluation of a behavioural alternative i with respect to motive m, i.e.:

$$E_{i,k,j}^{t_n} \; = \; I_{k,j}^{t_n} \, S_{i,k,j}^{p,t_n}, \qquad \text{(Equation 2.3)}$$

can be perceived by resident j at time t_n as:

- Dissatisfying (i.e., $I_{k,j}^{t_n} \, S_{i,k,j}^{p,t_n} \in < -1; 0)$),
- Neutral (i.e., $I_{k,j}^{t_n} \, S_{i,k,j}^{p,t_n} = 0$),
- Satisfying (i.e., $I_{k,j}^{t_n} \, S_{i,k,j}^{p,t_n} \in \; (0; 1 >$).

In other words, residents of Onsbjerg experience dissonance between cognitions when a behavioural alternative is perceived to have pros (be satisfying) and cons (be dissatisfying) at the same time. For example, psychological tension occurs when a resident is in the process of making a decision and activates the following two beliefs:

- “my current heating system is already expensive and the prices are rising” - current system’s negative evaluation of the need of affordability - an argument to change the heating method, and
- “my current heating system does not require building a smelly, ugly heating plant next to my house” - current system’s positive evaluation of an aesthetic value - an argument not to join the district heating network.

Amount of dissonance that a behavioural alternative i evokes in resident j at time t_n ($D_{i,j}^{t_n}$) is quantifiable as follows:

$$D_{i,j}^{t_n} = \frac{2d}{d+c}, \quad \text{(Equation 2.4)}$$

where:

d - dissonant cognitions ($min(\sum\ satisfying\ E_{i,k,j}, \sum\ dissatisfying\ E_{i,k,j})$,

c - consonant cognitions ($max(\sum\ satisfying\ E_{i,k,j}, \sum\ dissatisfying\ E_{i,k,j}$).

Cognitive dissonance is a motivational force for a change in knowledge (Festinger 1954) or behaviour (Harmon-Jones, Harmon-Jones 2002). Occurrence of cognitive dissonance leads to a psychologically unpleasant state of facing a dilemma. There are two types of such dilemmas. A **social dilemma** occurs when the alternative i yields satisfaction of any of the experiential needs or values AND dissatisfaction of social needs. It corresponds to a situation where, for example, the resident is convinced that new district heating has a sufficient number of pros, but at the same time he/she feels secluded with this opinion, because not enough neighbours want to join the new heating network. To resolve a strong social dilemma, the resident **signals** to his/her neighbours to try to convince them to join the district heating network (for details please see the *Signalling* section of the *Information exchange submodel*). A **non-social dilemma** occurs is any other instance of cognitive dissonance. For example, the resident is convinced that new district heating is popular enough with other neighbours, but in his/her personal opinion has a sufficient number of cons (e.g., requires building an ugly heating plant next door (negatively evaluated aesthetics value), which will be very smelly (negatively evaluated high air quality experiential need)). To resolve a strong non-social dilemma, the resident **inquires** with other alters in his/her ego network to find more arguments for the preferred alternative (for details please see the *Inquiring* section of the *Information exchange submodel*).

Harmon-Jones and Harmon-Jones (2002), in their action-based model of dissonance, hypothesise that the reason for discomfort from dissonant cognitions is due to the fact that inconsistent cognitions have the potential of interfering with effective action. Cognitions serve as guides for behaviour, so when cognitions are in conflict, behaviour will be impeded (Harmon-Jones & Harmon-Jones 2018, p. 74). Brehm's motivation intensity theory proposes that people manage their resources following a conservation principle (Brehm et al. 1983; Brehm & Self 1989). Therefore, effort required to execute a behaviour will only be exerted (1) to the extent that it is needed, and (2) only when its expenditure is justified (return on the effort is expected). Most often dissonant cognitions are being suppressed or ignored as an effective dissonance reduction strategy (McGrath 2017). Therefore, in HUMAT architecture used in the Samsø agent-based model, dissonance needs to be actively resolved so that behaviour can occur only when it exceeds the individual's tolerance threshold (T). As a consequence, at time t_n a behavioural alternative i evokes a certain fraction of above-tolerance-threshold non-dissonance in resident j:

$$F_{i,j}^{t_n} = 1 - \frac{D_{i,j}^{t_n} - T_j}{1 - T_j}, \quad \text{(Equation 2.5)}$$

IF $F_{i,j}^{t_n} > 1$, $F_{i,j}^{t_n} = 1$.

If both alternatives are perceived as similarly dissonant (within 0,1 i.e., 10% of theoretical range of subjective dissonance perception), Onsbjerg resident chooses the alternative that was chosen in the previous time step. If a previous decision is unavailable (at initiation of the model), a random decision is made.

2.3.2.2 Information exchange (steps 1-9)

If the resident is hesitant about the chosen alternative, dissonance resolution strategies are employed only to confirm the decision (signalling and inquiring).

Signalling

When signalling, Onsbjerg residents try to find an alter who would be easiest to convince to change their opinion. Three factors play a role when making a decision. Ego inquires first with alters who:

- have not been inquired with yet,
- choose the different behaviour, and
- are the most gullible.

Inquiring

When inquiring, Onsbjerg residents try to preserve their cognitions and activate a search that maximises the probability of receiving information that fits their preferred alternative. Three factors play a role when making a decision. Ego inquires first with alters who:

- have not been inquired with yet,
- choose the same behaviour, and
- are the most persuasive.

Once the most suitable alter is chosen for information exchange, the degree to which inquiring/signalled to ego is influenced depends on persuasiveness of the inquired to/signalling alter. Persuasiveness of a typical node in the Samsø ABM depends on the result of comparing ego-alter similarity with respect to needs/motives. The calculation for need/motive similarity is performed for each need/motive for both behavioural alternatives as follows:

$$0.4(1 - abs\left(I_{m,e}^{t_n} - I_{m,a}^{t_n}\right)), \qquad (\textit{Equation 2.6})$$

where

$I_{m,e}^{t_n}$- importance of motive m for ego,

$I_{m,a}^{t_n}$ - importance of motive m for alter.

When Samsø residents influence each other, they affect the perception of importance of a need/motive they are discussing. The degree of similarity between interacting agents is therefore applied as a weighing factor to calculate the new importance of the need/motive for both agents. The maximum value of similarity is set at 0.4. As a result, when two agents find similar motives similarly important, they influence each other to a maximum of 40%. The new value of importance is calculated as 60% of the old importance of the influenced agent and 40% of the old importance of the influencing agents. If interacting agents don't find the same needs important (i.e., evaluation of a need is positive for one and negative for the other), the influencing agent does not affect the influenced agent.

The attitude formation and information exchange submodels are also used when adults living together interact to make a joint decision on the household heating system (for details see *Household decision* submodel). The difference in step 5 is that the resident does not strategically choose who to exchange information with – the choice is the housemate.

2.3.2.3 Household decision (steps 5, 10 and 12)

The decision on the heating system for the household is made jointly by two household decision-makers, if the household has more than one person older than 15. If the decision-makers have different preferences, they engage in a dialogue in the form of inquiring. If after discussion the decision a consensus between decision-makers is not reached, the preference is chosen at random.

2.3.2.4 Heat network construction (step 11)

The heat network is built on a patch-by-patch basis, starting from the south of the city where the heating plant is located. When the heating infrastructure reaches a household to the left or right, the household inhabitants re-evaluate their social satisfaction on the basis of all the Onsbjerg residents whose households were already passed by the infrastructure and formulate their preference with respect to joining the heat network. This way, the neighbours' decision becomes visible and creates additional social pressure.

3 Case study cluster 3: Sustainable district regeneration

3.1 Overview

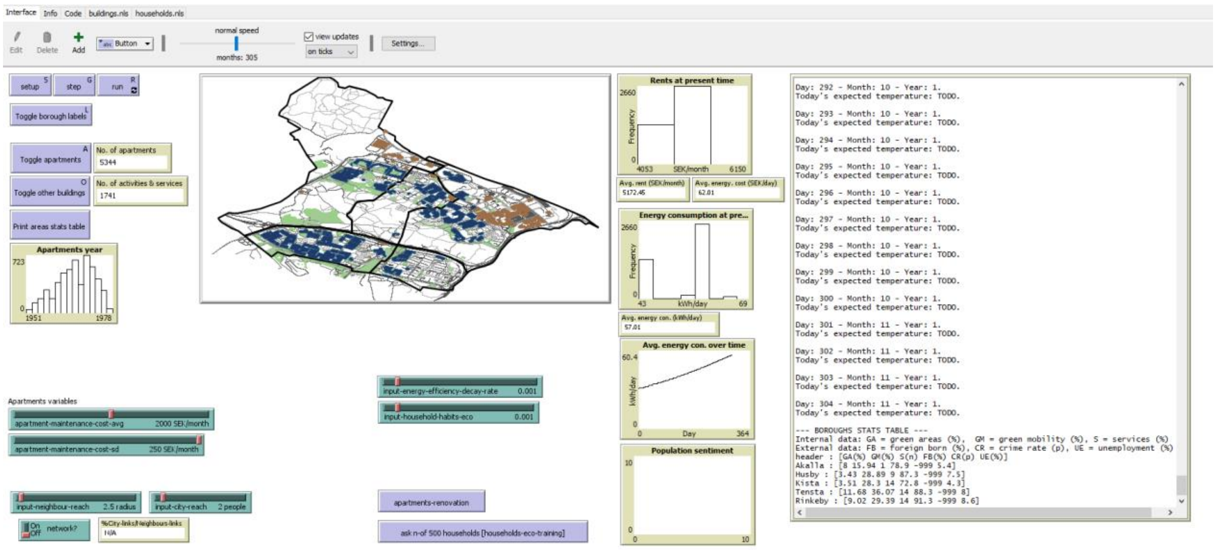
3.1.1 Purpose

For the Stockholm and Malmö case studies, successful social innovations are related to building renovations and neighbourhood participation in socially diverse and economically challenged neighbourhoods. The purpose of these models is to anticipate the long-term impact activities and policies aimed at sustainable district regeneration have on cities accounting simultaneously for multiple outcomes (e.g., energy performance and people satisfaction).

3.1.2 Adapting the model to the Malmo case

Stockholm and Malmo studies shared many commonalities (see SMARTEES Deliverable 6.1). Both the interventions and policies aimed at sustainable district renovation were built upon the same principles and implemented over the buildings built during the Swedish Million House Programme. Likewise, the network of actors sees the collaboration of citizens, municipality, and the housing association in both cases. Therefore, the agent-based model is going to be initially built for the Stockholm cases and later adapted to Malmo. Differences between the models are related to the different data and data sources used to feed the models.

Figure 3.1 Interface of the Stockholm ABM.



3.1.3 Entities, state variables and scales

3.1.4 Agents

A set of agents representing different elements of the Stockholm/Malmö social system are included in the model.

- **Buildings**. Buildings are a representation of real-world buildings and have three categories:

- ○ ***Apartments***. Apartments are the dwelling owned by the housing association of the city. Important variables are their size, energy efficiency, energy consumption, and energy cost. Building renovation can be performed on any building of type apartment.
- ○ ***Services***. They are used by agents of type 'residents' to satisfy their needs.
- ○ ***Activities***. A virtual representation of commercial and industrial activities. They represent workplaces where households' agents can move to during the day.

- **Roads**. Roads are taken from the GIS datafiles and classified in three categories.
  - ○ ***Roadways***. Only cars can move over these roads.
  - ○ ***Cycleways***. Green mobility, only bicycles.
  - ○ ***Footways***. Green mobility, only walking.
- **Households**. Households represent residents of the city. Each household is uniquely linked to an apartment. Households rather than individuals were chosen because it seemed reasonable that any meaningful decision with respect to a district regeneration model (e.g. to leave the apartment as part of a renovation project) would be made at the household level. Households can be employed or unemployed. At each step, households move on the map. Agents representing employed households move to a unique workplace (i.e. activities), whereas unemployed households move to services or green areas. Energy consumption of apartments is coupled to the household environmental habits.

3.1.5 Networks

The model uses a network structure called social circles as proposed by Hamill and Gilbert (2009). However, while social circles represent well neighbourhood ties (i.e., local communities), they hardly account for weak ties that may be encountered in urban social networks. Thus, the model asks to each household to draw a variable number of global connections with households outside their local neighbourhood. The ratio between local and global connections can be varied from the interface.

3.1.6 Temporal framework

Each tick corresponds to a day. The model is expected to run for 10 years.

3.1.7 Spatial resolution

For the present moment the model has been limited to the Jarva area of Stockholm city, which comprises the boroughs of Akalla, Husby, Kinsta, Rinkeby, and Tensta. The reason is to speed up the development process. Because Malmo area is less than half than Stockholm's, its model will consider the whole city.

3.1.8 Exogenous factors

Exogenous factors will include the weather and possible environmental issues caused by climate change.

3.1.9 Process overview and scheduling

Daily schedule

- Retrieve and set the temperature/weather
- Households leave houses for daily routine
- Households evaluate if daily routine is disrupted by any intervention

- If any intervention is active and encountered by households, households will evaluate the level of "frustration" caused by the intervention
- Households go back home
- Households consume energy

Monthly schedule

- Households receive wage
- Apartment's energy system degrades and/or fails randomly
- Households pay rent to housing association
- Housing association receives rent
- Households pay utility bills

3.2 Design concepts

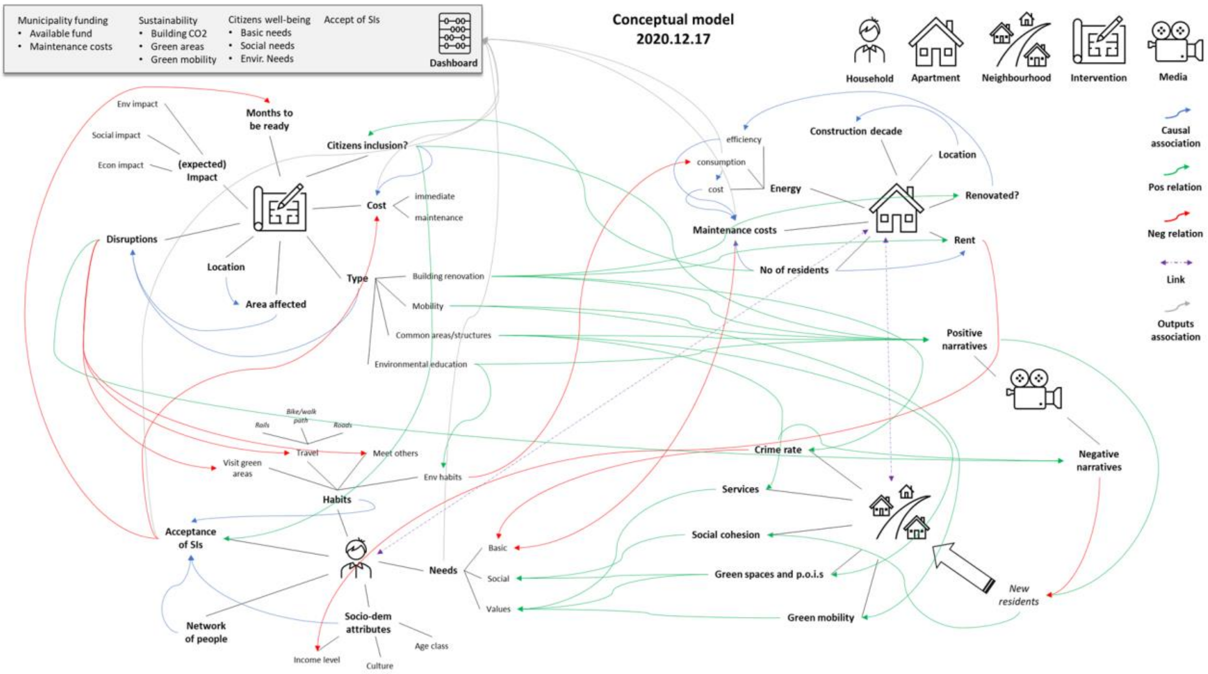
3.2.1 Theoretical and empirical background

Stockholm and Malmö are complex social systems composed by different actors (e.g. citizens, businesses, housing companies) related by an intricate set of relationships. Thus, the design of the model is based on the specific work conducted during the SMARTEES project and the deliverables produced. In particular, D6.1 "Report on social innovation drivers, barriers, actors and network structures" provided the foundations of the system elements and their relationship (see figures 4.1).

Tipping points theory is also included in the model. Households may reach a certain threshold where they feel the need to react (i.e., protest) against the interventions imposed by the municipality. This will trigger a change of phase in the social system, where the municipality will incur an unplanned cost to regain the trust of the residents and reinstate the normal functioning of the social system.

Some concepts of the HUMAT are loosely incorporated. For instance, households have basic, social, and value needs that are connected to the properties of their apartments or to the neighbourhood properties.

Figure 3.2 Conceptual model drawn based on the theoretical model and the data available and driving the development of the agent-based model.



3.2.2 Individual decision-making

3.2.3 Subject and objects of decision

- Households can decide to accept/not accept innovations.
- Municipality (i.e., end user) can decide what type of innovations to apply and where.
- Municipality (i.e., end user) can decide what buildings are going to be repaired and to what extent.

Innovations for Cluster 3 are defined as interventions aimed at sustainable district regenerations. Examples can be the renovation of buildings energy systems, the creation of green paths (cycleways and footways), or the creation of green areas (e.g., parks).

3.2.4 Decision rules

As described in D6.1, households have a limited agency with respect to the planning and execution of sustainable district regeneration projects. Therefore, households' decisions are limited to the acceptance/not acceptance of social innovations.

3.2.5 Social influence

Households can influence and be influenced by other households in the network with respect to the acceptance of social innovations. For instance, a household that has gone through a building renovation project may "share" its experience with a household from another district who has not received a renovation yet. The acceptance of a renovation project of the second household will depend on the experience of the first.

3.2.6 Learning

Households learn the degree of acceptability of social innovations from their first-hand experience and from the experience of households in the network.

3.2.7 Interaction

Households can share the experience of district renovation projects with other households. Interventions affect households within a certain area.

3.2.8 Collectiveness

No collectiveness is present.

3.2.9 Heterogeneity

Households are heterogenous with respect to their network, acceptance of social innovations, and socio-demographic characteristics (e.g., income).

3.2.10 Stochasticity

Stochastic processes include:

- Apartment construction year and size is randomly assigned from observed distribution (see section 3.3.1 about inputs).
- Household location on the map is randomly assigned.
- Household social network is randomly built.

3.2.11 Observation

Observations collected from the model include:

- Average energy consumption per day of apartments
- Percentage of renovated buildings
- Average apartments' rent
- Households' acceptance of social innovations
- Households' sentiment
- Percentage of green areas/mobility

3.2.12 Emergence

Protests or a greater acceptance of social innovations may emerge from the management of district regeneration interventions.

3.2.13 Validation

The validation of the model will be conducted by comparing the outputs of virtual interventions with the outputs of real-world interventions.

3.3 Details

NetLogo 6.1. The model is split into different files to increase human comprehension (e.g., a separate file for household and their behaviour, another file about apartment, etc.).

3.3.1 Initialisation/Inputs

Inputs were collected, analysed, and adapted to feed the model from a variety of sources. The following list reports the source and the information retrieved from each source.

- **Open Street Map**
    - GIS datafiles (roads, green areas, buildings, boundaries)
- **Stockholm Census**
    - Percentage of foreign born per borough
- **Stockholm City Council. Sustainable Jarva (automated English translation).**
    - Number of apartments owned by housing company in Jarva area
- **Persson, A., Högdal, K. (2015). Sustainable cities – Energy efficiency Renovation and its Economy. Environment and Health Administration / Energy centre & Sustainable Järva: Stockholm (Sweden).**
    - Unemployment rate per borough
    - Average rent price
    - Average energy consumption (before/after renovation)
    - Average price of energy
    - Energy efficiency (before/after renovation)
- **Structural Systems of the Million Program Era**
    - Households sizes (p. 84)
- **Lind, Annadotter, Björk, Högberg, and Af Klintberg (2016). *Sustainable Renovation Strategy in the Swedish Million Homes Programme: A Case Study*.**
    - Average apartment maintenance cost

3.3.2 Submodels

3.3.3 Estimation of apartments energy consumption and associated cost

A series of equations tie apartment energy consumption and their cost together with household energy behaviours. This series starts with the computation of the actual apartment energy efficiency:

actual apartment energy efficiency = apartment energy efficiency * (1 + household environmental habits) * apartment energy efficiency decay rate

Where the household environmental habits range from 0 to 1.00, the apartment energy efficiency is equal to 1 if the apartment has not been renovated or to 0.67 if the apartment was renovated, and the decay rate is a constant that represents the deterioration of the energy system over time. The actual consumption is then computed as:

apartment energy consumption = actual apartment energy efficiency * apartment size * 12.78

Where 12.8 kWh/month per square meter is the average energy consumption per month before any renovation intervention. The cost are then calculated as:

apartment energy cost = apartment energy consumption * 1.1

Where 1.1 SEK/month per kWh is the average price of electricity in Sweden.

4 Case study cluster 4: Urban mobility with super-blocks

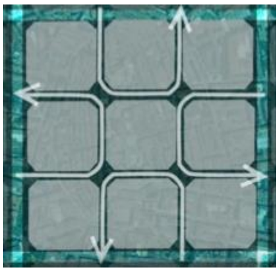
For the urban mobility with super-blocks case study cluster, we describe the agent-based model that has been developed to simulate the Vitoria City case study, and for which we have used as a basis for modelling the citizens the HUMAT model. The other main reference case in SMARTEES in this case study cluster is based in Barcelona, and though a separate model is being developed, the two models are by-and-large the same in terms of their design and contents, with some small variations to account for differences in data sources, entities and actors involved in the model and also in the policy strategies implemented for that case.

4.1 Overview

4.1.1 Purpose and patterns

A superblock is an area of the city free from passing traffic. It is surrounded by roads where perimeter traffic is allowed while inside it is only allowed in the form of loops (see Figure 4.1) so that the cars that enter are again expelled to the perimeter roads. They also have some other internal restrictions like the type of parking allowed or a low speed limit. The objective is to recover space for citizen activity.

Figure 4.1 Example of traffic transit in a superblock.



This model was designed to explore questions about citizen acceptability regarding the implementation of superblocks as a SI project and how this can be influenced by some actions of the policy makers. More specifically, the purpose of the model is to simulate the temporal evolution of citizens' opinions about the superblocks project and how it changes as policy actions take place in order to, finally, answer the question: what percentage of citizens will be against, and what percentage in favour of the superblock project based on different policy scenarios?

This model is created to simulate the specific case of Vitoria-Gasteiz and it is calibrated with field data from this city. As a criterion of utility, the model will reproduce the two phases of the creation process of the Superblock "Sancho El Sabio". These are the Preliminary Phase (October 2006 to April 2007) and the Implementation Phase (from 2007 to 2012).

Additionally, other policy strategies can be tested as the model is aimed at becoming a general simulation framework for usage in different urban scenarios.

4.1.2 Entities, state variables, and scales

The main entity of this model is the citizen. Citizens are characterized following the HUMAT model, see Antosz et al. (2019). In this model each citizen has three categories of needs: (1) experiential needs, which, among others, refer to comfort and costs, (2) social needs, referring to belongingness, relatedness (i.e. to feel close and accepted with important others and with important groups of others), social safety, social status, and (3) values, referring to autonomy, biosphere and societal goals. Each of these needs is conditioned by the importance that each citizen gives to it.

Agents representing citizens can choose one of two behavioural alternatives, thus changing their internal state: accept or reject the SI. The overall expected satisfaction a citizen gets from an alternative is an additive function of the degree to which that alternative satisfies her in each group of needs multiplied by the importance that the agent gives to each of these groups (more details in Section 4.3.3). There will be two satisfaction levels, one per behaviour (accept or reject). When one of these behavioural alternatives evokes sufficient levels of both satisfaction and dissatisfaction in one (or more) group of needs, a motivational state of cognitive dissonance is experienced. When this dissonance is above a threshold that denotes the tolerance to dissonance, then the citizen faces a dilemma. The possible dilemmas are: experiential dilemma, social dilemma and values dilemma (Antosz et al. 2019). There will be a Boolean state variable for each of them to know if the citizen is facing it or not. In addition, each agent is represented by some sociodemographic variables and is located in a specific place on the city map. Finally, an influence parameter (trust) is included for each type of relationship that a citizen may have (friends, neighbours...), as well as with the critical nodes that we will comment on below. To summarize, the following state variables are used to represent a citizen:

Table 4.1 HUMAT state variables.

Variables	**States (if applicable)**
Sociodemographic variables	
Age (years)	integer in [18-100]
Gender	male/female
Education level	primary/ secondary/ tertiary
Economic activity	employed/ unemployed/ inactive
Location	neighbourhood section code
Homeowner	yes/no
Time in the neighbourhood (years)	< 3 / 3-10 / 10-30 / > 30
Opinion about the project	
Chosen behavioural alternative	accept/reject

Importance of each block of needs	
Importance of experiential needs	[0,1]
Importance of values	[0,1]
Importance of social needs	[0,1]
Satisfaction of Needs by each behavioural alternative	
Satisfaction of experiential needs when accepting	[-1,1]
Satisfaction of values satisfaction when accepting	[-1,1]
Satisfaction of social needs when accepting	[-1,1]
Satisfaction of experiential needs when rejecting	[-1,1]
Satisfaction of values when rejecting	[-1,1]
Satisfaction of social needs when rejecting	[-1,1]
Global Evaluation	
Evaluation for accept	[-1,1]
Evaluation for reject	[-1,1]
Dissonance	
Dissonance tolerance	[0,1]
Dissonance strength of chosen behaviour	[0,1]
Dissonance for accept	[0,1]
Dissonance for reject	[0,1]
Dilemmas	

Experiential needs dilemma	yes/no
Social needs dilemma	yes/no
Values dilemma	yes/no
Trust on other agents (influence parameter)	
Neighbours	Likert scale (0 – 6)
Friends	Likert scale (0 – 6)
City council	Likert scale (0 – 6)
Merchants Associations	Likert scale (0 – 6)
Other associations (Neighbourhood, Cyclist)	Likert scale (0 – 6)
Local media	Likert scale (0 – 6)

Critical nodes are another type of entities, representing persons and/or organizations (key-stakeholders) important in co-creation and diffusion of the social innovation. The following critical nodes are included (Antosz et al. 2019):

- The city council as the main promoter of the SI in the city.
- Opposition political parties. Although in the case of Vitoria-Gasteiz SI, a broad political consensus was achieved and there was hardly any opposition, this entity has been considered to allow the model to be more general, as well as to facilitate the simulation of more adverse political scenarios.
- Merchants Associations. These associations manifested a clear rejection of the measures promoted to implement the SI (e.g., prohibition of driving in the superblock area) and are considered the major opponents.
- Other associations, that cover several associations such as neighbours and cyclists. This critical node may vary its opinion about the SI throughout the process.
- Local Media. Both the press and the radio have favoured the acceptance of SI.

Critical nodes can influence citizens to accept (or reject) the SI and can apply different strategies for it. In this model, a strategy is always a communicative act (one-shot or repeated over a period). Table 4.2 denotes the variables of the critical nodes, whereas Table 4.3 indicates the relevant variables of these strategies.

Table 4.2 Critical nodes state variables.

Variables	States (if applicable)
Name	City Council/ Merchants Associations/ Other associations / Local media
Scope (% of citizens that can be reached)	[1,100]

Table 4.3 Strategy state variables.

Variables	States (if applicable)
Primary Critical Node (promoter of the strategy)	City Council/ Merchants Associations/ Other associations / Local media
Secondary Critical Node (executor of the strategy by order of the promoter)	City Council/ Merchants Associations/ Other associations / Local media
Behaviour	supporter/opponent
Strategy starting month	integer in [1,12]
Strategy starting year	integer in [2006, 2012]
Strategy ending month	integer in [1,12]
Strategy ending year	integer in [2006, 2012]
Frequency per month	integer in [1,2]
Reach (citizens affected by the strategy, % of Scope)	[0,100]

There are different social networks between citizens that allow them to communicate with the purpose of convincing the receiver to accept/reject the SI. The networks' links contain important information that will determine the effectiveness of this communicative act (see Table 4.4).

Table 4.4 State variables of the Links between citizens.

Variables	States (if applicable)
Citizen/critical node sender	
Citizen receiver	
Sender and receiver have the same behavioural alternative	yes/no
Receiver has been previously inquired by sender	yes/no
Receiver has been previously signalled by sender	yes/no
Persuasion (influence the sender can exert on receiver)	[0, 0.4* (number of needs –1)]
Gullibility (influence the receiver can perceive from sender)	[0, 0.4* (number of needs –1)]
Trust that the receiver has on the sender	[0,1]

The model world is composed of grid cells representing Vitoria-Gasteiz city, each cell represents around 110 square meters. The city is drawn through its census sections, so that each grid cell group represents a section of the city. Finally, there are some system variables necessary to represent the evolution of time (see Table 4.5).

Table 4.5 System state variables.

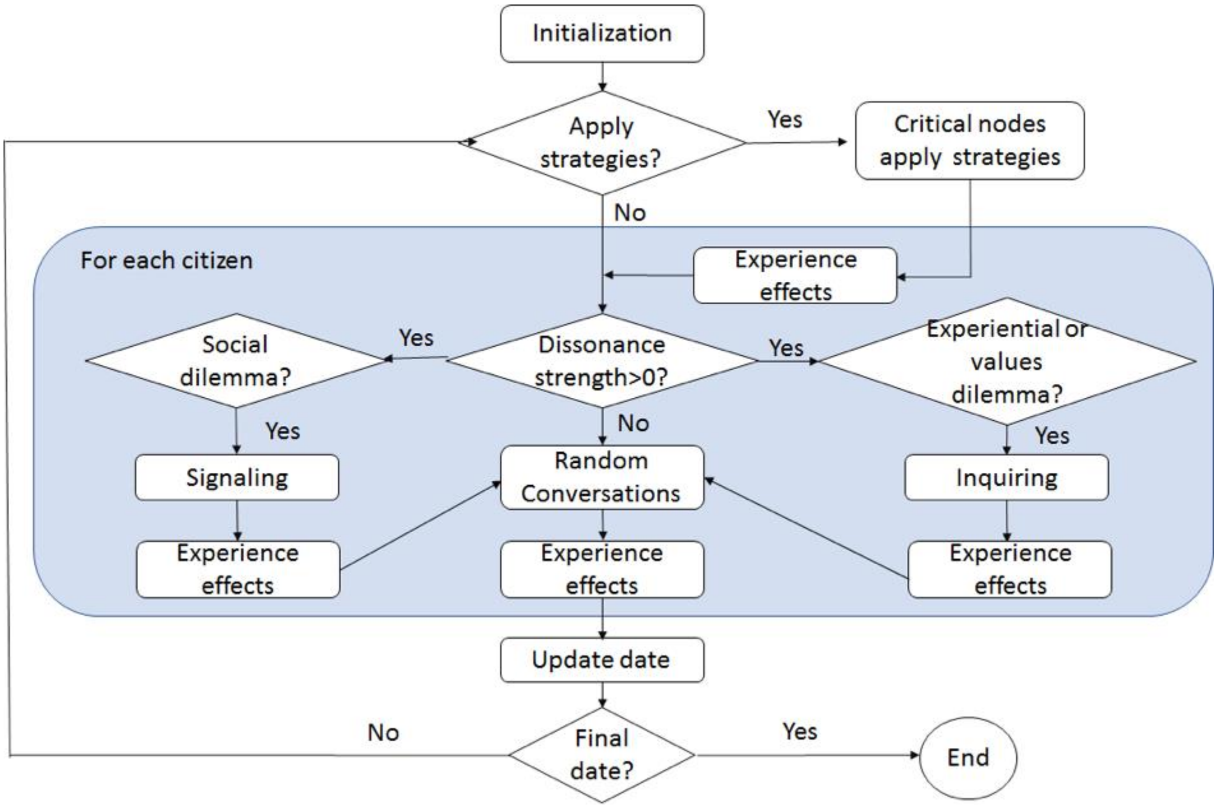
Variables	States (if applicable)
Month	integer in [1,12]
Year	integer in [2006, 2013]

4.1.3 Process overview and scheduling

Figure 4.2 shows the main process overview. After initialization, critical nodes can execute a strategy if it has one associated to the current moment. Subsequently, the citizen experiences its effects first-hand, that is, for both alternatives, she updates her satisfaction of needs, dilemmas and dissonances variables in Table 4.1. When the dissonance strength in the chosen behaviour exceeds a dissonance tolerance level, she signals her satisfaction or disappointment to other citizens in her network or she inquires to get more information on the issue. In addition, even if a citizen does not experience dissonances, she maintains random conversations with other agents that may cause a change in her opinion. See Section 4.3.3 for more details on submodels.

Time is modelled in discrete time steps, representing two weeks.

Figure 4.2 Process overview.



4.2 Design concepts

4.2.1 Basic principles

The basic hypothesis addressed by this model is the idea that the acceptability of the SI by a given citizen depends on how it affects her on an individual basis in matters related to her comfort or the alignment with her values, but also on the opinion of the citizens around her and the external information inputs that can reach her. Both the position that the citizen agent adopts and how it evolves according to its environment are solved in the system by following the HUMAT model (Antosz et al. 2019), therefore it affects only in the submodel and not on the system level. HUMAT is based on cognitively grounded decision-making that motivates information sharing in social networks.

4.2.2 Emergence

In this ABM, the behaviour of Citizens is obtained by general rules derived from HUMAT. The behaviour of Critical Nodes is simpler, more deterministic and built-in in the model and conditioned by the policy scenarios. However, no rules affect the behaviour of the model as a global system. The key results of the model refer to the final position of the HUMATS as a population not as individuals. This global behaviour emerges from the adaptive traits of HUMATS to their environment and it is affected by the different policy scenarios considered in the system. In this sense, it is expected that all model results could vary in complex and perhaps unpredictable ways. This situation, far from being a problem, can be an opportunity to better understand or discover what unexpected mechanisms can tip the balance in favour or not of social innovation.

4.2.3 Adaptation

In this model, only agents representing citizens have an adaptive behaviour. The reason for this adaptation is that we want the agents to be able to evolve in their opinion as they “listen” to the opinion of others and “experience” the results of the SI project. Again, this evolution follows the HUMAT model, but there is no learning involved in the agent’s adaptive traits. What drives, in part, the adaptation of citizens is their dissonance level. The dissonance comes from different dilemmas depending on which groups of needs were in conflict. Table 6 shows which type of dilemma is activated depending on whether a behavioural alternative satisfies (+) or not (-) a given group of needs (Antosz et al. 2019).

Table 4.6 Relationship between dilemmas and groups of needs

	Experiential Needs	Social Needs	Values
Experiential dilemma	+	-	-
	-	+	+
Social dilemma	-	+	-
	+	-	+
Values dilemma	-	-	+
	+	+	-

When an agent experiences an experiential or values dilemma they ask other agents for their opinion and adapt their own behaviour based on that opinion, their gullibility, the trust on the alter-agents and their persuasiveness, as detailed in the Submodels Section.

4.2.4 Objectives

The evolution of citizens is guided by a fixed objective. This objective is to see their experiential needs as well as their values satisfied to the maximum while feeling socially accepted with regard to their decision to support or not the SI (social needs). With this aim, and following the HUMAT model, the citizens calculate their satisfaction on each behavioural alternative (supporting or rejecting the SI project) as a weighted sum on the satisfaction of every group of needs. As a result, eight numbers are obtained for each citizen representing the global satisfaction as well as the satisfaction per groups of needs (see Table 4.1). Sometimes a behavioural alternative is perfect, and all groups are satisfied but, very often, alternatives have both pros and cons causing the agent a cognitive dissonance. To identify this situation, together with satisfaction the citizens calculate the dissonance caused by each alternative as a balance on the consonant and the dissonance cognitions. Finally, the agents will use as criteria to choose one alternative or the other to maximize their global satisfaction on the three groups of needs; if similar satisfying, they choose the one that produces less dissonance level; if similar dissonant, they choose the best satisfying their experiential needs (hedonism) and, finally, they choose at random.

4.2.5 Prediction

Although the system can be used as a sort of tool to evaluate what-if scenarios, there is no prediction involved in the agent's adaptive traits.

4.2.6 Interaction

Each citizen belongs to two interaction networks: the social network of neighbours and the social network of friends. Interaction occurs mainly by means of two communicative processes among connected citizens: signaling and inquiring. Signaling implies informing other alter agents about the ego opinion on the SI project, while inquiring implies asking other alter agents about their opinion.

Signaling and inquiring are the processes the citizens use to reduce their global dissonance any time it is above their individual tolerance level. When they experience either a values or an experiential dilemma, they inquire other agents, while if they experience a social dilemma, they signal them. These processes are described in more detail in Section 4.3.3. For citizens to communicate with as many citizens of their networks as possible, in each new communicative action the sender of the message will prioritize as receivers those citizens of her network who have not been previously signaled/inquired by her. In addition, once in a while, citizens hold conversations, in a process similar to signaling, randomly choosing the receiver which leads the citizens involved to re-evaluate their dissonances.

Besides, each critical node is connected to several citizens depending on its scope. Every so often a critical node can apply a strategy or policy that, in the end, consists of a massive communicative act towards some of the citizens that it can reach in order to convince them to accept or reject a behaviour.

The citizens and critical nodes to which a citizen can communicate are represented in the model by explicit links. The critical nodes are connected to citizens through weighted unidirectional links coming from the critical node, the weight representing the trust the citizen has on the critical node (see Table 4.1). Besides, each pair of citizens in the same network are connected through a pair of weighted links, the weight representing the trust one agent has on the other (notice that trust does not have to be reciprocal). Finally, to determine up to which point a citizen is persuaded by others, the communication process also involves, in addition to trust, the persuasiveness of the sender of the message and the gullibility of the receiver, both variables of the Link Entity (see Table 4.4).

4.2.7 Sensing

Every citizen can perceive the opinion of other citizens in her social networks (family, neighbours). This can occur on their own initiative (inquiring) or on the initiative of other citizens when they launch a signaling process or a random conversation.

The citizens can also perceive the opinion of the Critical Nodes, but only by initiative of the Critical Nodes.

On the contrary, the Critical Nodes cannot sense the opinion of other critical nodes nor the citizens as individual entities, but they can sense the global position of the citizenry as a whole with respect to the SI project.

4.2.8 Stochasticity

Randomness in the model affects to the following aspects:

- As mentioned, the creation of the Social Networks has a random component.
- The choice of a behaviour by a citizen when she has to choose between equally satisfying behaviours.
- The dissonance tolerance level of every agent is also assigned at random within a given interval.
- In mass communication events launched by Critical Nodes, the specific citizens they reach are chosen at random.
- When a citizen has to choose which other citizens to signal/inquire, if the result of applying the sorting criteria among the recipients produces ties, it is also chosen at random.
- As explained, every once in a while, with a given probability citizens maintain spontaneous conversations with recipients chosen at random within their social networks.

4.2.9 Collectives

Although the Critical Nodes represent organizations of people, in the model they are represented only as an entity, not by the set of individuals that belong to that organization. Therefore, there are no collectives in this model.

4.2.10 Observation

As a final output, several data are collected and offered for observation and analysis of the citizen behaviour with respect to the SI:

- The evolution curve of the percentage of citizens that are in favour and against the SI project.
- The evolution curve of the mean of the citizens satisfaction on every group of needs with regards to option A (accepting SI).
- The evolution curve of the mean of the citizens' satisfaction one for every group of needs with regards to option B (rejecting SI).
- Three histograms that represent the importance of each of the needs for all citizens.
- Visual representation of the state of the citizens (against, in favour) over the map of Vitoria

All these data are gathered and updated every tick. In addition, when the historical process is simulated in Vitoria, a legend will be displayed that explains the step of the process that has just been applied to the model.

4.3 Details

4.3.1 Initialization

4.3.1.1 Initial population of citizens

The initial population is created from the profiles of the citizens that completed a survey carried out in Vitoria in November 2020 as part of the SMARTEES project. That survey (see Appendix I, in Spanish) includes questions to know their position about the SI plus some demographic variables. After running a decision tree using these data, it was determined that the more influential demographic variables are Education level, Homeowner or Time in the neighbourhood. On the other hand, the real distribution of these variables in 2016 has been made available by the Vitoria City Council for each of the sections into which the Vitoria map is divided. Once the user chooses the number of agents, the system distributes them along the map of Vitoria following the real density population of every section. Inside every section the agents reproduce the population with regards to the real distribution of the influent demographic variables.

Regarding the profile of each citizen, the importance of each block of needs plus the initial satisfaction on each block for the two behavioural alternatives should be initialized. With this aim, first each available questionnaire is transferred to an agent located in the same section of the city. After that, for every empty citizen agent it is transferred one profile from the surveys randomly chosen among those that meet the same demographic characteristics on the influent variables and is also located in the same section of the city.

Finally, the dissonance tolerance level for every citizen is assigned at random within the corresponding interval.

4.3.1.2 Critical Nodes

The Critical Nodes are initialized as follows, where the scope has been obtained from the analysis of secondary data sources:

Table 4.7 Initialization of critical nodes

Name	Scope
City Council	100
Merchants Associations	3
Other Associations	1
Local media	63

4.3.1.3 Interaction Networks

The social network of neighbours follows the "Social Circle Model" as proposed by Hamill and Gilbert (2009). It is established through pseudo-random links between citizens within the same cell (radius=1). Only in the event that it is not possible to find the desired number of links, the system will attempt to link to agents within a distance of two cells (radius=2) or three cells (radius=3).

The social network of friends is established by pseudo-random links between a set of citizens previously chosen by the homophily principle: similar age (+/- 5 years) and same educational level, see Antosz et al. (2019). Additionally, with 5% probability some random links are also established.

In any case, the number of links and trust towards friends and neighbours is determined by the information provided by the surveys carried out on the population of Vitoria. Persuasion and gullibility are initially set to 0 and later modified in corresponding submodels (see section 4.3.3).

With respect to the interaction networks of the Critical Nodes, they are connected with as many citizens as indicated by the scope variable. Once again, citizens' trust in critical nodes is drawn from the surveys.

4.3.1.4 Policies

The state variables of the Strategies entity are started in order to follow those used in the historical process of Vitoria. For this, data acquired from documentary analysis from various sources have been used. Appendix II contains the tactics that were carried out and the milestones that triggered them.

4.3.1.5 Time

In the System State Variables time is initialized to January 1st, 2006.

4.3.2 Input data

The model does not use input data to represent time-varying processes.

4.3.3 Submodels

In this section the pseudocode of the more relevant submodels is detailed.

4.3.3.1 Evaluate Dissonances

```
for each behaviour
      dissatisfying = absolute sum negative values of needs evaluations
      satisfying = absolute sum positive values of needs evaluations
      dissonant = min (dissatisfying, satisfying)
      consonant = max (dissatisfying, satisfying)
      dissonance = (2 * dissonant) / (dissonant + consonant)
 dissonance-strength = (dissonance - dissonance tolerance) / (1 - dissonance
tolerance)

dissonance-strength = dissonance-strength of current behaviour

     if (experiential-evaluation > 0 and social-evaluation < 0 and values-
          evaluation < 0) or
          (experiential-evaluation < 0 and social-evaluation > 0 and values-
          evaluation > 0)
    experiential-dilemma? = 1
     if (social-evaluation > 0 and experiential-evaluation < 0 and values-
          evaluation < 0) or
          (social-evaluation < 0 and experiential-evaluation > 0 and values-
          evaluation > 0)
    social-dilemma? = 1
     if (values-evaluation > 0 and experiential-evaluation < 0 and social-
          evaluation < 0) or
          (values-evaluation < 0 and experiential-evaluation > 0 and social-
          evaluation > 0)
    values-dilemma? = 1
```

4.3.3.2 Choose preferred alternative

```
if evaluation-reject-0.1 < evaluation-accept < evaluation-reject+0.1
      if dissonance-reject-0.1 < dissonance-accept < dissonance-reject+0.1
     if experiential-reject-0.1<experiential-accept<experiential-reject+0.1
```

```
            choose random behaviour
     else
            if experiential-accept > experiential-reject
                  choose behaviour accept
            else
                  choose behaviour reject
      else
      if dissonance-accept < dissonance-reject
            choose behaviour accept
      else
            choose behaviour reject
else
      if evaluation-accept> evaluation-reject
      choose behaviour accept
      else
      choose behaviour reject
```

4.3.3.3 Sort-Signaling

```
sorted-list = sort links by
      (1)ascendingly by signaled (not signaled to first)
      (2)descendingly by not the same-behavioural-alternative (different
      behaviour first)
      (3)descendingly by gullibility (the most easily persuaded first)
```

4.3.3.4 Calculate-Need-Similarity

```
if (need-evaluation-ego > 0 and need-evaluation-alter > 0) or
   (need-evaluation-ego < 0 and need-evaluation-alter < 0)
   need-similarity=0.4*(1−abs(need-importance-ego -need-importance-alter))
else
      need-similarity = 0
```

4.3.3.5 Signaling

```
sorted list = Sort-Signaling links
signaled-citizen = citizen receiver of first link in the sorted list
ask signaled-citizen
      get link trust
```

```
        foreach need of both behaviours
        get need evaluation of signaling-citizen
        get need importance of signaling-citizen
        Calculate-Need-Similarity
        persuasion = need-similarity * link trust
        satisfaction = (1-persuasion)*satisfaction + persuasion * satisfaction-
signaling-citizen
        experience effects
experience effects
update link gullibility
link signaled = 1
update both links same-behavioural-alternative
```

4.3.3.6 Sort-Inquiring

```
sorted-list = sort links descendingly by
        (1) ascendingly by inquired (not inquired first)
        (2) descendingly by same-behavioural-alternative (same behaviour first)
        (3) descendingly by persuasion (strongest persuasion first)
```

4.3.3.7 Inquiring

```
sorted list = Sort-Inquiring links
inquired-citizen = citizen receiver of first link in the sorted list
get link trust
foreach need of both behaviours
   get need evaluation of inquired-citizen
   get need importance of inquired-citizen
   Calculate-Need-Similarity
   persuasion = need-similarity * link trust
    satisfaction = (1 - persuasion) * satisfaction + persuasion *
satisfaction-inquired-citizen
experience effects
update link persuasion
link inquired = 1
update both links same-behavioural-alternative
```

4.3.3.8 Random Conversations

```
if random number < conversation-probability
    selected-citizen = a random citizen of the social network
      ask selected-citizen
      get link trust
      foreach need of both behaviours
            get need evaluation of asking-citizen
            get need importance of asking-citizen
            Calculate-Need-Similarity
            persuasion = need-similarity * link trust
            satisfaction = (1-persuasion) * satisfaction + persuasion * satisfaction-asking-citizen
      experience effects
      experience effects
      update link gullibility
      update both links same-behavioural-alternative
```

4.3.3.9 Experience effects

```
percentage-similar = citizens with same behaviour in social net/citizens in social net
percentage-dissimilar= citizens with different behaviour in social net/citizens in social net
social satisfaction of current behaviour = normalize percentage-similar in [0,1]
social satisfaction of opposite behaviour = normalize percentage-dissimilar in [0,1]
foreach each need of each behaviour
   evaluation = satisfaction * importance
   evaluation accept = average of accept evaluations
   evaluation reject = average of reject evaluations
   Evaluate Dissonances
Choose Preferred Alternative
```

4.3.3.10 Critical Node Strategy

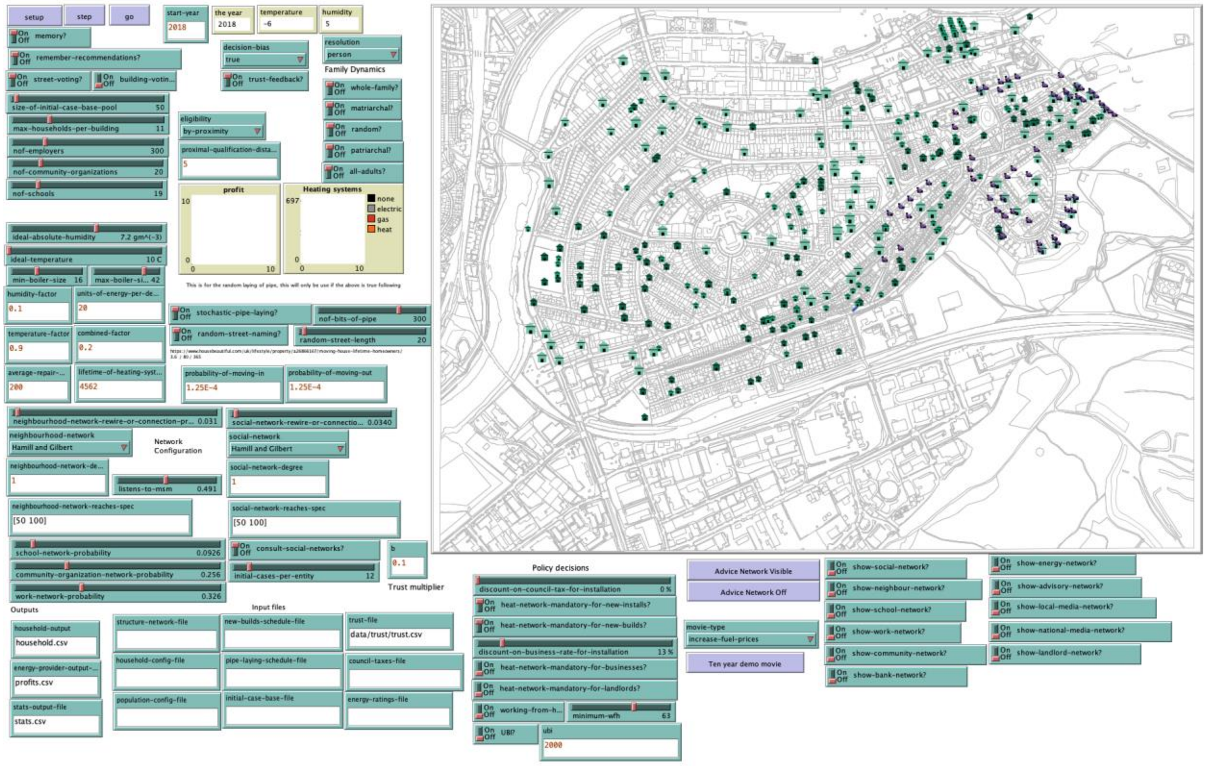
```
if strategy trigger
      ask strategy primary critical node
      selected-citizens = choose randomly citizens in social network according to strategy reach
```

```
      ask selected-citizens

            persuasion = link trust

            foreach need of both behaviours

                satisfaction = (1-persuasion) * satisfaction + persuasion * 
satisfaction-critical-node

            experience effects
```

5 Case study cluster 5: Fuel Poverty

For the fuel poverty case study cluster, we describe the ACHSIUM (Aberdeen City Heat network Social Interaction and Uptake Model) agent-based model (see figure 5.1), which is centred on the simulation of the Aberdeen City case study. The other main reference case in SMARTEES in the fuel poverty case study cluster is based in Timişoara, and though a separate model (HOTNESS -- Heuristic Optimisation for Timişoara district heating Network Experimental Social Simulation) is being developed for that case, the two models are by-and-large the same in terms of their design and contents, with some small variations to account for differences in data sources and importance of various processes (particularly around trust) in the two case studies.

Figure 5.1 ACHSIUM interface after model initialization. Though we have the aim to simulate the whole of Aberdeen, we have been working on an area within Aberdeen called Torry for reasons of efficiency while developing the model.



5.1 Overview

5.1.1 Purpose and patterns

The purpose of ACHSIUM is to explore scenarios of increasing adoption of Aberdeen City's district heating network system by householders in the city, responding to questions of interest elicited from colleagues in Aberdeen City Council. The main system-level variable of interest is the proportion of households in fuel poverty (at least 10% of income after rent, tax and other essential expenditure is, or would need to be, spent to keep the house at a comfortable temperature) and severe fuel poverty (at least 20%). Other variables of interest include the proportion of households connected to the heat network, and the cost-effectiveness and resilience of the heat network system.

The main patterns observed in implementing heat networks so far has essentially been that doing so in large apartment blocks owned by the Council is, though not trivial, more straightforward. This is for two reasons: first, large apartment blocks are more efficient per household in terms of metres of heat pipe laid; second, fewer parties are involved in negotiating the installation when the building is owned by the Council. There are seven separate heat network installations in Aberdeen. Connecting them together has several benefits including improved resilience to boiler failure, but will entail more connections to smaller and privately-owned buildings. As such, it is 'uncharted territory' with respect to providing strict quantitative evidence-based criteria for model acceptance. This places much greater emphasis on the model's *ontology* (essentially, the information in sections 5.1.2 and 5.1.3, together with details in section 5.3) than on its quantitative predictions. The model has therefore been the subject of regular discussion with Aberdeen City Council, and relevant parties outwith SMARTEES, most notably Aberdeen Heat & Power (the not-for-profit company responsible for running the heat network) and SCARF (an organization created to offer people advice on saving money on their energy bills). Polhill and Salt (2017) have in any case argued that quantitative criteria for model acceptance are not on their own a sound basis for validation in complex systems, and the greater ontological expressivity agent-based models offer over alternatives means there is a need for more emphasis on developing acceptance criteria around ontologies.

5.1.2 Entities, state variables and scales

The classes of entity in the model, and their attributes, are:

- buildings: building-street-name (from GIS data), postcode (from GIS data), nof-households, energy-rating (A-G), council-tax-band (A-H), building-fuel-poverty (0 -- no fuel poverty, 1 -- fuel poverty or 2 -- severe fuel poverty). Of these only building-fuel-poverty is affected by model dynamics. Buildings also have data about the infrastructure they have for heating: electric, gas and heat network.
- heat-pipes
- persons: age (0-81), sex (M or F), case-base, recommendations, degree (number of network connections), name, trust, income (GBP), ongoing-costs (GBP), hours-away-from-household, attitude
- households: name, trust, degree, case-base, recommendations, dynamic, income (GBP), owns-property? (Boolean), owns-outright? (Boolean), ongoing-costs (GBP), balance (GBP), heating-status, heating-system, heating-system-age, boiler-size (kWh), air-conditioner-size, last-energy-provider, max-units-of-energy-per-day, min-units-of-energy-per-day, units-of-energy-used, hours-away-from-household, last-bill, fuel-poverty, history-of-fuel-poverty, attitude. Households also store information on whether their rent includes energy build, payments they have made, whether yearly maintenance is required for their heating system, and whether that maintenance has taken place.
- main-stream media: name, organization-type (national or local), case-base, recommendations
- businesses: name, case-base, recommendations, min-electrical-units-of-energy-per-day, units-of-energy-per-day-for-heating, units-of-energy-used, rateable-value (GBP), heating-system, last-bill, balance (GBP). Businesses also store data on payments they make
- banks: name, case-base, recommendations, and details about purpose, principal, payment, frequency and nof-payments for loans they create.
- landlords: name, case-base, recommendations, rent (GBP) for each property, frequency of rent payment for each property.
- energy providers: name, case-base, recommendations, profitability (GBP), profits, retail-unit-cost (GBP), wholesale-unit-cost (GBP), frequency (of billing: daily, weekly, monthly, quarterly or yearly), and details of tariffs including energy-type, standing-charge, disconnection-cost, installation-cost and yearly-maintenance for each tariff.
- grant bodies: name, case-base, recommendations, energy-type, amount (GBP), maximum-income (GBP -- income of applicant above which not eligible), and the x, y and radius of a circle defining where the grant applies.

- advisory bodies: name, case-base, recommendations, action (information about what clients could do), energy-type, recommended-institution, finance, calendar, and the x, y and radius of locations in which awareness and advice offered by the advisory body applies.
- institutions: name, organization-type, case-base, recommendations, catchment-radius, calendar, fixed-holidays, floating-holidays, probability-of-attendance, working-from-home.
- pixels, patches or discrete regular cells of land: pipe-present? (Boolean), pipe-possible? (Boolean), street-name, voted? (Boolean)

Rationale

The entities simulated in the model are the outcome of discussions in the Hutton team between case study researchers (psychologists) and modellers, as well as conversations with Aberdeen City Council and other external stakeholders. We have used case bases to provide the basis for decision-making, together with a social element allowing agents to exchange cases to cover knowledge they do not have personal experience of. This is important because joining a heat network is a one-off decision that, if (as may typically be expected) a household has not had experience of living with heat network heating, is made without information based on personal experience. People then have to ask others about their experiences, and assess the information received there.

Some of the discussion in the team has been around the locus of decision-making. Agent-based modellers are typically less concerned about simulating decision-making by social aggregations as single agents -- and especially households and businesses. (Agent-based models have even simulated entire countries as agents.) Methodological individualism, an ontological commitment expected of disciplines that study individual humans (such as psychology), would regard such practices by modellers as controversial. To address this, the model has the capability of simulating intrahousehold decision-making explicitly, but can also simulate households as the locus of agency as an option.

5.1.3 Process overview and scheduling

The schedule in ACHSIUM operates on a daily time step. Various 'events' can occur daily depending on input to the model and probabilistic parameters. There are then a series of activities that take place per day, per week, per month, per quarter, and per year. Activities at time resolutions of coarser grain than daily effectively take place on the appropriate day. Hence, weekly activities take place every seventh day, and monthly activities take place on the last day of each month, etc.

5.1.3.1 Daily events

- New pipe is laid
- New homes are built
- Households move out
- New households move in to buildings with vacancies
- City-wide energy infrastructure failures are fixed
- Regional energy infrastructure failures are fixed
- New city-wide energy infrastructure failures can occur
- New regional energy infrastructure failures can occur
- New whole building energy infrastructure failures can occur
- New household energy infrastructure failures can occur
- Advisory bodies can run awareness-raising events
- Review of trust dynamics

5.1.3.2 Daily

- Businesses consume electricity, and (other) energy for heating
- Businesses pay energy providers for energy consumed if the tariff is daily
- Household heating systems age
- Households consume energy
- Households pay energy providers for energy consumed if the tariff is daily
- Households maintain their gas or electric heating system if it is time to do so
- Households or individuals attend work, school and/or community events
- Energy providers record profits

5.1.3.3 Weekly

- Businesses pay energy providers for energy consumed if the tariff is weekly
- Households pay energy providers for energy consumed if the tariff is weekly
- Households pay banks for loans if the frequency of repayment is weekly
- Households pay rent to landlords if the frequency is weekly
- Street voting can take place

5.1.3.4 Monthly

- Businesses pay energy providers for energy consumed if the tariff is monthly
- Households pay energy providers for energy consumed if the tariff is monthly
- Households pay banks for loans if the frequency of repayment is monthly
- Households pay council tax
- Households pay rent to landlords if the frequency is monthly
- Households determine their disposable income
- Energy providers update their tariff according to the scenario
- Pipe may be laid

5.1.3.5 Quarterly

- Households pay energy providers for energy consumed if the tariff is quarterly

5.1.3.6 Yearly

- Grant bodies update the grants they offer
- Energy providers update their tariffs according to the scenario
- Landlords update their rents according to the scenario
- Banks update their interest rates according to the scenario
- Advisory bodies update their status according to the scenario
- Households update their heating and demographic status
- Weather data is updated
- Holiday data is updated

5.2 Design concepts

5.2.1 Basic Principles

The main principle behind the decision-making is in giving agents the capability to share experiences from an episodic memory. This then allows the exploration of one-shot decision-making processes, and the simulation of an advice-giving body.

5.2.2 Emergence

- The heat network can be emergent when not imposed by scenario
- The numbers of households in fuel poverty is an emergent property

5.2.3 Adaptation

Adaptation in terms of populations adjusting characteristics through processes of environmental selection does not occur in ACHSIUM. However, various events in the model act as triggers for agents to update their behaviour:

- Households moving in
- Power restored after city-wide outage
- Power restored after regional outage
- Occurrence of a city-wide outage
- Occurrence of a regional outage
- Occurrence of a whole building outage
- Repair of an energy system
- The need to replace an energy system
- Awareness-raising event by an advisory body
- Connection to the heat network
- Payment of yearly maintenance

5.2.4 Objectives

- Energy providers have the implicit goal of maintaining profitability
- Households have the implicit goal of keeping themselves warm and financially solvent

5.2.5 Learning

- As agents gain experience of their heating system, the case base is updated with relevant information.

5.2.6 Prediction

- Effectively, when consulting the case base to evaluate alternative options, agents are using that information to predict the outcomes of each option.

5.2.7 Sensing

- Person and/or household agents are aware of the temperature and humidity from the weather when determining their energy usage.

5.2.8 Interaction

- The main interaction among the agents concerns exchange of cases when seeking advice about heating systems.
- Interaction occurs when households vote on pipe-laying.
- Household agents also interact with institutional agents when paying bills.

5.2.9 Stochasticity

- Households move in and out of the area simulated with a random probability.
- Heating systems fail at household, building, regional and city-wide levels using random samples from power-law distributions.

5.2.10 Collectives

- When configured accordingly, the model's household agents are collectives of the people in it.
- Households act as collectives when voting to have heat pipe installed in their street.

5.2.11 Observation

- A spatial visualization of buildings, located on a vector GIS map shows where there are issues with fuel poverty.
- The spatial visualization also depicts the streets in which the heat pipe is laid.
- The profit and numbers of people using different heating systems are shown in a time-series graph.
- Experiments collect data on the energy spending of households and the profits of energy suppliers.
- CSV files are output from the model containing data about households, profits, and the numbers of households and businesses that could and did connect to the heat network.

5.3 Details

5.3.1 Initialization

Initialization comprises the following activities, more detail on which can be found in section 5.3.3 (Details):

- Reading energy provider data from files. Six energy companies are created corresponding to the 'Big 6' in the UK, and two more, one for Aberdeen Heat and Power, and one for DEAL (Aberdeen's for-profit heat network aimed at business customers rather than households).
- Reading bank data from files. Two banks are created.
- Reading landlord data from files. Three landlords are created, one representing Aberdeen City Council, one Housing Association agent, and one private landlord agent.
- Reading grant awarding bodies from a file. One agent is created to represent Aberdeen City Council.
- Reading advisory body data from files. Four agents are created, one for SCARF, one for the Scottish Government, one representing a dementia charity, and one social worker.
- Creating employers. Data are either read from files or employers are created at random until there are nof-employers (a parameter) employer agents.
- Creating community organizations. Data are either read from files or community organizations are created at random until there are nof-community-organizations (a parameter) community organizations.
- Creating schools. Data are either read from files or schools are created at random until there are nof-schools (a parameter) schools.
- Case bases are created for energy-providers, banks, landlords, institutions, grand bodies and advisory bodies. These cases are initialized from a 'pool' of cases that can be loaded from a file and created at random.
- Mainstream media agents are created. Two national and two local agents are created.
- The population is loaded from a file.
- Households are loaded from a file.
- Buildings are loaded from GIS shape files.
- The heat pipe network is initialized.
- Council tax and business rate data is initialized.
- Trust data are initialized.
- Social networks are created.

- Buildings are created from GIS data.
- Businesses are created from GIS data.

5.3.2 Input data

The following is a summary of data that can be input to the model to affect its dynamics while it is running:

- Heat pipe laying scenario data -- GIS data from Aberdeen City Council
- New build housing data -- GIS data from the local plan
- Tariffs for energy providers
- Grants available
- Rents required by landlords
- Interest rates on loans
- Advisory body data
- Weather data
- Holiday data

5.3.3 Submodels

5.3.3.1 New pipe is laid

New pipe is laid according to a schedule in a CSV file that specifies the year and day of that year in the simulation at which data in a GIS shape file containing pipe layout data are to be used to install new pipe. To install new pipe, the model finds which patches intersect with the data in the GIS file, and sets the pipe-present? and pipe-possible? flags in those patches to 'true'.

Buildings within a specified Euclidean distance (a parameter proximal-qualification-distance) of these patches (or optionally, on the same street), are then notified of the pipe being installed. If the building contains businesses, these businesses then uninstall their old system and connect to the network.

If the building contains a single household, if it is owned by the residents, then the residents are prompted to decide to join. In a rented single-occupancy building, if the landlord wants to join, then the old heating system is uninstalled, and the building is connected to the network. Landlords wanting to join is a policy scenario parameter: that is, we assume that unless connecting to the heat network is mandatory for landlords, they will not do it.

In buildings with multiple occupants, all occupants have to vote for installation for the old heating systems to be uninstalled and the heat network installed. (The model also has an option to just connect everyone in a building, and not use building voting.) Tenants will vote for installation if their landlord does. Otherwise, homeowners use information they can access through people they know to make the decision, as described in section 5.3.3.54.

5.3.3.2 New homes are built

New homes are built according to a schedule that specifies the year and day of that year in the simulation at which data in a GIS shape file containing new building data are to be used. The GIS data expects features for the street, number of residences and postcode. Patches intersecting the vector data are then told to create a building on them. The energy rating for the new build is either set from postcode data on typical energy ratings in the area, or from a truncated (range [1, 7]) normal distribution with mean 4 ('D') and standard deviation 2. A similar approach is used to allocate the building a council tax band (N(4, 2) truncated to [1, 8]).

Buildings are initialized with connections to the gas and electricity networks, but not to the district heating network. (A future enhancement will implement policies that make the new builds connect.)

Households are then created to occupy the buildings. These are loaded from a file if data for households in the new postcode are available, or a new household is created randomly. The household file must provide data on tenancy, which of the model's banks the household has a mortgage with or which of the model's landlords the household rents the property from, minimum and maximum units of energy per day, whether the rent includes electricity and if not which of the model's energy companies the household uses for electricity, the same information for gas and the district heating, the degree of the household, the household's dynamic, the boiler size, and the people in the household (which are also expected to be in a separate file). The social networks are also initialized by adding the household to the neighbourhood and social networks, probabilistically (according to a probability parameter 'listens-to-msm') assigned to each of the mainstream media agents, and connected to advisory body agents. Finally, the household's case base is initialized from the case base pool.

When creating a random household, the data are initialized from random distributions. The household has an equal probability of renting or owner-occupying, and if an owner-occupier, an equal probability of owning the property outright or having a mortgage. The minimum and maximum units of energy consumed per day are initialized from normal distributions with means assuming annual consumption of 2900 kWh for the minimum and 12900 kWh for the maximum (data from OFGEM). Standard deviations are mean / 8, based on the 'range rule' (which says that the standard deviation of a range is approximately (max - min / 4)[7] and the assumption that the range for each of the energy consumption distributions is half the mean. The minimum daily energy consumption distribution is truncated at 0, the maximum is truncated in the lower end at the value sampled for the minimum. The age of the household's heating-system is initialized at a daily resolution assuming a random uniform distribution in the range [0, 15 years], from information about the typical lifespan of boilers. The boiler-size is initialized from a truncated normal distribution with mean set from model parameters and standard deviation 3. The number of individuals in the household is initialized from a normal distribution with mean 2.58 (from census data) and standard deviation 1, truncated to 1. The social network of the household is initialized as per loading from a file, as is the household's case base. The household's initial income is set according to the household composition based on the procedure outlined below. The ongoing costs is a random number in the range [0, income] and the initial household balance is the income.

The household is then populated with randomly created people, with age chosen from a normal distribution with mean 40.3 (from census data) and standard deviation set to 81 / 4 (using the range rule), and then truncated to the range [0, 81]. Sex is set to male with probability ~0.492 (or 0.97 men for every 1 woman), based on data on the UK at https://countrymeters.info/. If the person is older than 18, then they are employed with probability 41.9%, and assigned a random employer and income from an exponential distribution with mean 23,833 based on mean earnings in Scotland. If universal basic income policy is in operation, the income is truncated at the lower end by the value of the universal basic income. The resulting income is then accumulated to the person's household. If the age

[7] 'min' and 'max' here refer to the range of a single distribution, and should not be confused with the fact that the two distributions in consideration here are the minimum daily energy consumption and maximum daily energy consumption. Specifically, each of these two distributions will have their own 'min' and 'max', which are only nominal values for the range for the purposes of estimating a standard deviation. Neither distribution is truncated to their 'min' and 'max'.

is in the range [4, 18], the person is randomly allocated to a school with a catchment containing the location. If the person is older than 14, they are assigned to a random number of local community organizations in the range [0, 0.1 * number of organizations]. The person is assigned to a a neighbourhood and general social network, and to mainstream media and advisory bodies as described for households above. Their case base is also initialized from the case base pool in the same way as for households.

Persons can be loaded from a file providing the above data. This happens when the household is loaded from a file.

5.3.3.3 Households move out

Households are selected at random to move out of the area, based on a probability that is a model parameter.

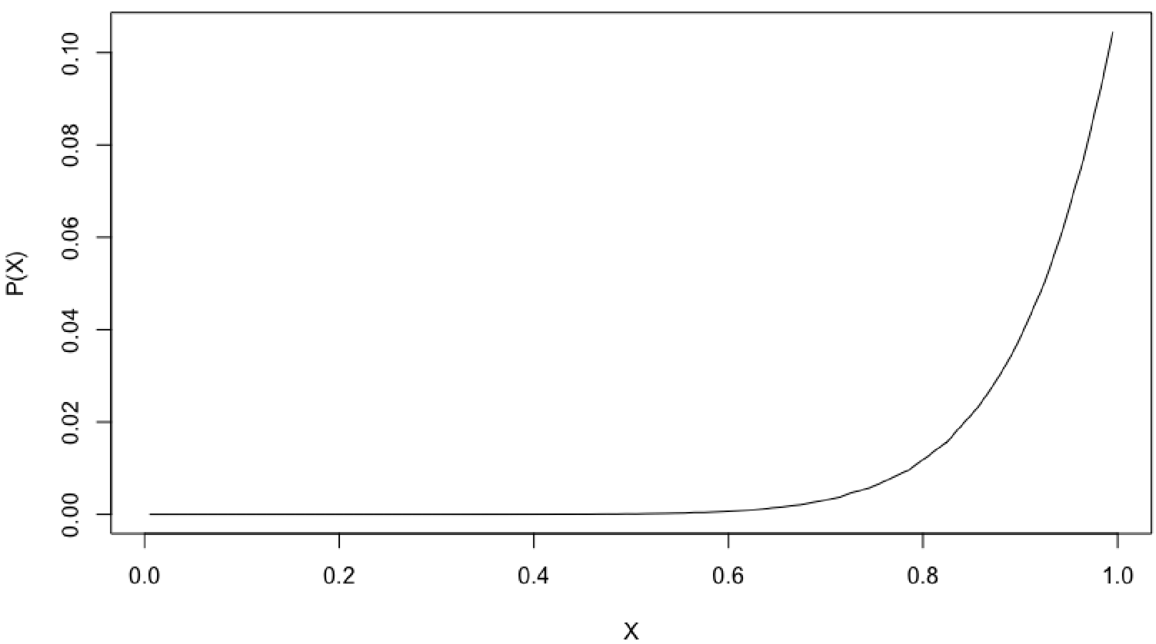
5.3.3.4 New households move in to buildings with vacancies

In accordance with a model parameter probability, a new household is created for each building with vacancies. The process for creating a new household is the same as that described in section 5.3.3.2, with the exception that moving in to the new house is an opportunity for them to decide whether to install a new heating system.

5.3.3.5 City-wide energy infrastructure failures are fixed

The city-wide energy infrastructure failures being fixed act as triggers for households to consider changing their heating system. The fix (setting heating-status to “working”) and consequent trigger act if a sample from a power law distribution in the range [0, 1] with α = 10 is less than 0.95. A plot of the power law distribution is given in figure 5.2, and since the distribution has a median of roughly 0.94, the fix will occur a little over half the time (roughly 0.57).

Figure 5.2 Plot of the power law distribution from which to sample probabilities of city-wide power outage failure fix. The distribution has a median of approximately 0.94.



5.3.3.6 Regional energy infrastructure failures are fixed

The process for fixing regional energy infrastructure is much the same as described for city-wide outages in 5.3.3.5, except that the probability is lower, the sample needed being 0.8 rather than 0.95, meaning that the fix occurs with probability roughly 0.09.

5.3.3.7 New city-wide energy infrastructure failures can occur

The occurrence of city-wide failures occurs per energy provider and heat-type combination, using a sample from the probability distribution in figure 5.2 as per section 5.3.3.5, which must be less than 0.1. This works out at a very small probability of occurrence; sufficiently small that it can only be expected to occur in fewer than one in 10,000 runs. Affected households have their heating-status set to “city-wide failure”.

5.3.3.8 New regional energy infrastructure failures can occur

The occurrence of regional failure is computed as per section 5.3.3.7 for city-wide failure, but with a sample from the power-law distribution that must be less than 0.2. This works out at a probability of occurrence of the order of 1E-8. Affected households have their heating-status set to “regional failure”.

5.3.3.9 New whole building energy infrastructure failures can occur

Whole building energy failure uses the same sample distribution as shown in figure 5.2, with the sample required to be less than 0.3. Per building, over the course of a single run of 10 years, the probability of occurrence is approximately 0.007. Affected households have their heating-status set to “building failure”.

5.3.3.10 New household energy infrastructure failures can occur

Individual households also use the distribution in figure 5.2 to compute the probability of having a heating failure. There are two kinds of failure, computed independently. A heating failure requiring repair has a threshold for the sample from the power law distribution given by the fraction of 15 years corresponding to the heating system’s age. A heating failure requiring complete replacement uses a threshold of 0.45, which corresponds to about 56% of households having such a failure over the course of a ten-year run.

5.3.3.11 Advisory bodies can run awareness-raising events

The scheduling of awareness-raising events is determined by an input file specifying the day of the year at which the advisory body will run the event, and the location of the event and intended geographic scope (which can be set to include the whole model). These events act as a trigger for households to reconsider their heating arrangements using the decision algorithm.

5.3.3.12 Review of trust dynamics

The ranking of relationship types in the social network according to trust can be adjusted. If a household (or person) moves out of fuel poverty, they will trust those who offered them advice more; if they move into fuel poverty, they will trust them less. Agents therefore review their social links for recommendations made to them, maintaining a count of the numbers of each trust category that have offered them advice. The count is a negative number if the agent has moved into fuel poverty, and a positive number if they have moved out. The counts then act as scores, with trust categories from whom agents have received no advice scoring zero. The trust list is re-ordered according to the calculated scores.

5.3.3.13 Businesses consume electricity, and (other) energy for heating

The units-of-energy-used for electricity and the heating system (which may be electricity too), are incremented by min-electrical-units-of-energy-per-day and units-of-energy-per-day-for-heating respectively.

5.3.3.14 Businesses pay energy providers for energy consumed

The bill is computed from the tariff the business has with the energy-provider, and is calculated as the standing-charge plus the retail cost per unit times the amount of energy used. The amount of energy used is then reset to zero, and the business reduces its balance by the amount of the bill; the energy provider increasing its profitability by the same amount.

5.3.3.15 Household heating systems age

The heating-system-age variable of the household is incremented by 1.

5.3.3.16 Households consume energy

The units-of-energy-used for electricity is incremented by min-units-of-energy-per-day. The energy consumed for heating (which may also be electric) is then calculated using Höppe's (1999) physical equivalent temperature index using the temperature and absolute humidity of the weather, and three model parameters (temperature-factor, humidity-factor and combined-factor). For convenience, let H be the humidity, T the temperature, TF the temperature factor, HF the humidity factor, and THF the combined factor. Each household also has an ideal-temperature TI and ideal-absolute-humidity HI. Then the effective temperature difference DT is calculated as:

$$DT = (TI * TF + HI * HF + TI * HI * THF) – (T * TF + H * HF + T * H * THF)$$

Another model parameter, units-of-energy-per-degree (UPT) is then used along with the building's energy efficiency (EE), the households' max-units-of-energy-per-day (HME) and boiler size (B), with max(B) as the maximum boiler size of any household, to calculate the nominal energy used today (NE) as follows:

$$NE = (DT * UPT / EE) * HME * B / \max(B)$$

The final energy consumption is given by NE times the fraction of time the house is occupied. This is then added to the units-of-energy-used for the heating-system.

In addition, the household's energy providers have their profitability decreased by the wholesale cost of providing the energy consumed to that household.

The energy efficiency of a building is currently 8/9 for energy performance certificate 'A', 7/9 for 'B', … 2/9 for 'G'.

5.3.3.17 Households pay energy providers for energy consumed

The procedure is the same as that described in section 5.3.3.14.

5.3.3.18 Households maintain their gas or electric heating system if it is time to do so

Yearly maintenance costs are included in the tariff data from the heating system energy provider. The household's balance is decremented by the maintenance cost, and the heating system's serviced? status is set to true. Annual maintenance acts as an opportunity for households to review their heating system.

5.3.3.19 Households or individuals attend work, school and/or community events

Households have weekly calendars for attending each of work, school and community events, and also have days of the year when they are on holiday. If they are not on holiday and with a random probability of attendance (to allow for sick leave), then households add three hours away from home for each community event, and if not working from home, 8 hours for attending school, and 9.25 hours for attending work.

5.3.3.20 Energy providers record profits

The profitability of energy-providers is set to 0 at the beginning of the year (ticks mod 365 = 0), and the data on profitability saved to a file each day.

5.3.3.21 Households pay banks for loans

The balance of the household is deducted by the repayment amount of the loan.

5.3.3.22 Households pay rent to landlords

The balance of the household is deduced by the rental amount of the property.

5.3.3.23 Street voting can take place

Street voting is enabled by a model parameter switch. For street voting to occur, at least one patch in the street must have a neighbouring patch with a pipe in it. Residents of buildings in the street not already connected to the heat network then get to vote on whether they want the heat network installed for the whole street. They make the decision using the case base as described in 5.3.3.54.

5.3.3.24 Households pay council tax

The balance of the household is deducted by the council tax payable for the council-tax-band of the house they live in. This operates monthly, so the amount paid is one twelfth of the annual council tax. The model has an option for the council tax to be discounted if the household is on the heat network.

5.3.3.25 Households determine their disposable income

The disposable income of a household is their income after costs for rent or mortgage, council tax, and energy bills.

5.3.3.26 Energy providers update their tariff according to the scenario

Energy providers look in a specified directory for a file named *name-of-energy-provider*.yearly.*year*.csv and then read in new tariffs from that file if it exists. As noted, the file has a CSV format. The first column should be the name of the tariff, the second the type of fuel the tariff is for (gas, electric or heat), followed by the wholesale unit cost, the frequency of payment (daily, weekly, monthly, quarterly or yearly), the retail unit cost, the standing charge, the disconnection cost, the installation cost and the yearly maintenance cost.

5.3.3.27 Pipe may be laid using stochastic rules

Under stochastic pipe laying, a parameter nof-bits-of-pipe determines a random number of patches with pipe-possible? and not pipe-present? that neighbour a patch with pipe-present? to change their status such that a pipe appears. Depending on whether eligibility is by-proximity or by-street, buildings within the proximal-qualification-distance of, or on the same street as, the patch are then connected to the heat network. Households in those buildings then connect to the heat network using the rules in section 5.3.3.1.

5.3.3.28 Grant bodies update the grants they offer

Grant awarding bodies look in a specified directory for a file named *name-of-grant-body*.yearly.*year*.csv and then read in new grants from that file if it exists. The CSV format file has as first column the type of the grant, which is used as a key for the table of grants the awarding body offers. The remaining columns specify what the grant is for (gas, electric, heat or insulation), the amount, the maximum income for households to be eligible for the grant, the x and y coordinates of the centre of a circle defining geographical limits to eligibility, and the radius of that circle (which may be 0 if everyone is eligible).

5.3.3.29 Landlords update their rents according to the scenario

Landlords look in a specified directory for a file named *name-of-landlord*.yearly.*year*.csv and then read in new rental contracts from that file if it exists. The CSV format has as first column a name for the rent, which is used as a key in table data about the rents. The remaining columns contain the frequency of rent payment (daily, weekly, monthly, quarterly or yearly) and the rental amount.

5.3.3.30 Banks update their interest rates according to the scenario

Banks look in a specified directory for a file named *name-of-bank*.yearly.*year*.csv and then read in new loan data from that file if it exists. The CSV format has as first column the name of the loan, which is then used as a key to access data about the loan. The remaining columns specify the purpose of the loan (mortgage, electric, gas, heat), the principal (i.e., amount lent), the repayment frequency (daily, weekly, monthly, quarterly or yearly), the repayment per unit frequency and the number of repayments.

5.3.3.31 Advisory bodies update their status according to the scenario

Advisory bodies look in a specified directory for a file named *name-of-advisory-body*.yearly.*year*.csv and then read in new advice data from that file if it exists. The CSV format has as first column a title for the advice, which is used as a key in table data about it. The remaining data contain the action, the energy type, the finance, and whom the advisory agent will advise people to approach, which must be the name of an existing grant awarding body, energy provider, landlord or bank. The next three columns contain the x and y coordinates and radius defining a circle in which the advice will be offered (the radius may be 0 if it is anywhere). All remaining columns are then used to specify days of the year (in the range [0, 364] -- so they act as valid remainders from dividing by 365) at which the advice will be offered. These columns can be unused if the advice is always available.

5.3.3.32 Households update their heating and demographic status

Households with gas and electric heating systems set the serviced? flag for these systems to false.

Modifying household demographics is based on rather rigid interpretations of Scottish demographic data. To modify household demographics, each member of the household is considered in turn. Men older than 77 die. Men aged 34 bring a randomly-created 32-year-old female into the household. Women aged older than 81 die. Women aged 30 have a child with probability 0.266. Women aged 32 leave the area (to join another household when they get married).

Persons aged 19 cease attending school, and with probability 0.419 become employed by a 'work' agent. Persons aged older than 67 retire with probability 0.419. Persons aged older than 4 join a school.

Persons attending a community organization may leave it with a probability sampled from the power-law distribution in figure 5.2 (threshold: sample < 0.5), and with the same probability may join another community organization.

The family's dynamic is updated to cater for any changes in composition by choosing a random one of the available family dynamic options (determined by parameters) and ensuring that matriarchal families can have a female head and patriarchal ones have a male head.

5.3.3.33 Weather data is updated

The weather data is in a specified directory; if the weather is to change from its current settings, then a file named weather.yearly.*year*.csv should be in that directory. Each year's weather data is contained in a CSV file that is expected to have 365 rows (one for each day of the year) and two columns containing temperature in celsius and absolute humidity in grams per cubic metre.

5.3.3.34 Holiday data is updated

All households set their 'holidays-used' for each of the institutions they attend to 0.

5.3.3.35 Reading energy provider data from files

An energy provider agent is created and initialized with empty data before using the same process as detailed in section 5.3.3.26, except that the filename expected is *energy-provider-name*.csv

5.3.3.36 Reading bank data from files

A bank agent is created and initialized with empty data before using the same process as detailed in section 5.3.3.30, except that the filename expected is *bank-name*.csv.

5.3.3.37 Reading landlord data from files

A landlord agent is created and initialized with empty data before using the same process as detailed in section 5.3.3.29 except that the filename expected is *name-of-landlord*.csv.

5.3.3.38 Reading grant awarding bodies from a file

A grant award body agent is created and initialized with empty data before using the same process as detailed in section 5.3.3.28 except that the filename expected is *name-of-grant-body*.csv.

5.3.3.39 Reading advisory body data from files

An advisory body agent is created and initialized with empty data before using the same process as detailed in section 5.3.3.31 except that the filename expected is *name-of-advisory-body*.csv.

5.3.3.40 Creating employers

Employers are initialized from files in a specified directory, each of which is expected to have the name 'employer-*i*.csv', where *i* is an integer in the range [0, nof-employers – 1]. If the file does not exist, a random employer agent is created.

The employer file is expected to have a CSV format. The first, second and third columns provide the x and y coordinates of the location of the employer, and the radius of its catchment. The remaining columns provide the employer's calendar, floating holidays, fixed holidays, probability of attendance and working from home attributes. The calendar and fixed holidays are in list format (begin and end with open and close square brackets, space-separated numeric entries). For example, a calendar might be [1 2 3 4 5] for Monday to Friday, or [0 6] for the weekend. Fixed holidays are for such things as bank holidays.

To create a random employer, the model assigns fixed holidays for Scottish standard bank holidays, 20 days' floating holiday leave, and assumes a Monday-to-Friday calendar. Based on data on sick leave, the probability-of-attendance is set to 0.984. The working-from-home attribute is also initialized using model parameters to indicate the number of hours per day worked from home, if another parameter switch indicates the model will simulate that.

5.3.3.41 Creating community organizations

Like employers, community organizations can be initialized from files (with the name 'community-organization-*i*.csv', where *i* is an integer in the range [0, nof-community-organizations – 1], or created at random. The community-organization file has the same format as that for employers, as described in section 5.3.3.40.

To create a random community organization, fixed holidays are set to Scottish bank holidays, floating holidays to 0, and the calendar to a random day in the working week. The probability of attendance is set to a random number in the range [0, 1] and working-from-home set to 0.

5.3.3.42 Creating schools

Schools can be created from files (with the name 'school-*i*.csv', *i* in the range [0, nof-schools – 1], or at random if the file cannot be found. The school file has the same format as that for employers, described in section 5.3.3.40.

To create random schools, the calendar is set to the working week, and floating holidays to 0, The fixed holidays is set to correspond to a typical pattern of school holidays in North East Scotland (available from the relevant council websites). The probability-of-attendance is set to 0.936.

5.3.3.43 Case bases are created for energy-providers, banks, landlords, institutions, grand bodies and advisory bodies

Case bases have a simple set of pre-defined decision contexts:

- power restored after regional outage
- power restored after city wide outage
- moved-in
- repair
- replace
- awareness-raising-event
- yearly-maintenance
- clean-install
- connection
- street-voting

And another set of possible decisions:

- install
- abandon
- repair
- get-advice
- follow-advice

Each combination of these can have one of two outcomes: ‘yes’ (true) or ‘no’ (false).

To create an initial case-base-pool, cases are created at random. The size of the case base pool is a model parameter. First, a random decision is chosen. Decisions are weighted for selection 8:1:12:3:4 install:abandon:repair:get-advice:follow-advice. Allocation of the state of the case is then made as follows according to the decision selected, with random choices of decision contexts weighted 1:1:10:0:10:0:1:6:6:6 in respective order of the decision context list above.

- install: energy-type “heat”, random decision context, random energy provider offering district heating, and a random affordability as per abandon below.
- abandon: random energy-type (in heat, gas or electric), random decision context, name of a random energy provider for the energy-type and a random affordability comprising the lifetime, installation costs, disconnection costs and maintenance costs of the system.
- repair: random energy-type, decision-context “repair”, name of a random energy provider for the energy-type, and a random affordability as per abandon.
- get-advice: energy-type “heat”, random decision context, random institution offering advice about district heating, and a random set of surveyed attitude values.
- follow-advice: energy-type “heat”, random decision context, and a random recommended institution offered by a random advisory body.

The outcome of the state is then set uniformly randomly from true or false.

Specific cases for agents can be loaded from a file. The case base file is in CSV format. The first column contains the name of the person, household, mainstream media, bank, institution (employer, business or school), energy-provider, landlord, business, grant body or advisory body agent the case is for, the second column contains the decision (one of the above list), the third column contains the outcome (true or false), while columns from four to the end of the line define a conjunction of state information:

an energy type, a decision context (see list above), a name of an institution, and any surveyed attitudes from the questionnaire that are relevant to the situation.

5.3.3.44 Mainstream media agents are created

Mainstream media agents are created with the specified name and type, with empty case base and recommendations.

5.3.3.45 The population is loaded from a file

The population file is a CSV format file with at least the columns name, age, sex, employer, income, node degree, and then remaining columns for attributes. Age is expected to be in the range [0, 109], sex in {male, female}, institution to be the name of an institution in the model, and income and node degree at least 0. The population file is intended to correspond to the questionnaire survey in Aberdeen, and is used as a basis for creating artificial agents.

5.3.3.46 Households are loaded from a file

The household file is a CSV format file containing the columns name, postcode, owns-property?, owns-outright?, bank-name-or-landlord, loans-or-rent-name, max-units-of-energy-per-day, min-units-of-energy-per-day, uses-electricity?, electricity-included-in-rent?, electricity-supplier, electricity-tariff, uses-gas?, gas-included-in-rent?, gas-supplier, gas-tariff, uses-heat?, heat-included-in-rent?, heat-supplier, heat-tariff, heating-system, council-tax-band, last-switched-supplier, degree, dynamic. The postcode must begin “AB”. All columns ending in a question-mark are expected to have values in {true, false}. Heating system should be in heat, gas, electric or ‘’ (empty). The file is used as a pool of data from which to create new households (see section 5.3.3.2).

5.3.3.47 Buildings are loaded from GIS shape files

Separate GIS shape files are expected for buildings containing single households, buildings with five or fewer households, and buildings with six or more households. Each GIS file is loaded separately and the locations stored in variables used in 5.3.3.52.

5.3.3.48 The heat pipe network is initialized

The initial heat pipe situation depends on whether there is street voting or stochastic pipe laying. If there is street voting, a random street with pipe-possible? is selected, and patches in those streets have pipe-present? set to true. If there is stochastic pipe laying, then one random patch with pipe-possible? is selected and has pipe-present? set to true. If neither of these flags apply, then a pipe-laying schedule must be provided. See section 5.3.3.1.

5.3.3.49 Council tax and business rate data is initialized

The eight council tax bands A-H and the business rate are assigned initial values according to current data. In a future enhancement, these could be updated year-on-year.

5.3.3.50 Trust data are initialized

Trust data are stored in a CSV file, with two columns, one a name for the ranking, the other a NetLogo list containing one or more of {social, neighbour, work, school, community, bank, landlord, family, advice, national, local, energy}. The name is used as a key in the trust-values table.

5.3.3.51 Social networks are created

This part of the setup entails checking that the parameters determining the structure of the neighbourhood and social networks are valid (they must be a NetLogo list format). The actual connections of agents are created as needed, and the model provides various options for the structure of the network, with Hamill and Gilbert (2009) being the preferred option for reasons discussed in that article. Under this network model, agents are connected if they are within a 'reach' of each other. This reach parameter determines how far the agent looks to find someone to connect to and is set from choosing a random member of the list for the neighbourhood and social networks parameters. As agents are added to populate buildings, they connect to all other agents not in their family within reach patches, to a maximum of 150 connections per agent.

5.3.3.52 Buildings are created from GIS data

The locations of single household buildings, those with 2-5 households, and those with 6 households or more read in earlier are used to create new buildings using the same process as described for new-builds in section 5.3.3.2.

5.3.3.53 Businesses are created from GIS data

Locations of businesses are in a GIS shape file.

5.3.3.54 Making a decision

Decisions are binary (yes/no). To make them households use an endorsement mechanism based on a trust rank given to different kinds of people (including themselves). Households ask everyone they know for a case to match their decision context, and whether the alter said 'yes' or 'no' in that case. The total endorsement for each of 'yes' or 'no' is the sum of a model parameter *b* raised to the power *t*, where *t* is the trust rank of the social link to the person or organization making that decision. Households choose the decision with the higher endorsement.

6 From agent-based models to the sandbox tool

This section documents a formal language we have developed that enables automatic mappings to be made from output of agent-based models to the Policy Sandbox Tool (PST) being developed in Work Package 8. It is based on collaborations involving David Hales, Niklas Mischkowski, Sara de Maio, Elma Meskovic, Gabriel Nock and Gary Polhill.

The section covers mapping terminology from agent-based models (ABMs) to the PST, and then presents a specification of the language. The language specification is designed to be included in the 'info' tab of a NetLogo model. The info tab in NetLogo is used for human-readable documentation of the model, and adopts a markdown format (Gruber 2004). Since markdown is a popularly-used format for documentation, including in R and for 'README' files on repositories such as GitHub, the sandbox tool specification described here should be applicable for models implemented in other programming languages.

The goal of the SandBox Language (SBL) is to provide an end-user model visualization tool with instructions on how to interpret and visualize selected model outputs. Modellers are expected to provide the PST with a Zip archive containing all the content needed to provide appropriate displays of model outputs. That Zip archive must contain:

- Exactly one NetLogo model file (with a .nlogo suffix). In the general case, a single file called 'sandbox.md' containing markdown documentation for the sandbox tool can be provided instead.
- At least one (and possibly several) of the following:
    - CSV formatted files containing tabulated model output data. These files must have a .csv suffix. Data in CSV files can be processed by the sandbox tool to create bespoke visualizations to the end-user.
    - PNG formatted files containing screenshots from the model and/or bespoke model visualizations prepared by the modelling team.
    - MP4 or WebM formatted video files containing animated visualizations prepared by modelling teams.

It is *not* acceptable for modellers to provide the policy sandbox tool team with standalone NetLogo, CSV, PNG or video files. The reason is that it is then impossible for the policy sandbox tool team to know what to do with it, or keep track of where the files fit with other visualizations.

6.1 Terminology

It is well-recognized that inter- and transdisciplinary research requires work to enable mutual understanding, especially around specialist terminology (Jahn et al. 2012; Bracken & Oughton 2006). The PST has a different vocabulary space than ABMs do. As is commonly understood in the literature on semantic heterogeneity, there are various ways in which terminologies can overlap, including *naming conflicts*, *scaling conflicts*, *confounding conflicts* and *representation conflicts* (Bellatreche et al. 2006, p. 713). Naming conflicts occur through such things as synonyms and homonyms, and are most likely in this case (e.g., 'parameter' is a word with multiple interpretations). Scaling conflicts occur through using different units of measurement and are less of an issue here. Confounding conflicts occur through shifting contexts meaning that concepts that apparently have the same meaning in the end do not really. Representation conflicts are the opposite to confounding conflicts: the same concept is represented in different ways, and so at face value looks different. Naming, confounding and representation conflicts can be expected to be most problematic in interdisciplinary collaborations.

In the rest of this section, we document relevant modelling terminology and PST terminology, and consider the potential mappings from one domain to the other.

6.1.1 Modelling terminology

Agent – a contested term lacking any universally-accepted definition. Polhill et al. (2019) effectively describe it pragmatically as an entity that has some attributes that are its and not anything else's, each entity having some dynamics it is responsible for causing, these dynamics having the potential to cause changes to the attributes of other entities. Ge and Polhill (2020, p. 60-61) articulate the sense in which such entities have 'responsibility' as being narrative in nature.

Algorithm – a set of computer instructions that implement some element of the behaviour of the model. HUMAT is an algorithm, for example.

Attribute – a variable the value of which 'belongs' to an entity in the sense that (potentially in conjunction with other attributes) its value could be used to tell one entity apart from another.

Dynamics – the general behaviour of the model (or a part thereof) over (space and) time, which could be described over a single run or several experiments.

Experiment – a set of runs, which may vary inputs and parameters, and perform one or more replications of runs with each setting. Experiments with a model may be conducted for academic reasons as well as with the intention of providing insights of relevance to stakeholders.

Input – a data file that is used to set a part of the initial state of a model or to provide values for variables in the model during a run.

Link – a connection between a pair of agents.

Metric – an output that is a scalar quantity from the whole system.

Output – a variable that is observed from the model; this can be spatial, temporal, individual or network-based as well as a scalar quantity from a whole system.

Parameter – a global variable in the model that can be set to different values to adapt or adjust the model's behaviour.

Run – a single execution of a model with specific settings of its parameters and inputs. An experiment typically consists of several runs, and, depending on the dynamics of the model, may lead to qualitatively different outcomes even with the same specific parameter and input settings.

Rule – an 'if-then' statement that specifies the conditions under which an agent undertakes a behaviour. Decision trees are rules, for example.

Seed – a special parameter of the model that is used to initialize the pseudo-random number generator; a seed and a setting will deterministically reproduce the output of a model.

Setting – a combination of input(s) and parameters(s) that uniquely specify conditions under which a model is run.

6.1.2 Sandbox tool terminology

Actor – a specific individual (person or organization – see D6.1 (Pellegrini-Masini et al. 2019)) who has a key role in a case study.

Actor Network – a group of individuals (persons or organizations) connected in various ways, causal and relational.

Barrier – a contextual condition that gets in the way of a positive outcome occurring.

Building Blocks – a collective term for Organizations, Contexts, Social Innovation, Social Behaviour, Policy Scenarios; they are things that are put together to make a case.

Context – a set of conditions for a case study that define the context in which an outcome may or may not occur; these conditions would typically not be things that the user of the sandbox tool would be able to control in the real world (e.g., global energy prices, the infrastructure present at the start of the case study, or national level policy).

Driver – a contextual condition that makes a positive outcome more likely to occur.

Metascenario – a collection of non-locally dependent contextual scenarios that will be shown in the sandbox tool.

Need – an outcome that pertains to the population in the case study; by implication some level of lack of this need being satisfied entails unhappy humans.

Organization – a group of humans with a collective goal.

Outcome – an effect in a case study of particular interest to the end-users.

Policy Scenario – A set of parameters that are predetermined by modellers and a set of specific additional parameters that can be changed by the end-user (in real-life and via the sandbox tool) with a view to achieving a desired outcome.

Scenario Parameter – an aspect of a case study that can be predefined by modellers ('invisible') or adjusted by a user of the sandbox tool ('visible') to see what happens.

Social Behaviour – how the people in the case study behave.

Social Innovation – a process of developing new ways of organizing and/or instituting the social and physical infrastructure by which an outcome might be achieved.

6.1.3 Mapping from sandbox tool to modelling terminological domains

For each of the sandbox tool terms, there are various ways in which a model might represent them. This means that the on-line version of the sandbox tool needs to be told where to look in a model and its data to display something relevant. The details of both are less important than the messages that (a) the mappings are not straightforward (e.g. mostly one-to-one) in general (though they may be more straightforward for any one specific model); and (b) flexibility needs to be provided in the language for any sandbox tool term to be represented by any (combination of) modelling terms. A summary of the overlaps in terminology (which should not necessarily be considered exhaustive) is provided in Table 6.1, with details specified in ensuing subheadings.

Table 6.1 Summary of terminological mappings. Grey cells indicate the PST and ABM combination is a potential match; blue and purple numbered cells indicate a dependence on interpretation (see main text). Green cells with a 'q' entry indicate a qualification on the agent term (see main text).

ABM term	Actor	Actor Network	Barrier / Drier	(Other) Context	Metascen ario	Need	Organizat ion	(Other) Outcome	Policy Scenario	Scenario Paramete	Social Behaviou	Social Innovatio
Agent												
Algorithm												
Attribute												2
Dynamics				q							q	1
Experimen t												
Input												2
Link												
Metric												1
Output												1
Parameter												
Run												
Rule												
Setting												

6.1.3.1 Actor

Agent – an agent would typically be used to represent an actor.

Attribute – actors might be identifiable by their attributes rather than having a specifically named class.

6.1.3.2 Actor Network

Agent – an agent could be used to represent an entire actor network if its internal workings were not central to the purpose for which the model is being constructed. Otherwise, agents are parts of actor networks.

Algorithm – algorithms can be used to determine how actor networks behave, and specifically to influence causal connections between agents.

Link – a special kind of attribute, links are typically used to determine which agents interact with which others and in what way. They don't implement the interactions (this is done with algorithms), but indicate the potential for interactions of certain kinds to take place.

6.1.3.3 Barrier or Driver

Agent – the presence of certain kinds of agent (e.g., media, lobby group) in the model might be used to implement a barrier or driver.

Attribute – agents with particular attributes (e.g., psychological properties) might be used to implement a barrier or driver.

Experiment – an experiment could be used to show or test the effect of one or more barriers or drivers by adjusting any conditions known or expected to make them effective.

Input – a barrier or driver could be part of the input data to the model (e.g., from processed questionnaire, census, time-series or GIS data, or any simulated existing infrastructure or agents when the model is initialized).

Parameter – certain (combinations of) parameters of the model could cause the barrier or driver to be effective in blocking or causing the outcome more or less easily.

Rule/Algorithm – agents with particular behaviours might be used to implement a barrier or driver (e.g., habit, imitation).

6.1.3.4 (Other) Context

As Barrier and Driver (but more neutral with respect to outcomes), plus:

(Emergent) Dynamics – an event or series of events that, if they occur, lead to the occurrence of distinct outcomes. As emergent dynamics, the behaviour leading to the event isn't wholly in control of the modeller: it could arise from a particular order in which agents are (randomly) asked to do something, or a specific (but arbitrary) feature of the initial conditions that is not known. In the real world, we'd understand this as a consequence of happenstance rather than design.

Experiment/Parameter – a 'parameter sweep' could be used in an experiment to identify the 'phase space' of different outcomes and identifying the 'tipping points' that form the boundaries between outcomes. (This is just a posh way of saying that under different parameter settings you tend to get different outcomes.)

6.1.3.5 Metascenario

Experiment – a metascenario would be defined as a context where the model takes place; its parameters are not in the local government's control. Several sub-scenarios/experiments can take place after the selection of a meta-context to feed into different outcomes within a metascenario.

Run – One or more runs would typically provide data for a specific experiment/sub-scenario.

6.1.3.6 Need

Algorithm – understood as a 'goal' (i.e., something the agent needs to do), a need could be implicit in the way its behaviour is encoded.

Attribute – the most likely representation of a 'need' is as an association with one or more attributes of an agent, specifying a threshold or range of values over which the need is said to be (un)fulfilled.

Dynamics – needs could be associated with dynamics insofar as they are not necessarily met all the time, and/or influence the algorithms used to decide what agents do.

Metric – a specific system-level metric could be used to determine whether the need is met. For example, a need for safety might be specified as some maximum number of traffic accidents over a defined period.

Output – one or more output files could be used to record numbers or proportions of agents with the need fulfilled a given proportion of the time.

Parameter – parameters could be used to set the thresholds for agents.

6.1.3.7 Organization

Agent – an organization could be implemented directly as a single agent.

Algorithm – an organization could be implemented indirectly through a collective of agents coordinating their behaviour.

6.1.3.8 (Other) Outcome

As well as (more generally-worded) modelling features associated with Need, the following are possibilities:

Experiment – an experiment could be used to demonstrate hypothesized conditions under which an outcome does or does not occur.

Run – an outcome could be demonstrated by a single run.

6.1.3.9 Policy Scenario

Agent – a policy scenario could be implemented using one or more agents that represent the policy in action.

Algorithm – agents representing the enaction of a policy would have algorithms that responded in accordance with the specifications of the policy to prevailing conditions in the model.

Attribute – a policy could be implemented as attribute values of agents where, for example, it unconditionally gave people money every time step. When agents are used to enact a policy, attributes of those agents could be used to set targets (goals) or constraints.

Input – a policy could be implemented as initial conditions of a model, or driving variables during the model. (A driving variable is one implemented by an exogenous time-series providing values for the variable in the model.)

6.1.3.10 Scenario Parameter

Setting – various settings for a model could be used to encode the representation of a scenario parameter.

6.1.3.11 Social Behaviour

Algorithm – agents' algorithms could be used to implement the ways in which they affect each other.

(Emergent) Dynamics – typically social (or aggregate) behaviour in agent-based models is emergent (not explicitly programmed to behave the way it does, other than through the algorithms and attributes of agents combining to make an observed macro-level phenomenon occur). Vocabulary for emergent dynamics is typically different from that used for behaviour of individuals.

Metric – a metric could record the number of times different behaviours occurred.

6.1.3.12 Social Innovation

Understood strictly as a process, this is a combination of Algorithm and Agents leading to particular kinds of emergent Dynamics that entail novel system states (that would be picked up, for example, using Metrics or other Outputs).

Understood more prosaically as a special kind of policy scenario that entails a novel way of realizing a desired outcome, then the same features as Policy Scenario could apply.

6.2 SBL specification

The SBL is read from a part of a NetLogo model file, which is a text file having a .nlogo suffix. The PST reads the NetLogo model file to find what the modeller has provided in the way of material to display. Other files provided in the Zip archive provide supporting data, videos and images. NetLogo model files are divided into sections using a special sequence of characters "@#$#@#$#@" appearing on its own as a single line. The PST needs to be capable of reading the markdown (Gruber 2004) formatted text between the second and third such lines, and the XML formatted text between the seventh and eighth.[8] (See Table 6.2.) The SBL pertains exclusively to the markdown formatted text, which to the modeller appears in the 'Info' tab of their NetLogo model.

Table 6.2 High-level layout of a .nlogo format file. Ellipses (...) indicate zero or more lines of content (such as NetLogo model code and interface geometry) of little interest to the PST. Italicized text describes the content. Non-italicized bold text should appear as is.

```
...
@#$#@#$#@
...
@#$#@#$#@
Info tab markdown text
```

[8] The format of the .nlogo file is documented at https://github.com/NetLogo/NetLogo/wiki/File-(.nlogo)-and-Widget-Format

```
@#$#@#$#@
...
@#$#@#$#@
...
@#$#@#$#@
...
@#$#@#$#@
...
@#$#@#$#@
XML formatted experiment data
@#$#@#$#@
...
```

The 'Info' tab may be used by the modeller to document other features of the model. The SBL therefore appears as a (sub)section of the documentation in the Info tab. To provide the modeller with flexibility in how the sandbox section appears in their documentation, the sandbox tool section can begin using any of the first three levels of heading. The SBL is used within that section only -- the rest of the markdown can be ignored. The end of the markdown section of interest to the sandbox tool is therefore indicated by either (a) a new section in the markdown with the same heading level as the sandbox heading; (b) the end of the info tab markdown text section of the NetLogo file.

The overall structure of the SBL is as follows:

1. A level 1, 2 or 3 'SANDBOX' or 'Sandbox' heading
2. A case study specification
3. One or more metascenario specifications
4. One or more scenario parameter specifications
5. Zero or more parameter combination specifications
6. Zero or more sandbox element specifications
7. One or more model file documentation specifications, one per file in the Zip archive
8. End of info tab section of NetLogo model file, or occurrence of another heading at the same level as that of 'SANDBOX' or 'Sandbox'

At the time of writing, the PST uses a Rubik's cube metaphor to help the end-user navigate each model's results. One metascenario should be seen as corresponding to one metascenario. A literal interpretation of the Rubik's cube metaphor would entail three scenario parameters that can be changed, with three values per scenario parameter, and something different to show on the PST about the model's behaviour for each of the 27 possible combinations of scenario parameter values. This means a modeller providing 27 parameter combination specifications in item 5 above. Table 6.3 provides a template for the sandbox section, assuming a level 1 heading in item 1. The rest of this section documents the means by which each of the 'contents' in Table 6.3 are specified.

Table 6.3 Template sandbox section overview, assuming a level 1 heading for the 'SANDBOX' start.

```
# SANDBOX

Case study specification content

## metascenario scenario name

Metascenario content

## scenario-parameter parameter name

Scenario parameter content

## parameter-combination combination name

Parameter combination specification

PST display content

## sandbox element heading

PST display content

## file file label

File description content
```

6.2.1 Case study specification content

The case study specification content is used to tell the PST which case study this model and its accompanying data are being used to display. They are provided using field-value pairs, as documented in section 7.2.8. The fields ‘Case’ and ‘Sector’ *must* be specified by the modeller. Valid values for the Case field are ‘Groningen’, ‘Zurich’, ‘Zürich’, ‘Samso’, ‘Samsø’, ‘El Hierro’, ‘Stockholm’, ‘Malmo’, ‘Malmö’, ‘Barcelona’, ‘Vitoria-Gasteiz’, ‘Aberdeen’, ‘Timisoara’, or ‘Timișoara’. Valid values for the Sector field are ‘Mobility’, ‘Energy Use’, ‘Energy Generation’. Example:

```
**Case**: Groningen

**Sector**: Mobility
```

Models may be used for more than one case. The Case field may then be repeated. However, the PST will then need to know which metascenarios apply to which Case. An unordered list should be used to give the scenario names appearing in the corresponding metascenario subheadings. A minimum of one metascenario scenario name must be provided for each case. In the example below, there is one metascenario for Malmö, with a scenario name that is then expected to appear in a subsequent metascenario heading, and two for Stockholm. All three of the scenario names must be different, and each have its own metascenario heading.

```
**Case**: Malmo

  + scenario name

**Case**: Stockholm
```

```
  + scenario name

  + scenario name

**Sector**: Energy Use
```

The PST is only obliged to display one of the metascenarios for a case. By providing more than one, a modeller is giving the PST development team a choice of which to use.

If only one Case field-value pair is provided, all metascenario headings are assumed to apply to that Case.

Other field-value pairs may optionally be provided in the case study specification content. These may or may not be displayed by the PST.

The case study specification content may (i.e., optionally) also contain other markdown text (none of which may have a heading -- that is, a # must not appear as the first character of any line in the optional case study specification content) after all field-value pairs have been given, which can be ignored by the PST. The case study specification content is terminated by the first metascenario subheading.

6.2.2 Metascenario content

The only required metascenario content is a specification of the scenario parameter names in an unordered list. Each scenario parameter name specified must appear as the parameter name in a scenario-parameter section. The unordered list may be preceded by markdown text describing the metascenario. This optional text must not itself contain any unordered list. An example of a full metascenario subsection is given below:

```
## metascenario Future exploration


  + Trust

  + Media

  + Technical details
```

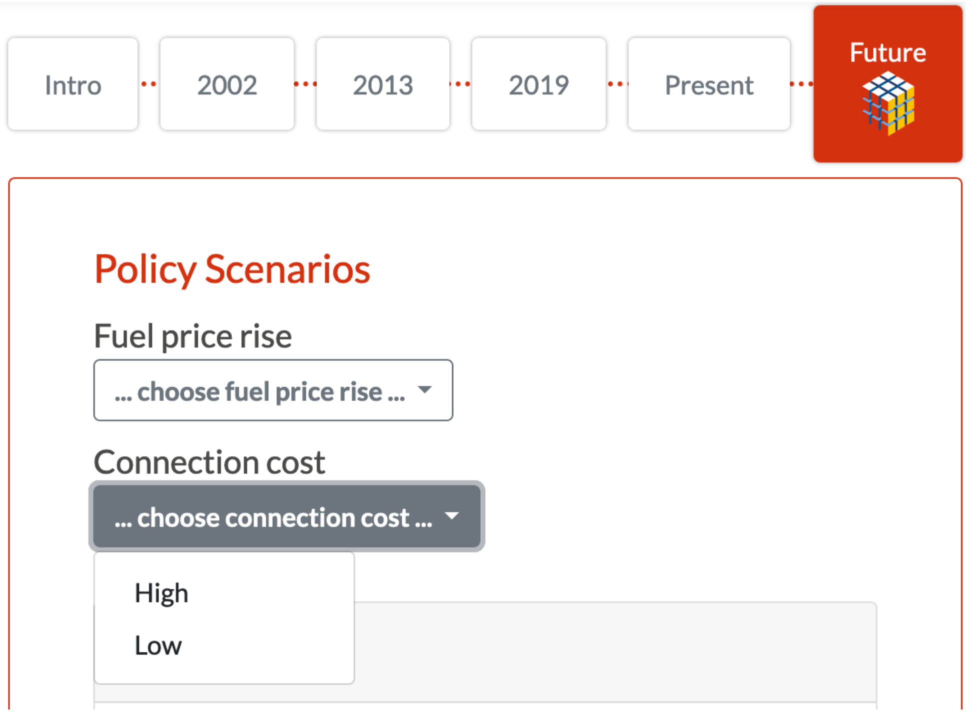
This specifies a metascenario with the scenario name ‘Future exploration’, and indicates that the metascenario has three scenario parameters, ‘Trust’, ‘Media’ and ‘Technical details’. ‘Future exploration’ could then have been used as a scenario name for a case in the case study specification content in section 6.2.1. Each of the three scenario parameters must have its own scenario-parameter subsection and content as specified in section 6.2.3.

6.2.3 Scenario parameter content

Scenario parameter content uses an unordered list to specify values for the scenario parameters. In the Rubik’s cube metaphor presentation of the PST, each scenario parameter has its own drop-down list labelled according to the name of the scenario parameter, and each scenario parameter value is an option to choose on that list. Figure 6.1 illustrates the concept from a prototype PST for Aberdeen. The SBL to specify that content would be as follows (the idea being that the page in Figure 6.1 would be generated automatically from this SBL):

```
## metascenario Prototype Aberdeen

  + Fuel price rise
  + Connection cost

## scenario-parameter Fuel price rise

  + Baseline
  + Prices Rise

## scenario-parameter Connection cost

  + High
  + Low
```

Figure 6.1 Screenshot from the prototype PST for the Aberdeen case study at the time of writing. In this case, there are two scenario parameters, 'Fuel price rise' and 'Connection cost'. The 'Connection cost' scenario parameter has two scenario parameter values ('High' and 'Low'), chosen from a dropdown list.



Though not relevant to the Rubik's cube PST (which displays content for the combined values after the user has selected values for each scenario parameter), the SBL provides syntax allowing modellers to specify single PST display content for each parameter value individually, as well as in combination with others (as in section 6.2.4). In the unordered list, after the parameter value, the modeller would write a colon, and then a single PST display content instruction. In the example below, the ‘Trust’ scenario parameter has four values, ‘High’, ‘Medium’, ‘Low’ and ‘None’. The modeller tells the PST that when Trust is High, the image ‘img/high trust.png’ can be displayed; when it is ‘Medium’ there is a video called med.mp4 that can be downloaded from rug.nl; and when Trust is Low, to use the information in the NetLogo BehaviorSpace output described in a subsequent ‘file’ subheading entitled ‘Low Trust’ (see section 6.2.7). When Trust is None, there is no specific content to show for this parameter value, and there will need to be a parameter combination specification containing that value for Trust if the user is to see anything pertinent to this setting.

```
## scenario-parameter Trust


  + High: show-image


![high-Trust runs](file:img/high%20trust.png)


  + Medium: show-video [medium](https://rug.nl/mov/med.mp4)
  + Low: behaviorspace `Low Trust`
  + None
```

Important: The scenario parameter name (‘Trust’ in the example above) and its values (‘High’, ‘Medium’, ‘Low’ and ‘None’ in the example) are intended for display to end-users of the PST. Though the modeller types in these values using the SBL and theoretically we could use this to autogenerate at least a template PST, the vocabulary used for the scenario parameter names and values *must* be recognizable to end-users. The PST developers and SMARTEES case study partners should not be ‘surprised’ by any vocabulary used here, and the language should avoid jargon and modelling terms, including the use of ‘kebab’ and ‘camel’ cases to replace whitespace. Currently we assume the PST will display content in English; we should not assume end users have excellent English language skills. You could try using ‘Up-Goer Five’[9] to test the vocabulary -- it highlights words that are not in the 1,000 most used words in English, and hence potentially less likely to be understood. In the example above, ‘Medium’ is not one of those 1,000 words, while ‘Middle’ is.

6.2.4 Parameter combination specification

Parameter combinations are the ‘endpoints’ of selecting combinations of values for parameters on the PST. The SBL provides flexibility to specify arbitrary parameter combinations: where they do not completely specify values for all scenario parameters, they would be treated by the PST as optional content to include at a more specific endpoint. Under the Rubik’s cube PST, modellers must specify one parameter combination for each of the possible combinations of parameter values the user can select on the PST. If there are three parameter values for each of three parameters, that means 27 parameter combination specification sections.

[9] https://splasho.com/upgoer5/

Each combination is specified using a bullet list of parameter = value pairs. The ‘hide’ keyword can appear after a colon at the end of a parameter = value pair to indicate that any parameter combination or scenario parameter with PST display content matching the parameter = value pair that is less specific than this parameter combination should not show that PST display content here. The general format of each parameter-combination section is given below. Grey text is used to indicate options. For the purposes of illustration, and because it links with the Rubik’s cube PST, three scenario parameters and parameter values are shown. The SBL only requires a minimum of one.

```
## parameter-combination

  + parameter-1 = parameter-1-value: hide
  + parameter-2 = parameter-2-value: hide
  + parameter-3 = parameter-3-value: hide
  + etc.

PST Display Content
```

In the example below, some PST display content (selected results from a BehaviorSpace output file, and a video) is specified for the combination of parameter values ‘High’ for the ‘Trust’ parameter, and ‘In Favour’ for the ‘Media’ parameter. Any more general content specified in other sections where ‘Trust’ is ‘High’ should not be shown. In section 7.2.3, for example, when specifying the scenario parameter ‘Trust’ and all the values it can have, the image ‘img/high trust.png’ was given as some content to show when ‘Trust’ is ‘High’. This is more general than the parameter combination below, as no values are specified for any other parameters. The ‘hide’ keyword would then say that ‘img/high trust.png’ is not appropriate content to show for this parameter combination.

```
## parameter-combination

  + Trust = High: hide
  + Media = In Favour

behaviorspace `High Trust`
  + select `media-support` = `pro`
show-video [best](file:mov/best_outcome.mp4)
```

6.2.5 Sandbox element specification

As noted in the opening paragraphs of section 6.2, there are optional subheadings allowing specification of PST display content for various sandbox elements. The general way to specify a sandbox element is to give a heading, and provide the PST display content to associate with it.

```
## sandbox-element sandbox-element-name

PST Display Content
```

In the specification above, ‘sandbox-element’ can be one of ‘Actor’, ‘Actor Network’, ‘Barrier’, ‘Context’, ‘Driver’, ‘Need’, ‘Organization’, ‘Outcome’, ‘Policy Scenario’, ‘Social Behaviour’ or ‘Social Innovation’. The ‘sandbox-element-name’ should be substituted for a meaningful (to the end-user) phrase that describes the instance of the sandbox element being shown. Since it is terminology for the end-user, the same points apply here as in section 6.2.3 about specifying names and values for scenario parameters: the language used must be non-technical and recognizable by the PST team and SMARTEES case study colleagues.

The Rubik’s cube PST does not provide for content of this kind at present, but ‘Outcome’ in particular might well be something end-users would be interested in seeing. That is, as well as being able to see what the effects of various scenario parameter combinations are simulated to be in a case study, they might be interested to see a range of outcomes, and explore the circumstances in which they arise. In the example below, a name for ‘Outcome’ (which is Up-Goer 5 compliant) is provided in the heading, and a BehaviorSpace file is provided by the modellers to generate PST display content, with qualifiers telling the PST which rows of data are relevant to the specified outcome, along with a display hint to indicate the rows of data that might be most interesting to emphasise when viewing the data.

```
## Outcome Lower use of things the world can't quickly make more of

behaviorspace `All Results`
  + select `total-fossil-fuel` < `1000000`
  + select `total-waste` < `10000`
  + highlight `policy` != `BAU`
```

6.2.6 PST display content

There are various options for modellers to tell the PST about content they could display in appropriate contexts. The three main options are images, videos and tabular data. Tabular data could be in plain CSV format, or, more likely, BehaviorSpace CSV format (table option). Besides these, there are two options that could be considered for the future: experiments and NetLogo’s CSV plot output format.

There are various contexts in which the SBL says PST display content should be provided. Mostly, these are just a series of lines providing options for the PST to display. However, the scenario parameter specification in section 6.2.3 provides for the SBL to provide ‘single’ PST display content, which is a simplified form of the syntax that does not provide for qualifications or display hints, nor for more than one PST display content option to be provided. In general, although multiple content options can be provided in other contexts, this should be something done with caution: the end-user should not be overwhelmed with data and visualizations when they interact with the tool, and the need to do so might suggest the modeller is not really clear what to display.

The ensuing subsections provide details on how modellers use the SBL to describe the content for the PST to display it.

6.2.6.1 Image

To show an image, use the 'show-image' command. There are two options. The first is structured as given below:

```
show-image ![image-label](image-URL)
```

The 'image-label' provides a name that is expected to appear in a subsequent 'file description content' section (see section 6.2.7). The 'image-URL' is a link to where the image can be found. The markdown syntax involving the square and round brackets is to specify a hypertext link, with the optional exclamation mark indicating the link is an image that should be rendered in the document. This provides for the modeller to provide content suitable for viewing in the Info tab in NetLogo. The PST is only interested in the image-label, with documentation for that appearing in a subsequent section. Should the modeller not want a clickable link or image to appear in the info tab, the show-image command can be invoked using backticks for the image-label, as below:

```
show-image `image-label`
```

Sublists can be used to provide legend information that helps the user interpret what they are seeing. This can be used in 'single' or 'multiple' PST display content specifications. See section 7.2.9.

6.2.6.2 Video

Similar options are provided for videos as they are for images, and legends can also be provided so that the user is helped to interpret simulation output videos. Note that the option to embed the video in the Info tab using a leading exclamation mark is not available. The 'video-label' must appear in a subsequent file description content section as described in section 6.2.7.

```
show-video [video-label](video-URL)
show-image `video-label`
```

6.2.6.3 General tabular CSV output

General table CSV formatted files have a first row containing headings, and the same number of columns in all rows of data. Qualifiers and highlights can be used (see section 6.2.10) to help the PST select and emphasize the right data for the context of the display. The general command is as given below, where 'table-label' must appear as a subsequent file description content section as described in section 6.2.7.

```
table `table-label`
```

6.2.6.4 NetLogo tabular CSV BehaviorSpace output

BehaviorSpace output is a special case of CSV formatting, with the following points worth noting:

- NetLogo CSV output uses quotes for every cell, regardless of formatting. CSV parsing should therefore make use of appropriate libraries, rather than assuming cell data can simply be extracted by splitting each line string on commas.
- All BehaviorSpace output has been generated from an XML formatted specification that in general, though not necessarily, appears in the XML format experiment data section of the .nlogo file (see Table 6.2). For the SBL, modellers must make sure that all BehaviorSpace output shared with the PST is generated from a uniquely-named experiment that is embedded in the .nlogo file, and *not* use the option the NetLogo command line provides to run their experiments using separate XML files. The reason for this is to ensure the information passed to the PST provides appropriate metadata about the content.
- The first six lines of the BehaviorSpace output contain metadata. The seventh line records the column headings that would appear in the first line of a 'general' tabular CSV output file. The PST *may* check the first six lines of metadata to validate consistency. Specifically:
    - Line 2 contains the name of the .nlogo file containing the model used to generate the BehaviorSpace output. This *must* be the same filename as that provided in the Zip file to the PST by the modelling team.
    - Line 3 contains the name of the experiment. This *must* appear in the XML format experiment data section of the .nlogo file as the value for the 'name' attribute of an 'experiment' element.
    - Line 6 contains comma-separated minimum and maximum patch *x* and *y* coordinates (in the order minimum *x*, maximum *x*, minimum *y*, maximum *y*). This *may* be useful for the PST to interpret spatial output data.
- On the seventh line, the first column heading is always '[run number]'. Data for the run number column are not guaranteed to be in numerical order. There is also always a column named '[step]' containing the 'tick' in NetLogo at which the data in the whole row were collected. Columns between '[run number]' and '[step]' are the NetLogo variable names of model parameters. Columns after '[step]' are the names (or NetLogo code) of model metrics -- data containing measured results from the model.
- The format of the BehaviorSpace tabular output file is not under the control of the modellers.
- Modellers must not supply 'spreadsheet' format BehaviorSpace output to the PST.

The general format of the BehaviorSpace output option is as given below. Note that there are two additional qualifiers that can optionally be given besides those in section 6.2.10. The 'after' qualifier can only be provided once, and is shorthand for `select `[step]` > `tick``. The 'drop' qualifier can be used as often as required, and is shorthand for `select `[run]` != `run``.

```
behaviorspace `behaviorspace-label`
  + after `tick`
  + drop `run`
```

6.2.6.5 NetLogo BehaviorSpace experiment (for future implementation)

Experiments can be run multiple times with the effect that there may be several BehaviorSpace output files for a single model. It would be convenient for modellers to be able to refer to the experiment rather than individual BehaviorSpace files. The sandbox tool would look through all the file subheadings for CSV files in BehaviorSpace format, and then inspect those files' third lines to find out which files were associated with the experiment named in the command, which would be formatted something like the following (red colouring is used to indicated that this is an unsupported extension to the SBL at the time of writing):

```
experiment `experiment-name`
```

These files would then be concatenated to effectively form a single BehaviorSpace file. To maintain integrity of the '[run number]' column in the concatenated file, a column could be added called '[file]' or similar containing the original BehaviorSpace filename from which the data came. Alternatively (for better compatibility with the 'drop' command in 6.2.6.4), the filename (or other unique file ID) could be prepended to the '[run number]' data entries such that the data in that column correctly and uniquely identified each run.

6.2.6.6 NetLogo plot CSV output (for possible future implementation)

NetLogo has a CSV output format that derives from plots, either single plots or all of them (e.g. through using the `export-all-plots` command in NetLogo). Though these could reasonably be supplied as output, the layout of the CSV is not such that it can conveniently and easily be processed programmatically. The proposal for now would be that should any model need to supply data from plots to the sandbox tool they either use a general CSV format (i.e. write the CSV file from within the NetLogo model), or we develop postprocessing scripts that can be used to provide a more convenient CSV format file from the data saved by commands such as `export-all-plots`. Code is available from Hutton that provides at least some of the latter functionality. The former functionality can be achieved relatively easily using the `csv` extension to NetLogo and the command `csv:to-file`, which writes a list of lists to a CSV file.

6.2.7 File description content

Apart from the NetLogo (.nlogo) file, every other file included in the zip file sent to the PST team must be described using a file description content heading. These are (mostly) provided as a series of field-value pair specifications (see section 6.2.8). Of these, only 'Location' is required for all four kinds of file (image, video, table and behaviorspace). The value of 'Location' should be a URI. In the ensuing subsections, the data to be provided for each of these four file types are described, with further subsections covering the information for fields that do not have a simple data value. The file subheading itself contains a label that is used to refer to that file in the data of other headings. In general, it looks like this:

```
## file label used to refer to the file elsewhere
```

A specific example, corresponding to one of the examples in section 6.2.3:

```
## file high-Trust runs
```

6.2.7.1 Image files

Required fields:

- Location -- URI of where to find the image file (e.g. file:img/example.png)
- Experiment -- Name of an experiment (in backticks) used to generate this file.
- Legend -- How to interpret shapes, line styles and colours: see sections 6.2.7.5 and 6.2.9.

Fields required under some circumstances:

- XLLCorner (if the image shows a real geographical space) -- Eastings for the lower left corner of the image. See section 6.2.7.9.
- YLLCorner (if the image shows a real geographical space) -- Northings for the lower left corner of the image. See section 6.2.7.9.
- NCols (if the image shows a real geographical space) -- Number of patches (i.e. NetLogo) in the X dimension.
- NRows (if the image shows a real geographical space) -- Number of patches in the Y dimension.
- CellSize (if the image shows a real geographical space) -- Length of one side of a patch in metres.
- Time (if the image shows a snapshot or graph) -- Real world time being simulated. If the graph is a time series, the time of the earliest point in the graph. See section 6.2.7.10.
- Run (if the image is a snapshot from one run) -- Run number in the experiment the image was obtained from.
- Tick (if the image is a snapshot taken at one tick from one run, but the Time field is not provided) -- Tick number in the run the image was taken at.

Optional fields:

- Format -- What kind of data the file contains (see section 6.2.7.6)
- MD5 -- MD5 checksum of the file (to check for corruption)
- Size -- Number of bytes in the file (to give hints about storage requirements or processing time)

6.2.7.2 Video files

Required fields:

- Location -- URI of where to find the video file (e.g. file:img/example.mp4)
- Experiment -- Name of an experiment (in backticks) used to generate this file.

Fields required under some circumstances:

- XLLCorner (if the video shows a real geographical space) -- Eastings for the lower left corner of the image. See section 6.2.7.9.
- YLLCorner (if the video shows a real geographical space) -- Northings for the lower left corner of the image. See section 6.2.7.9.
- Time (if the video shows a model animation) -- Real world time being simulated when the video starts. See section 6.2.7.10.
- TimeUnit (if the video shows a model animation) -- Amount of time to add per frame. A number followed by a unit specification. See section 6.2.7.10.
- Run (if the video is an animation from one run) -- Run number in the experiment the video was obtained from.

- Legend -- How to interpret shapes, line styles and colours in the video: see sections 6.2.7.5 and 6.2.9.

Optional fields:

- Format -- What kind of data the file contains (see section 6.2.7.6)
- MD5 -- MD5 checksum of the file (to check for corruption)
- Size -- Number of bytes in the file (to give hints about storage requirements or processing time)
- PopUp -- Provide text to explain what is happening in the video (see section 6.2.7.8).

6.2.7.3 Table files

Required fields:

- Location -- URI of where to find the video file (e.g. file:img/example.mp4)
- Experiment -- Name of an experiment (in backticks) used to generate this file.
- Format -- What kind of data the file contains (see section 6.2.7.6).
- Columns -- The columns in the CSV and information about them (see section 6.2.7.7).

Fields required under some circumstances:

- XLLCorner (if the table contains spatial data) -- Eastings for the lower left corner of the data in the table. See section 6.2.7.9.
- YLLCorner (if the table contains spatial data) -- Northings for the lower left corner of the data in the table. See section 6.2.7.9.
- NCols (if the table contains raster spatial data) -- Number of patches (i.e. NetLogo) in the X dimension.
- NRows (if the table contains raster spatial data) -- Number of patches in the Y dimension.
- CellSize (if the table contains raster spatial data) -- Length of one side of a patch in metres.
- PolygonID (if the table contains vector spatial data) -- Column name (in backticks) containing the ID of a polygon in a GIS vector file to which the rest of the data in each row applies.
- PolygonFile (if the table contains vector spatial data) -- Name of the GIS file (such as an ARC shapefile) containing data on polygons.
- XCol (if the table contains raster spatial data) -- Column name (in backticks) containing X coordinates
- YCol (if the table contains raster spatial data) -- Column name (in backticks) containing Y coordinates.
- TCol (if the table contains temporal data) -- Column name (in backticks) of column containing a (numeric) time indicator.
- Time (if the table contains temporal data) -- Real world time corresponding to a value of 0 in TCol. See section 6.2.7.10.
- TimeUnit (if the table contains temporal data) -- Amount of time to add to the real-world time in the Time field, per unit value in the column indicated by the TCol field. See section 6.2.7.10.
- AgentID (if the table contains data about individual agents) -- Column name (in backticks) containing the ID of an agent.
- LinkData (if the table contains data about links between pairs of agents) -- Column name (in backticks) containing an ID of a 'from' agent, then the keyword 'to' (for directed links) or 'with' (for undirected links), then the column name (in backticks) containing an ID of a 'to' agent, followed by a description for the type of link (e.g., 'friend' or 'colleague'), or the name of a column in backticks containing the information about the description. Two examples are given below. The first says that the table contains information about the undirected 'sibling' link with

columns ‘Agent1’ and ‘Agent2’ providing information about which pairs of agents are siblings. The second says that there are several kinds of business-to-business directed links in the table data, ‘Business1’ and ‘Business2’ being the columns containing which businesses are connected in any one business-to-business relationship, and ‘B2BType’ containing information about what kind of relationship that is. (Entries in such a column could be such things as ‘subcontractor’, ‘supplier’, ‘partner’, ‘subsidiary’.)

- Run (if the table contains data from a single run) -- Run number in the experiment the table was obtained from.
- Tick (if the table contains data from one tick from one run, but the Time field is not provided) -- Tick number in the run the table data was saved.

```
**LinkData**: `Agent1` with `Agent2` sibling

**LinkData**: `Business1` to `Business2` `B2BType`
```

Optional fields:

- MD5 -- MD5 checksum of the file (to check for corruption)
- Size -- Number of bytes in the file (to give hints about storage requirements or processing time)

6.2.7.4 Behaviorspace files

Required fields:

- Location -- URI of where to find the video file (e.g. file:img/example.mp4)
- Columns -- The columns starting in row 7 of the CSV and information about them (see section 6.2.7.7).
- Time -- Real world time corresponding to a value of 0 in ‘[step]’. See section 6.2.7.10.
- TimeUnit -- Amount of time to add to the real-world time in the Time field, per unit value ‘[step]’ (i.e. per tick). See section 6.2.7.10.

Optional fields:

- Format -- What kind of data the file contains (see section 6.2.7.6)
- MD5 -- MD5 checksum of the file (to check for corruption)
- Size -- Number of bytes in the file (to give hints about storage requirements or processing time)

6.2.7.5 Legend field

Section 6.2.9 contains information on how to specify legend data. In addition to this, the legend field can be used to say that an image or video already contains its own legend by giving the ‘embedded’ value to the field, thus:

```
**legend**: embedded
```

Otherwise, the legend field value comprises an unordered list as per the options section 6.2.9. An example legend field-value pair might be:

```
**legend**:
  + legend #D73229 `person`: someone who is too hot
  + legend #345DA9 `person`: someone who is too cold
  + legend solid: friend
  + legend dashed: colleague
  + legend #F16A15: heat network pipe present
```

6.2.7.6 Format field

The value of the format field is a space-separated list of the symbols in {`space`, `time`, `agent`, `link`, `system`}. The symbol 'space' means that the file contains spatial data (e.g. a screen-grab, or a table with columns having data about cells with specified *X* and *Y* coordinates); 'time' means there is temporal data (e.g. a time-series graph, animation of model dynamics or table with a column specifying what time the data in the rest of the row correspond to).

The 'agent' and 'link' symbols are used to indicate that the file contains information about individual agents and social links respectively. Such data would typically appear in table format files, but arguably also in visualizations of models in images and videos, showing such things as social network topologies. There are potential GDPR issues if the agents shown are identifiable real people. *Modellers must **not** share such data for use in the PST: identifiable individual agents must be artificially-generated (e.g. by sampling from distributions calibrated over a sufficient number of 'typical' people in an area that no-one could identify an individual living human), and not directly use data from individual human respondents. The PST should display a disclaimer indicating that individual agents do not correspond to real people*.

6.2.7.7 Column field

Any column referred to in other parts of the Sandbox section will need to be described, with the exception of '[run number]' and '[step]' in BehaviorSpace files. The values for the 'Column' field are descriptors for each column as an unordered list, with sublists providing further information as needed. Providing this information to the PST is important in enabling tabular data to be interpreted appropriately by the PST when preparing visualizations of it. Columns for which metadata are not provided will be ignored by the PST.

Each column is specified by its column name in backticks, which should be equal to the entry in the column heading cell in the CSV file. After the column name in backticks, the specification then states its measurement scale type in {Boolean, nominal, ordinal, interval, ratio}. If the measurement scale type is ordinal, the ordering of entries in the column must then be specified as a list from lowest valued entry to highest valued entry, with each entry in backticks, separated by less-than (<). Some examples are given below:

```
**Columns**:
  + `written-numbers` ordinal `one` < `two` < `three`
```

```
  + `temperature` interval
  + `scenario` nominal
  + `savings` ratio
```

Sublists for each column then give further information that might be helpful to the PST in meaningfully displaying and analysing the data. All are optional:

- **`unit`** -- provide a string given the unit of the data. This applies more to nominal and ratio types, and helps the PST avoid metaphorically adding apples and oranges.
- **`stats`** -- provide an indication of how the entries were calculated -- e.g., if they are means, medians, modes, or sums, that summarize data in the model.
- **`description`** -- provide some human readable description of the data in the column.
- **`min`** -- minimum meaningful value of the data. This is not a guarantee on the part of the modellers that all rows of data will be more than or equal to the value, but suggests to the PST that rows of data not meeting this constraint could be ignored.
- **`max`** -- maximum meaningful value of the data
- **`missing`** -- entry used to indicate missing data if not 'NA' or a zero-length string (e.g., if there are two consecutive commas in the file).
- **`value`** `` `*entry*` `` **`means`** *`text`* -- provide human-readable indications of what different values mean. This applies more to nominal and ordinal data. In the case of Likert scale data, for example, '+ value `1` means strongly disagree' could be used to explain what the data mean.

```
**Columns**:
  + `happiness` ordinal `1` < `2` < `3` < `4` < `5`
    + description Simulated response to question 42 on the questionnaire
    + value `1` means strongly disagree
    + value `5` means strongly agree
  + `temperature` interval
    + description Room temperature
    + unit Celsius
    + min -10
    + max 50
  + `scenario` nominal
    + value `subsidies` means households get free insulation
    + value `50%` means households get 50% reduction on heating
  + `savings` ratio
```

```
    + description Median savings of household agents
    + unit EUR
    + stats median
    + missing -9999
```

6.2.7.8 PopUp field

Entries for the pop-up field are an unordered list of pop-up text messages that the PST could optionally display while running a video to help explain what is happening. Each entry in the list gives a time specification and an optional pixel or rectangle to point to in the video. The time specification is either a range of minutes and seconds in the format mm:ss-mm:ss, or a start time in minutes and seconds and a duration in seconds in the format mm:dd+d. If the optional pixel is specified, this is indicated using the @ symbol, followed by the x,y coordinate, or x,y:x,y coordinates of the bottom-left and top-right of a rectangle. An example is given below:

```
**PopUp**:
  + 00:10-00:20 Initially the fuel poverty is mixed
  + 00:30-00:40 @500,30:800,240 Notice how households connected to
    the heat network are less likely to be in fuel poverty
  + 00:50-01:00 @100,400 This household is now in severe fuel poverty
  + 01:20+20 As fuel prices increase, more and more households not
    connected to the heat network become fuel poor, and then severely
    fuel poor
```

6.2.7.9 Georeference fields

The ‘eastings’ and ‘northings’ specified in the XLLCorner and YLLCorner fields are given in degrees longitude and latitude, respectively, with decimal fractions (not minutes and seconds). For example, a simulation of Aberdeen featuring St. Paul Street in a map at its bottom right-hand corner might have XLLCorner -2.099075 and YLLCorner 57.149651.

6.2.7.10 Time and TimeUnit fields

The time field value should conform to one of the following, where *YYYY* is a four-digit year, *MM* a two digit month, *DD* a two digit date, *HH* a two digit (24-)hour, *q* a one digit quarter, and *ww* a two-digit week number.

- *YYYY*-*MM*-*DD*T*HH* -- the corresponding TimeUnit would then be **Hour**
- *YYYY*-*MM*-*DD* -- the corresponding TimeUnit would then be **Day**
- *YYYY*-*MM* -- the corresponding TimeUnit would then be **Month**

- *YYYY* -- the corresponding TimeUnit would then be **`Year`**
- *YYYY*`-Q`*q* -- the corresponding TimeUnit would then be **`Quarter`**
- *YYYY*`-W`*ww* -- the corresponding TimeUnit would then be **`Week`**

6.2.8 Field-value pair specification

Various elements of the SBL require a field-value pair to be specified. This consists of a bold font field name, followed by a colon, followed by a space, followed by a value for the field name. The general form is as below:

```
**field name**: field value
```

6.2.9 Legend specification

A legend is provided as an unordered list indented one level below that at which the associated show-video or show-image commands appear. There are two options to supply a legend. One is to simply have an image that is used for the whole legend. The other is to specify the shape and colour for each item to appear by hand.

The first option is easier, but less user-friendly as it embeds the legend text in an image, and hence does not expose the text for the visually impaired or for translation:

```
  + legend-image image-URL
```

The second option repeats one of the following lines for each item to be described:

```
  + legend #image-RGB-hex `NetLogo shape`: description text
  + legend #image-RGB-hex U+unicode-id: description text
  + legend #image-RGB-hex line-type: description text
  + legend ![alt-text](legend-item-image-URL): description text
```

The first three options provide for optional colour specification using standard '#RRGGBB' hexadecimal notation, followed by a shape from the NetLogo library in backticks, a hexadecimal Unicode character after 'U+', or a line-type ('solid', 'dashed' or 'dotted'), and then some description text to tell the user what the item is. The fourth option allows little images to be used for the legend item, together with description text.

6.2.10 Qualifiers and display hints

Tabular data supplied by modellers for PST display content may be reused in several contexts -- for example in the case where all the results of the model are in a single CSV file. To provide for this, the SBL allows for qualifiers and display hints to be used to specify which rows of data are relevant or worth highlighting, and whether certain columns should be ignored as options for display. These are all given as sublists, indented one level beyond the level of indentation of the enclosing command.

6.2.10.1 Ignoring columns

The ‘ignore’ command gives the name of a column (in backticks) for which no data should be shown. The command should be repeated for every column to be treated this way.

```
+ ignore `column-name`
```

6.2.10.2 Highlighting columns

The ‘highlight’ command gives the name of a column (in backticks) the data in which are particularly relevant for the context. If the PST has options to highlight or emphasize these data (e.g. by using different colours or symbols), then these options should be taken. Though the command can be repeated to highlight data in more than one column, this is not something that should be overused.

```
+ highlight `column-name`
```

6.2.10.3 Highlighting rows

The ‘highlight’ command can also be used with a comparison operator to highlight data in matching rows. Both the column name and the value should be in backticks. Valid comparison operators are ‘=’, ‘!=’, and for ordinal, cardinal and ratio measures, ‘<’, ‘<=’, ‘>’ and ‘>=’ are available. If the PST has options to highlight or emphasize these data (e.g., by using different colours or symbols), then these options should be taken.

While highlighting columns act to expand the set of data to highlight for repeated ‘highlight’ commands (i.e., highlight data in this column or that column or the other one), successive row highlights act restrictively (i.e., only highlight data in rows that match this condition and that condition and the other).

```
+ highlight `column-name` comparison-operator `value`
```

6.2.10.4 Selecting rows

The ‘select’ command can also be used with a comparison operator to select data for display in matching rows. Both the column name and the value should be in backticks. Non-matching data should not be processed by the PST for display in the enclosing context.

```
+ select `column-name` comparison-operator `value`
```

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Appendix I. Survey carried out to the citizens of Vitoria

Questions (in Spanish) included in the survey carried out in November 2020

Q1. ¿Con quién vive en su casa habitualmente?
En el caso de que viva en más de un lugar, responda en donde vive en este momento

- ◯ 1
- ◯ 2
- ◯ 3
- ◯ 4
- ◯ 5
- ◯ 6
- ◯ 7
- ◯ 8 o más personas

Q2. ¿Cuál es su relación con el barrio?
En el caso de que exista otra opción, especifíquela en el apartado de OTRO.

- ◯ Residente
- ◯ Tengo un negocio en el barrio
- ◯ Soy residente y tengo un negocio en el barrio
- ◯ Ni soy residente, ni tengo un negocio en el barrio
- ◯ Otro: ____________________

Q3. ¿Podría decirme cuál es su estado civil?

- ◯ Soltero/a
- ◯ Casado/a o en pareja
- ◯ Separado/a
- ◯ Divorciado/a
- ◯ Viudo/a
- ◯ N.C.

Q4. Por favor, rellene la edad y género de las personas (incluidos niños) que viven en su hogar
Rellene la primera columna con los datos correspondientes

	Edad	Género			
	(por favor, rellene la columna)	Hombre	Mujer	de otro modo	prefiero no responder
Persona 1 (tú)		◯	◯	◯	◯
Persona 2		◯	◯	◯	◯
Persona 3		◯	◯	◯	◯
Persona 4		◯	◯	◯	◯
Persona 5		◯	◯	◯	◯
Persona 6		◯	◯	◯	◯
Persona 7		◯	◯	◯	◯
Persona 8		◯	◯	◯	◯

Q5. Por favor, indique su estado laboral en la actualidad. Marque aquellas opciones que aparecen reflejadas:

- ☐ Trabajador a tiempo completo
- ☐ Trabajador a tiempo parcial
- ☐ Autónomo
- ☐ Estudiante
- ☐ Ama/o de casa
- ☐ Discapacitado/a
- ☐ Desempleado/a
- ☐ Jubilado/a
- ☐ Otro

Q6. ¿Cuál es tu nivel de educación más alto?

- ◯ Sin educación / Preescolar
- ◯ Escuela primaria
- ◯ Escuela secundaria
- ◯ Bachillerato
- ◯ Formación Profesional
- ◯ Grado universitario

- ○ Grado de Máster
- ○ Grado de Doctorado
- ○ Otra opción (por favor, especifique cual)

Q7. ¿Cuál de las siguientes categorías representa el ingreso neto mensual de todos los miembros de su casa?

Q8. ¿Cómo te sientes en la actualidad respecto a los ingresos de su casa?

- ○ Menos de €600
- ○ €601 - €1500
- ○ €1501 - €3000
- ○ €3001 - €4500
- ○ €4501 - €6000
- ○ €6001 o más
- ○ NC

- ○ Vivimos cómodamente
- ○ Afrontamos los gastos
- ○ Pasamos dificultades económicas
- ○ Pasamos muchas dificultades económicas

Q9. ¿Con qué frecuencia te relacionas socialmente con los siguientes grupos de personas?

	Nunca	Una vez al año	Varias veces al año	Una vez al mes	Varias veces al mes	Una o dos veces por semana	Casi todos los días
Amigos	○	○	○	○	○	○	○
Familiares	○	○	○	○	○	○	○
Compañeros de trabajo/estudio	○	○	○	○	○	○	○
Vecinos	○	○	○	○	○	○	○

Q10. Por favor, indique su nivel de

acuerdo o desacuerdo con la siguiente cuestión: Estoy muy apegado a Vitoria.

- Muy en desacuerdo
- Algo en desacuerdo
- Ni de acuerdo, ni en desacuerdo
- Algo de acuerdo
- Muy de acuerdo

Q11. Por favor, indique cuánto tiempo lleva viviendo en el barrio actualmente.

- Menos de 1 año
- Entre 1 y 3 años
- Entre 3 y 5 años
- Entre 5 y 10 años
- Entre 10 y 15 años
- Entre 15 y 20 años
- Entre 20 y 25 años
- Entre 25 y 30 años
- Mas de 30 años

Q12. ¿Es dueño/a o inquilino de su actual vivienda?

- Dueño/a
- Dueño/a con una hipoteca
- Soy dueño/a y alquilo (propiedad compartida)
- Soy inquilino
- Vivo libre de alquiler

Q13. Vitoria ha adoptado un modelo de desarrollo urbano de supermanzanas iniciadas hace 10 años. La supermanzana de Sancho el Sabio, se desarrolló hace más de 10 años, con las nuevas intervenciones realizadas en el centro de la ciudad se están planeado nuevas supermanzanas en la ciudad. Estamos interesados en saber su opinión sobre estas nuevas intervenciones urbanísticas. Indique por favor, en qué medida está de acuerdo o en desacuerdo con las siguientes cuestiones:

Q13.1 Creo que Vitoria debería seguir ampliando el modelo de supermanzana.

0	1	1	2	3	4	5	6 Completamente de acuerdo

Completamente desacuerdo							
○	○	○	○	○	○	○	○

Q13.2 ¿Le recomendaría vivir dentro de una supermanzana?

0 Completamente desacuerdo	1	1	2	3	4	5	6 Completamente de acuerdo
○	○	○	○	○	○	○	○

Q13.3. ¿Cómo de favorables o desfavorables son sus opiniones sobre las supermanzanas?

0 Completamente desacuerdo	1	1	2	3	4	5	6 Completamente de acuerdo
○	○	○	○	○	○	○	○

Q13.4¿Hasta qué punto apoyaría o se opondría a la creación de nuevas supermanzanas en su ciudad/barrio?

- ○ Muy opuesto
- ○ Algo opuesto
- ○ Ni lo apoyaría ni me opondría
- ○ Algo a favor
- ○ Muy a favor
- ○ NC

Q13.5. Si este año le pidieran votar si se deberían implementar nuevas supermanzanas en Vitoria, ¿Cuál sería su voto?

- ○ Si, definitivamente deben crearse más supermanzanas
- ○ No deben crearse más supermanzanas
- ○ Depende del impacto social que tengan

Q14. Le pedimos que piense en la época que se comenzó a plantear la supermanzana de Sancho el Sabio. ¿Cuál era su posición inicial sobre su implementación? Muy en desacuerdo

- ○ Algo en desacuerdo
- ○ Ni de acuerdo, ni en desacuerdo
- ○ Algo de acuerdo
- ○ Muy de acuerdo

Las siguientes preguntas están relacionadas en lo que podría influir en su decisión de votar a favor o en contra de implementar más supermanzanas en Vitoria (en el caso de que tuviera que hacerlo).

Q15. ¿Qué importancia cree que tendrían las siguientes cuestiones para ayudarle a tomar su decisión

	0 Nada importante		1	2	3	4	5	6 Muy importante	Q16. De
Personas de mi hogar	○	○	○	○	○	○	○	○	
Ayuntamiento de Vitoria	○	○	○	○	○	○	○	○	
Tus vecinos	○	○	○	○	○	○	○	○	
Los miembros de tu familia	○	○	○	○	○	○	○	○	
Tus amigos	○	○	○	○	○	○	○	○	
Compañeros de estudio	○	○	○	○	○	○	○	○	
Agentes sociales, colectivos, ongs, agrupaciones de vecinos, etc.	○	○	○	○	○	○	○	○	
Escuelas locales	○	○	○	○	○	○	○	○	
Comerciantes locales	○	○	○	○	○	○	○	○	
El gobierno vasco	○	○	○	○	○	○	○	○	
Periódicos locales	○	○	○	○	○	○	○	○	
Medios nacionales (periódicos, tv, etc.)	○	○	○	○	○	○	○	○	
Redes sociales	○	○	○	○	○	○	○	○	
Diputación provincial	○	○	○	○	○	○	○	○	
Gobierno español	○	○	○	○	○	○	○	○	
Respuesta abierta:									
Otros: especifique									

media, ¿Cuánto diría que confía en las siguientes fuentes de información?

	0 Nada	1	2	3	4	5	6 Muchísimo
Personas de mi hogar	◯	◯	◯	◯	◯	◯	◯
Ayuntamiento de Vitoria	◯	◯	◯	◯	◯	◯	◯
Tus vecinos	◯	◯	◯	◯	◯	◯	◯
Los miembros de tu familia	◯	◯	◯	◯	◯	◯	◯
Tus amigos	◯	◯	◯	◯	◯	◯	◯
Compañeros de estudio	◯	◯	◯	◯	◯	◯	◯
Agentes sociales locales, colectivos, ongs, asociación de vecinos, etc.	◯	◯	◯	◯	◯	◯	◯
Escuelas locales	◯	◯	◯	◯	◯	◯	◯
Comerciantes locales	◯	◯	◯	◯	◯	◯	◯
El gobierno vasco	◯	◯	◯	◯	◯	◯	◯
Periódicos locales	◯	◯	◯	◯	◯	◯	◯
Medios nacionales (periódicos, tv, etc.)	◯	◯	◯	◯	◯	◯	◯
Redes sociales	◯	◯	◯	◯	◯	◯	◯
Diputación provincial	◯	◯	◯	◯	◯	◯	◯
Gobierno estatal	◯	◯	◯	◯	◯	◯	◯
Respuesta abierta							
Otro: especifica							

Q17. ¿Cómo de importante son para Ud., las siguientes cuestiones?

	0 Nada importante	1	2	3	4	5	6 Extremadamente importante
Vivir en una Sociedad donde todos tienen las mismas oportunidades para usar energía en función de sus necesidades	○	○	○	○	○	○	○
Vivir en una Sociedad donde todos tienen la misma responsabilidad para evitar la contaminación	○	○	○	○	○	○	○
Vivir en una Sociedad donde todos tienen las mismas oportunidades para acceder a espacios públicos de calidad	○	○	○	○	○	○	○
Reducir los niveles de contaminación en Vitoria	○	○	○	○	○	○	○
Lograr la sostenibilidad Ambiental en Vitoria	○	○	○	○	○	○	○
Lograr una Buena calidad de vida para todas las personas de Vitoria	○	○	○	○	○	○	○
Crear espacios saludables y seguros para la gente de Vitoria	○	○	○	○	○	○	○
Preservar la belleza natural de Vitoria	○	○	○	○	○	○	○
Mi ciudad siendo reconocida como innovadora	○	○	○	○	○	○	○
Sentirme orgulloso/a de Vitoria	○	○	○	○	○	○	○
Formar parte de las decisiones que afectan a mi entorno	○	○	○	○	○	○	○
Disponibilidad de información transparente del ayuntamiento de Vitoria respecto a los planes de desarrollo	○	○	○	○	○	○	○
Posibilidades para comunicarse con el ayuntamiento	○	○	○	○	○	○	○
Ser parte de una comunidad que decide sobre su futuro	○	○	○	○	○	○	○

Q18. ¿Cómo de importantes son las siguientes cuestiones para Ud., relacionadas con su vida en el barrio?

	0 Nada importante	1	2	3	4	5	6 Extremadamente importante
Tiempo de viaje en mis desplazamientos diarios	○	○	○	○	○	○	○
Facilidad de desplazarme	○	○	○	○	○	○	○
Calidad del aire	○	○	○	○	○	○	○
Seguridad vial	○	○	○	○	○	○	○
Tu estado de salud	○	○	○	○	○	○	○
Ambientes saludables	○	○	○	○	○	○	○
Calidad del transporte público	○	○	○	○	○	○	○
Tener acceso a zonas peatonales	○	○	○	○	○	○	○
Reducción del ruido del tráfico	○	○	○	○	○	○	○
Costes económicos relacionados con el Desarrollo urbano	○	○	○	○	○	○	○
Acceso a espacios públicos de calidad en tú barrio	○	○	○	○	○	○	○
Molestias causadas por la implementación de supermanzanas	○	○	○	○	○	○	○
Accesos a espacios verdes	○	○	○	○	○	○	○
Infraestructura de Bicicleta	○	○	○	○	○	○	○
Incidencia en el comercio local	○	○	○	○	○	○	○
Disponibilidad de aparcamiento	○	○	○	○	○	○	○
Seguridad vial	○	○	○	○	○	○	○
Cambio en el coste de la vivienda	○	○	○	○	○	○	○
Incidencia en los servicios	○	○	○	○	○	○	○

Q19. Pensando en los últimos 12 meses, ¿Con que frecuencia has realizado las siguientes actividades?

	Nunca	Casi nunca	A veces	Habitualmente	Casi siempre	Siempre
Quedar con amigos y vecinos	○	○	○	○	○	○
Llevar a mis hijos a que jueguen	○	○	○	○	○	○
Participar en eventos o actividades del barrio	○	○	○	○	○	○
Realizar ejercicio	○	○	○	○	○	○
Ejercitarme/jugar con otras personas	○	○	○	○	○	○
Sentarme fuera y contemplar	○	○	○	○	○	○
Salir fuera para leer/trabajar	○	○	○	○	○	○
Caminar por el comercio local para mis necesidades diarias	○	○	○	○	○	○
Usar el transporte público, Bicicleta o caminar para trayectos de 2/3 Km	○	○	○	○	○	○
Desplazarme en coche por trabajo	○	○	○	○	○	○
Desplazarme en coche por razones personales como el ocio	○	○	○	○	○	○
Pasear	○	○	○	○	○	○

Q20. A continuación, hay una serie de afirmaciones acerca de tu barrio. Por favor, indique en qué nivel de acuerdo o desacuerdo se encuentra para cada una de ellas

	0 Completamente en desacuerdo	1	2	3	4	5	6 Completamente de acuerdo
Mi barrio es un lugar atractivo	○	○	○	○	○	○	○
Es seguro	○	○	○	○	○	○	○
Hay mucha contaminación	○	○	○	○	○	○	○
Hay suficientes lugares donde los niños pueden jugar seguros	○	○	○	○	○	○	○
Hay suficientes lugares donde yo y mi familia podemos quedar con amigos y vecinos	○	○	○	○	○	○	○
Hay suficientes lugares para mí y mi familia donde hacer ejercicio y practicar deportes al aire libre	○	○	○	○	○	○	○
Hay mucho ruido del tráfico	○	○	○	○	○	○	○
Es fácil caminar en mi barrio	○	○	○	○	○	○	○
El precio de la vivienda es muy elevado	○	○	○	○	○	○	○
El barrio es una comunidad	○	○	○	○	○	○	○
El barrio es un excelente lugar para vivir	○	○	○	○	○	○	○

Q21. Las siguientes afirmaciones se refieren a la confianza y las relaciones con sus vecinos. Por favor, lea cada una de estas afirmaciones e indique hasta qué punto está de acuerdo o desacuerdo en cada una de ellas

	0 Completamente en desacuerdo	1	2	3	4	5	6 Completamente de acuerdo
La gente de este barrio haría algo si una casa fuese ocupada	○	○	○	○	○	○	○
La gente de este barrio haría algo si hubiese un desahucio	○	○	○	○	○	○	○
En este barrio, la gente pararía a jóvenes que realizasen actos vandálicos	○	○	○	○	○	○	○
La gente tendría miedo de caminar por la noche	○	○	○	○	○	○	○
Las personas de este barrio se aprovecharían de ti	○	○	○	○	○	○	○
Si estuvieses en problemas, habría muchas personas en este barrio que te ayudarían	○	○	○	○	○	○	○
Se puede confiar en la mayoría de personas de este barrio	○	○	○	○	○	○	○
Las personas de este barrio se tratan entre sí de una manera agradable	○	○	○	○	○	○	○
Me siento como en casa con las personas que viven en este barrio	○	○	○	○	○	○	○
Vivo en un barrio unido y cercano	○	○	○	○	○	○	○
Las personas de este barrio apenas se conocen	○	○	○	○	○	○	○

Q22. ¿Qué nivel de control sientes que tienes a la hora de tomar decisiones que afectan a tu barrio/ciudad?

○ Ningún control

○ Control sobre muy pocas decisiones

○ Control sobre algunas decisiones

○ Control sobre casi todas las decisiones

○ Control sobre todas las decisiones

Q23. ¿Sientes que tienes el poder de tomar decisiones importantes que cambian las condiciones de tu barrio? Califíquese en una escala del 1 al 5, donde 1 significa ser totalmente incapaz de cambiar su vida y 5 significa tener el control total sobre su vida.

○ Totalmente incapaz de cambiar las condiciones de mi vida

○ Mayormente incapaz de cambiar las condiciones de mi vida.

○ Ni capaz ni incapaz

○ Mayormente capaz de cambiar las condiciones de mi vida.

○ Totalmente capaz de cambiar las condiciones de mi vida.

Q24. ¿Qué impacto cree que tiene sobre hacer su calle/su barrio/su ciudad un mejor lugar?

○ Un gran impacto

○ Un pequeño impacto

○ Ningún impacto

Q25. Estamos interesados en conocer los tipos de actividades físicas que las personas realizan como parte de su vida cotidiana. Las preguntas tratarán sobre el tiempo que realizó actividad física en los últimos 7 días. Responda cada pregunta, incluso si no se considera una persona activa. Piense en las actividades que realiza en el trabajo, como parte de su trabajo de casa, para desplazarse de un lugar a otro y en su tiempo libre para disfrutar, ejercitarte o hacer deporte.

Piense en todas las actividades vigorosas que realizó en los últimos 7 días. Las actividades físicas vigorosas se refieren a actividades que requieren mucho esfuerzo físico y que te hacen respirar mucho más fuerte de lo normal. Piense solo en esas actividades físicas que realizó durante al menos 10 minutos a la vez.

1. Durante los últimos siete días, en ¿Cuántos días realizó actividades físicas vigorosas como levantar objetos pesados, excavar, hacer ejercicios aeróbicos o andar rápido en bicicleta?
_____ días por semana ____Ninguna actividad física vigorosa (pasar a la pregunta 3)

2. ¿Cuánto tiempo pasas generalmente realizando actividades físicas vigorosas en uno de esos días?
_____ horas al día _____ minutos al día ____No lo sé/No estoy seguro/a

Piense en todas las actividades moderadas que realizó en los últimos 7 días. Las actividades moderadas se refieren a actividades que requieren un esfuerzo físico moderado y te hacen respirar un poco más fuerte de lo normal. Piense solo en esas actividades físicas que realizó durante al menos 10 minutos.

3. Durante los últimos 7 días, ¿En cuántos días realizó actividades físicas moderadas como cargar pesos ligeros, andar en bicicleta a un ritmo regular o nadar, yoga, gimnasia de mantenimiento, etc.? No incluye caminar.

_____ días a la semana _____Ninguna actividad física moderada (pasar a la pregunta 5)

4. ¿Cuánto tiempo pasaste realizando actividades físicas moderadas uno de esos días?
_____ horas al día _____ minutos al día _____No lo sé/No estoy seguro/a

Piensa en el tiempo que pasaste caminando en los últimos 7 días. Esto incluye en el trabajo y en el hogar, caminar para desplazarte de un lugar a otro y cualquier otra caminata que haya hecho únicamente por gusto, deporte, ejercicio u ocio.

5. ¿Cuántos días caminó durante al menos 10 minutos?
_____ días a la semana ____ No caminé (pasar a la pregunta 7)

6. Normalmente, ¿Cuánto tiempo caminaste uno de esos días?
_____ horas al día _____ minutos al día ____No lo sé/ No estoy seguro/a

La última pregunta es sobre el tiempo que pasó sentado entre semana durante los últimos 7 días. Incluya el tiempo que pasa en el trabajo, en casa, mientras realiza el trabajo del curso y durante el tiempo libre. Esto puede incluir el tiempo que pasa sentado en un escritorio, visitando amigos, leyendo, sentado o acostado para ver la televisión.

7. Durante los últimos 7 días, ¿Cuánto tiempo pasaste sentado un día de la semana?
_____ horas al día _____ minutos al día ____No lo sé/No estoy seguro/a

Q26. En general, ¿Diría que su salud es?

- ○ Excelente
- ○ Muy buena
- ○ Buena
- ○ Normal
- ○ Mala

Appendix II. Policy scenarios: triggers and tactics for Vitoria.

Primary Critical Node	Behaviour	Start Month	Start Year	End Month	End Year	Frequency	Reach	Secondary Critical Node
City Council	supporter	11	2006	11	2006	1	70/NºHumats	City Council
Other associations	supporter	11	2006	11	2006	1	0,2	Other associations
Local Media	supporter	4	2007	4	2007	1	0,2	Local Media

Local Media	supporter	9	2007	7	2007	1	0,1	Local Media
Local Media	opponent	3	2009	3	2009	1	0,1	Local Media
Other associations	opponent	3	2009	3	2009	1	Depends on neighborhood	Other associations
City Council	supporter	7	2009	9	2009	2	0,3	City Council
City Council	supporter	9	2009	9	2009	1	0,3	City Council
City Council	supporter	10	2009	10	2009	2	0,3	City Council
Local Media	opponent	9	2009	9	2009	2	0,2	Local Media
Local Media	supporter	10	2009	11	2009	2	0,3	Local Media
Local Media	opponent	10	2009	10	2009	2	0,1	Local Media
City Council	supporter	11	2009	11	2009	1	0,2	City Council
Other associations	opponent	11	2009	11	2009	2	0,1	Local Media
Local Media	supporter	3	2009	7	2009	1	0,3	Local Media
Local Media	opponent	9	2009	12	2009	2	0,3	Local Media
City Council	supporter	3	2009	3	2009	1	0,3	City Council
Other associations	supporter	4	2009	4	2009	1	0,1	Local Media
Other associations	opponent	6	2009	11	2009	1	0,2	City Council
Local Media	opponent	7	2009	11	2009	1	0,1	Local Media
Local Media	opponent	11	2009	11	2009	2	0,3	City Council
Merchants associations	opponent	10	2009	11	2009	2	0,3	Merchants associations
City Council	supporter	3	2012	3	2012	1	0,3	Local Media
Local Media	opponent	3	2012	10	2012	1	0,3	Local Media
City Council	supporter	4	2012	4	2012	1	0,3	Local Media
City Council	supporter	4	2012	7	2012	1	0,1	City Council
City Council	supporter	4	2012	8	2012	1	0,1	City Council

Merchants associations	opponent	6	2012	6	2012	1	0,1	Local Media

Table A.II.1: triggers and tactics for Vitoria-Gasteiz.