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D3.2 – Report on Agent Based Analysis Approaches identifying citizen agents and their behaviours for Nature based Solutions

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Nature4Cities – D3.2 – Report on Agent Based Analysis approaches to identify citizen agents and their behaviours for Nature Based Solutions. This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730468

Executive Summary

Purpose of study - The Nature4Cities project aims to deliver a holistic approach for assessment of Nature Based Solutions (NBS), such as rainwater gardens and green roofs, as viable solutions that bring the properties of natural ecosystems as services in a smart, 'engineered' way. This deliverable is the second output of activities leading towards development of the Nature4Cities *Environmental Assessment Methodology*, which has two main objectives:

- Provide decision support during planning phase of NBS projects for the *selection of NBS alternatives* with the highest potential benefit.
- Provide *Performance evaluation* of NBS during their implementation phase.

A key objective is to gain insights in citizen's behavioural impacts of introducing new NBS in the urban environment, and through those on the social and economic lives of citizens. Since the benefits of NBS for citizens are largely influenced by how citizens utilise and interact with NBS in leisure and work, mapping these interactions is instrumental. It is not sufficient to map local air quality and citizen health improvements due to introducing NBS like large parks, as also the extent to which citizens of various demographics visit such spaces, given factors like health and income, is key to understand potential benefits.

To study interactive socio-economic effects of NBS on citizens this deliverable provides a novel application of an existing behavioural simulation method: Agent Based Modelling (ABM). ABM allows for many interactions and possibilities to be modelled, as described in chapter 2, by representing the world from individual objects called "agents". An agent (as a person) can be simulated with a set of characteristic and a number of states" that indicate social, economic or other aspects of a person, as long as an understanding exists of how to model the relationship between the characteristic and the behaviour that one seeks to model. The object oriented approach in ABM allows for describing hundreds to thousands or greater number of variation possibilities for citizens. As such ABM is well suited to simulate the impact of Nature Based Solutions on citizens and the urban environment. Prior to this project, although ABM is employed to assess behaviours of people of cities, the application in the context of NBS does not yet exist, as described in Chapter 3 on previous works, which makes Nature4Cities a project that for the first-time studies to connect concepts in in ABM to concepts in NBS*.* In this sense, not only does Nature4Cities create an extension to the field of applicability for ABM, it also introduces a new approach for assessing NBS in a systematic way by allow for measuring citizen interactions with NBS and the impacts of NBS on citizens lives and livelihoods.

Methodologies - In order to initiate the development of the environmental assessment methodology for Nature4Cities Project, Task 3.2, aimed to:

- Deliver a methodology to utilize agent-based modelling to assess citizen requirements, possible behaviours and resulting perceptions due to implementing NBS.
- Deliver a methodology that allows for simulating possible actions of people as agents in the urban context, and support NBS measurement in terms of aspects like wellbeing & health.

- Allow for analyzing different types of citizens in a quantitative approach, including vulnerable citizens and social equity. differences in types of
- Address impacts of climate change in relation to specific citizen groups and behaviours.

Task 3.2 provides a systematic approach for the delivery of ABM models based on an ontology that was developed as per chapter 4, that allows for standardised social and equitability related descriptions of people as agents in the context of NBS, based on aspects of people's characteristics (e.g age, income, health), activities (travel, work, sleep etc.), behavioural routines (travel model choices), relationships (family, friendships), mental perceptions (wellbeing and motivational factors), and abilities (financial, physical, knowledge). The ontology allows for describing the characteristics of people as agents in a uniform way across simulation scenarios and their intended inputs and outputs and can also be utilised by future projects for the simulation of NBS.

The ontology framework was used to develop 10 scenario concepts as described in Chapter 5 that define potential models that can be used to study various NBS. The scenario concepts demonstrate the flexibility of Agent Based Modelling as a modelling framework to simulate a variety of physical, behavioural, economic and social elements. Subsequently, three of these scenario concepts were implemented in an Agent Based Model, selected using a multi-criteria analysis using the indicator framework developed in Nature4Cities task 2.1. Generic data needs for the simulations were described in Chapter 6, and the models themselves in terms of the concept, model equations, model framework, and how the results can be interpreted, were described in Chapter 7.

Key findings and conclusions - The three models demonstrated the capabilities of ABM to assist with simulating NBS based on the results which were provided for all four partner cities in the project, Cankaya municipality, Città Metropolitana di Milano, Szeged, and Alcalá de Henares:

- ***Conclusions for Urban heat mortality impact reduction through NBS.*** The simulation results showed substantial variation of the impacts of green roofs across cities on heatwave mortality. In case of Szeged, Alcalá de Henares, and Çankaya Municipality a substantial reduction in mortality was found to occur in case of green roofs for the present and more so for future especially as it becomes hotter across the 21st century. This contrasted with Città Metropolitana di Milano where green roofs had little mitigating impact, because heatwaves had little additional mortality effects in the first place in the simulations.
- **Result Conclusions for Socio-economic and commercial development resulting from NBS changes.** The simulations provide insights in the number of retail shops that can be sustained based on the purchasing behaviour of citizens that walk in parks. In case of Szeged about 5-6 retail shops emerged on average for about 800 walking citizens, In case of Alcalá de Henares as well as Çankaya Municipality about 7 to 9 retail shops emerged for around 1500 walking citizens. The simulation for Città Metropolitana di Milano provided an average number of retail shops of 12 to 14 for a simulated population of 2900 that walks in parks
- **Result Conclusions for Water runoff and catchment improvement by NBS promotion in private gardens.** The simulation results demonstrated that changing the make-up of private gardens from paved to green gardens can have up to a 20% impact on water run-

off and catchment in cities with mostly paved gardens and large private garden areas, but that the typical impact of such changes is in the order of 5% to 10%. The linkage between promotion of changing paved into NBS gardens, and how this affects the water balance was thereby showcased including how qualitative factors of relevance can be incorporated including environmental, social, financial and knowledge related aspects.

The results were showcased to the city partners in in-depth open interviews to assess their usefulness, as summarised in chapter 9. On overall, the interviewees regard agent-based modelling as a useful and complementary decision-support tool. Especially when the model allows for flexibility in adjusting certain elements, or a comparison between alternative interventions (and thus policy options) is possible. Challenges were also presented including the organisational structure of the municipality, where departments operate in silos, does concerns both access to data and information necessary to develop ABM-models, as well as the day-to-day responsibilities in policymaking. Also developing ABM requires specific expertise which is generally not present in public administration and thus requires hiring external advisors.

Link with N4C platform - The task provides three different models that can be utilised for purposes of integration with the Nature4Cities platform that is under development, either based on direct linkage via an API or by integration of results set in a standardised manner, so as to interrogate the results in parallel to information from other tasks and outputs. The task also provides for a more broad understanding of which KPI's from task 2.1 can potentially be modelled with ABM approaches, which can be linked to a KPI data relationships and associations as built in the platform.

Lessons learned and recommendations - The task 3.2 thereby found that the ABM method is capable of delivering insights in NBS in terms of people's interactions, heterogeneous effects and social and economic dimensions on various benefits and impacts of NBS such as for climate change challenges. It also found that the results are potentially useful to gain further insights for city planners and decision makers. Its dynamic nature also facilitates the delivery of the dynamic assessment methodology of Nature4Cities project to be established in Task 3.5. Dynamic environmental assessment of NBS is envisioned to involve successive execution of the urban assessment for the NBS cases modelled.

Further work would be required to provide meaningful mechanisms in terms of feeding into NBS decision making. Critical is to take into account the organisational hierarchy of responsibilities within the municipality and partner organisations, and how different model information is useful for different stakeholders. Thereby further understanding is needed on what particular insights would be needed to further the implementation of NBS. To this end the implementation models typology used in WP1.2, that will be furthered in WP5.4 within the context of socio-economic assessment will be of use to provide further alignment with municipal stakeholder processes and how methodologies like ABM can assist with studying such delivery models.

1 Introduction

1.1 Purpose

Nature based solutions (NBS) offer opportunities to protect, sustainably manage and improve urban ecosystems whilst addressing societal changes providing well-being and multiple environmental benefits.[1] Considering the fact that over 70% of Europe's population currently lives in cities, with an expected increase to 80% by the middle of the century,[2] NBS are key in tackling urbanization and planning issues including climate adaptation or flood management. Because there are multiple provided co-benefits on environment and society, NBS potentially are “more efficient and cost-effective solutions that traditional approaches”.[3] However, for this to be justifiable by decision-makers, investors, and benefactors, an evidence based assessment methodology needs to be employed that can measure the effectiveness of NBS and possibly make comparisons to traditional urban development strategies. For this purpose, within the Nature4Cities Project, the environmental and socio-economic assessment of NBS is addressed.

The assessment methodology studied under Work Package 3 (WP3) of the Nature4Cities project is comprised of a collection of different modelling, simulation and evaluation methods focusing on socio-economic and environmental aspects, so as to identify benefits under different urban challenges as well as potential trade-offs or shifting of burdens. In this sense, WP3 is dedicated to environmental impact assessment with an urban metabolism approach through a life cycle perspective, and its connection to socio-economic urban citizen relationships. WP3 has been designed around five different tasks:

- Development of an urban metabolism framework including definition of system boundaries, system components and the urban nexus accounting for different spatial scales (Task 3.1)
- Development of the use of simulations of citizen behaviour and environmental assessment for providing Nature Based Solutions decision support insights, using Agent Based Modelling (ABM) (**Task 3.2 – this report**).
- Based on the system boundaries and urban nexus identified in the urban metabolism framework of Task 3.1, the urban data inventories are identified and quantified using Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) (Task 3.3).
- An urban climate resilience methodology to shed light on the contribution of NBS to the climate resilience of cities (Task 3.4)
- A dynamic assessment methodology will be developed with the ability to handle time-based urban datasets and to reflect on the future trends in the assessment as much as possible (Task 3.5).

As the output of Task 3.2, this report’s purpose is to explore the usefulness of Agent Based Modelling (ABM) for urban planning of NBS and for evaluating NBS projects to build computer simulations of citizens and their behaviour and their interaction with the urban environment. The report starts with an overview of ABM methodology in relation to behavioural modelling as well as social science approaches utilised in the project under WP5. To our knowledge, as outlined in Chapter 3, ABM has not been utilised within the context of NBS to present. The research in this report thereby gives a State of the Art contribution by developing and deploying the first methodology to implement ABM for NBS decision support. These are captured as citizen description requirements in terms of agent definitions, as outlined in Chapter 4. Subsequently, a range of possible uses of ABM to study NBS are explored in ten modelling concepts provided in Chapter 5, which are linked to possible behaviours and NBS modelling relationships, including links to Nature4Cities WP2 on NBS definitions and assessment indicators. Out of these ten modelling concepts three have been implemented in ABM simulations, which are described in Chapter 7, covering their rationale, background literature, technicalities, and data inputs and outputs. The selected modelling concepts cover different types of behavioural change modelling and urban planning scales, as well as different types of citizens. The approach covers how to take into account impacts of climate change in relation to specific citizen groups and behaviours in a quantitative manner. The results of the simulations and overall findings, including a city partner review are outlined in Chapter 8. Finally, the report ends with a series of recommendations on further ABM modelling methodology to make future assessments more meaningful for city NBS decision support capabilities.

1.2 Contributions of partners

The collective work under Task 3.2 was carried out in three ways. Collectively all research partners assisted with suggesting and developing the ten relevant scenarios for Nature Based Solutions, as presented in Chapter 5, out of which three were simulated. Knowledge expert partners also assisted with literature research to inform the modelling efforts, based on their disciplinary backgrounds, with contributions in Chapter 7. Finally, city partners helped with review of the modelling works in terms of usability for their cities, as included in the discussion and recommendations in Chapter 8 and 9.

Table 1. Partner responsibilities in Task 3.2

Tasks carried out	**Incl. in Chapters**	**Involved Partner(s)**
Development of ABM modelling concepts relevant for Nature Based Solutions	5	METU, CLR, IIL, LIST, UN, DW
Literature research on private city garden greening	7.1	DW
Literature research on Urban Heatwave Mortality Impacts and Environmental Quality of Life	7.2	UN
Literature research on firmographics and economic development around park based Nature Based Solutions	7.3	METU
Model Review for Quality Assurance covering all three developed ABM-NBS models	7	LIST
Model usability Review for Cities	9	DW, AH, CAN, SZEG, CMM

1.3 Relationships to other deliverables

Task 3.2 is directly related to other Tasks in the Nature4Cities work packages as it utilises inputs in how NBS have been defined and what indicators can be utilised to measure them, and provides an output layer for the time-series assessment tool being built in the work package and the socio-economic assessment of NBS implementation models in task 5.4 (Figure 0). The links are explained below.

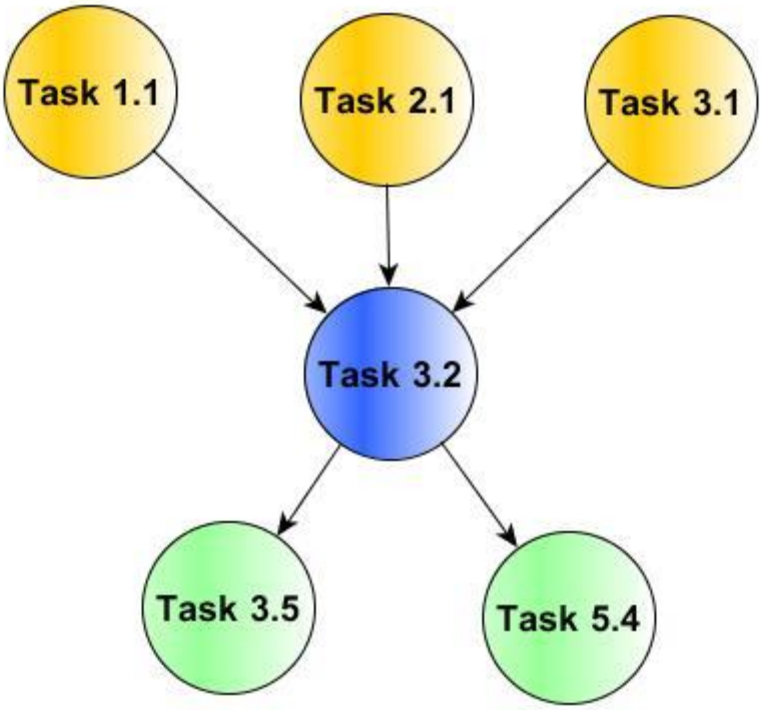

Figure 0. Diagram of direct relations with Task 3.2

Work package 1
Task 1.1. Definition of typology of NBS and building an NBS database
The typology of NBS developed in Task 1.1 which provides for a structured depiction or catalog of various types of NBS is used as a basis for the typology used in Task 4.1. The typology is used to define the relationship between NBS types and the modelling concepts in Chapter 5, to ensure compatibility with NBS projects and socio-economic assessments (see Chapter 5 for further details).

Work Package 2
Task 2.1. Definition of urban performance indicators (and urban challenges)
The task provides the list of KPI's investigated in Nature4Cities, which are used to evaluated the KPI's that can be assessed from a socio-economic ABM analytical perspective. The linkages were also utilised to evaluate which of the ten concepts were selected for implementation in a NBS-ABM model (See chapter 5 for more details).

Work package 3

Task 3.1. Development of Nature4Cities urban metabolism framework

A relevant exchange of information between Task 3.1 and Task 3.2 exists regarding the definition of urban system boundaries and the selection of indicators. This link ensures the harmonisation between the urban metabolism (UM) elements that need to be modelled and the ABM NBS modelling work (see chapter 5 for further details).

Task 3.5. dynamic analyses and interpretation methodology.

The task seeks to develop a way of interrogating the analytical data provided from work package 3 for environmental, social and economic datasets per city and between cities. The work in Task 3.2 forms an output layer for the data analytics module methodology developed in task 3.5 (see section 9.3 for further details).

Work package 5

Task 5.4. Socio-economic assessment of NBS implementation models

The Task 5.4 will be informed by the approach to model social and economic drivers as developed in task 3.2, and potentially also enhance the models utilised in Task 3.2, in terms of building model code on the implementation models and routes for NBS implementation given social and economic barriers and drivers. The link between T3.2 and T5.4 will facilitate the understanding of the contribution of implementation models to the social and economic values of NBS (see section 9.3 for further details).

1.4 Technical Glossary

Table 2. Technical Definitions used in this report

Technical Term	Definition	Context
Agent-Based-Modelling (ABM)	Computational approach for modelling entities with behaviour, such as people, that are interrelated through network type interactions	Social Science
Biophilia	The concept that humans hold a biological need for connection with nature on physical, mental, and social levels, and that this connection affects our personal well-being, productivity, and societal relationships.	Social Sience
Body Mass Index (BMI)	Ratio between weight and height as an indicator of food intake	Human Health, nutrition
Ceteris Paribus	Term used in economics to imply changing one parameter at a time in a modelling context	Economics
Cluster Analysis (CA)	The task of grouping a set of objects in such a wat that objects in the same group (called a cluster) are more similar (in some sense) to eachother than to those in other groups (clusters).	Statistics
Computer simulation	A simplified representation of the real world in the computer to gain qualitative and quantitative insights of real world phenomena, based on a series of connected equations that represent various relationships of said phenomena.	Computer Science
Exploratory Data Analysis (EDA)	The critical process of performing initial investigations on data so as to discover patterns, to spot anomalies, to test hypothesis and to check assumptions with the help of summary statistics and graphical representations	Statistics
Firmographics	The study of development and decline of firms from a geographic and structure perspective, similar to demographics of populations	Economics
Functional Urban Area (FUA)	The functional urban area consists of a city plus its commuting zone. This was formerly known as LUZ (larger urban zone).	Spatial datasets and EU data conventions
Geographical Information Systems (GIS)	A system designed to capture, store, manipulate, analyse, manage, and present all types of geographical data.	Spatial analysis

Nature Based Solutions (NBS)	Nature-based solutions are positive responses to societal challenges, and can have the potential to simultaneously meet environmental, social and economic objectives. They are actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions. Nature Based Solutions are ideally are resilient to change, as well as energy and resources efficient. They recognise the importance to develop a systemic approach and at the same time to adapt interventions to the local context.	Environment, Social, Economy, Climate, Resource
Reflexive Change	Changes between two or more variables that occur in a co-dependent bi-directional manner (if the economy grows there is more expenditure, and if there is more expenditure the economy grows). In contrast to a one-directional causal if-then relationship (if the sun shines, then there is light).	Logic, statistics
Urban fabric	The physical aspect of urbanism, emphasizing building types, thoroughfares, open space, frontages, and streetscapes but excluding environmental, functional, economic and sociocultural aspects.	Urban Systems Science

2 About Agent Based Modelling for NBS

This chapter explains the methodological approach in Agent Based Modelling (ABM) in Section 2.1 by contextualising it within simulation modelling and describing the basic building blocks of ABM. Subsequently, three different perspectives for describing people's behaviours from different social science fields are described in section 2.2. Economics, psychology, and sociology perspectives are provided in brief, so as to demonstrate the importance of taking into account how different disciplines look at behaviour. In the next section 2.3 these are linked to a generalised description of different ways that computer models can be constructed in relation to ABM in general and for NBS impact and behavioural interaction modelling purposes. At the end of the section the model design categories are related to how different types of questions can be answered. Finally, the chapter ends with an overview of different Agent Based Modelling Packages to show which main packages are in existence and discuss the choice of the Netlogo package for the modelling work in this report.

2.1 Simulation and Agent Based Modelling

The modelling methodology used to simulate citizen's behaviour within Task 3.2 is Agent-Based-Modelling (ABM). It is part of the simulation class of modelling, where changes in the states of entities (like a person) and their characteristics (variables like work status or body temperature) over time are modelled using behavioural algorithms and/or so-called difference-differential equations.

In broad terms there are two types of simulation approaches. First, system dynamics (using difference-differential equations) also referred to as state-space modelling or stock-flow modelling. The main tools here are mathematical differential equations, which in a simplified view express how a variable (like temperature) changes within a time-period (say a day), and a difference equation states how the same variable changes between time-periods (between days). This simulation approach thus consists out of a large series of mathematical equations, each relating to one or a few physical entities and characteristics in the world. For example, one set of difference-differential equations could calculate temperature in a city block based on available sunlight, reflection and other physical phenomena, another set could calculate heat absorption of the buildings in the block in relation, and a final set could calculate the heat requirement to keep a building at comfort level temperatures for citizens inside the building. System Dynamics is especially useful for studying such physical, economic, or environmental cases where there is a reasonable limit to the number of interactions (e.g. types of buildings and comfort levels in our example), as otherwise the number of required equations will lead to an intractable setup to implement (e.g. for each building type a new set of equations is needed that needs to be parametrized). This also falls in line with the philosophy of system dynamics, namely to represent the world in an simplified and abstracted as possible yet valid manner, so that the a focus can be made on the core relationships for study and understanding and to input into decisions.

The second simulation approach, Agent-Based-Modelling (ABM), was developed to go in the other direction, namely to create a modelling approach where many interactions and possibilities can be modelled, by representing the world from individual objects called “agents”. Each agent, a building in our example, can be represented as an individual entity in this modelling approach, with its own unique characteristics. Even a subsection of a building could be an individual “agent”. ABM therefore allows for the finest representation of the real world as is possible, albeit with the limitation that typically only a very limited set of relationships is described in a model relative to the real world. Agent Based Models have been made for people, as well as blood cells, households, vehicles, and many more entities (see table 2).

Table 3. Examples of existing Agent Based Models and their purpose

Model Example	Description	Source
Leukocyte ABM	Modelling of key cellular behaviours over space and time of leukocytes, a key element of immune system	Bhui et al. (2017)[4]
Dıstrict-Heat Network ABM	An agent-based model for the adoption of heat networks in cities, based on variability in policies, regulation, and governance by local authorities	Busch et al. (2017)[5]
Transport MATSsim ABM	Transport model with people and trips and vehicle options, to study the effect of Electric Vehicles on electricity demand	Novosel et al. (2015)[6]

The way ABM works is by defining a series of agents with a number of set characteristics, in this report people. Characteristics can be anything that defines varied “states” or “identities” or “relation to the environment” of the agent, such as the characteristic “activity” defining the states asleep or being awake, or the characteristic “hungry” with the states being hungry or not being hungry, or the characteristic “health” with the states being sick or not being sick, or the characteristic “location” being at home or at work, or the characteristic “drink” preferring coffee over tea or vice versa, and so forth. Any characteristic with any number of states can be modelled, as long as an understanding exists of how to model the relationship between the characteristic and the behaviour that one seeks to model.

The “states” of agents change using two types of behavioural logic or “rules” around a time-clock, also depicted in Figure 1 below. First, rules that initiate agent behaviour to change a state regardless of other characteristics, or other agents, or the outside environment in the simulation, which are evaluated at regular periods or continuously in an agent-based model. As an example of rules that initiate behaviour, this could be a rule that defines that a person as an agent goes to sleep and wakes up eight hours later, regardless of what happens. The only response is within the same characteristic “activity”. The logic that would be set is “if time-clock reaches 11 pm, set agent state to sleep” and “If time-clock reaches 7 am, set agent state to awake”. Such a rule can be made more realistic by adding a probability rule that makes an agent wake up anywhere between 6am and 9am, for example. Second, rules that act out only if another characteristic of the same agent, or other agents, or the outside environment changes, usually in the form of an “event” response type. These only act conditional to something happening outside of the particular characteristic. For example, a rule that an agent will also wake-up if there is loud noise in the outside environment, assuming that such noise is also included in the simulation, or if another agent (say a partner of a couple) decides to wake-up the agent. Such rules form interactions between agents and/or their simulated environment.

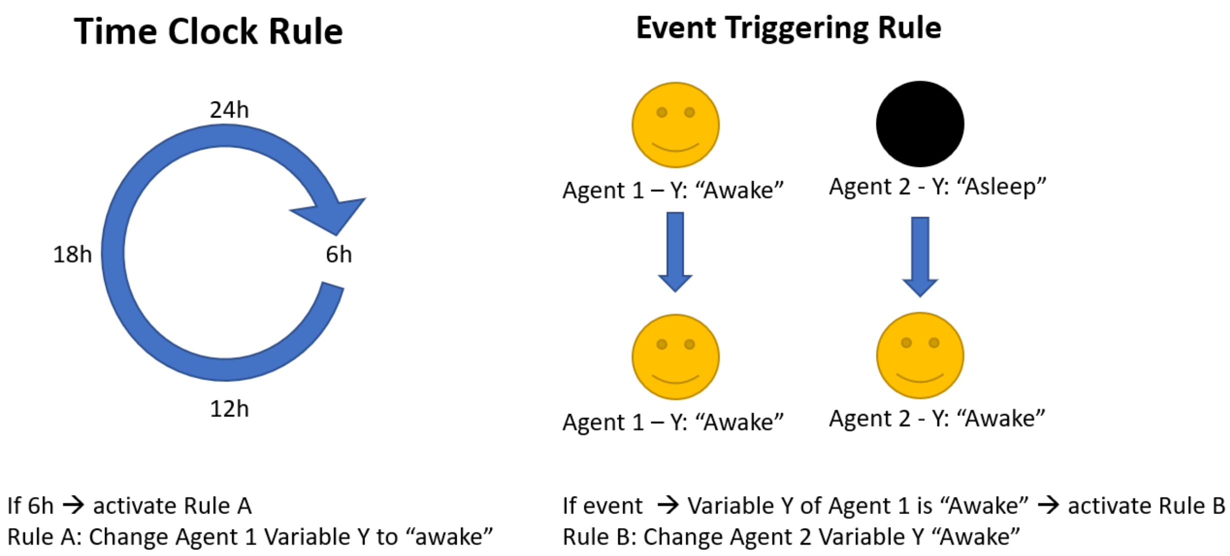

Figure 1. Conceptual overview of ABM rule types

The object oriented approach in ABM allows for describing hundreds to thousands or greater number of variation possibilities for each agent (or person), making it very flexible to describe the world from a bottom-up approach (North and Mackal 2007).[7] This makes ABM best suited to model the following situations:

- Where there is a need to track "agents" characteristics in detail over time.
- Where an understanding is needed of the micro (e.g. individual agents), the meso (citizen groups in neighbourhoods), and the macro (e.g. the entire city population).
- Where heterogeneity between agents plays a key role.
- Where learning from past behaviour or experiences is relevant
- Where we need to include spatial information in the simulation.
- Where there are networks that exchange information.

Because of these advantages, ABM is well suited to simulate the impact of Nature Based Solutions on citizens and the urban environment. Decision support for cities requires an understanding of the multi-varied impact on different groups of people given particular policies and projects, taking into account social and economic characteristics of citizens. As such, ABM is the best suited modelling method to support insight generation within an urban-citizen context.

2.2 Behavioural perspectives

An important value of ABM lies in that can be used to analyse complex real-world challenges by modelling the various interactions between a variety of social actors like e.g. individuals, households, organisations. In an ABM there are two main entities, namely the agents (representing social actors) and the environment (the virtual world in which agents are embedded and where they act and interact with each other). Without needing central coordination, agents can interact, and base their decisions on these interactions. An ABM allows us to understand "*how the model processes and rules lead to the emergence of an outcome, which resembles a real-world phenomenon*." (Narasimhan et al 2016)[8].

Real-world questions that policy makers, planners, initiators of NBS initiatives and others are likely to have when it comes to implementation, relate to a large extent to acceptance and behavioural change. For instance, questions like "*How can we ensure that these planned NBS interventions are going to be supported by or at least acceptable for our citizens?*" or "*What type of interventions are needed to invite, seduce, or encourage people to change their behaviours?*"

Changes in behaviours or practices can involve acceptance of interventions as well as changes in the current ways of doing. Below we first address how social acceptance is relevant when considering ABM, for which we build on Deliverable 5.3. Next, we address change in behaviours and practices, from three different social-scientific strands: economics and neo-classical perspectives on rational behaviour; psychology and the theory of planned behaviour; and the sociological perspective informed by social practice theory. This introduction is provided because the resulting ABM scenarios that have been developed all rest on slightly different understandings of behavioural change. These differences relate to the differences in the type of challenge and level of aggregation that differs across these cases.

However, we also need to consider the type of change asked for: a one-time decision about making an investment, routine behaviours, a combination of these. The transition towards a more sustainable world confronts us with a variety of behavioural challenges and increasingly efforts are made to translate social scientific insights about behavioural change into knowledge for policy makers.[9–11]These efforts reflect discussions about how economics, psychology, social psychology and sociology help us understand the dynamics of behavioural change. As a result of these discussions, increasingly, interdisciplinary perspectives are emerging. For instance, behavioural economics borrow insights from psychology. Psychology itself has moved from a perspective focused on individuals towards acknowledgement of the role of social context. Within sociology, the 'social practice theory' perspective has developed theoretically and empirically in recent years[12–14], whereby the unit of analysis is not the individual but socially shared practices. Hence, the distinction in the following sections is for the sake of conceptual clarity, and does not reflect the ongoing debates and (ex)changes between perspectives (see Darnton 2008b for a more comprehensive discussion of perspectives on behaviour and change)[15]

2.2.1 Economics: Neo-classical and Heterodox perspectives

When describing people's behaviour in economics, the discipline is focused on understanding how purchasing transactions come about. The dominant frame of economic thinking relies on the neo-classical utility concept, which denotes that each individual in an economy strives to maximize their utility through consumption, by using money provided by productive activities (work).[16] The allocation of money across consumptive possibilities comes about through assumed fixed preference relationships for any consumptive choice that is made on an individualised basis. A key simplifying assumption here is that of a "homo economicus" who has full access to information, who is capable to process all this information, is aware of its (static) preferences and is thus able to make the "best" choices in any given context.[17] The implication is that the world is well understood and that the impact of choices is certain and not limited by the cognitive ability to process information nor dependent on contextual conditions.[18]

Preference variation is provided by ranking consumptive choices in terms of utility gains, usually correlated with monetary value, which can also include the influence on utility gains due to the quantity of a consumed good or service within a time period. And these preference relationships are normally assumed to be static or fixed over time in economics.[19]

The economic system of utility and preference driving behavioural choices is not easily applicable to activities that become available through NBS interventions which are often free such as walking in urban parks or enjoyment of green facades. In such cases often an "opportunity cost" principle is applied in economics, where the costs saved by doing something, if it can be tangibly assessed, provides for the value of the activity or choice.[20] For instance, the saved health costs from walking. In line with the neo-classical utility perspective, a "willingness to pay" survey can be utilised, to express how much citizens would be willing to pay for their choice if it would have a fictitious monetary value. However, people do not necessarily act in the same way that they will say that they will act.[21]

The simplification as described above results in a limitation on how behavioural change is perceived. Based on the idea that providing information and financial incentives are sufficient to induce behavioural change.[18] The first part of the logic is that financial incentives improve consumptive choice options given existing preferences that result in better outcomes, as consumers will maximize their utility. For example, if it is sufficiently affordable people will prefer organic over non-organic consumptive choices given their superior quality, and it is thereby a matter of reducing the costs of organic produce to increase the rate of organic produce consumptions. The second part of the logic is that citizens or consumers in economic terms will change their future behaviours if it results in greater utility, such as when new information is provided about the (utility) benefits and induces a reconsideration of earlier made decisions. When behavioural choice is due to a simple selection of one outcome over another, and a resultant of a difference in preferences, associated utilities and correlated costs or benefits, there is no limitation to changing behaviours or decision dilemma's, which is far removed from reality.[22]

Empirical work shows that people often do not change their behaviours as neo-classical models predict.[22] First, because the impact of interventions to influence behavioural choices on actual outcomes is both uncertain and much more unknown, in other words people do not aim at maximising utility in the manner predicted by neoclassical economics, which in economics is captured under the heterodox umbrella of 'bounded rationality'.[23] Behavioural options are not only constrained cognitively, but also influenced by norms and values. Second, many choices are simply not considered and therefore no 'preferences' exists for these choices. Either because these options are not available, or because non-financial barriers exist by which they are out of reach or deemed out of reach. Third, choices are often not made in an isolation and in a void, but within a social context where social interactions with others (e.g. other household members, friends, peers) affect choices, where the physical context may constrain choices and where existing institutions (norms, rules, policies) also affect the eventual (lack of) changes in behaviour.[24]

The usefulness of the neo-classical framework of utility ranked preferences driving behaviour for ABM of NBS is limited to cases where different choices related to using or implementing NBS by citizens or other actors are transparent, where the choices can be individualised to a single actor or a series of single actors, where clear costings can be provided, and where financial incentives are the overriding factor for these single actors that results in one outcome over the other.[25] An example is the implementation of permeable paving as identified in the NBS typology under WP1.1, over impervious paving by city planners as a singular choice, whilst leaving out more difficult to implement options such as pocket gardens or other NBS within a street. Thereby reducing the decision process in which cost effectivity and effectivity is dominant in steering the decision, limiting the nature of change into a choice between pavement types, which from a citizen perspective maintains the status quo, and from an implementation perspective provides similar infrastructure. The difference in the types of paving can be easily expressed in cost difference values with benefits of improved water management that can also be expressed in monetary terms based on m3 of rainwater that is now locally dealt with instead of run-off into sewer systems.

In contrast, in case of pocket gardens in public spaces these may reduce parking options, and may meet strong resistance from citizens. In addition, such changes may affect other values and norms about these spaces, whereby views on e.g. street aesthetics, safety, ecological value and perceived potential nuisances may play a role. Furthermore, the long-term benefits that are difficult and uncertain to express in monetary values such as air quality, improved social relationships by increasing the likelihood that citizens want to spend time outside in the street are easily overlooked.[25] Hence, while in the example of permeable pavement decisions, this could be modelled in ABM based on a neo-classical framework of utility ranked preferences, for the example of pocket gardens this is not possible without excluding many crucial variables that affect behaviour and acceptance.

2.2.2 Psychology: Theory of planned behaviour

According to the Theory of Reasoned Action, developed in the seventies by Fishbein and Ajzen, beliefs about behavioural outcomes and the evaluation of these outcomes determine ones attitude towards behaviour.[26] The gap between attitude and behavioural outcomes is tackled by adding the notion of 'intentions'. The Theory of Reasoned Action (TRA) regards intentions as leading to behaviour. Other intervening variables have been identified and added to the model over time, resulting in the more widely used Theory of Planned Behaviour (TPB) developed in the eighties. Since then, the psychological perspectives on behaviour have continued to evolve. For instance, empirical studies have revealed that attitudinal factors (knowledge and awareness) are of little direct influence on behavioural outcomes.[9,15]

The TPB is still evolving it has allowed for consideration of societal, group and other contextual influences through beliefs, norms and perceived behavioural control.

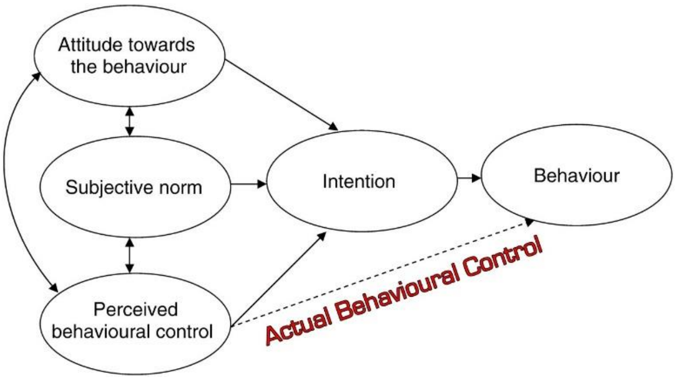

Figure 2. Conceptual schematic of the theory of planned behaviour[27]

The attractiveness of the Theory of Planned Behaviour lies in a system of causal linkages or chains, which make it appear as if changes in behaviour can be achieved through changing one or more variables. This conception on behaviour is common in modelling approaches and based on the assumption that individuals plan ahead and make assumptions based on available information (Azjen, 2002).[27] The popularity of this perspective is evidenced by the fact that it underpins a wide variety of policy interventions. The model has however also received significant criticism, and the assumed universality of the concepts and their unidirectional causality has been demonstrated to be false based on psychological experiments.[28]

The idea of a unidirectional causal link between attitudinal changes, resulting in behavioural change (action, experience) has been difficult to establish. In experiments where people were asked to change their behaviour whereby it became visible that often the attitude change took place *after*, rather than *before* the behavioural change. A simple cycling to work experiment, where participants received a bike and a rain suit, showed that the experience of cycling to work resulted in a change in attitude and not vice versa. The experiment itself led a positive influence on peoples' decision to continue cycling after the experiment was finalized. Attitudes, like preferences, are dynamic and can be reflexive, in that they can change as a result of an experience and experience seeking is influenced by attitudes (Spotswood, F. et al, 2015).[29]

Studies have also shown that environmental attitudes via intention, are not the best predictors of environmentally associated behaviours. Comfort and convenience are more important in this regard.[30,31] For instance having the time to cycle to work in view of the busy morning schedules is a more influential factor (compared to a pro-environmental attitude), which is not taken into account in the Theory of Planned Behaviour. In essence, the model of planned behaviour remains a methodologically individualist model, even if social norms are taken into consideration.

The Theory of Planned Behaviour is relevant for ABM of NBS in cases where involved choices can be simplified to attitudes and norms as behavioural drivers that are relatively fixed given a snapshot decision. In general terms, in cases where different choices related to using or implementing NBS by citizens or other actors are quite transparent, where choices need to be individualised to a single actor or a series of single actors, and where norms and attitudes are the overriding relationship to behavioural choices and can at least in theory be quantified through surveys.

2.2.3 Sociology: Social practice theory

More attention for choice architecture in social psychology has laid bare the limitations of the neoclassical perspective of individualised choice through preferences. The acknowledgement that individual conduct and individual choices are also affected by contextual influences (both physical and social). The popularity of nudging reflects this change. Regardless of differences in methodology, and in the choice as to what the unit of analysis should be (e.g. individuals, social groups, social practices), the importance of context is become increasingly accepted in most social scientific disciplines.

Within sociology, social practice theory differs from psychology and economical approaches in that it takes socially shared practices as a unit of analysis, not individual behaviours., These social practices (‘ways of doing’) change over time in interaction with physical, normative, cultural and other influences. Individuals are understood as carriers of such practices (Reckwitz, 2002).[32] For example, social practice theory has been used to show ex-post how, with the introduction of the washing machine, changes in practices of washing have resulted in changing social norms of cleanliness and how these norms have reinforced the frequent use of the washing machine, as a way to show how household energy consumption in relation to this practice has changed over time (Shove 2003).[33] Social practice theory goes back to Giddens structuration theory which stipulates that agency shapes *and* is shaped by structure (Giddens, 1984).[34] In this understanding individuals are structured and influenced by the social, institutional and physical context when they go about their daily lives. It is also understood that these contexts are not static and change over time as a result of peoples’ collective and individual actions.

Social practice theory thereby regards people/humans as agents that ‘carry’ the practices that they ‘perform’. Hence the focus is not on the individual and his/her motivation, intention, and behavioural choice. Rather the practice itself is the focus of attention. Practices consist of three constitutive elements (see figure 3) that we illustrate using the example of cycling:

- **Materials**, that form part of the practice which exist in physical reality, such as NBS spaces and their accessibility, or bike and cycling paths.
- **Competences,** that enable the practice such as knowledge about the existence of nearby NBS spaces, or the right skills for cycling and related time-management and geographical orientation.
- **Meanings,** that provide a shared understanding about the practice, such as the value of NBS spaces for healthy living, or the social status and health benefits attached to cycling.

The practice of walking in an NBS space, or cycling in a specific context (e.g. in a particular country, city or a particular neighbourhood) will depend on a combination of these elements. Changes to any of these elements create a change and or an evolution in the practice. In addition, practices can become interwoven with other practices.

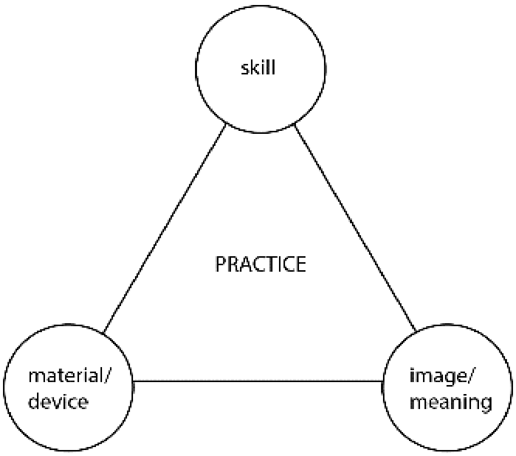

Figure 3. Conceptual definition of practice (Shove, 2003).[33]

Translated to the notion of walking in NBS spaces, social practice theory can be used to conceptualise walking as a 'practice' that is made up of several constitutive elements that together make up the way walking comes about and is performed. A definition of the materials and the competences involved as well as the meanings associated with walking in NBS spaces would be required.

When we consider the question of how to encourage households with tiled yards into transforming their garden into green or partially green yards, we need to consider social practices that relate to what people do in their yards (e.g. barbecuing or having dinner outside; playing (kids); do-it-yourself hobbies) with the distinct materials, competences and meanings associated to this. Empirical research (e.g. observations, interviews, surveys etc.) could help to achieve context-specific descriptions of such practices. The challenge of social practice theory lies in its translation into policy relevant knowledge, its main achievements so far lie in ex-post (longitudinal) inquiries.

Social Practice Theory is relevant for ABM of NBS because it explicitly takes into account the physical and social contexts in which behaviours as practices occur. It is relevant for simulations of routine behaviours involving using NBS spaces. For example, to simulate the daily routes citizens take when walking or cycling to work and how these routines may change due to infrastructural changes from an NBS intervention. While we do see how it would be interesting to have an ABM scenario that takes practices into consideration, additional and extensive empirical work is necessary to establish how these practices look like in a particular context.

2.3 Behavioural Modelling Approaches

The conceptual insights on how societal and behavioural changes come about, as perceived from different disciplines, are discussed in this section 2.3 in relation to how and when implemented, they result in different agent-based modelling approaches. The disciplinary approach to conceptually construct the relationships between agents, their environment and social context, as well as the key questions that are asked, determine the requirements of the chosen modelling approach. As such, before starting any modelling work, the design structure of the ABM needs to be considered, so as to tailor it to fit with the social science and related behavioural simplification of reality. Both to ground a model to make it usable and useful, as well as to understand its potential and limitations in terms of what can be modelled and how the results should be interpreted.

Any modelling always implies a chosen simplification of reality that means that many factors are not taken into consideration, or when taken in consideration are intentionally simplified. Not only due to knowledge constraints or time constraints, but also because parsimonious models are easy to interpret and can still be valid for particular uses. Therefore, as long as models are simplified whilst still valid and relevant, within the context of insights creation for which they are used, such simplifications are often desired. Simplifications create clearer interpretable insights that can more easily show what decisions would work and which will not, in what way they can work, and to what extent. Understanding the overall modelling approach and model structure, in terms of causal and/or reflexive logic is thereby essential, so as to provide a grounded basis for interpreting modelling results.

2.3.1 Individualistic “Ceteris Paribus” Approaches

A common scientific method to understand relationships are statistical assessments that look at how one factor or a few factors are related to each-other through correlation. The process often works like this: based on deductive reasoning a hypothesis is formed. For example, more walkable parks in urban environments improve the well-being or health of citizens, because they can walk in those parks. Subsequently, data can be collected to prove or disprove the hypothesis using statistics. Data for different cities on the occurrence of urban parks, on well-being factors, and walking behaviors.

Before translating these rules into a model, they are typically validated using statistical analysis to see if indeed there are correlations, such as to whether citizens that walk substantially in NBS spaces have improved health, whether citizens that walk substantially but not in NBS spaces also have improved health, and whether citizens that do not walk have reduced health. The resulting outcome of such a statistical analysis is usually either a statistically significant result at a high enough confidence level, or not significant because there are too many other factors at play.

The reason is that all other factors are not considered as the aim is to single out one or a few factors only. For example, other sports people carry out besides walking activities, the background air quality in the city, the ability for citizens to easily travel outside of the city into natural areas, the existing variety in health status among citizens, the suitability or popularity of NBS spaces for walking, people’s diet, smoking or not smoking, the Body Mass Index (BMI) as the ratio between weight and height as an indicator of food intake, and so forth. Such factors can influence as a contribution or a negating factor to the earlier hypothesis that urban parks improves health through walking, as well as fully falsify that relationship because other overriding factors are at work. For example, substantial walking may not be beneficial to health in environments with high air pollution loads.

When translating the statistical knowledge to a model, the way the models are built and run, usually is based on a “Ceteris Paribus” or “all other things being equal” approach, relationships are seen in isolation, and the complexity of all these factors together are ignored, by only adjusting a single change in a significant relationship when running a model.[35] As such, simplified models are built by taking a limited number of simplified one directional causal logic relationships, where a single or a limited number of factors provides the driving outcome. Such as in our example “the magnitude of urban parks for walking improves health” or the “walking time of citizens improves health”. Modelling approaches based on “Ceteris Paribus” are commonly utilized in economics, to assert economic impacts of policies. For example, as a causal one factor rule the assumption that companies reduce investments due to increased taxation, ignoring other factors that influence company investment decision making, as well as ignoring qualitative interferences due to the type of taxation.

2.3.2 Causal Chain Layering

Complex forms of modelling are built by conceptually separating out individual causal relationships into modules to build them, which together form causal chains that are layered on top of each other. To do this, well-defined aspects of a modelled system are separated out, and usually studied independently, so as to formulate a series of model relationships which define changes from initial inputs to provide outputs of interest. For example, transport simulations are usually approached from a modal choice decision building block and a transport route building block. The modal choice building block is based on a series of causal relationships that define why a person chooses a car, public transport, walking, cycling and so forth. Various factors can be included here such as time of day, distance of the trip, weather, income and affordability of transport mode, and so forth, which each can be a causal relationship which together forms a causal layer that defines the behavior behind the modal choice.

The aim in this causal chain layering approach is to try to factor in various different factors that can play a role in the decision-making process, going beyond the parsimonious “Ceteris Paribus” approach. The approach acknowledges that when relating to decision making it is not possible to simplify the causal relationships that govern behavior to one or a few factors. Many factors and their relationships are considered and layered on top of each-other, also considering that depending on the socio-economic group in society different factors are of importance. It is not possible to

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homogenize citizens into a single individual entity, but there are many groupings of individuals possible. In the transport example, depending on whether a person belongs to a low-income group, what their age is, what social norms the person conforms to, what family a person belongs in, all vary from person to person and trigger different causal relationships. The approach is therefore far better suited to take into account behavioral situations with large heterogeneity and choice influences. The limitation is still that the relationships are seen as causally unidirectional and fixed in time, as they are usually coded as a fixed relationship.

The challenge with operating such complex models based on causal changes is that many outcomes are possible. The more layers in the model the greater the outcome possibilities become. Usually to operate such models a “what-if” approach is used to compare a baseline from the current situation, to a limited number of “what-if” scenarios that force the model to consider a new situation, such as a new road transport route, or reducing the cost of public transport. The model is then run with the project or policy intervention to understand how it impacts different groups in society and affects their modal choices. Models are thereby run based on more complex pallets of options that citizens can choose from, yet still remain quite deterministic in that the model rules stay the same.

2.3.3 Systemic Multi-Level Reflexive Change

The most challenging setup to model are situations where the idea of a fixed causal relationship is dropped and incorporated as a fluid changeable relationship. Social practice theory is based on this systemic perspective, where the social and physical context is perceived as evolving aspects over time which influence behaviour and decision making. As such new relationships can form, and rather pointing towards direct causal mechanisms, there is a myriad of conditions that together work towards a particular outcome. Furthermore, relationships can be reflexive and multidirectional, such that causality can go both ways. Behaviour is fluid over time as agency and structure are mutually shaping each other. In our earlier example of the “the magnitude of urban parks available for walking improves health” this perspective extends to a situation where the recognition of health improvement by walking can drive the emergences of NBS, and mutually reinforces each-other in a dynamic process.

Hence, behavioural change is not something that can be treated in separation to the physical and/or social context, but the context shapes behaviour and the behaviour shapes the context (in the sociological sense that agency shapes structure). Behavioral responses that may occur in lab-situations are unlikely to repeat themselves in real-life when various other conditions also affect each other as well as the outcomes. In terms of implementing such a dynamic perspective in an ABM model, changes should be incorporated to take place on multiple levels, not just at the level of the individual. For example, in case of cycling, the physical context of availability of cycling lanes changes as there are an increasing number of cyclists that actively promote cycling up to a political level. At the same time the number of cyclists increases as cycling lane infrastructure increases, as well as other aspects that influence social norms (for instance having showers at work), or tax incentives that promotes purchasing a bike for commuting rather than leasing a car. As such several levels are necessary including individual decisions, social norms, and attitudes towards physical infrastructure investment, within a web of relationships. Furthermore, some of these relationships adjust over time in non-linear ways. For example, in cities where for a long time there is no investment in cycling lanes, after a number of conditions are met or reached, cycling lane infrastructure investment begins to accelerate. These conditions are often not known a-priori nor are they static per environment or over time, because of which the conditions required in one city can well vary from another that are needed to make cycling infrastructure investment happen.

A key question in operationalising this reflexive and multi-level framework is how to account for the extent to which a simulated decision or behavioural change links in with a large number of contextual variables, and how to adequately interpret the results. To do so lots of survey and case study analysis is needed to find out how change processes happen at each of the multiple levels, and what has led to changes in individual behaviour, what has made investments in altering the physical structure possible, and what led to a change in social norms. Implementing this complexity adequately in an ABM context thereby requires substantial research effort to come up with a validated framework of dynamic and reflexive relationships.

2.3.4 Summary: Different Setups to Simulate behaviour in ABM

The behavioural approaches above can be summarised based on their level of complexity as well as functionality, which will be outlined in the conceptual summary of chapter 5 (see table 6). To summarise, the simplest form is “ceteris paribus”, where a limited number of unidirectional causal relationships are built and the models are run by looking at the effects of changing one individual input variable at a time. A medium form of complexity is a causal chain layering approach, where a substantial number of unidirectional causal relationships are connected to each other that relate to one or multiple decisions, with models that can contain many up to dozens of individual models that are all interrelated and dependent on each-other, from inputs to outputs. And the most complex form is that where causal relationships can be multidirectional or reflexive and operate between an individual and societal level, such that they can be reinforcing or cancelling. Moreover, these relationships are dynamic in that their magnitude effect can diminish over time, and different factors can play a stronger or weaker role depending on the changing context.

The choice of building the ABM model based on these different levels of complexities has substantial implications for the functionality of the model. An ABM that takes into account changes in the physical context and social context is more rich and can better explain and provide insights in changes that can be insightful to answer “how” questions, such as “how do decisions about whether NBS are implemented in private gardens come about”. Answering such questions requires incorporation of the social, institutional, economic, and physical context in which behaviours are embedded. In contrast a simplified “ceteris paribus unidirectional causal model is apt at providing “how much” type of questions within a limited scope context, such as “how much rain water garden NBS are needed to capture 10% of the rainwater in the city”. And the intermediate Causal Chain Layering is useful to interrogate more complex cases of “What” type of questions, such as “What are the best locations for NBS in the city to reduce air pollution impacts”, since these questions require quite a lot of linkages between modules, such as air pollution quantifications, transport behaviour, modal choice behaviour, NBS air pollution impacts, and so forth.

2.4 Agent Based Modelling Packages

There are a growing number of software packages that facilitate ABM by providing existing logic that can simulate time-clocks, sets of behavioural rules, interactions between objects in time and space, and so forth.[36] These provide the abstract tools to implement many types of entities and behaviours in Agent-Based Models. A selection of the main ABM packages from oldest to most recently developed include:

- **Netlogo**, first developed in 1999 using the Logo programming language, latest release June 14 2018, open-source, includes a General User Interface (GUI), designed for rapid example model development without the need for a background in programming as models are built with the intuitive Logo programming language. Website: https://ccl.northwestern.edu/netlogo/
- **MASON**, first developed in 2005 using the Java programming language, latest release 2018, open-source, excludes a General User Interface (GUI), designed for creating swarm multi-agent simulations of many (up to millions) of agents in an efficient manner, to run up to hundreds of thousands of simulations rapidly. Requires an extensive Java programming background. Website: https://cs.gmu.edu/~eclab/projects/mason/
- **Repast-Simphony**, first developed in 2006 using the Java programming language, latest release October 27 2017, open-source, excludes a General User Interface (GUI), designed for development of simulations of agents with many networks focusing on social interrelations, can also be linked to system dynamics simulations, including a parallel computing using clusters based on the C++ programming language. Website: https://repast.github.io/index.html
- **StarLogo TNG**, first developed in 2008 using C and Java programming languages, latest release January 18 2011, closed-source, includes a General User Interface (GUI), designed for educational simple 3D game model development without the need for a programming background as the GUI allows for creating models. Website: https://education.mit.edu/portfolio_page/starlogo-tng/
- **MESA**, first developed in 2016 using the Python programming language, latest release July 17 2018, open-source, excludes a General User Interface (GUI), designed to develop web-based agent-based models to leverage python's scientific and visualisation libraries. Website: https://mesa.readthedocs.io/en/master/

Out of these modelling package the Netlogo software was selected because it is one of the most developed ABM package's in terms of versatility, it is well suited to simulate social and economic aspects of people in networks, and its programming language makes it the best suited package for rapid model development and experimentation. This makes it the best suited to rapidly explore behavioural change modelling and planning at the urban level for nature based solutions for different types of citizens.

3 Literature and Past Work Review

The academic literature was screened for previously built Agent Based Models that incorporated green infrastructure as an approximation of NBS. The literature search approach employed was to search for keywords “Agent Based Modelling” in combination with “green infrastructure”, “urban environment” and “Nature Based Solutions”. The search did not yield any specific results that addressed the concept of NBS, indicating that both disciplines have not yet been combined in a multi-disciplinary approach, but more generic examples of environmental and socio-economic systems analysed using ABM. Because of this instead of a structural analysis of all available results, a snowballing literature search approach was utilised, where the few relevant results that were found, were further explored by looking at subsequent studies that cited these results. As such a total of ... literature studies were found as summarised in section 3.1.

In addition to a direct literature search, also the online CoMSES repository of open source ABM’s was explored (www.comses.net). This repository, launched in 2014, was setup to enable a standardised repository to share ABM’s in a structured and organised manner, so as to enable reproduction of scientific results and to disseminate models [37]. Models available in the repository are also linked to available peer review papers when published, so as to ensure available simulations are of a high quality. At the time of writing 532 ABM’s were described in CoMSES, and 4 of these are described in section 3.2. The models were selected based on database searches using the same keywords “green infrastructure”, “urban environment” and “Nature Based Solutions”.

Note that the literature and past work review does not cover Nature Based Solution as a standalone concept, as this is already covered in Work Package 1 within the Nature4Cities project in D1.1, D1.2 and D1.4, which cover an innovative NBS typology, NBS implementation models, and pioneering NBS experiences.

3.1 Literature Summary

Existing agent based simulation efforts that are related to NBS as retrieved from the literature can be grouped into four use domains (see Table 4 for details). The analysis of housing markets and prices and the effect of green infrastructure therein, focusing on large and small parks within the city.[38–40] The study of travel behaviours from work to home including cycling, walking and other modes of transport, and how green spaces alongside travel corridors can influence and/or support the choice of transport modes.[41–45]. The demographic and associated land use development of a city including green space and other urban ecosystems,[46–49] including impacts on human well-being and quality of life.[50,51] And the diffusion of rainwater catchment and collection green infrastructure, systems, and knowledge among citizens,[52–54] drawing from similar approaches for energy systems.[55]

Beyond these main areas specific models were constructed including the analysis of diets and physical activity such as available from green infrastructure on obesity rates,[56] building energy management strategies taking into account building use behaviours and thermal comfort indicators,[57] the study of investment policies that could lead to more green infrastructure investment,[58] analysis of urban greenspaces of biodiversity improvement and managent of a particular species of turtle,[59] a simulation of the evacuation of vulnerable groups in light of a major earthquake taking into account the role of parks and open spaces[60], and the behaviour of people under urban flood scenarios.[60]

The existing works, whilst not specifically tailored to NBS, already provide a number of helpful ABM simulations to gain insights in the role of NBS within an urban context. The costs and benefits of green spaces are evaluated in various contexts, which relate to many NBS, including demographics, housing prices, urban planning and development, and human well-being. The effect of information and knowledge distribution in spreading NBS type infrastructures from a bottom-up perspective is studied. And the importance of green infrastructure in particular domains, such as transport, infrastructure investment, biodiversity, and natural disasters has been studied. The literature thereby provides an excellent starting point for these areas. At the same time there are gaps for other domains relevant for the implementation of NBS, for example citizen health impacts, required regulatory change, NBS scenario planning, Moreover, studies where particular NBS and their impacts are simulated are missing, as the current literature focuses on green infrastructure in general and not specific for types of NBS as per the ontology developed in WP1.1 of Nature4Cities.

Table 4. Summary of ABM literature studies related to green infrastructure

Reference	Field/Type of Simulation	Agents Identified	Potentially Related Indicators from NATURE4CITIES WP2.1	Related Urban Flows	Utilised Methods and Software	Identified mathematical formulas
Filatova, T. Empirical agent-based land market: **Integrating adaptive economic behavior in urban land-use models**. Comput. Environ. Urban Syst. 54, (2015).	Housing Market Pricing model (incl. distance to parks effect)	Housing buyers, housing sells, housing traders/realtors	11.3.2 Housing Pricing Index (HPI)	n/a	GIS / Netlogo / R	Average preference for environmental amenities as part of a utility function (based on Wu and Plantinga)
Orr, M. G., Kaplan, G. A. & Galea, S. **Neighbourhood food, physical activity, and educational environments and black/white disparities in obesity: A complex systems simulation analysis**. J. Epidemiol. Community Health 70, 9 (2016).	Physical activity simulation of agents with impact on Body Mass Index	Household residents by age, economic and racial distributions	7.2.1 Quality of life 7.3.1 Perceived Health 8.1.3.1 Gentrification	Physical Activity Infrastructure	Not specified	Relationship between physical activity and environment and BMI
Azar, E., Nikolopoulou, C. & Papadopoulos, S. **Integrating and optimizing metrics of sustainable building performance using human-focused agent-based modeling**. Appl. Energy 183, December 2016 (2016).	Sustainable building performance based on thermal comfort of agents	Students and Staff in educational buildings	1.2.3 AC - Adaptive Comfort (indoor) 6.1.9 Buildings Energy needs	Energy Consumption of Buildings	Anylogic 7 / Matlab	Thermal comfort equations and energy consumption from regressions
Aziz, H. M. A. et al. **A high resolution agent-based model to support walk-bicycle infrastructure investment decisions: A case study with New York City**. Transp. Res. Part C Emerg. Technol. 86, November 2016 (2018).	Home - Work Travel	Working Agents	1.1.2 GHG - Avoided GHG emissions, 3.1 CAQI - Common Air Quality Index,	Traffic, Particulate Matter, GHG emissions	Repast-HPC	Utility formulas for selection between walking, biking, car, and public transit to work from home including agent interactions due to social influence
Saarloos, D., Arentze, T., Borgers, A. & Timmermans, H. A **multiagent model for alternative plan generation.** Environ. Plan. B Plan. Des. 32, 4 (2005).	Home - Work Travel	Working Agents	1.1.2 GHG - Avoided GHG emissions 3.1 CAQI - Common Air Quality Index	Traffic, Particulate Matter,	Repast-HPC	Utility formulas for selection between walking, biking, car, and public transit to work from home including agent

				GHG emissions		interactions due to social influence
Wissen Hayek, U. et al. **Quality of urban patterns: Spatially explicit evidence for multiple scales.** Landsc. Urban Plan. 142, October (2015).	Demographics and location choice based on 10 spatially defined indicators	Residents	4.1.1. UGSP urban Green Space Proportion 8.2.1 SC - Social Capital 11.3.2 HPI Housing Price Index	n/a	UrbanSim	Multinomial logit functions for choice of housing location, influenced by spatially defined indicators
Brown, S. & Ferreira, C. **Agent-Based Modeling of Urban Tropical Green Infrastructure Investment**. Alam Cipta 6, December (2013).	Favourability level of space based on green infrastructure investment	Property investors	11.3.2 Housing Price Index	Green Space Infrastructure	Netlogo	Spatial proximity algorithm
Schwarz, N. & Ernst, A. **Agent-based modeling of the diffusion of environmental innovations - An empirical approach**. Technol. Forecast. Soc. Change 76, 4 (2009).	Investments in water saving innovations	Households by lifestyle	6.1.11 Water scarcity	Water flows	Unknown	Decision rules for adoption of green technologies influenced by social network interactions
Ligmann-Zielinska, A. & Jankowski, P. **Agent-based models as laboratories for spatially explicit planning policie**s. Environ. Plan. B Plan. Des. 34, 2 (2007).	Urban demographic development	Individuals with demographic/socio-economiv variation	4.1.1 urban green space proportion	Urban spatial development	CommunityViz (C++, Visual Basic, Avenue)	Land use preference and belief algorithms
Montalto, F. A. et al. **Decentralised green infrastructure: The importance of stakeholder behaviour in determining spatial and temporal outcomes**. Struct. Infrastruct. Eng. 9, 12 (2013).	Green infrastructure adoption by residents/property owners	Residents	11.3.2 Housing Price Index	Green space Infrastructure	Netlogo	Green infrastructure adoption probabilities
Rai, V. & Robinson, S. A. **Agent-based modeling of energy technology adoption: Empirical integration of social, behavioral, economic, and environmental factors**. Environ. Model. Softw. 70, (2015).	adoption of solar-PV technologies by households	Households by lifestyle	6.1.2 energy security 11.3.2 Housing Price Index	Energy flows	ESRI ArcGIS agent extension	Agent social network influence on technology adoption
Roebeling, P. et al. **Assessing the socio-economic impacts of green/blue space, urban residential and road infrastructure projects in the Confluence (Lyon): a hedonic**	Land use price impacts of green infrastructure projects	Households	11.3.2 Housing price index	n/a	Microsimulation	Hedonic pricing model with environmental preferences

pricing simulation approach. J. Environ. Plan. Manag. 60, 3 (2017).						
Robinson, D. T., Murray-Rust, D., Rieser, V., Milicic, V. & Rounsevell, M. **Modelling the impacts of land system dynamics on human well-being: Using an agent-based approach to cope with data limitations in Koper, Slovenia**. Comput. Environ. Urban Syst. 36, 2 (2012).	Land use transitions	Household, Developer, Business	5.1.4 soil biological activity, 5.1.5 Soil classification factor 7.1.1 day-evening-night-noise level, 7.2.1 QAL quality of life	Agriculture and green land use	Unknown	Integration of socio-economic and physical indicators using utility
Melorose, J., Perroy, R. & Careas, S. **Implementation of a Model of Dynamic Activity-Travel Rescheduling Decisions: an Agent-Based Micro-Simulation Framework**. Statew. Agric. L. Use Baseline 2015 1, February 2014 (2015).	Activity travel scheduling	Household, residents	4.1.1 Urban green space proportion	Green space use	Aurora	Utility based decisions for travel routes
Murray-Rust, D., Rieser, V., Robinson, D. T., Miličič, V. & Rounsevell, M. **Agent-based modelling of land use dynamics and residential quality of life for future scenarios.** Environ. Model. Softw. 46, (2013).	Land use transitions	Household, Developer, Business	5.1.4 soil biological activity, 5.1.5 Soil classification factor 7.1.1 day-evening-night-noise level, 7.2.1 QAL quality of life	Agriculture and green land use	Not specified	Integration of socio-economic and physical indicators using utility
Gaube, V. & Remesch, A. **Impact of urban planning on household's residential decisions: An agent-based simulation model for Vienna**. Environ. Model. Softw. 45, (2013).	Demographic development in cities	Households	11.3.2 Housing price index	Green space use	Not specified	Preference functions for location choice based on green space
Brown, D. G. & Robinson, D. T. **Effects of heterogeneity in preferences on an agent-based model of urban sprawl**. Ecol. Soc. 11, 1 (2006).	Demographic development in cities	Residents	8.1.1.1 place attachment 8.1.1.3 Availability ES	n/a	SOMO	Location preference utility function influenced by aesthetic quality and closeness to natural areas
Vallejo, M., Corne, D. & Rieser, V. **Evolving Urbanisation Policies - Using a Statistical Model to Accelerate Optimisation over Agent-based Simulations.** Proc. 5th Int. Conf.	Green space use based on proximity, price and utility	Households	11.3.2 Housing price index	Green space use	Not specified	N/a

Agents Artif. Intell. January (2013). doi:10.5220/0004261001710181						
Teillac-Deschamps, P. et al. **Management strategies in urban green spaces: Models based on an introduced exotic pet turtle**. Biol. Conserv. 142, 10 (2009).	Influence of greenspace on turtle abundance	Turtles	4.1.1 Urban green space proportion 4.1.2 Ecological habitat diversity	Green space availability	Not specified	Probability of turtle capture and survival
Kountouriotis, V., Thomopoulos, S. C. A. & Papelis, Y. **An agent-based crowd behaviour model for real time crowd behaviour simulation**. Pattern Recognit. Lett. 44, (2014).	Crowd behaviour Movement of People	Pedestrians in a building environment	10.2.3 Number of people injured, relocated and evacuated	n/a	Not specified	Crowd behaviour
Omer, I. & Kaplan, N. **Using space syntax and agent-based approaches for modeling pedestrian volume at the urban scale**. Comput. Environ. Urban Syst. 64, (2017).	Pedestrian movement on streets	Residents	10.2.3 Number of people injured, relocated and evacuated	n/a	GIS / Netlogo	attractiveness of land use and distance weighting for residential movement with shortest path algorithm
Gabriele Bernardini, Marco D'Orazio, Enrico Quagliarini, Luca Spalazzi (2014). **An agent-based model for earthquake pedestrians' evacuation simulation in urban scenarios.** Transportation research Procedia 2, 255-263	Pedestrian evacuation	Adults, hand assisted child, invalid, rescuer	10.2.2 Number of Deaths and Missing People 10.2.3 Number of People injured, relocated and evacuated	n/a	TROPOS, TAJ, Alan and Java	modified social force model is used to describe behavior during evacuation
Aerts,JCJH, Botzen, WJ, Clarke, KC, Cuter, SL, Hall, JW, Merz, B, Michel-Kerjan, E, Mysiak, J, Surminski, S, Kunreuther, H (2018) **Integrating human behavior dynamics into flood disaster risk management.** Nature Climate Change, Perspective, 193-199	Behavior change after floods (proposed for ABM)	Individuals	2.1.3 Peak Flow Variation 2.2.1 Total runoff volume 2.2.4 variation of flooded area 2.2.5 water detention time	Urban water flows	Not specified	n/a
Kandiah, V, Binder, AR, Berglund, EZ. (2017) **An empirical agent-based model to simulate the adoption of water reuse using the social amplification of risk framework**. Risk Analysis 37, 2005-2022	community opinion dynamics	households	6.1.7 water security 6.1.12 absolute water consumption 6.1.13 water efficiency 8.1.2 social capital	water reuse	Not specified	risk and benefit perception equations; social amplification of risk framework; risk public model

3.2 Description of relevant previously developed ABM's

The Comses databases was screened for Agent Based Models that are potentially relevant for NBS analyses, based on a search with the keywords "green infrastructure", "urban environment" and "Nature Based Solutions", as described at the start of this chapter. The following four ABM models were found:

- **Social and Ecological Feedback in Greening Behaviour**, the simulation of feedbacks between observations of greening (by other households), how this influence greening of households, and how this results in increased well-being. The simulation assumes that there is a linear feedback between observation and investment in greening with an observed probability, which can be varied.

  Link: https://www.comses.net/codebases/4545/releases/1.0.0/

- **A model of urban expansion policy scenarios using an agent-based approach: a case of the Guangzhou Metropolitan Region of China**, the simulation of policy scenarios for urban developments in terms of influence on land use and patterns. The agents include regional authorities, real estate agents, resident agents, and farmers and interaction patterns between these. The micro-behavioural patterns analysed in the simulation can potentially be related to changes in NBS in urban areas.

  Link: https://www.comses.net/codebases/4159/releases/1.0.0/

- **Alternative scenarios of green consumption in Italy: an empirically grounded model,** the simulation of household consumption of food, transport and energy consumption. The simulation considers household agents and their consumption patterns, and how these are influenced by environmental considerations and pricing (carbon taxes) and the spread of information via campaigns on environmental concerns. Whilst it does not directly simulate NBS the framework could be used for studying consumption patterns in relation to NBS such as of food and drink.

  Link: https://www.comses.net/codebases/3708/releases/1.1.0/

- **Land use in an eXurban Environment v1.0 (SLUCEII LUXE),** the simulation of land use changes due to economic market regulatory changes at a macro-scale, and the willingness to pay (WTP) and willingness to accept (WTA) and its relation to utility for land buyers. The simulation is an economic simulation that seeks to maximize utility within the budgets of land buyers via a bidding strategy. As a result, different land use patterns emerge which can be utilised to simulate green spaces.

  Link: https://www.comses.net/codebases/3942/releases/1.2.0/

4 Agent Framework for the Urban NBS Ecosystem

To improve the usefulness of ABM as a decision support tool for cities, municipalities, and metropolitan areas a standardised framework is needed. Otherwise it is likely that new projects wherein agent-based models are built for purposes of exploring ABM will continue to reinvent the wheel in terms of structuring how to describe the city, the behaviours of the citizens, and the role of NBS in addressing some of the challenges faced by the municipality and the citizens at large. In this chapter an effort is made to create a standardised framework, used in describing the conceptual ABM-NBS interactions (chapter 5) and the implemented models (chapter 7), which can also be used for future purposes in expanding these models or describing new concepts and building new agent-based models.

The standardised framework is elaborated in section 4.1, where the behavioural roles that citizens and visitors perform within the city boundaries are described. This is done by developing an ontology describing citizen and visitor archetypes and behaviours that can be used as a standardised framework. It complements the earlier developed ontology built in the Nature4Cities project, which names and describes different NBS, covering 74 types of NBS (see Nature4Cities WP1.1). The ontology drawn up here is based on the author's experience in building ABM and built together with the expertise from technical task partners.

4.1 Citizen and visitor agent behaviour ontology

The object oriented structure of ABM makes it possible to simulate any type of behaviour that is associated with a person, as long as such behaviours are sufficiently understood in their complexity. To create a uniform approach an ontology is here developed to standardise the semantic description of agent behaviours within the context of NBS (provided in Table 5).

As a starting point two types of agents are described, citizens and visitors, which differ based on their relationship to an area. A citizen lives within the area of study such as a municipality, and therefore typically resides there until she/he moves out, whilst a visitor temporarily enters the area for a particular purpose, and once that purpose is fulfilled it then exits the area. The roles that each fulfils can thereby vary substantially.

The attributions in the simulation to each of these two agent types is in the ontology divided between six aspects:

- **Characteristics**, the age, gender, life phases, income, and health characteristics that define a person's life and status from a physical and economic perspective. Typically, these are recorded and change in a simulation on an annual basis.
- **Activities**, the daily activities carried out by people, categorized by general activities (sleeping, travelling, working, etc.) and activities which can be related to NBS (e.g. nature walks, outdoor sports)
- **Activity behaviour routines,** that consist of a set of algorithms to define particular aspects of activity behaviours (e.g. travelling mode choice routines). These are defined as routines because people usually exhibit similar behaviours over longer periods of time.

- **Relationships**, the social relationships between population agents associated with family, friendships, and acquaintances.
- **Mental Perceptions**, the views of the agent of itself which define how it relates to the social context, the physical context, the local environment and other factors, such as wellbeing and motivational factors, as well as routine behaviours.
- **Abilities**, a set of states that defines the possibility for the agent to carry out particular behaviour's due to restrictions or enabling factors (financial, physical, knowledge).

Each of these types is explained here in more detail to define them and discuss the relevance for particular city population simulations.

Characteristics, each citizen agent and visitor agent can have a similar set of physical characteristics, including the age group of the population, and the gender. Age groupings are selected to split the population into life phases to denote schooling and working life, and potentially vulnerable groups, such as infants from 0 to 5 years and elderly from 65-75 and 75+ years. Each agent also can be defined by gender so as to simulate demographics as well as current and changing socio-cultural differences and health differences.

An agent can also be defined by a number of overall life-phase roles, divided into the first years of life for children of young age up to 5 years which need substantial 24 hour care and are growing up at home. Subsequent phases include schooling, working, jobless, and retired. A jobless agent can be unemployed or outside of the workforce and is not of retirement age.

The health status can be attributed to an agent as a characteristic, as either healthy or unhealthy. Under unhealthy a series of chronic conditions can be attributed which can lay a role for particular NBS related aspects, such as mobility restriction, respiratory conditions that can be alleviated by NBS, and other chronic conditions including respiratory, cardiovascular, neurological and mental conditions.

Finally, an agent is described from a socio-economic perspective by its income level, either in qualitative terms (low, medium, high) or in quantitative terms for which a quintile system is selected to group the agent into which of the fife relative income bracket it belongs. This approach is selected for a quantitative characterisation, since specific income values differ per country or region.

Activities, each agent can be simulated to carry out a set of activities around a 24-hour time clock in a simulation. Thereby location changes across the city are simulated due to travelling, as well as the occurrence of production, consumption, leisure or other aspects of daily life. The incorporation of activities also allows for simulating specific NBS related activities, so as to identify agent-environment interactions.

Activity behavioural routines, an agent can also be attributed with routine behaviours, which relate to the likelihood of an activity in how it is carried out. For example, for the travelling activity people form routines for mode selection based on distance, familiarity and the mobility related health status. Such routines are simulated based on selection algorithms that form behavioural routines that can determine activities.

Relationships, the agents in the simulation can be linked for purposes of knowledge sharing or creating a framework by which activity decisions are influenced due to group formation. In the ontology the links are divided between family (close or distant relative), households (parent, child, sibling, and partner), friendships (close and normal), and acquaintances (work colleagues and other acquaintances).

Mental perceptions, the decisions made by agents that trigger various behaviours can be defined based on their perspectives in various categories. Whether these are related to their behavioural attitudes and norms, as per the theory of planned behaviour (section 2.2.2), meanings as per social practice theory (section 2.2.3) or utility of goods or services (section 2.2.1). It can also include broader status perceptions about the agent itself, such as well-being, happiness or life satisfaction indicators or motivational factors. Thereby the mental perceptions define how the agent relates to the social context, the physical context, the local environment and other factors.

Abilities, the abilities of the agent are similar to the competences as defined in social practice theory (section 2.2.3), which constrain or enable the possible behavioural space of an agent. Abilities thereby are a set of states that defines the possibility to carry out particular behaviours. Abilities can cover any domain such as physical, financial or knowledge related abilities. In a model they can be implemented in a binary manner as on/off factors (ruling out or enabling particular decisions to be made that result in behaviours as a switch) or in a gradual manner based on likelihoods associated with the occurrence of a decision.

Table 5. Citizens and agent behaviour ontology

Citizen	Visitor
Characteristics	
• Physical characteristics • Age • 0-5 years • 6-18 years • 19-55 years • 56-65 years • 66-75 years • 75+ years • Gender • Male • Female • Other	
• Chronic Health characteristics • Healthy • Unhealthy • Respiratory condition • Cardiovascular condition • Neurological condition • Mental disorder • Mobility restricted	
• Life phases • First years • Schooling • Working • Jobless • Retired	
• Household income level • Qualitative • Low income • Medium income • High income • Quantitative (country specific) • 1^{st},2^{nd},3^{rd},4^{th}, and 5^{th} income quintile	
Activities	
• Activity behaviour • Sleeping • Studying • Working • Travelling	• Activity behaviour • Sleeping (at hotel/b&b) • Travelling • Visiting family or friends home • At hotel/b&b leisure

• Indoor leisure • Outdoor leisure • Sports • Eating • Drinking • House-care • Cleaning • Cooking	• Outdoor leisure • Site visit • Eating • Drinking
• NBS Activity behaviours • Park reading • Nature walking • Travelling • Dog walking • Children playing • Outdoor eating (picnic/lunch/bbq) • Outdoor drinking • Outdoor swimming • Outdoor sitting/resting • Outdoor sports • Other outdoor recreation	
Activity behavioural routines	
• Travelling routines • Leisure routines • Eating and drinking routines	
Relationships	
• Agent Relationships • Family • Close relative • Distant relative • Household • Parent • Child • Partner • Sibling • Friendships • Close friendships • Friendships • Acquaintances • Colleagues • Other	
Mental Perceptions	
• Attitudes • Norms	

• Motivations • Meanings • Wellbeing • Happiness • Life Satisfaction
Abilities
• Physical ability • Financial ability • Knowledge ability

5 Agent NBS Interaction Concepts

Questions that policy makers, planners, developers of NBS projects and other involved parties are likely to have when it comes to NBS implementation, relate to a significant degree to what broader benefits NBS can have for citizens, to personal acceptance of NBS changes, and to how to accomplish behavioural change and participation to successfully develop and implementing NBS. Questions such as: What type of approaches are beneficial in motivating and encouraging people to participate in developing NBS? How can NBS be planned to so that socio-economic benefits are provided for all demographic groups in an area? In what ways and how will NBS project(s) improve the well-being of local citizens?

The development of agent based models that are relevant for NBS, so as to gain insights in questions like those posed above, was started in Task 3.2 by defining and iteratively developing a series of model scenario concepts. The aim was to build a body of scenario concepts, ten in total, that could be compared and contrasted, out of which three scenario concepts would be implemented in ABM simulations. By jointly with all technical partners developing a large number of concepts from various modelling, social and economic science expertise and backgrounds, the scope for using ABM to study various possible behaviours and their relationship with NBS is explored.

The defining and development process led to the following ten scenario concepts:

1. Simulation of activities in NBS spaces
2. Simulation of building utilisation with NBS
3. Simulation of demographic neighbourhood changes with NBS influence
4. Simulation of property value changes caused by NBS
5. Simulation of water runoff and catchment improvement by NBS promotion in private household gardens
6. Simulation of climate extreme events rescue improvement through NBS
7. Simulation of inclusive neighbourhood planning using NBS interventions
8. Simulation of socio-economic and commercial development resulting from NBS changes
9. Simulation of motorway transformation to underground transport and green park areas
10. Simulation of urban heat mortality impacts reduction through NBS

The ten developed scenarios are described in a standardised format in the sections 5.1 to 5.10 of this chapter. In the format three elements are described: the purpose of the scenario, its potential added value for the municipality/city in terms of studying population behaviour and NBS, as well as the agents and an initial listing of environmental and NBS interactions.

Out of the ten conceptual scenarios, three were selected (number 5, 8, and 10 above) to implement as ABM models under task 3.2, which are described in chapter 7. The selection of the 3 scenario concepts for which ABM's were built from the list of 10 concepts was carried out on the basis of their complementarity in modelling methodology and approaches, area of relevance, and linkages to NBS relevant indicators. The selection was done together with technical partners for the task. To ground the selection procedure a criteria matrix was developed as per Table 6 that highlighted the area of focus on each of the concepts, and how they link to NBS indicators developed under Task 2.1 of the Nature4Cities project.

Table 6. Overview of criteria for selection of 3 out of the 10 scenario concepts to implement as ABM models.

	#1 Simulation of activities in NBS spaces	#2 Simulation of Building Utilisation with NBS	#3 Simulation of demographic neighbourhood changes with NBS influence.	#4 Simulation of Property Value changes caused by NBS	#5 Simulation of water runoff and catchment improvement by NBS promotion in private household	#6 Simulation of Climate Extreme Events rescue improvement through NBS	#7 Simulation of inclusive neighbourhood planning using NBS interventions	#8 Simulation of socio-economic & commercial development resulting from NBS	#9 Simulation of motorway transformation to underground transport & green park areas	#10 Simulation of urban heat mortality impacts reduction through NBS
Focuses on Social Interactions	Y/N	N	N	N	Y/N	Y	Y	Y/N	Y/N	Y
Focuses on Market Interactions	N	N	N	Y	N	N	N	Y	N	N
Incorporates Climate Change Mitigation	N	N	N	N	Y	Y	N	N	N	Y
Includes variations due to Individual Behaviour differences per agent type	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Can be related to Social Acceptance Surveys	Y	N	N	Y	Y	N	Y	N	Y	Y
Includes a Spatial Element	Y	Y/N	Y	Y/N	Y/N	Y	Y	Y	Y	Y
Complexity to Model (S, M, H)	M	S	M	M	M	H	H	H	M	M
Behavioural Modelling approach as per section 2.3(Ceteris Paribus CP, Causal Chain Layering CSL, Multi-level reflexive change MLR)	CSL	CP	CSL	CP/CSL	CSL	MLR	CLR	CSL	CP	CP
NATURE4CITIES Indicator relations (referencing to indicators from T2.1):										
1.1 Climate Mitigation	1.1.1	-	-	-	1.1.2	-	-	-	1.1.1	-
1.2 Climate Adaptation	-	1.2.3 to 1.2.10			1.2.1	1.2.4 to 1.2.10			1.2.2	1.2.1 to 1.2.5

2.1 Urban Water management & Quality	-	-	-	-	2.1.1 to 2.1.3	-	-	-	-	-
2.2 Flood Management	-	-	-	-	-	2.2.1 to 2.2.5	-	-	-	-
3.1 Air quality at district/city scale	3.1.1 to 3.1.3	-	-	-	-	-	-	-	-	-
3.2 Air quality locally	3.2.1	-	-	-	-	-	-	-	3.1.1 to 3.1.3	-
4.1 Biodiversity	4.1.1 to 4.1.6	-	-	-	-	-	-	4.1.1, 4.1.6	4.1.1 to 4.1.6	-
4.2 Urban Space Development and regeneration	4.2.1 to 4.2.2	-	-	-	-	-	-	4.2.1 to 4.2.2	4.2.1 to 4.2.2	-
5.1 Soil management and quality	-	-	-	-	5.1.3	-	-	-	-	-
6.1 Food, Energy and Water	-	6.1.1, 6.12, 6.1.9, 6.1.10	-	-	6.1.11 - 6.1.14					6.1.9
6.2 Raw Material	-	-	-	-	-	-	-	-	-	-
6.3 Waste	-	-	-	-	-	-	-	-	-	-
6.4 Recycling	-	-	-	-	-	-	-	-	-	-
7.1 Acoustics	-	-	-	-	-	-	-	-	-	-
7.2 Quality of Life	7.2.1	7.2.1	7.2.1	7.2.1	-	-	7.2.1	7.2.1	7.2.1	7.2.1
7.3 Health	7.3.3 - 7.3.4	-	-	-	-	7.3.2	-	7.3.1	7.3.1, 7.3.3, 7.3.4	7.3.2
8.1 Environmental Justice	-	-	-	-	8.1.5	-	8.1.1.1	8.1.3.1	-	-
8.2 Social Cohesion	8.1.1.3, 8.2.1	-	8.1.1.3	8.1.1.3	-	8.2.1	8.1.1.3, 8.2.1	8.1.1.3	8.1.1.3	-
9.1 Urban planning and form	-	-	-	-	-	-	-	-	-	-
9.2 Governance in planning	-	-	-	-	-	-	-	-	-	-
10.1 Control of Crime	-	-	-	-	-	-	-	-	-	-
10.2 Control of extraordinary events	-	-	-	-	-	10.2.1 - 10.2.3	-	-	-	-
11.1 Circular Economy	-	-	-	-	-	-	-	-	-	-

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11.2 Bioeconomy activities	-	-	-	-	-	-	-	-	-	-
11.3 Direct economic value of NBS	11.3.3 , 11.3.4	-	11.3.3, 11.3.4	11.3.2	11.3.3 - 11.3.4		-	11.3.2 - 11.3.4	11.3.3, 11.3.4	11.3.2

5.1 Simulation of activities in NBS spaces

The simulation looks at variation in the use of green spaces in a neighbourhood by different groups of people. The main agent groups include local residents and daytime workers that do not live in the area, each with variations among them due to socio-economic characteristics (e.g. age, gender, income). The idea is to simulate for these groups activities that require or are enhanced by NBS, such as walking in parks, jogging and outdoor recreation (e.g. picnics, lunches, meetups).

The simulation would look at how people's activity patterns change due to the existence of NBS in their neighbourhood, including the influence of weather patterns. Social family and friendship form a key part of the simulation, in terms of how they shape communal activities and the use of NBS. Also work relationships can be analysed as a social network, to study the influence of collegiality on the use of NBS for parks. Agent activities can be linked to wellbeing indicators to understand how NBS improves well-being by facilitating activities in green spaces.

Two types of potential agents are envisaged. Neighbourhood resident agents who live in the simulated area of which a portion also work in the area (and the remainder work outside the simulated area). And daytime worker agents who only work in the simulated area and reside there only during work hours, as they live in other areas. Potential aspects that could be simulated for these agents are summarised in tables 7 and 8 below.

The added value of this simulation would be to create a 'test-bed' to analyse how NBS in a neighbourhood are utilised. As such several scenarios can be tested to simulate and adjust the creation of new NBS and their make-up in terms of services offered, so as to get a quantified estimate how they would affect both interactions (people's activities and social relationships) and people's wellbeing.

The NBS types that potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
  - Large urban public parks
  - Heritage Gardens
  - Botanical Gardens
  - Green Cemeteries
  - Public urban green spaces with specific uses
  - Woods
- Structures associated to urban networks
  - Green strips
  - Green water front city
  - Planted car parks
- Structures characterized by food and resource production
  - Urban orchards
  - Urban vineyards
  - Meadow
  - Urban farms

- Urban forests

Table 7. Neighbourhood Resident Agent Description

Name	Neighbourhood Resident
Description	The agent lives in the simulated area/neighbourhood and a set % also works in the area (whereas the other set % works in other areas in the city).
Characteristics	Age, Gender, Health characteristics, Life phases, Income Level
Activities	Sleeping, Studying, Working, Travelling, Indoor leisure, Outdoor leisure, Sports, Eating, Drinking, House-care, Cleaning, Cooking
NBS Activities	Park reading, Nature walking, Travelling, Dog walking, Children Playing, Outdoor eating, Outdoor drinking, Outdoor sitting/resting, Outdoor sports
Behavioural Routines	Travelling routines, Leisure routines, Eating and Drinking Routines
Relationships	Parents-Children, Friendships, Work Colleagues
Mental Perceptions	Attitudes, Norms, Motivations, Meanings, Wellbeing, Happiness
Abilities	Physical abilities, Financial abilities
Probabilities	Probability of Activities, Probability of gaining/losing friendships, Probability of leaving/moving into neighbourhood
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs
NBS Effects	Change in agent activities, Change in Mental Perceptions, Change in friendship encounters.

Table 8. Daytime Worker Agent Description

Name	Daytime worker
Description	The agent works in the simulated area/neighbourhood and commutes to and from it and does not reside there.
Characteristics	Age, Gender, Health characteristics, Life phases, Income Level
Activities	Working, Travelling, Eating, Drinking
NBS Activities	Nature walking, Travelling, Outdoor eating, Outdoor drinking, Outdoor sitting/resting
Behavioural Routines	Travelling routines, Eating and Drinking Routines
Relationships	Work Colleagues
Mental Perceptions	Attitudes, Norms, Motivations, Meanings, Wellbeing, Happiness
Abilities	Physical abilities
Probabilities	Probability of Activities, Probability of staying longer in neighbourhood after work
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs
NBS Effects	Change in agent activities, Change in Mental Perceptions

5.2 Simulation of building utilisation with NBS

The simulation looks at a multi-storey building and the space surrounding it. The idea is to simulate how different groups of people (building residents, daytime workers) carry out their activities in/around the building during work and weekend-days (indoor and roadside). The simulation would look at the impact of green roof and green facades and potentially in-door gardens on the agent's activities. It could simulate the effect on building satisfaction indicators, indoor air quality, building energy use and building water usage, or a subset of these, as well as the impact of these indicators on human health.

Two types of potential agents are envisaged. Building resident agents who live in the simulated building(s) of which only a small portion also work in the building with the majority working elsewhere. And building daytime workers who only work in the simulated building and reside there only during work hours, as they live elsewhere. Potential aspects that could be simulated for these agents are summarised in tables 9 and 10 below. A simulation could be built for one of these type of agents or both depending on the type of building.

The added value would be to evaluate whether the type of activities, inside and outside of the building (roadside), are substantially affected by green roofs, green facades and in-door gardens, and whether these NBS have an impact on people's health directly as well as due to changing activity patterns.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- On building structures
    - Green Roofs
    - Intensive Green Roofs
    - Semi-intensive green roofs
    - Extensive green roofs
    - Roof ponds
- Vertical structures
    - Climber green walls
    - Living wall systems
    - Building attached planter systems

Table 9. Building Resident Description

Name	**Building Resident**
Description	The agent lives in the building on weekdays typically within the hours 18:00 PM to 08:00 AM and in weekends on varied hours. Some of the agents work in the building as well during day-times.
Characteristics	Age, Gender, Health characteristics, Life phases
Activities	Sleeping, Studying, Working, Indoor leisure, Outdoor Leisure, Sports, Eating, Drinking, House-care, Cleaning, Cooking
NBS Activities	Nature walking, Outdoor sitting/resting
Behavioural Routines	Leisure routines, Eating and Drinking Routines
Relationships	Parents-Children, Friendships
Mental Perceptions	Attitudes, Norms, Motivations, Meanings, Wellbeing, Happiness
Abilities	Physical abilities
Probabilities	Probabilities of activity start and end time, Probability of change in activity routines due to building NBS features
NBS Changes	Creation of new building NBS features to run scenarios with varying building NBS designs
NBS Effects	Change in agent activities, Change in building use and building living mental perceptions

Table 10. Building daytime worker

Name	**Building Daytime Worker**
Description	The agent works in the building within daytime hours from 08:00 AM to 19:00 PM
Characteristics	Age, Gender, Health characteristics, Life phases
Activities	Working, Indoor leisure, Outdoor leisure, Eating, Drinking
NBS Activities	Nature walking, Outdoor sitting/resting
Behavioural Routines	Leisure routines, Eating and Drinking Routines
Relationships	Parents-Children, Friendships
Mental Perceptions	Attitudes, Norms, Motivations, Meanings, Wellbeing, Happiness
Abilities	Physical abilities
Probabilities	Probabilities of activity start and end time, Probability of change in activity routines due to building NBS features
NBS Changes	Creation of new building NBS features to run scenarios with varying building NBS designs
NBS Effects	Change in agent activities, Change in building use and building living mental perceptions

5.3 Simulation of demographic neighbourhood changes with NBS influence

The simulation looks at changes in the demographic make-up of neighbourhoods over time as a consequence of land use planning including various NBS. The idea is to evaluate different city planning scenarios and simulate how they could impact the relative popularity of city neighbourhoods, looking at the effects of demographics and agent characteristics in relation to NBS on location choice (age, household types, others).

The idea is to simulate location preferences of agents varying by agent characteristics given socio-demographic variation. The number of neighbourhood migrations within the city and from outside into the city and vice versa is set exogenously as a % defined by the user. The simulation thus focuses solely on the influence of NBS on location choice (not on why people move) over longer time periods. One type of archetype agent is envisaged, a neighbourhood resident agent (see Table 11). The agent lives in the simulated area and a portion of agents also work in the area and go to school there, whereas the remainder travels to other non-simulated areas for work and schooling.

The added value would be to capture how NBS affect the popularity relative to different socio-demographic groupings, so as to assert which variants of NBS within neighbourhoods are needed to create better more attractive neighbourhoods for a wide variety of groups. As such planning can be better informed on which combinations of NBS work well to improve neighbourhood quality from a social and liveability perspective.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
    - Large urban public parks
    - Heritage Gardens
    - Botanical Gardens
    - Pocket gardens
    - Green Cemeteries
    - Public urban green spaces (with/without specific uses)
    - Hedge & planted fences
    - Vegetated pergolas
    - Flower fields
    - Woods
    - Lawns
    - Single trees
- Structures associated to urban networks
    - Green strips
    - Green water front city
    - Planted car parks
- Structures characterized by food and resource production
    - Urban orchards
    - Urban vineyards

- Meadow
- Urban farms
- Urban forests
- Natural and semi-natural water bodies and hydrographic network
- Reopened streams
- Remeander rivers

- On building structures
    - Green Roofs
    - Intensive Green Roofs
    - Semi-intensive green roofs
    - Extensive green roofs
    - Roof ponds
- Vertical structures
    - Climber green walls
    - Living wall systems
    - Building attached planter systems

Table 11. Neighbourhood Resident Agent Description

Name	**Neighbourhood Resident**
Description	The agent lives in the neighbourhood and a set % also works in the area (whereas the other set % works in other areas in the city).
Characteristics	Age, Gender, Health characteristics, Life phases, Income Level
Activities	Not applicable (activities not simulated)
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Locational choice routine when finding a new home
Relationships	Parents-Children, Friendships, Work Colleagues
Mental Perceptions	Attitudes towards locations to life in a neighbourhood including importance of activities, friendships, NBS availability
Abilities	Financial abilities, Knowledge abilities
Probabilities	Probability of Activities, Probability of gaining/losing friendships, Probability of locational choice when moving into/within neighbourhood
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs to assert differences in location choice due to NBS availability
NBS Effects	Change in agent activities, Change in Mental Perceptions about location choice.

5.4 Simulation of property value changes caused by NBS

The simulation services to evaluate the monetary value of individual properties (buildings and flats therein) and the influence of NBS, based on a market simulation between sellers and buyers. The premise is that NBS increases property monetary values for a multitude of reasons: ability to carry out NBS activities (walking, jogging, leisure), aesthetics (view from the window), air quality improvements.

The idea is to simulate a property market of buyers (potential residents) and sellers (property developers and owners) based on bidding mechanisms for seller bids and buyer bids with bid matching. Settling can be determined in various algorithms including highest price bid is awarded, time constrained number of bids, random elements. Buyer bid value is influenced by characteristics of the agents (income levels, NBS preferences, demographics), seller bid value is influenced by cost of property construction and estimated surplus value of property (rent seeking). The ability of rent seeking can be set by altering the relative degree of buyers and properties for sale/sellers by the user (to reflect a buyers' market or a seller's market).

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
    - Large urban public parks
    - Heritage Gardens
    - Botanical Gardens
    - Green Cemeteries
    - Public urban green spaces with specific uses
    - Woods
- Structures associated to urban networks
    - Green strips
    - Green water front city

The added value would be to qualify the mechanisms in which NBS influences the monetary value of individual properties and quantify the increase in monetary value for each mechanism and in aggregate. This can benefit the support case for NBS by providing a quantified value of the indirect economic benefit (capital value added) for planning purposes. Another factor that could be analysed is the impact of gentrification due to property increases which is relevant for local councils and citizens for holistic development of areas. It could be of direct use for large scale property developers, to considering the impact of inclusion of NBS in their design on the valuation and sales price of the property.

Table 12. Property buyer

Name	**Property buyer**
Description	The agent lives wants to settle in the neighbourhood and is looking for a property in the area
Characteristics	Age, Gender, Life phases, Income Level

Activities	Not applicable (activities not simulated)
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Selection choice routine when looking for purchasing a property
Relationships	Parents-Children
Mental Perceptions	Attitudes towards housing qualities
Abilities	Financial abilities, Knowledge abilities
Probabilities	Probability of Interest in a property for purchasing, Probability of placing a bid on a property to buy it.
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs to assert impact of buying due to NBS availability
NBS Effects	Change in Mental Perceptions about quality of houses available and likelihood of buying a property

Table 13. Property Owner

Name	**Property Owner**
Description	The agent lives in the neighbourhood or owns property there and has the possibility to sell the property.
Characteristics	Age, Gender, Life phases, Income Level
Activities	Not applicable (activities not simulated)
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Selling choice routine to determine when to sell a property
Relationships	Parents-Children
Mental Perceptions	Attitudes towards housing qualities,
Abilities	Financial abilities, Knowledge abilities
Probabilities	Probability of Interest in selling the owned property and putting it on the market, Probability of pricing of the property
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs to assert impact of selling due to NBS availability
NBS Effects	Change in likelihood of selling of the owned property or properties

5.5 Simulation of water runoff and catchment improvement by NBS promotion in private household gardens

The simulation evaluates the water flux and retention capacity of NBS in a block of buildings and surrounding streets. The Agent concept is to focus on the adoption of NBS on private property, such as raingardens, based on a mix of preferences, monetary incentives, and social interactions between agents (beliefs about the use and need of raingardens). The adoption or lack thereof of NBS like raingardens over time, based on different boundary conditions will be examined. These could include size of financial incentives, social cohesion in the neigbourhood, beliefs about future weather patterns and the need for rain retention to prevent local floods.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
  - Pocket gardens
  - Lawns
  - Vegetated pergolas
  - Private gardens
- Constructed wetlands and built structures for water management
- Rain/infiltration gardens
- De sealed areas (and associated systems such as permeable paving)

The added value would be to understand how “soft” (social / information about NBS) and “hard” (monetary) incentives can help to further the adoption of NBS on private property. Several scenarios and ideas on factors of influence can be tested to enable improved discussion on what approaches could be implemented, so as to improve boundary conditions for NBS adoption by households within the context of urban planning and property development.

Table 14. Private Garden Owner Agent Description

Name	**Private Garden Owner**
Description	The agent lives in the neighbourhood and owns a garden that is either tiled or green with a varying number of NBS
Characteristics	Age, Gender, Life phases, Income Level
Activities	Not applicable (activities not simulated)
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Choice routine when determining what type of garden to establish either when moving into a new property or when already living somewhere
Relationships	Parents-Children, Friendships
Mental Perceptions	Attitudes towards gardening and garden use
Abilities	Physical abilities associated with gardening, Financial abilities associated with investing in the garden, Knowledge abilities about gardening
Probabilities	Probability of choosing to change the garden into a different type of garden

NBS Changes	Creation of new private garden NBS spaces in scenarios to assert impact on rainwater management in the city
NBS Effects	Change in private garden type and associated NBS

5.6 Simulation of climate extreme events rescue improvement for through NBS

The simulation looks at the flood evacuation process by different groups of people (residents, elderly citizens, rescuers). The idea is to simulate evacuation routes and safe grounds for these groups that require or are enhanced by NBS. The simulation would look at how NBS improves the evacuation times of residents including elderly citizens and response times of rescuers (Bernardini et al., 2014).

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
  - Large urban public parks
  - Public urban green spaces with specific uses
- Structures associated to urban networks
  - Green strips
  - Green water front city

The added value would be to analyze how NBS can be used in support of flood management plan to optimize type and location of NBSs to improve response and evacuation times. Several scenarios can be tested for adjustment/creation of new NBSs and get a quantified estimate of how many people are rescued and how NBSs affect the rescuer response and evacuation times of residents and elderly citizens.

Table 15. Resident

Name	**Resident**
Description	The agent lives in the neighbourhood and can be of varying ages and socio-demographic groupings
Characteristics	Age, Gender, Life phases, Income Level
Activities	Seeking higher or dry ground, waiting for rescuers
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Walking routine to find places that are safer for rescuing purposes, helping routines to aid family and neighbours
Relationships	Parents-Children, Friendships
Mental Perceptions	Perceptions about the risk of not seeking higher ground/safe spaces, attitudes towards assisting others
Abilities	Physical abilities associated with walking and running
Probabilities	Probability of following an evacuation path, probability of helping others reach higher ground, probability of being rescued, Probability of emergency medical assistance needed.
NBS Changes	Creation of large NBS spaces in scenarios to assert impact of having safer grounds available for the change on rescue

NBS Effects	increased number of people rescued or medical help provided reduced time of response and evacuation

Table 16. Rescuer

Name	**Rescuer**
Description	The agent reaches the flood zone and rescues citizens or provides medical assistance
Characteristics	Age, Gender, Life phases, Income Level
Activities	Arriving at the flood zone, seeking people who need help, helping people to get to safe ground, providing medical help
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Walking routine to find places that are safer for rescuing purposes, helping routines to aid family and neighbours
Relationships	Parents-Children, Friendships
Mental Perceptions	Perceptions about the risk of not seeking higher ground/safe spaces, attitudes towards assisting others
Abilities	Physical abilities associated with walking and running
Probabilities	Probability of finding and reaching people who need help, probability of rescuing, probability of providing medical assistance
NBS Changes	Creation of large NBS spaces in scenarios to assert impact of having safer grounds available for the change on rescue
NBS Effects	Easier access to flood zone, Improved response and evacuation time

5.7 Simulation of inclusive neighbourhood planning using NBS interventions

Community gardens can be considered a measure for social transformation in introverted urban settlements where active use of public space is less than desired / a platform for social interaction is needed. The aim of the simulation would be to look at how NBS makes neighbourhoods more inclusive and participative based on community gardens. Elderly residents in a neighbourhood are often isolated in navigating public space and spend most of their time at home, resulting in a poor social quality of life. The aim is to investigate the extent to which NBS can assist, such as engaging elderly in public functions by offering the possibility to tend to community gardens.

A participative community gardening approach can lead to contentment, increased mobility, increased dialogue, and an increased sense of belonging and purpose. For the community, this leads to increased intergenerational dialogue, familiarity with neighbours, capacity for participation and community decision making, mobilizing multiple segments of the neighbourhood social profile together, traditional learning (through observation and dialogue based on experience) for the youth, and a sense of place and community.

The simulation would consist of two main types of agents, local community residents and single elderly residents. Social networks would be simulated between these groups to understand the extent and conditions under which community gardens could provide for an inclusive and communal activities that provide the benefits as listed as above.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Structures characterized by food and resource production
    - Vegetable gardens
    - Urban orchards
    - Urban vineyards
    - Urban farms
    - Urban forests

Table 17. Neighbourhood Resident Agent Description

Name	**Neighbourhood Resident**
Description	The agent lives in the neighbourhood and a set % also works in the area (whereas the other set % works in other areas in the city).A special subset are single elderly residents.
Characteristics	Age, Gender, Life phases, Income Level
Activities	Sleeping, Studying, Working, Indoor leisure, Outdoor Leisure, Sports, Eating, Drinking, House-care, Cleaning, Cooking
NBS Activities	Gardening, Outdoor sitting/resting, Park reading, Nature Walking
Behavioural Routines	Walking routine to go outside for day-to-day activities with the possibility to learn about community gardening.

Relationships	Parents-Children, Friendships
Mental Perceptions	Perceptions about the ability to carry out community gardening activities, Attitude perceptions about community gardening
Abilities	Physical abilities associated with gardening and other NBS activities
Probabilities	Probability of joining a community garden, Probability of making new friendships in the community garden, Probability of making friendships and hearing about community gardening
NBS Changes	Creation of vegetable gardens and urban gardens that can form a community space, to find out how the design of such spaces can assist with creating an inclusive community with elderly participation
NBS Effects	increased number of elderly people participating in the community on an inclusive basis.

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

5.8 Simulation of socio-economic and commercial development resulting from NBS changes

The simulation aim is to assess the increase of commercial activities and/or change of their characteristics based on a market and demographic flow simulation. This concept is based on the notion that an NBS (or collection of NBSs) like an urban park has the ability to attract people in areas previously not frequented by outsiders. The increase (and the possible diversification) of day-time and sometimes night-time demographics should favour the growth of pre-existent commercial activities and the flourishing of new ones.

To cite an example of this dynamic, the installation of the faculty of Architecture in a depressed area of the historic city-centre of Genoa, has triggered a requalification of the neighbourhood and a great increase in commercial activities for the needs of a large number of students that needed to eat, buy supplies, print works or just hang out. While it is not an NBS example it's still relevant to explain the dynamic.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
    - Large urban public parks
    - Heritage Gardens
    - Botanical Gardens
    - Green Cemeteries
    - Public urban green spaces with specific uses
    - Woods
- Structures associated to urban networks
    - Green strips
    - Green water front city
    - Planted car parks

The indirect economic benefit of NBS on a neighbourhood's economic structure is a key reason to support the development of large scale NBS in an area. The added value would be to quantify this benefit in terms of commercial revenues that spring from NBS, and to better understand the mechanisms by which NBS influence economic retail and hospitality development.

Table 18. Neighbourhood Resident

Name	**Neighbourhood Resident**
Description	The agent lives in the neighbourhood and either works in the area or goes to school there
Characteristics	Age, Gender, Life phases, Income Level

Activities	Sleeping, Studying, Working, Travelling, Indoor leisure, Outdoor leisure, Sports, Eating, Drinking, House-care, Cleaning, Cooking
NBS Activities	Park reading, Nature walking, Travelling, Dog walking, Children Playing, Outdoor eating, Outdoor drinking, Outdoor sitting/resting, Outdoor sports
Behavioural Routines	Walking routine as part of leisure time to spend time in the NBS space, Purchasing routing associated with buying a drink or food item from a retail places
Relationships	Parents-Children, Friendships
Mental Perceptions	Attitudes towards spending time in an NBS space as a daily or weekly activity
Abilities	Physical abilities associated with going to NBS spaces
Probabilities	Probability of walking in NBS space, probability of purchasing a food or drink item
NBS Changes	Creation of new large NBS spaces in scenarios to assert impact on viability of retail places associated with these spaces
NBS Effects	Change in layout of retail spaces in the neighbourhood in and around the NBS space

Table 21. Shop Owner

Name	**Shop owner**
Description	The agent owns a retail place in the neighbourhood or is planning to establish a retail place
Characteristics	Not applicable
Activities	Not applicable (activities not simulated
NBS Activities	Not applicable (activities not simulated)
Behavioural Routines	Locational choice routines to select where to establish a new retail shop
Relationships	Not applicable
Mental Perceptions	Perceptions about the best locations to establish a new retail shop that will provide for optimal revenue
Abilities	Financial abilities

Probabilities	Probability of choosing a location for retail shop establishment, probability of closing the retail shop if significant losses are made
NBS Changes	Creation of new large NBS spaces in scenarios to assert impact on viability of retail places associated with these spaces
NBS Effects	Change in layout of retail spaces in the neighbourhood in and around the NBS space

5.9 Simulation of motorway transformation to underground transport and green park areas

The simulation is based on a motorway transformation to an underground transport corridor, freeing up the surface for green NBS spaces. As an example, the Rio de Madrid Project in Madrid, Spain, looks at the use of the Manzanares River bank by various people/agents. Such a large-scale intervention will bring various benefits for a lot of people but may also bring (unintended) negative effects. By modelling the case we develop a scenario that allows to have a (future) idea of who will benefit from the newly created green space, and who has to carry the adverse effects (if any). The idea of the simulation is to look at the economic impact in terms of daily travelling needs, and environmental impact in terms of air pollution effects, and social impact in terms of expanding family activities.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- Parks and Gardens
  - Public urban green spaces with specific uses
- Structures associated to urban networks
  - Green strips

It is useful to run different scenarios to analyse the impact of an NBS intervention. When changing the parameters of the model and/or adding or omitting some elements the scenario will be even more beneficial (such as increasing or decreasing the percentages of certain agents, leaving out or adding policy related effects). By confronting the different scenarios with the intended vision from the simulated model outputs, we can see which scenario matches best and if the adopted strategy is suitable to meet the project's ambitions.

Table 22. Neighbourhood Resident

Name	**Neighbourhood Resident**
Description	The agent lives in the neighbourhood with 1 or more children
Characteristics	Age, Gender, Life phases, Income Level
Activities	Sleeping, Studying, Working, Travelling, Indoor leisure, Outdoor leisure, Sports, Eating, Drinking, House-care, Cleaning, Cooking
NBS Activities	Park reading, Nature walking, Travelling, Dog walking, Children Playing, Outdoor eating, Outdoor drinking, Outdoor sitting/resting, Outdoor sports
Behavioural Routines	Travelling routines, Leisure routines, Eating and Drinking Routines
Relationships	Parents-Children, Friendships, Work Colleagues

Mental Perceptions	Well-being indicators associated with possible activities, air quality, and travel time, Attitudes towards safety due to traffic changes
Abilities	Physical abilities, Financial abilities
Probabilities	Probability of Activities, Probability for travelling from/to the neighbourhood
NBS Changes	Creation of new NBS spaces to run scenarios with varying NBS designs
NBS Effects	Change in agent activities to make more possibilities for family activities, change in air pollution quality in the area, Change in travel time due to new transport corridor

5.10 Simulation of urban heat mortality impacts reduction through NBS

The simulation looks at the impact of temperature in the city on local mortality during heatwave episodes. It is anticipated that the frequency and duration of heatwaves will significantly increase across the 21st century due to climate change. Urban citizens are adversely affected due to the urban heat island effect, which causes locally higher temperatures to occur. Especially vulnerable are elderly people with limited mobility, who have limited means to seek cooling.

The simulation would investigate the impact of NBS building infrastructure on reducing mortality rates, by lowering indoor temperatures. Green roofs can have a temperature lowering effect that provide a co-benefit in addition to water retention, energy efficiency improvement, and aesthetic improvements of a building. The temperature lowering effect is simulated versus non-green roof situations to assess the difference in effect.

The NBS types that the simulation potentially can be applied to this simulation, drawing from the WP1.1 classification, include*:*

- On building structures
  - Green Roofs
  - Intensive Green Roofs
  - Semi-intensive green roofs
  - Extensive green roofs
  - Roof ponds

The added value would be to analyze how NBS can be used to mitigate future temperature increases in terms of heatwave impacts. It gives an indication of the extent to which green roofs are needed and can result in quantifying the health co benefits of green roofs. Results could be used to inform city planning on where green roofs can be most effectively placed for dealing with heatwave impacts, assuming that data on where elderly citizens live in the city is available.

Table 23. Elderly Resident

Name	**Neighbourhood Resident**
Description	The agent lives in the neighbourhood in a building and is of 65+ years of age
Characteristics	Age (65+ years), Gender, Health characteristics
Activities	Not applicable
NBS Activities	Not applicable
Behavioural Routines	Routines to cool down the body during heatwaves
Relationships	Parents-Children, Friendships

Mental Perceptions	Not applicable
Abilities	Physical abilities
Probabilities	Probability of Cooling Activities and behaviours
NBS Changes	Creation of new green roof NBS spaces to run scenarios with varying NBS designs to assert the mortality impact of green roofs
NBS Effects	Change in indoor air temperature and thereby mortality reducing impacts

6 Spatial and Population Data Needs

To implement the concept simulation scenarios, of which three were selected as described in the previous chapter, data is required for each of these. Generic data needs to be collected and processed as well, since for each simulation a description of the population agents is needed with as the minimum descriptors the number of people and age, as well as a minimum representation of the spatial landscape of the cities in terms of where households, work locations, green spaces, travel infrastructure, and so forth is located.

In addition to the above, ideally specific data would be available that defines the locations of NBS based on the developed typology of 74 NBS types under Nature4Cities work package 1.1, but as this is a novel typology developed in Nature4Cities such data is not yet available. Also ideally building level and use type data would be available to enable micro level simulations. For example, to simulate the initial number of retail shops, or to understand particular case studies. In the absence of this data it is more challenging to look at site specific case studies, and as such instead the simulations are focused more at looking at neighbourhood or municipality wide effects.

Instead of looking for bespoke datasets for each of the four cities in the Nature4CitiesProject, a decision was made to use a standardised and uniform dataset, so as to describe populations and the spatial environment. This has the advantage that the simulations are consistent across cities as they run with exactly the same input data that has been harmonized to a similar quality standard. To this end the Urban Atlas 2012 dataset was used from the EU Copernicus programme. The dataset provides 29 types of land use in Geographic Information System (GIS) datasets for 800 Functional Urban Areas (FUA) in the EEA39 countries, which includes the project cities/municipalities Szeged, Alcalá de Henares, Città Metropolitana di Milano, and Çankaya municipality.[61] Also population distributions for 2012 including age groupings are provided by the EU Copernicus programme which were linked to the spatial data. The population values were obtained by Copernicus developers through down-scaling census data from country and city censusses to polygons in the Copernicus FUA datasets.

To make the datasets usable for the simulation a number of post processing steps were carried out. First, from the obtained FUA a smaller urban area subset was selected based on the neighbourhood/city area of the case studies in the Nature4Cities programme. The selected areas relate to either covering the city centre or areas around the early preliminary selected case study cites as provided in WP4.1 (see for example for Szeged figure 4 below). Second a number of land use types were aggregated into eleven distinct land use types for simplification purposes, such that the following spatial distinctions remained:

- Continuous urban fabric (S.L. : > 80%)
- Discontinuous dense urban fabric (S.L. : 50% - 80%)
- Discontinuous medium density urban fabric (S.L. : 30% - 50%)
- Discontinuous low density urban fabric (S.L. : 10% - 30%)
- Discontinuous very low density urban fabric (S.L. : < 10%)
- Transport infrastructure (aggregates. fast transit roads and associated lands, other roads

and associated lands, and railways and associated lands)

- Work sites (aggregates airports, construction sites, isolated structures, mineral extraction and dump sites, industrial, commercial, public, military and private units, and sports and leisure facilities)
- Agricultural sites (aggregates arable land (annual crops), pastures, permanent crops (vineyards, fruit trees, olive groves)
- Green spaces (aggregates forests, green urban areas, herbaceous vegetation associations, open spaces with little or no vegetation (beaches, dunes, bare rock, glaciers) and wetlands)
- Water
- Land without current use

Figure 4. Example of boundary selection for a city/municipality from the full urban area in the Copernicus urban atlas 2012 dataset (left) into the selection for the main urban areas of Szeged (right).

7 Explored Agent Based Models

The chapter provides a description of the three implemented agent based models under Task 3.2 that were developed. The selection of these models was carried out from the ten conceptual models describes in Chapter 5 based on the criteria table 6 in that chapter, taking into account complementarity in modelling methodology and approaches, area of focus and relevance, and linkages to NBS relevant indicators.

In section 7.1 the ABM model for "*Water runoff and catchment improvement by NBS promotion in private gardens*" is described. Followed in section 7.2 by the ABM model for "*Urban heat mortality impact reduction through NBS".* And finally in section 7.3 the ABM model for "*Socio-economic and commercial development resulting from NBS changes".* Each model is first described based on a reworked concept summary which focuses the of the final built, which includes a selection of the model boundaries to make the modelling effort feasible within the scope and time available under Task 3.2. Subsequently, a literature study to ground the model dynamics that was carried out is summarised in the next section. Followed by one or several sections that technically describe the relationships built in the model including variables and parameters, and where applicable the parameter values that were introduced. Finally, each model section ends with a description on the limitations of the model and how the model results should be interpreted given these limitations, which also forms input in the discussion on conclusions and recommendations in Chapter 9.

7.1 Water runoff and catchment improvement by NBS promotion in private household gardens

7.1.1 Concept Summary

The simulation evaluates the water flux and retention capacity in private gardens and how NBS in private gardens can help to improve water management at the household level, so as to improve resilience for increasing rainfall, and to make more water available for urban farming purposes. NBS such as rainwater gardens, infiltration gardens and permeable paving are here seen as an intervention that transforms gardens covered with impermeable tiles, bricks or other paved infrastructure into those that can absorb and retain water that is put to use for plant growth. The scenario focus is on privately owned gardens by households. A water balance model is built to incorporate rainfall to soil dynamics in the model.

The agent concept is to focus on factors by which a transformation can take place to a larger share of NBS based gardens for water management on private property, utilising a causal chain layering modelling approach (section 2.3.2) and drawing from both social-psychological perspectives and and elements of social practice theory (section 2.2.2) The type of NBS is not specified but generalised into green gardens, partially green gardens, and paved gardens. The adoption or lack thereof of green gardens over time, based on different potential policy instruments by the municipality and other stakeholders is examined. Three instruments are assessed, a subsidy that affects financial incentives, the organisation of gardening workshops facilitated by the municipality, and the establishment of gardening networks including garden space provisioning, garden sharing and knowledge exchange (see Figure 5).

The added value at a municipal level is an improved understanding of the extent to which substantial rainfall in short periods of time can be mitigated by increasing the number of green private gardens in the city. Within this context the model allows to assess how “soft” (garden networks and gardening workshops) and “hard” (monetary) incentives can help to further the adoption of NBS on private property. Several scenarios can be tested to create a tool to further discussions on what approaches could be implemented and how, so as to improve the success for NBS adoption by households through facilitation at a municipal level.

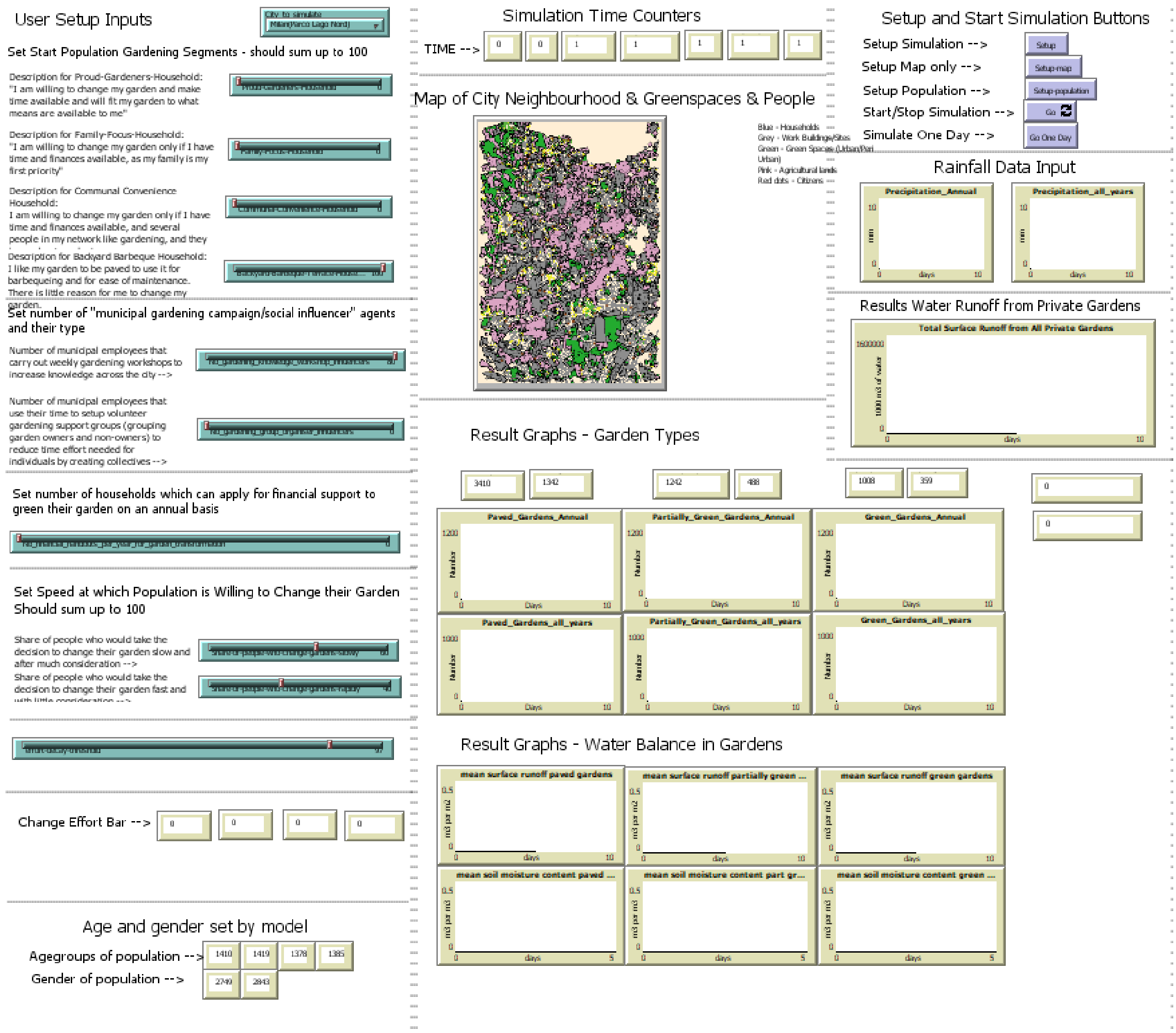

Figure 5. interface of Netlogo model for Water Runoff and Catchment improvement by NBS promotion in private household gardens.

7.1.2 Background: Water management and choice of private garden

Heavy rain showers cause serious water management problems in urban areas, when sewage systems overflow, streets are submerged, and lower-lying buildings and basements face the risk of nuisance or even damage resulting from flooding. An increase in soil sealing in urban areas has been acknowledged as an important factor in these urban water management problems. Increased soil sealing results from increasing land use due to population growth, urban sprawl but also from a trend to pave private gardens. Urban water management is not just a public issue, but increasingly one in which a diversity of private actors have a role as well. Due to the share of privately-owned land through homeownership, households can play an important role in preventing these water management problems. Homeowners could reduce soil sealing by changing their 'grey' paved garden into a permeable, green garden with plants and grass that allow for better absorption of rainwater. This raises the question as to how private households that have a yard in the back or in front of their homes, can be encouraged to green their paved garden.

Based on a broad scoping of the literature, the following important conditions, informed by social practice theory (section 2.2.3) have been identified to be of relevance to the practice of garden transformation[1]:

- **Willingness to change**: what makes it that people are willing to change and how is that affected by social, physical, institutional and economic conditions.
- **(Competences) Ability to change**: what do people need to be able to change in terms of knowledge -, relational- and financial resources, time, and physicality.
- **(Meaning) Motivation**: what motivates people to adopt this change, such as environmental values, financial values, comfort-related values, social or even religious values, social status.

Having identified these conditions, it should be noted that the dynamics of behavioural change are not straightforward. The value that a private garden represents varies substantially across people, and different types of behavioural change need different supportive measures to enhance the likelihood of successful and lasting transformation.

First of all, based very loosely on sociological understandings of behaviour as being influenced by socially shared meanings and practices, there is the need to consider the (symbolic) meanings, uses and values of the yard and the related practices to the householders. Next, the extent to which these meanings are maintained when (part of) the yard is greened, and perhaps complemented or replaced by new meanings over time, through supportive interventions. If people like gardening and they spend considerable time doing so, this is the best guarantee for a green garden (Kullberg, 2016). If the greened garden is not suitable or supportive of the previous practices,

[1] The approach reflects both the acknowledgement of structuredness that is characteristic of sociological approaches, while not discarding the notion of (individual) behavioural change altogether. Furthermore, it should be noted that this is a secondary analysis based on existing empirical materials rather than an empirical study structured and organised in line with e.g. social practice theory. For that, in-depth empirical fieldworks would have been necessary to assess the relevant material, competence- and meaning-related dimensions.

and values connected to these, then this is not likely to affect peoples' willingness to consider the change in a positive manner. If the values that the garden represents are no longer supported by the newly designed green garden, these values cannot be referred to as motivations to adopt the changes. Moreover, if the greened garden asks for new practices that need to be learned, then active support is needed to ensure that there is an ability to adopt the change.

Changing one's grey backyard into a (partially) green garden, involves both one-shot behaviours (the decision to take out tiles and plant vegetation) and routine behaviours (adopting new routines of watering and maintaining this vegetation; or even gardening practices). So-called one-shot behaviours are conscious decisions that often ask for an investment (money, effort, time), and credible information and some support (financial or otherwise) can help in this regard. As for adopting new routines, these new routines need to be supported by the social, institutional and physical environment. It then becomes important that peers also adopt these routines, that norms and rules do not work against these routines and that the physical environment also is not discouraging.

To better identify the behavioural aspects that can play a role a number of overarching questions were formulated for purposes of guiding the literature research. This resulted in the following set of questions:

- What sort of longer term trends are discernible that affect how people use their gardens?
    - How and to what extent do these provide starting points for interventions (if at all)?
- How do people use their gardens?
    - What are the current uses and practices around the garden?
    - What purpose, functions, values does the current garden support?
    - How and to what extent does this provide starting points for interventions (if at all)?
- What are the relevant characteristics of people?
    - What are characteristics of the people that already have green gardens?
    - What are characteristics of people that do not have green gardens?
    - What are other characteristics of people that influence gardening behavior?
- What conditions are likely to keep people from changing their grey into (partially) green gardens?
    - What are conditions that encourage keeping a tiled garden?
    - What are conditions that keep people who would like a green garden and currently have a tiled garden, from doing so?
- What conditions are likely to encourage people to change their tiled garden into (partially) green gardens?

In table 24 below a summary to potential insights in these questions above are provided based on a literature review. It is important to note that the literature on greening gardens is limited, there are however several doctoral theses from Dutch students due to collaborations between universities and organizations working in the field. Many of the statements in the table below are based on these studies that have deducted conclusions from inquiries into attitudes, willingness and stated behaviour, with little evidence from research into real life before and after behavioural changes. Similarly, the statements in table 24 below about the effectiveness of interventions is not based on an extensive in-depth evaluation of interventions but rather on secondary evidence. As such, the findings are a mix of conclusions that derive from theory, supported by empirical studies of how respondents state that they might change their behaviour, segmentation studies that distinguish between different types of grey and/or green garden users, and analyses of peoples' statements about what keeps them from changing to green gardens.

Table 24. Literature insights in aspects relevant to the question of household decisions on greening private gardens from tiled to green gardens

1a. What longer term trends are discernible on how people use their gardens?
- In the Netherlands, there is an increase towards soil sealing and fencing in private gardens (Linssen 2011; Linssen en Hamstra 2002; Linssen en Vermeire 2008). The trend towards more paving is also reflected in the sales figures of Dutch gardening stores (Kullberg, 2016) - Having a green garden is increasingly a phenomenon among older people (Kullberg 2016) - Gardening is increasingly regarded as an inconvenience or a 'duty' (Linssen 2011) - Enthusiasm for garden use remains, as a place for relaxation and rest" (Reijnders 2017) - Gardening behaviour is changing also through media influence and commercial interventions that hint towards a re-appreciation of the garden (Kullberg 2016) - People with full and active social lives feel there is no time for gardening (Rietkerk et al 2016) - Increasing numbers of women working affect time availability for gardening (Kullberg 2016) - Ageing: the populations in Europe are ageing - Digitalization: digitalization affects possibilities for information sharing and exchange, also about gardening; and it can facilitate online community initiatives - Knowledge: rising awareness about the importance of nature and green vegetation
1b How and to what extent do these provide starting points for interventions (if at all)?
Trends span longer periods of time, interfere with other trends and changes in circumstances and are difficult to influence because they involve a variety of different actors (e.g. government/public organisations, NGOs, DIY (gardening) stores, home-lifestyle tv and magazines). A number of interventions can be identified, the effect of these is however uncertain. - Efforts at knowledge exchange - ensuring that experiential and tacit knowledge, if not passed on via family, gets passed on via other existing or new social networks (social learning) - Maintaining attention to school gardens in cities (as a long-term investment) - Promoting a green garden as a place for relaxation - Promoting green gardening as a relaxing and healthy activity that decreases stress - Promote gardening as appealing to young people (e.g. engage through their kids)

- A public awareness campaign that builds on emerging trend towards more appreciation of green spaces in the city (e.g. compare with public flexitarian campaigns) - Attention to the trend of re-appreciation of vegetation, green space, coupled to actionable suggestions to green ones' own garden in garden stores' marketing, lifestyle magazines and home-related lifestyle TV shows - Continue and support collaborations between organisations that promote green gardens, local governments, semi-governmental organisations and gardening stores
2. How do people use their garden?

- Living: extension of the home (Rietkerk et al 2016) (e.g. more space and designing your garden (lifestyle-related; to attune the garden to the design of the house)
- Storing things: e.g. parking the car, bicycle, scooter (due to lack of space, safety considerations, ease)
- Playground for children
- Holding pets (e.g. birds, rabbits, fish(pond)
- Drying the laundry
- Eating: regular meals throughout the day, family gatherings and barbecuing
- Performing hobbies not related to gardening: e.g. craftswork, sports, DoItYourself (DIY) hobbies (e.g. using a shed where tools are stored and used)
- Gardening, this can take many forms and may include activities like:
    o Sowing seeds and growing plants and flowers (perennials and annual plants)
    o Having a garden in part of the back garden (with the rest paved with tiles or grass)
    o Maintaining a couple of larger shrubs or small trees with grass/garden/tiles
    o Having and maintaining a hedge
    o Having and maintaining small or large pots with plants, trees or vegetation
    o Growing food
    o Going to gardening stores at set times each year
    o Exchanging experiences, seeds, and plants with other gardeners
All these practices, are supported by lifestyle values, e.g. homeliness, comfort, safety, autonomy, creativity, freedom, relaxation, privacy, nature-related and environmental values, etc. Social norms and status around the garden as an extended home (type of furniture, BBQ, etc.) are likely to be different from the social norms related to maintaining a high-quality green garden.

3a What are characteristics of people that already have green gardens?
Based on (limited) evidence in the Netherlands (Correlations only): - Older people - Higher income - Religious people (gardening is highly appreciated within confessional social circles) (Rietkerk et al 2016) - People with a preference for nature more often have a green garden (Reijnders 217) - People who own more luxurious types of houses, like stand-alone houses and corner houses, more often a green front garden (Kullberg 2016) - People with green gardens increasingly get support from a gardening professional (e.g. older people, people with physical inabilities and people with higher incomes) (Kullberg 2016)

3b What are characteristics of people that do not have green gardens?
Based on (limited) evidence in the Netherlands and the USA (correlations only): - Young people - People who are very busy with work and social life
4a What conditions likely keep people from changing tiled into (partially) green gardens?
- Having a small garden - Household compositions: e.g. old age, or having children that use the garden as a play ground - The expectation to be moving to another home soon - The availability of alternatives that are easier to adopt, to maintain and/ or require lower investment (e.g. rain barrels) (Shin, McCann 2018) - The expectations that a soil sealed garden is easier to maintain compared to a green garden - Having a garden that is situated north (or a shaded garden) - Time availability: time spend on e.g. work, education, taking care of children, influences the amount of time available for gardening - Perception that green gardens demand greater time investments compared to grey yards (Rietkerk et al 2016) - The view of gardening as a non-relaxing activity (for people that regard the garden as place to relax) - Worries about what others incl. the neighbours might think (Sijsenaar 2016) - A lack of patience (which discourages people who want to see quick results) (Kullberg, 2016) - Perception that it is costly; that grey is less expensive than green elements (Rietkerk et al 2016) - Declining physical ability decreasing the ability to change gardens (Shin and McCan 2018) - Expectations of annoyances such as hay fever and insects (Rietkerk 2016) - A lack of knowledge on how to adopt green gardening (Rietkerk et al 2016) - The presence of many grey gardens (social norm: adapting to the garden style norm in the neighbourhood) (Rietkerk et al 2016) - General perception that the government is responsible for green/ environmental management (including water management) (Beumer 2015). - Lack of motivation and lack of sense of urgency - Housing corporations with responsibilities regarding greening gardens but no ambitions or plans to act (Sijsenaar 2016) - Municipalities lack resources and have limited influence on how privately-owned land is being used (Sijsenaar 2016) – lack of laws or regulations limit options for local government to intervene - A desire to maintain current use and function of the garden (a spot to be able to sit in the sun; tiles more suitable for the kids to play, sit outside with family and friends; using the garden as parking space for the bike or scooter (Reijnders 2017). - Not having the right knowledge and skills. Including fear that the plants won't survive because the garden is too shady; when earlier efforts to grow plants have failed; the

conviction that they do not have ‘green fingers’ (talent for gardening); no ideas about how to design their garden (Reijnders 2017). - Fear that animals will destroy the vegetation (sleeping on it, eating it, pulling it out); or fear of nuisance due to cat poo (Reijnders 2017). - Aesthetic reasons: some people find a green garden messy; sometimes a paved garden is referred to as being more fashionable (Reijnders 2017).
4b. What conditions are likely to encourage people to change their grey into (partially) green gardens?
- Practical experience contributes to people’s ability to adopt green gardening behaviour and could increase green garden adoption likelihood (Shin and McCan 2018) - People who express a willingness to adopt green gardening behavior often perceive less constraints, such as limitation by financial resources, complexity, socials norms and physical issues (Shin and McCan 2018) - Providing materials (e.g. plants) can help as part of a neighbourhood intervention to remove tiles (Kullberg 2016) For people willing to consider climate-friendly gardening, a targeted approach is helpful (e.g. when gardening stores offer bespoke solutions that can easily be adopted (Kullberg 2016; Sijsenaar 2018) - Participation in neighbourhood activities is likely to contribute to higher willingness to become engaged in greening activities as well (Sijsenaar 2016) - Many people feel the need to be part of a community, look for shared commitment in formal and informal networks, social norms. The sense of community can be a strong motivator to take part in some sort of collective action (e.g. towards greening) (Sijsenaar 2016) - Taxation schemes that aim to prevent soil sealing could motivate people to adopt green gardens (Rietkerk 2016) - Interventions like e.g. NGOs that coach people to plant vegetation and teach them about natural gardening (e.g. IVN) - Provide gardening stores with the necessary information and (subsidized) solutions for people to green their gardens (Kullberg 2016) - Use of role models (as ambassadors) but also in translating green expert knowledge to a broad public e.g. via TV and lifestyle programmes (Kullberg 2016) - Municipalities informing and engaging residents through support and subsidies - Attempt to reach specific target groups by addressing them in their own language (Sijsenaar 2018) - An active neighbourhood network (addressing multiple issues and perhaps being supported by the municipality as well to some extent) that takes on greening activities. - Making use of peer-to peer approaches (ambassadors). (Sijsenaar 2018)

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7.1.3 Model Setup: Change in Garden Type

The framework as described in section 7.1.2 was adopted to simulate agent decisions to change their gardens based on the *motivation*, *ability to change*, and *willingness to change* concepts. These pillars are used to come to a probability by which change happens, which varies depending on segments of the population as defined by motivation and ability to change. The framework is summarised in this section and depicted in Figure 6 below.

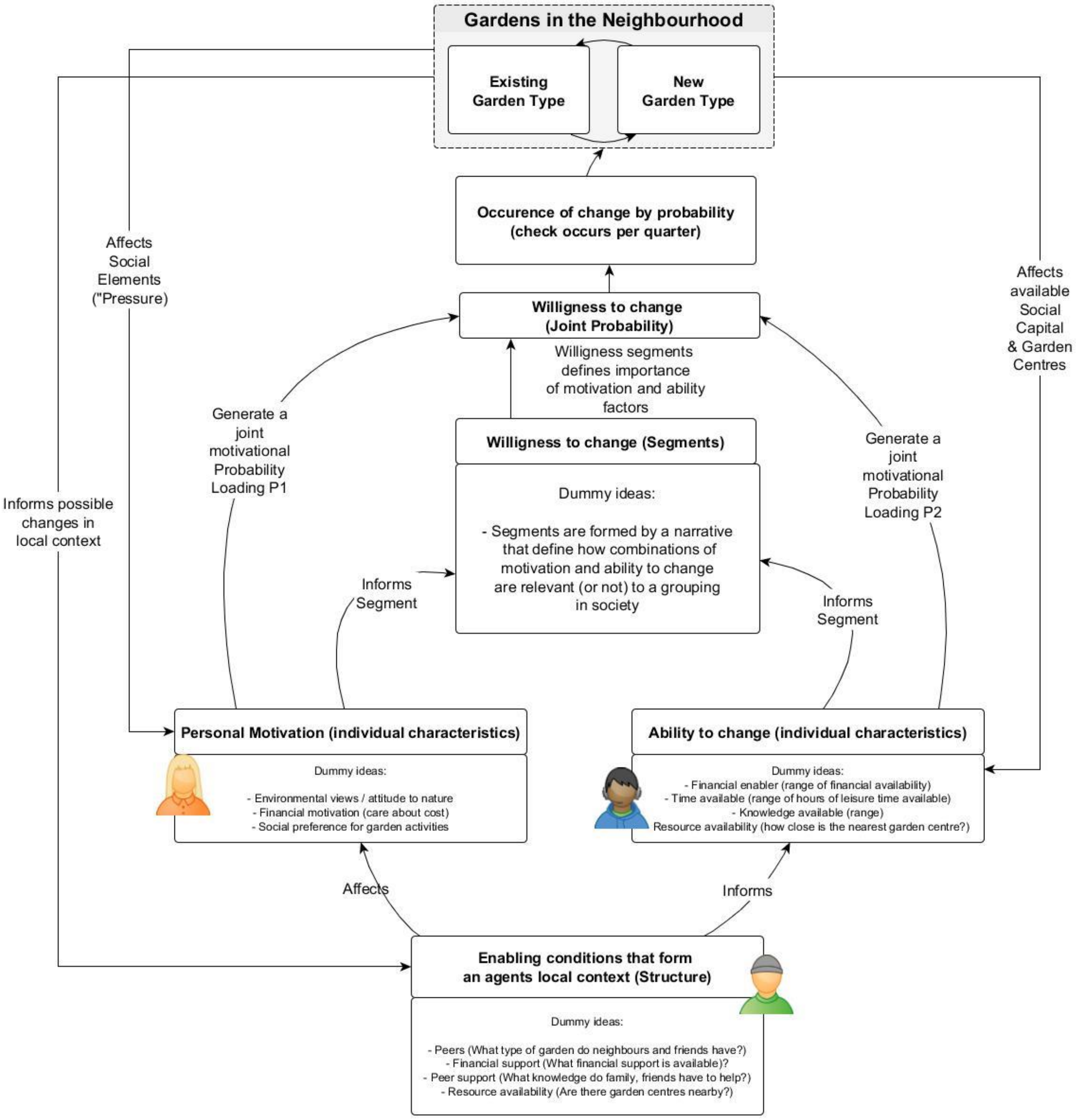

Figure 6. Relational model used to build the simulation.

7.1.3.1 Agents Selection: Resident Garden Owners

The simulation limits itself to agents that own gardens. The simulation will need to identify the baseline situation for private gardens based on their land use type at least three categories, whether they are a) fully paved, b) partially green gardens, or c) fully green gardens.

7.1.3.2 Simulation of Garden Change Behaviour

The change in a person's garden is not a trivial swift decision. As such it is not implemented in the simulation as a binary 0/1 switch. Instead each agent will have a "effort made to make a change bar" in the simulation from 0 to 100%, and only once 100% is reached a garden is transformed. A step towards the 100% is simulated depending on a successful probability exceedance roll that is carried out per time period, in the simulation set to a quarter (3 months). Such a roll compares the *probability of change* for an agent, say a probability of change of 1 to 10. If the draw is 0.8 (80%), no "change step" occurs, but if it is 0.9 or higher (90%) a "change step" occurs in the simulation, adding a set % to the change bar.

The *probability of change* is formed by the linkage between motivations, ability to change, and willingness to change segments, as described in the next sections below. All qualitative elements are thereby combined to represent a likelihood by which change will happen between 0 and 1. How this is done is described in sections 7.1.3.5 and 7.1.3.6.

To set heterogeneity in the simulation the increase in "effort to make a change bar" is further varied between two types of agents called "transformative decision" and "incremental decision" agents. An incremental decision agent needs four successful probability exceedance rolls (4 x 25%) to change their garden, whilst a transformative agent needs two successful probability rolls (2 x 25%) to change their garden. The rationale behind the transformative – incremental setting is that some people will make changes in their lives swiftly, and others gradually, with large variations between people on the pace of change.

Thereby, multiple steps are required before the 100% value is reached indicating successive efforts required before a garden change occurs. Also such efforts can "erode" in the simulation, representing the idea that plans for making change can be deprioritised or cancelled as other events happen in life. This "decay" or "erosion" is simulated with a decline in the "effort made to make a change bar" that can occur every quarter and can be varied.

The additional rationale for introducing the process of "decay" or "erosion" is also that if the simulation is run for a very long period of time, say 1000+ years, it will not lead to all gardens becoming green. This is because without such a "decay rate" all gardens will green given enough time at positive probabilities of change, even at very low levels, unless these probabilities are zero. This is deemed unrealistic, given that we assume there always is a probability of change, even though it may be very low under particular conditions.

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7.1.3.3 Motivational factors

Each agent is initialized with motivational characteristics, which define their motivation to create change. In the simulation these motivations are related to the following environmental, financial and social aspects:

- M1: Environmental values → What is my attitude to nature?
- M2: Financial values → I am/am not financially motivated when greening my garden
- M3: Social preference → Do you consider gardening a pleasure?
- M4: Social network → Are my friends interested in gardening?

The motivational characteristic influences the agent using a Likert scale from 1 to 5 (indicating very low to very high motivation) (see Table 25). For example, for the question "what is my attitude to nature?", a value of 1 means that the agent gives a very low importance to the natural environment, and vice versa for a ranking of 5.

To simplify the simulation, it is assumed that motivations are fixed for simplification purposes except for the influence of the three municipality interventions that the user can set. A subsidy that affects financial incentives, the organisation of gardening workshops facilitated by the municipality, and the establishment of gardening networks including garden space provisioning, garden sharing and knowledge exchange. Each of these interventions form enabling conditions that either affect motivational factors or ability to change factors or both as follows:

- **Organisation of garden workshops**, when connected to a garden workshop influencer increases the Likert Scale ability A3 knowledge available by 2 up to a maximum of 5
- **Establishment of gardening networks**, when connected to a garden networking influencer increases the Likert scale for motivation M4 related to social network to 5.
- **Gardening subsidies**, improved the Likert scale rating for ability finances available to 5, and increases the Likert scale rating for motivation A1-finances-available by 1 to a maximum of 5.

The model could be extended to further address changes in motivation. For example, "are my friends interested in gardening?" will change depending on the friendships of the agent with other agents and the gardens that these agents possess, and this can affect the social network motivation of the agent. Such changes are informed by enabling conditions and barriers that form an agent's local context. In this case an enabling condition is the type of gardens that friends have, which informs whether friends are interested in gardening.

7.1.3.4 Ability to change factors

Each agent is also initialized with characteristics that sum up their ability to change, in terms of what physically, socially, economically, external to their mental perceptions, will help them in the process of change. In the simulation this relates to the following financial, timing, knowledge and resource abilities:

- A1: Do I have the finances available to change my garden?
- A2: Do I have the time available in my schedule to change my garden?
- A3: Do I have the knowledge or is there knowledge support in my network to change my garden?
- A4: Is there a garden center nearby where I can obtain the items needed for my garden's change?

Each agent always has a ranking for an ability to change on a Likert scale, similar to motivation, from 1 to 5 (indicating very low to very high ability) (see Table 25). In reality abilities to change are never fixed but always vary depending on the agent's circumstances as simulated (such as for time available), friends network with levels of gardening knowledge, and the existence of garden centres. To simplify this, however, aspects in the simulation will be fixed as otherwise each individual ability will need to be simulated (such as income level variation), and this is not the purpose of this simulation.

Table 25. Motivation and Ability Likert Scale Rating for Segments in the simulation

Segments	**Motivations**				**Abilities**			
	M1	M2	M3	M4	A1	A2	A3	A4
Proud Gardener	5	1	3	1	2	4	2	3
Family Focus	3	4	3	1	3	4	2	3
Communal Convenience	3	2	3	5	3	3	4	3
Backyard Barbeque	1	2	1	1	3	3	1	3

7.1.3.5 Willingness to change Segments

An agent is part of a population segment that defines their willingness of change that is expressed as a probability for purposes of the simulation. Before expressing this a qualitative description of the segment is made, as informed by the three aspects:

- People in a segment will either carry out change rapidly (called transformative),or carry the change out slowly (called incremental) as defined above.
- A segment is assumed homogenous in how important particular motivations are
- A segment is assumed homogenous in how they score on particular abilities to change

An example of a dummy segment is an "Incremental Pioneering Gardener", which is described as a person who "cares substantially about nature, is willing to take incremental steps to change my garden if I have time available and will fit my garden to what means are available to me, is thus not reliant on financial resources, considers gardening a pleasure, and the social influence of friends does not matter substantially."

In terms of motivation this imaginary segment (imaginary in that it is conceived here purely for testing the logic) ranks high (value 4) on attitude to nature, ranks very high on the absence of financial motivation when greening my garden (value 5), ranks high (value 4) on considering gardening a pleasure, and the interest of friends in gardening is not an important motivation (no ranking).

In terms of ability to change this segment is typically initialized based on a ranking of low (value 2) for financial resources available, a ranking of high (4) for time available, a ranking of 5 for knowledge available/support (very high), and a ranking of medium (3) for a garden centre nearby. The logical for such initializations relates to different segments. In the simulation this will be done by a normalised initial distribution of the preferences, with the mean being the typical ranking.

A dummy logic fitting the dummy example above, could be that pioneering gardeners are likely younger people that are environmentally conscious and as such live in areas where there are gardening resources available. The willingness to change of this person is thus defined by the combination of their motivational attitude to nature and pleasure in gardening, and their ability is usually underlined by seeking out conditions to have the ability to fulfil these motivations.

7.1.3.6 Transformation to probability of change per segment

A single probability of change value P^c is formulated for each segment. This is done on the basis of obtaining a separate probability for motivation P^M and one for ability P^a and multiplying these:

$$P^c = P^M \cdot P^a \qquad , \; 0 < P^c, P^M, P^a < 1 \tag{1}$$

The probability values are multiplied such that all probabilities fall between 0 and 1. The probabilities are set based on a Sigmoid function that relates to the Likert, L, ranking values from 0 to 1. A sigmoid function has an “S” shaped because its resulting dependent variable first accelerates from a low value until a mid-point after which the results decelerate up to a maximum. It is often used to represent a growth process. In this case it is chosen to represent low probabilities for low Likert ratings, and high probabilities for high Likert ratings, assuming that the resulting probabilities are – not – linear to the Likert rating. The standard logistics function as a version of the sigmoid function is chosen for its simplicity, ease of interpretation, and proven applicability for statistical analysis:

$$P = \frac{1}{1+\mathrm{e}^{-(\beta 0+\beta 1 L)}} \tag{2}$$

The selection of the parameters $\beta 0$ and $\beta 1$ define the result of the Likert ranking translation into a probability value.

In case of motivation the function of (2) is utilised as is. It is also assumed that motivation probabilities are multiplicative, such that if all motivations are high the probabilities are high, and if one motivation is very low the probability will drop significantly forming a constraint. In other words, different motivations influence each other and having just a single very high motivation is insufficient for change. If we choose $\beta 0 = -3$ and $\beta 1 = 1.3$ we obtain the probability curve for motivation as per figure 4 below.

The joint motivational probability for the "Incremental Pioneering Gardener" as per the description above using these parameters would be:

$P^M = 0.9 * 0.97 * 0.9$

$P^M = 0.787$

In case of ability to change an adjusted version of function (2) is taken based on the idea that abilities to change are not multiplicative but additive. One can score low on one ability to change but this does not affect other abilities to change. As such to make the total joint probability of the ability to change sum to one an adjustment factor is needed based on the number of ability factors, f that are summed. The adjusted function becomes:

$$P = \frac{1/f}{1+e^{-(\beta_0+\beta_1 L)}} \quad (3)$$

If we choose $\beta_0 = -7$ and $\beta_1 = 2.5$ we obtain the probability curve for motivation as per figure 7 below.

The joint motivational plus ability probability for the"Incremental Pioneering Gardener" as per the description above using these parameters would be:

$P^a = 0.03 + 0.238 + 0.03 + 0.03$

$P^a = 0.328$

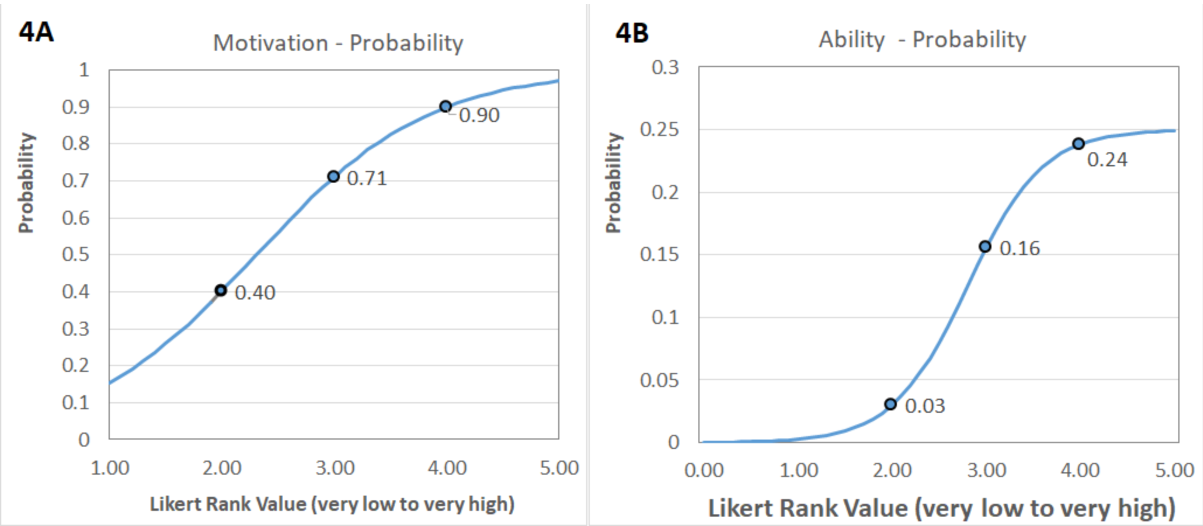

Figure 7. Left (4A) motivation probability curve example and right (4B) ability probability curve example.

The final joint probability for this example is formed by formula (1) the multiplication of the probability formed by the motivation and the probability by the ability to change. In our example this would be:

$P^c = 0.787 \cdot 0.328$

$P^c = 0.25$

There is thus for this segment based on the conditions as set in the example a 25% or 1 in 4 chance to make a step wise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (once per quarter), ignoring “effort decay” on average the “Incremental Pioneering Gardener” will change their garden within a 1 to 2 years time. Assuming a stable motivation and a stable ability to change.

The importance of motivation becomes clear if we adjust the values to show what how low motivations impact the outcomes. If the interest of friends in gardening was important and the scoring here was very low, the motivation probability outcome would translate to:

$P^M = 0.9 * 0.97 * 0.9 \ * 0.154$
$P^M = 0.122$
The joint probability would then change into:

$P^c = \ 0.122 \cdot \ 0.328$
$P^c = 0.040$

Now there is for this segment a 4% or 1 in 25 chance to make a step wise effort of change in the change bar. Given that four steps are required to reach 100% and a probability check is done four times per year (once per quarter), ignoring “effort decay” this implies that this agent segment will change their garden within 6-7 years. Unless a growing number of friends become interested in gardening and motivate the agent to change their garden, thereby improving the 0.154 motivational score for the “social network” motivational factor.

7.1.4 Model Setup: Water Balance Model

A key purpose for the simulation is to understand the impact that private gardens without and with Nature Based Solutions can have on water management across the city. To this end a water balance model was introduced in the simulation which assesses how different types of private gardens affect the soil water balance and water run-off following rainfall events, as an indicator for potential flooding.

The water balance simulation links with the change in garden type by taking into account the type of garden, including paved gardens, partially paved/green gardens and green gardens. For each of these garden types different parameter values are introduced due to which soil moisture content, and runoff varies. As such a picture for individual gardens and the entire city emerges over time as rainfall affects runoff and soil moisture over time, along with changes in garden types.

The soil water balance model takes into account four processes: rainfall, plant transpiration, soil evaporation, and net runoff. For simplification purposes water transfer processes between soil layers, including percolation and lateral water exchanges were not considered. The main water balance equation used was adopted from [62,63]:

$$\Delta s_t = \frac{P_t - R_t - E_t - T_t}{d * 1000} \tag{4}$$

Where Δs_t is the change in soil moisture, in m^3 per soil layer volume in m^3), d is the depth of the soil layer in meters, P_t is precipitation in mm, R_t is net runoff in mm, E_t is evaporation in mm, and T_t is transpiration in mm. The numerator divides values by 1000 to convert from one mm to one metre, so as to translate to a m^3 of water per m^2 of soil surface area.[2] Thereby the water content in the soil s_t changes in every period as:

$$s_{t+1} = s_t + \Delta s_t \tag{5}$$

Precipitation was incorporated as an exogenous variable using daily data for each city from 2007 to 2017 taken from the European Climate Assessment Dataset project.[3] Runoff was simulated based on the SCS Curve Number Procedure developed in the US documented in [64] which was also adopted by [62]. The value calculates the runoff in mm based on the amount that is “abstracted” before it reaches the soil (in plants, puddles) and the amount that is “retained” by the soil. The general equation is:

$$R_t = \frac{(P_t - I_t)^2}{(P_t - I_t + S_t)} \tag{6}$$

Where I_t is the abstraction of precipitation P_t before it reaches the soil as a combined variable for surface storage (puddles), interception by plants, and root infiltration, and S_t is the retention of precipitation water in the soil. Thereby both the higher the soil retention of precipitation and the higher the abstraction of precipitation, the lower runoff will be, inclusive of interaction between these elements. To simplify the equations the value of I_t is typically simplified to 0.2 times the soil retention, resulting in the following equation:

[2] One mm of rainfall is equivalent to one litre of water per m2

[3] https://www.ecad.eu/

$$R_t = \frac{(P_t - 0.2S_t)^2}{(P_t + 0.8S_t)} \quad (7)$$

The value of soil retention are calculated from so-called curve number (CN) values, which indicate the share of imperviousness of an area, based on a parameterized equation [62,63]:

$$S_t = 25.4\,(\frac{100}{CN} - 1) \quad (8)$$

The values for the CN number or share of imperviousness are described in [64] varying by hydrological soil group (A: sandy soils, B: loam soils, C: sandy clay loam soils, D: clay soils), and type of land use (agricultural lands and urban areas). In the simulation the values taken are 98 for paved gardens based on being nearly impervious, 75 for partially green gardens being somewhat permeable, and 50 for green gardens indicating a permeable soil. Soil evaporation is calculated based on the calibrated crop water balance model in [65] based on seven years of observation of evapotranspiration for several different soil covers. The empirical equation is based on first calculating the total potential evapotranspiration, and subsequently adjusting this with crop specific adjustments, and soil water content and capacity impacts. The equation was adopted as:

$$E_t = PET_t \cdot (1 - \frac{k}{k_{max}}) \cdot (\frac{S_t}{S_{max}} \cdot E_{min} + 1 - E_{min})^b \quad (9)$$

Where PET_t is the potential evapotranspiration (PET) of the soil layer which is first adjusted by the crop foliage. This is done based on k is a crop or foliage specific evaporation coefficient divided by k_{max}, a boundary parameter such that there is no evaporation if k equals k_{max}. Subsequently, potential evapotranspiration is adjusted by the soil water situation, where S_t is the soil moisture content, and the closer the soil moisture content is equal to the maximum soil moisture S_{max} the higher evaporation is.

Finally, an adjustment parameter E_{min} is introduced as a minimum evaporation rate that varies per soil type, regardless of soil moisture content. Finally, the soil water situation component is adjusted by a power factor parameter b which is empirically estimated, which was introduced to add a weighting on the soil moisture effect versus the crop effect in the equation.

Several calculations for PET are possible, of which the “Thorntwaite formula” approach was used because of its parsimoniousness [66] and validity in providing a reasonable approximation of PET [67] based solely on daily and monthly temperature values for a location. The formula is empirically established:

$$PET_t = 1.6 \cdot (\frac{10T_t}{I})^e \quad (10)$$

Where I is a heat index that captures the relative warmth for the location across the year, T_t is the daily temperature in degrees Celsius, and e is an empirically fitted parameter that adjusts the result based on the heat index. The heat index is calculated as:

$$I = \sum_{m=1}^{12} (\frac{T_m}{5})^{1.514} \quad (11)$$

 This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 730468

Subsequently, the value of parameter e can be calculated using the polynomial:

$$e = (6.75 * 10^{-7})I^3 - (7.71 * 10^{-5})I^2 + (1.792 * 10^{-2})I + 0.49239 \quad (12)$$

The calculation of transpiration, T_t, is based on the DREAM model (Distributed model for Runoff Evapotranspiration, and antecedent Soil Moisture Simulation) as described in [68]. The model utilises the potential evapotranspiration (PET) that is adjusted with soil moisture content and a canopy fraction specific parameter. The equation is formulated as:

$$T_t = m \cdot \min(1,1\frac{1}{3}\frac{S_t}{S_{max}}) \cdot PET_t \quad (13)$$

Where similar to equation (6) the potential evapotranspiration PET_t is adjusted by the soil water situation, where S_t is the soil moisture content, and the closer the soil moisture content is equal to the maximum soil moisture S_{max} the higher evaporation is. Subsequently, the resulting value is adjusted by a canopy specific parameter value m. The value has been evaluated as 0.35 for grass, 0.45 for crops, and 0.5 - 0.77 for trees. A value of 0 was chosen for paved gardens, a value of 0.25 for partially open gardens, and a value of 0.5 for open gardens, assuming an urban setting with limited coverage.

7.1.5 Model Results Interpretation

The simulation provides two key outputs. First, changes in the number of gardens based on paved, partially green, and green NBS based garden types. Second, the runoff across the city at a cumulative level based on local rainfall patterns and soil types associated with the garden types. Generic garden types are chosen to make the model parsimonious for showcase purposes, so as to establish a valid relationship between private garden transitions and city water management. NBS specific water management data would be required for a real-world usable model, ideally tailored to different soil types on which the NBS are placed within an urban context. Similarly, to assess the transition from one garden type to another the population is segmented with different loadings for motivation and abilities. In a real-world usable model these segments would need to be investigated based on localised statistical survey work. Inclusive of motivational and ability related questions from which different segments can be deduced, such as through Exploratory Data Analysis (EDA) or Cluster Analysis (CA). To ground the model historic patterns of garden change would need to be studied in more detail and the causes of change, so as to provide boundary conditions on how these changes occur that can be built in the model. For example, if these are event based such as when moving to a new house, or happening on an on-going basis, or both. At present the possibility of a garden type change occurring is set to be on an on-going basis, with decision moments happening on a weekly basis. Finally, another limitation is that the effect of the interventions has not been evaluated with real world data relative to no interventions. In the model three interventions are currently available as inputs, setting the number of subsidies, the number of influencer agents that organise local gardening workshops, and influencer agents that facilitate the setup of gardening networks.

Based on the assumption simplifications above the values cannot be interpreted on an absolute basis of the number of gardens transformed to green NBS based garden, or on the absolute size of run-off in cubic metres of water. In other words, the results cannot be taken as a direct transition pathway, where the interventions can be used to evaluate the impact a municipality has on the number of private gardens in the city. Instead the values should be interpreted on a comparative basis between model runs, whereas changes and the speed thereof can be analysed, within the context of demonstrating that these relationships can be made. The results inform to assess whether this type of modelling is useful from a planning perspective, especially in terms of providing insights in the ways in which municipal incentives could assist with the greening of private gardens for NBS promotion in relation to quantification of city water management.

7.2 Urban heat mortality impacts reduction through NBS

7.2.1 Concept Summary

The simulation looks at the impact of temperature in the city on local mortality during heatwave episodes. It is anticipated that the frequency and duration of heatwaves will significantly increase across the 21st century due to climate change. Urban citizens in densely built cities are adversely affected because of the to the urban heat island effect, which causes locally higher temperatures to occur. Especially vulnerable are elderly people with limited mobility, who have limited means to seek cooling.

The agent concept is to focus on a number of elderly citizens in a city area and how they are affected by heatwaves in terms of the likelihood of mortality. The simulation utilises a ceteris paribus modelling approach (section 2.3.1) and simplifies behaviour to identify vulnerabilities that increase or decrease the likelihood of heatwave mortality. The type of NBS is not specified but generalised into large green spaces. In future versions of the model this could be further subdivided into specific NBS such as large urban parks, heritage gardens, green cemeteries, woods, and so forth.

Temperature scenarios can be inserted in the simulation to analyse impacts of current and future climate (see Figure 8). To provide this capability temperature datasets for future years for 2030, 2050, 2070 and 2090 are provided for simulation purposes based on IPCC climate scenario projections. As such the resilience of the city for future temperatures can be assessed in terms of heatwave mortality, and the importance of NBS temperature reduction can be asserted.

The simulation would investigate the impact of NBS building infrastructure on reducing mortality rates, by lowering indoor temperatures. Green roofs can have a temperature lowering effect that provide a co-benefit in addition to water retention, energy efficiency improvement, and aesthetic improvements of a building. The temperature lowering effect is simulated versus non-green roof situations to assess the difference in effect. As such insights in the co-benefits of green roofs are provided in a quantified manner for current years and future years.

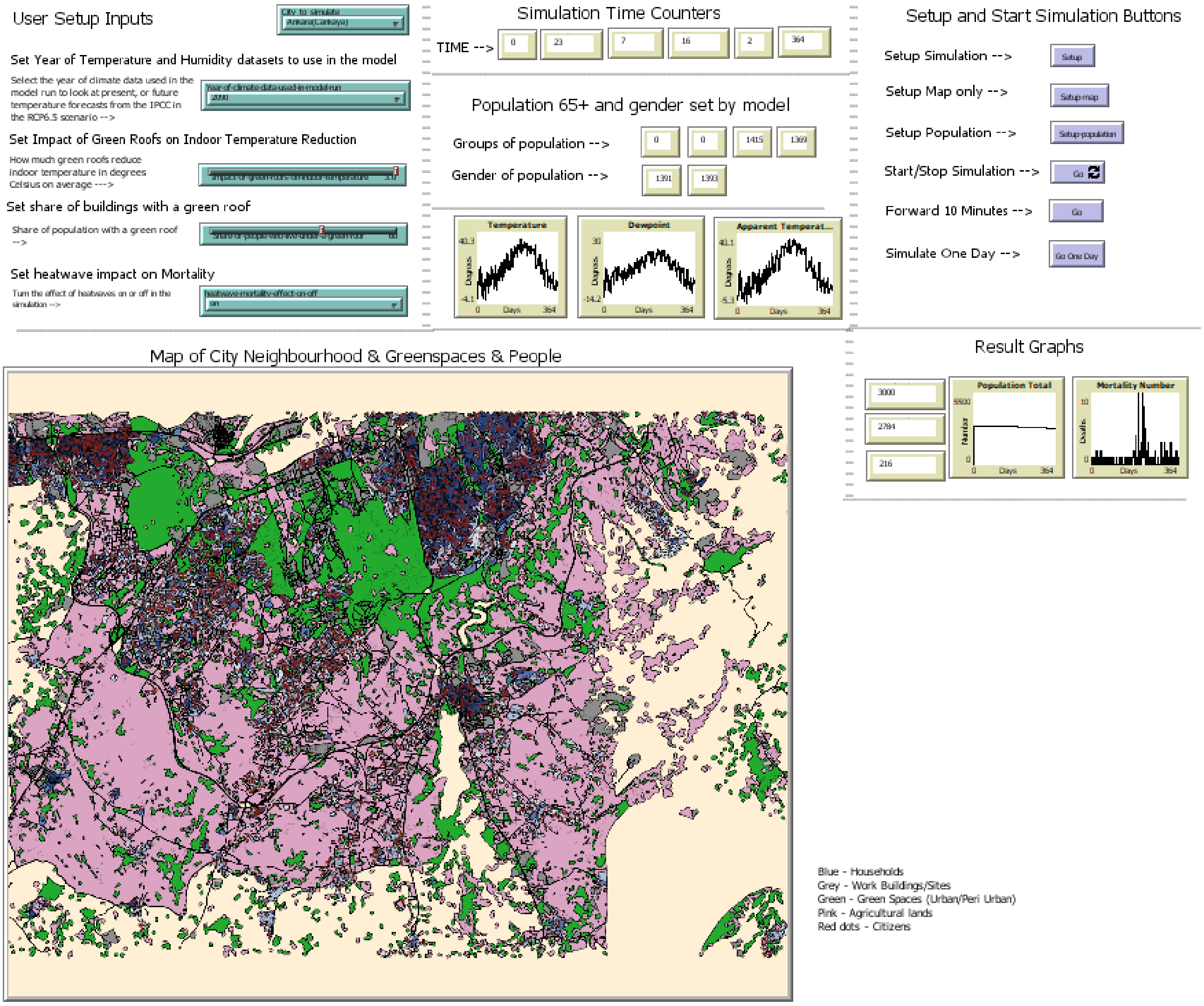

Figure 8. Interface of Netlogo model for urban heat mortality impacts reduction through NBS

7.2.2 Heat Wave Background

Heat risk occurs when the body cannot dissipate its excess heat into the environment, because temperatures are above the body temperature around 37°, resulting in body heat accumulation. If humans are in such an environment for too long their body heats up and hyperthermia can occur.

The concern over heat mortality risks has grown considerably in recent years because such events will become increasingly common due to climate change.[69] Currently about 30% of the world's population is affected by deadly heatwaves for at least 20 days a year, and this percentage is anticipated to increase to about 75% of the world's population under a growing emissions scenario.[70]

The mortality risk of heatwaves has been analysed at a macro-level by Mora et al. (2017).[70] Data from 911 heat-wave studies including 1949 case studies was analysed to understand conditions under which heatwaves result in excess mortality, above non-heatwave mortality levels. To do so an equal number of non-heatwave episodes that were considered non-lethal were introduced for the same cities as the meta-literature data. Out of 16 different variables analysed, the two conditions found most relevant were mean daily surface air temperature and relative humidity. Combined these two variables explained at 82% accuracy the occurrence between lethal and non-lethal heat episodes (See Figure 9)

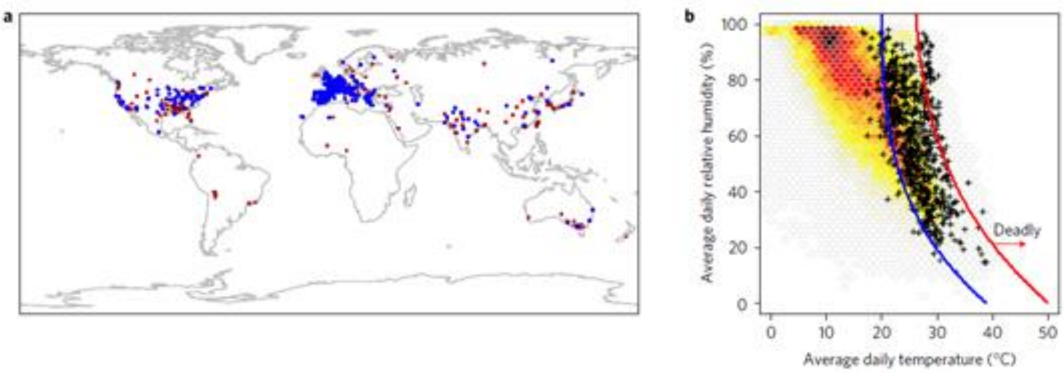

Figure 9. Global Heatwave Risk Plot based on data assessed from 911 heat-wave studies indicating relationship between heatwave mortality, temperature and humidity. Adopted from Mora et al. (2017).[70]

The effect of humidity is due to its impact on sweating. Sweating is a key process by which the body dissipates heat, which becomes less effective when the air is very humid. In case of high humidity heat accumulation can thus occur when the temperature is below 37°, as one of the most effective heat dissipation mechanisms is not functioning well. [70] Baccini et al. (2008) investigated the relationship between apparent temperature, a combined measure of temperature and dew point as a proxy for humidity, on heat mortality risk in 15 European cities. They found a 2% to 3% heat mortality increase associated with a 1 degree rise in apparent temperature.[71] Ho et al. (2017) looked at the humidex index, a measure of apparent temperature used in Canada, and its relationship to heat wave mortality from 1998 to 2014. They found that above a humidex cut-off point of 34.4°C there was a significant increase in heat mortality.

Studies have also shown that the duration of heat accumulation is of importance. An analysis of heatwaves for Australian cities by Xu and Tong (2017) found the highest mortality risk when extremely-hot days (the hottest days in a given month) were followed by extremely-hot nights. When extremely-hot days were followed by lower temperature nights (not-extremely-hot) mortality increases were lower. Similarly, when extremely-hot nights were followed by lower temperature (not-extremely-hot days) the effects were much lower.[72] The finding was corroborated by Murage et al. (2017) who studies heat mortality in London from 1993 to 2015. The authors found that hot days followed by hot nights have a higher mortality risk then hot days followed by cooler nights, with the highest risk caused by stroke and heart failure.[73]

7.2.2.1 Heat Wave Age risk groups

Baccini et al. (2017) established a greater mortality risk for 65-74 year age-groups, and even greater at 75+ versus 15-64 age groups, associated with a 1°C rise above the apparent temperature mortality thresholds. Specifically, the % change for populations in Mediterranean located cities was 0.92%, 2.13%, and 4.22% for 15-64, 65-74, and 75+ age groups, respectively. The variation for North-Continental cities was established at 1.31%, 1.65%, and 2.07% for the same age groups, with as main causes cardiovascular and respiratory mortality. Rey et al. (2007) analysed the impact of heat waves on all-cause mortality in France for six heatwaves from 1971-2003.[74] They investigated groupings from <35 years, 35-44 years, 45-54 years, and further 10 year groupings up to 95+. Mortality ratios were analysed based on observed mortality during heatwaves, divided by expected mortality based on average mortality per group in the three preceding years. In five out of six heatwaves the Mortality ratio's grow substantially from the age of 55 years and above. Especially populations of 75+ years had a 40%+ higher mortality rate then in the background non-heatwave data. In addition, for this group females had a 5%-28% higher mortality rate than men.[74]

7.2.2.2 The urban context in which mortality occurs

The specific conditions under which heat wave mortality among elderly occurs was studied for elderly people by Van der Torren et al. (2006) for the 2003 heatwave in France.[75] A total of 315 mortality cases and 282 control subjects were analysed who lived at home at least 24 hours before death or hospital admission were analysed across the city based on random selection. Living conditions were directly observed and information as obtained from interviews with friends, neighbours and next-of-kin either face to face or by phone. Specific heat conditions for the houses were obtained from satellite data using Landsat 5 profiles for thermal images and a vegetation index to calculate the surface temperature within a 200 meter around each home.

The average age of the mortality cases was 85.1 years, and that of the control group 82.1 years. Main causes of death for the 315 mortality cases were cited as a cardiovascular cause (37%) and heat (35%) with other causes including cancer (7.5%), respiratory diseases (6.3%) and neurological diseases (4.3%), with about 10% from other causes. The large majority of deaths occurred in the house, with 233 out of 253 cases hospitalised at home.

The results of the study were expressed as an odds ratio which can be interpreted as a risk multiplier versus if the condition did not exist, the higher the greater the risk. Key condition specific risk factors for a univariate analysis (only one condition is analysed), were found to be:

- Being **confined to a bed**, odds ratio of 7.52
- **Pre-existing medical conditions**, odds ratio ranging from 1.5 to 5.9 depending on the condition, especially neurological and mental disorders highly increased mortality risks (odds ratio 4.7 and 5.9)
- An **absence of social activities** whether religious, cultural or leisure, odds ratio of 6.0
- The **use of home attendants for cleaning or moving or meal delivery**, odds ratio of 3.84, plausibly spurious factor associated with lack of mobility or pre-existing medical conditions or both.
- Living in a house constructed before 1975, odds ratio of 1.83
- Living on the top floor of a building, odds ratio of 2.33
- Living **in a house with the bedroom** under the roof, odds ratio of 2.16
- The outdoor temperature index in (200 meter radius), odds ratio of 1.21
- Bath or shower frequency
    - More than one per day, odds ratio of 1
    - One per day, odds ratio of 3.14
    - One per 2 days, odds ratio of 12.09
    - One per week, odds ratio of 15.61
    - Never, odds ratio of 20.76
- Quantity of liquids drinking per day
    - One litre or more, odds ratio of 1
    - Between 0.5 and 1 litre, odds ratio of 2.64
    - Less than 0.5 litre, odds ratio of 16.8
- Opening of windows
    - At night, odds ratio of 1
    - Never opening the windows, odds ratio of 2.29
    - Only in the afternoon, odds ratio of 3.27
- **Good insulation lowered** the risk of mortality, at an odds ratio of 0.48, versus an odds ratio of 1.0 in houses with very bad insulation.

Key condition specific risk factors for the multivariate analysis (all significant conditions were considered in a combined correlation), were found to be:

- **Not leaving the home** during heat waves, odds ratio of 2.0, versus **visiting cooler places**, odds ratio of 0.46
- **Confined to bed**, odds ratio of 9.59
- Not confined to bed but unable to dress and to wash oneself, odds ratio of 4.03
- History of cardiovascular disease, odds ratio of 3.72
- Temperature index (200 m radius), odds ratio of 1.82

The analysis clearly shows that for older age groups, behaviours and conditions that aid in reducing body heat, including showering or bathing, opening windows, living in cooler and better insulated indoor spaces, and being mobile enough to seek cooler conditions, help significantly in reducing mortality.

7.2.2.3 Impacts of green infrastructure on building temperatures

Green roofs have a thermal effect on buildings because of several effects. Soil has a high capacity for thermal heat storage, lowering heat transmittance to a building. In case the green roof includes foliage it can also act as a shading device, by absorbing part of the thermal energy for photosynthesis, and lowering heat exchange under the foliage. Finally, soil and vegetation create cooling effects through evapotranspiration.[76] In quantitative terms green roofs reflect about 20%-30% of solar radiation, and absorb about 60% of heat in photosynthesis, with only 20% transmitted to the growing medium below. Thereby they reduce heat flow by 70%-90% in summer, and about 10%-30% in winter. [76]

Yeom and Roche (2016) compared the indoor temperature effects of a green roof without insulation (WOI), a green roof with 140 mm glass wool insulation (INS), a green roof with 140 mm glass wool insulation and a radiant cooling system (RAD), and a control with a regular insulated roof (CTRL). They also looked at the effect of night ventilation and window shading and used a little insulated test building made out of plywood situated in California, USA during summer. The indoor maximum temperature for WOI was a full 9˚C lower versus the control, and 1.5 ˚C to 3˚C when including window shading or night ventilation.[77]

Koura et al. (2017) investigated the difference in temperature profiles between gravel ballasted roofs and two green roofs in Lebanon, one with an 8 cm and another with a 16 cm growing medium/soil layer. Temperatures were measured on top of the roofs and within the roof substrate for the year 2016 on a minute to minute basis. Relative to the gravel ballast roof, the green roof at 8 cm depth had a 2˚C lower temperature difference between maximum and minimum daily temperature (temperature amplitude). Similarly, at a 16 cm depth a 3˚C lower temperature amplitude was established.[78]

Ran and Tang (2018) investigated the effects of a green roof on a warehouse building with a flat roof in Shanghai. The building's four rooms with a similar floor space were divided, with a green roof with an 8-centimetre substrate installed on top of one room, and a bare roof on the other rooms. The indoor temperature in the room with the green roofs was found to have limited temperature fluctuations, whilst during daytime the bare roof temperature grew by 4˚C. On average the green roof room indoor temperature was 2.3˚C lower when ventilation at night was also introduced.[79]

Jaffal et al. (2012) investigated a theoretical thermal model for a single-family house in La Rochelle France, Athens and Stockholm. The simulation found that mean indoor air temperatures on average would be reduced by 2.6˚C in Athens, 2.0˚C in La Rochelle, and 1.4˚C in Stockholm, indicating larger impacts for warmer climates. It also was found that green roofs significantly can reduce building cooling demand.[80] Bevilacqua et al. (2016) compared the effect of green roofs versus black bituminous flat roofs in summer and winter in Calabria, Italy. The average indoor temperature reduction during summer found for the green roof was 2.3˚C, whilst in the winter the temperature was maintained at several degrees higher levels.[81]

The studies summarised above show that green roofs can lower indoor air temperatures by 1.5 ˚C to 3˚C, relative to flat conventional roofs, and that this effect can be amplified when combined with ventilation measures during the night.

7.2.3 Model Setup

The relationships as established from the literature are translated into a set of model functions. First, the outdoor temperature datasets were established. Location specific datasets for ground station based air temperature and dew point evolution over time are loaded as inputs, with variations per hour (for temperature) and per month (for dew point).

Temperature are thereby incorporated "exogenously" or external to the model. Datasets that were used include a year of recent daily global surface temperature and Dew point to simulate the past (available up to 2018) were taken from local weather stations.[4] Also temperature for climate change projections up to 2100 for used based on an ensemble of climate models, for each of the four emission pathways scenarios globally agreed by climate modellers (RCP2.6, RCP4.5, RCP6 and RCP8.5). Such data is available per country per month for average temperature, maxima and minima, number of summer days (>25˚C), number of hot days (>35˚C), number of very hot days (>45 ˚C), and number of tropical nights (>20˚C).[5] The monthly average data was superimposed on the variability for the recent year so as to generate a dataset with daily variability, in the absence of future projections on a daily interval.

A simplifying assumption is made that the outdoor temperature for the data-series is similar across the city. Alternatively, in a future version of the model, urban heat island effects based on land use maps can be used to simulate temperature variation effects across the city.

The simulated temperature is subsequently translated into an indoor air temperature directly as a simplifying assumption. In case of green roofs, it is assumed based on the literature (section 7.2.2) that an indoor temperature reduction of between 1.5 ˚C and 3˚C is possible, versus not having a green roof. Given the uncertainty within this range, caused among others by the variation in green roof and climate conditions, the specific degree within this range of the effect can be set by the model user. Thereby the simulation allows for exploring the impact of very effective and less effective green roofs.

7.2.3.1 Agents Selection: Elderly Background Mortality

The population that is analysed in the simulation are elderly people at 65 years of age or higher as a single category. The reason for selecting this range is data availability, given that Urban Atlas data only specifies age groups from 0-14, 0 to 64 years, and 64+ years of age.

Background mortality rates are analysed for each city to understand the non-heatwave rate of deaths for 65 or older population members. Number of deaths per year, D^t, are divided by population numbers, P, to obtain number of deaths per 1000 people, and translated to a daily mortality rate, M^d, by division with the number of days in a year.

[4] https://catalog.data.gov/dataset/integrated-surface-global-hourly-data, https://www.ecad.eu//dailydata/predefinedseries.php

[5] http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=futureGCM

$$M^d = \frac{\frac{D^t}{P}}{1000 \cdot 365} \qquad (13)$$

To simulate the background mortality, in the simulation on each 24 hour period for each agent a probability roll is made between 0 and 1, and if the roll falls below the mortality rate per day, the agent will be removed from the simulation as if mortality has occurred.

7.2.3.2 Heatwave Mortality Impacts

The impact of heatwaves was based on the study of Baccini et al. (2008)[71] whom established a combined measure of temperature and dew point as a proxy for humidity, on heat mortality risk in 15 European cities. The study was selected because of three reasons:

- First, the widespread coverage across 15 cities in Europe including: Athens, Barcelona, Budapest, Dublin, Helsinki, Ljubljana, London, Milan, Paris, Prague, Rome, Stockholm, Turin, Valencia and Zurich. These cover three out of the four case study countries in the NATURE4CITIES project, and also values for North-continental and Mediterranean cities that can be used for the missing city.
- Second, the inclusion of temperature and humidity effects by a measure of apparent temperature.
- And third, the split of results into different age group types (15-64, 65-74, and 75+ years).

The formula utilised to calculate apparent temperature, AT, in degrees Celsius, was defined by Baccini et al. (2008) as:

$$AT = -2.653 + 0.994\,T + 0.0153\,W^2 \qquad (2)$$

With T as temperature in degrees Celsius, and W as dew point in degrees Celsius. The temperature and dew point data is fed into this equation to calculate the apparent temperature. Subsequently, this value is compared versus the threshold apparent temperatures in Baccini et al. (2008) above which increased mortality occurs, as summarised in Table 26 below.

Table 26. City specific estimates of Threshold above which Mortality increases occur, and percent change in mortality associated with a 1˚C increase in maximum apparent temperature above the threshold.

Region	**Threshold (˚C)** (95% CI)	**% Change - All** (95% CI)	**% Change 65-74 years** (95% CI)	**% Change 75+ years** (95% CI)
North-continental	23.3 (22.5 - 24.0)	1.84 (0.06 - 3.64)	1.65 (-0.51 - 3.87)	2.13 (-0.42 - 4.74)
Mediterranean	29.4 (25.7 - 32.4)	3.12 (0.60 - 5.72)	2.07 (0.24 – 3.89)	4.22 (1.33 – 7.20)
City				
Athens	32.7 (32.1 - 33.3)	5.54 (4.30 - 6.80)	Not available	Not available
Barcelona	22.4 (20.7 - 24.2)	1.56 (1.04 - 2.08)	Not available	Not available

Budapest	22.8 (21.9 - 23.7)	1.74 (1.47 - 2.02)	Not available	Not available
Dublin	23.9 (20.7 - 27.1)	-0.02 (-5.38 - 5.65)	Not available	Not available
Helsinki	23.6 (21.7 - 25.5)	3.72 (1.68 - 5.81)	Not available	Not available
Ljubljana	21.5 (15.0 - 28.0)	1.34 (0.32 - 2.37)	Not available	Not available
London	23.9 (22.6 - 25.1)	1.54 (1.01 - 2.08)	Not available	Not available
Milan	31.8 (30.8 - 32.8)	4.29 (3.35 - 5.24)	Not available	Not available
Paris	24.1 (23.4 - 24.8)	2.44 (2.08 - 2.80)	Not available	Not available
Praha	22.0 (20.4 - 23.6)	1.91 (1.39 - 2.44)	Not available	Not available
Rome	30.3 (29.8 - 30.8)	5.25 (4.57 - 5.93)	Not available	Not available
Stockholm	21.7 (18.2 - 25.3)	1.17 (0.41 - 1.94)	Not available	Not available
Turin	27.0 (25.2 - 28.9)	3.32 (2.53 - 4.13)	Not available	Not available
Valencia	28.2 (23.7 - 32.7)	0.56 (-0.35 - 1.47)	Not available	Not available
Zurich	21.8 (16.5 - 27.0)	1.37 (0.49 - 2.25)	Not available	Not available

In the simulation for each day at which the apparent temperature is above the threshold in the city, the mortality percent increase ratio is applied, as per Table 26. This simulates the compound effect of heat wave impacts on mortality including and excluding green roofs.

7.2.4 Model Results Interpretation

The model provides insights in the effect of heatwaves on mortality under current and future temperatures specified to per city effects. The model in its current form has several limitations. First, it uses outdoor temperature measurements based on a single weather station within the city, and extrapolates that across the entire simulated city area. As a consequence, the results are not representative of particular locations, and can only be interpreted at a macro-level of the area simulated in aggregate. City block or building specific models can be built but would require an understanding of how the make-up of a locality in terms of building types and built area influence localised temperatures, as well as data to enable an accurate up-to-date localised representation of said built area. It also would require a larger number of temperature point measurements across the area given potential gradients, especially if the area is several to tens of kilometres across.

Second, the future temperature scenarios are based on a monthly average increase or decrease estimate per month in a future year. The value has been superimposed on variability in the present because of which increasing or decreasing future variability is not accounted for. This superimposition approach was selected as currently climate change models cannot provide valid local future fluctuations in temperature, but only provide reasonable estimates for country level to regional long term trends. However, since mortality depends on reaching threshold temperatures the variability between days within a month can increase or decrease, which can dampen or aggravate the future impact, as there may be more or less extreme temperature variations within a single month. To incorporate variability climate change models would need to provide valid daily variations, which is currently not feasible. As such it is not a limitation that can be lifted in the foreseeable future for this type of model.

Third, the outdoor temperatures were assumed to be representative of indoor temperatures as a substantial simplification, as understand the impact of different building construction types on temperature gradients from outdoor to indoor was outside of the scope of the model study. For a realistic impact assessment such effects would need to be taken into account, as some buildings will worsen, and others will reduce the temperature effects across the day and night. This reinforces the earlier point that the results cannot be interpreted on a localised basis in the current state of the model but can be interpreted only based on a macro-effect.

Finally, the relationship between apparent temperature and mortality was taken as established from the literature by Baccini et al. 2008[71], which found substantial heterogeneity between cities in terms of at which temperatures mortality begins to occur, and also in the degree of the effect per degree of temperature above the threshold. The rationale for this heterogeneity is not known at any level of precision. Various reasons can cause this variation, including socio-demographic, health related due to pre-existing conditions, and the existing ability of buildings to provide cooler in-door spaces or to exacerbate higher temperatures from outdoor to indoor. Heat augmenting or reducing impacts would need to be studied relative to temperature variations as well as mortality on a longitudinal basis to better understand these impacts.

7.3 Socio-economic and commercial development resulting from NBS changes

7.3.1 Concept Summary

The simulation aim is to assess the change in commercial activities by small and midsize companies in retail due to the development of large NBS such as parks. This concept is based on the notion that an NBS (or collection of NBSs), like an urban park, has the ability to attract people in areas previously not frequented by outsiders. The increase (and the possible diversification) of day-time and sometimes night-time activities potentially favour the growth of pre-existent commercial activities and attract new hospitality and retail activities in an area.

The agent concept is to focus on the number of retail companies that can be sustained via NBS green spaces, and the revenues and profits provided by these spaces. The simulation utilises a causal chain layering modelling approach (section 2.3.2) and draws from neo-classical economics theory about profit maximization (section 2.2.1) The type of NBS is not specified but generalised into large green spaces. In future versions of the model this could be further subdivided into specific NBS such as large urban parks, heritage gardens, green cemeteries, woods, and so forth.

The simulation contains two agents, residents of whom some carry out activities in green spaces, and as such sometimes purchases drinks and food items, and shop owners who establish shops across the city. The simulation is initialised with a number of initial shops as set by the user, and new ones form whilst running the model (see Figure 10). Factors that attract new retail shops to settle in an area are simplified based on attractor points, which identify areas such as large green spaces within and around which shops can form.

The added value of the modelling effort is to analyse the indirect economic benefit of NBS on a neighbourhood's economic structure. In specific on the ability for large green spaces to provide revenue for their maintenance and upkeep, through café's within and around the NBS. This benefit in terms of commercial revenues that spring from NBS can be quantified, and so provide a basis for establishing NBS infrastructure on a more healthy financial basis.

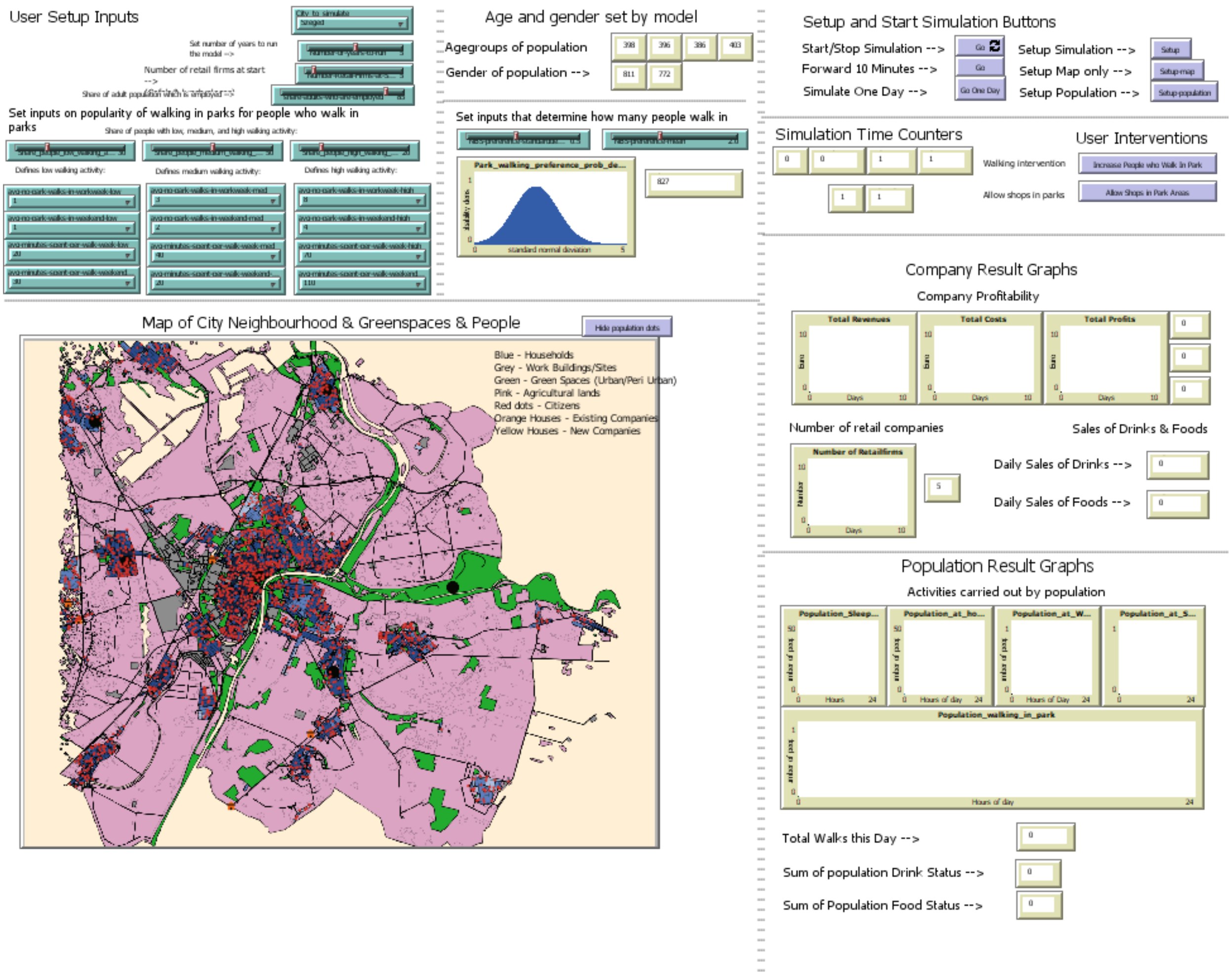

Figure 10. Interface of Netlogo model for Socio-economic and commercial development resulting from NBS changes

7.3.2 Firmographics Background

United Nations Department of Economic and Social Affairs states that currently 55% of the world's population lives in urban areas and this proportion is expected to increase to 68% by 2050. Together with the expected increase in world's population, the number of people living in urban areas will be considerably high. Particularly, 73% of Europe's population live in cities and this is projected to increase to over 80% by 2050. New techniques and approaches are required to design the sustainable cities of dense populations in narrower areas (Pataki et. al., 2011). Population growth has caused cities new revitalization schemes have been adopted, market dynamics have reshaped the retail scene, with retailers attempting to increase their adaptive capacity through innovative strategies (Ozuduru and Guldmann, 2013).

The concept of biophilia implies that humans hold a biological need for connection with nature on physical, mental, and social levels, and that this connection affects our personal well-being, productivity, and societal relationships. Studies show that our ability to directly access nature can alleviate feelings of stress (Grahn and Stigsdotter, 2010). Brengman et al. (2012) demonstrated that environments using natural stimuli also have a significant and positive effect on emotional responses in retail-store settings, another positive influence of natural environment can be seen on various psychological states. Urban green and blue spaces, such as urban parks, forests, gardens or green roofs and water courses, not only result in multiple co-benefits for health, the economy, society and the environment, but also provide habitats for a range of species (Niemela, 1999).

The benefits of biophilic design are listed as follows (www.oliverheath.com):

- **Office design**: productivity can be increased by 8%, rates of well-being up by 13%, increases creativity.
- **Hospitality design:** Guests willing to pay 23% more for rooms with views of nature.
- **Education spaces**: increased rates of learning 20-25%, improved test results, concentration levels and attendance.
- **Healthcare spaces**: post-operative recovery times decreased by 8.5%, reduced pain medication by 22%.
- **Retail**: the presence of vegetation & landscaping has been found to increase average rental rates on retail spaces with customers indicating they were willing to pay 8-12 % more for goods and services.
- **Homes**: can become more calming & restorative, with 7-8 % less crime attributed to areas with access to nature and can command an increase of 4-5% in property price.

To share the mentioned benefits of Nature Based Solutions (NBS), it is expected that new retail and hospitality companies/firms to settle in such areas. As stated in the first paragraph, with the foreseen increase in the number people in urban areas, one of the possible boundary conditions for the willingness of the companies to take place in these areas is change in popularity. Rates of vacant spaces (Waddell et al., 2003) and firm population can be considered other boundary conditions as well. There are several factors mentioned in literature. For instance, the settlement of companies can be done in different ways: new companies may enter the market, part of an existing chain may want to open a new facility or relocate. Studies show that old firms prefer to stay at their home-region or fixed locations (Brouwer, 2004). New entrepreneurs often take their hometown as a natural start-up location (van Dijk and Pellenbarg, 2017). van Dijk and Pellenbarg (2000) use data from the Netherlands and show that firm internal factors such as economic sector, firm size and previous migration behavior are good predictors to explain firm relocation. Similar results can be found in Brouwer et al. (2004) and de Bok and van Oort (2011). Considering the relations between a firm and other organizations in its environment is shown to significantly enhance the explanatory power of the models, and this effect varies according to the strength and geographical distance of their relationships (Knoben and Oerlemans, 2008). Bodenmann and Axhausen (2012) show that local taxes have a very positive effect on firm relocation; they find that distance is an important indicator and there exists significant differences with respect to sectors. The location selection models for firms in urban areas and the details of the simulations can be found in de Bok (2006) and Waddell et al. (2003).

The design of ecological spaces and environments has a potential effect on visiting and shopping intentions (Ortegón-Cortázar and Royo-Vela, 2017). This is somehow in line with the increase in the likelihood of making a retail drink or food purchase for a person whilst visiting/recreating in a large green space (either en-route in travel, or at the NBS site). The effects of ecological design of hotels on behavioural intentions and the resulting competitive advantage in terms of intention to revisit, willingness to pay more, etc. are discussed in Lee et al 2010. Servicing and commercial environments offering natural settings has been studied and analyzed in terms of comfort, customer behavior and psychological responses (Tiffet and Vilnai-Yavetz, 2017; Purani and Kumar, 2018). Some studies investigating nature based application as a variable of attraction (Ortegón-Cortázar and Royo-Vela, 2017), some studies suggest natural settings in retail areas support attention and brings cognitive benefits (Amerigo, Garcia and Sanches, 2013; Berman, Jones and Kaplan, 2018).

7.3.3 Model Setup

The simulation considers two main types of agents, population agents, and retail shop owning agents. Population agents are segmented further based on two characteristics, the proportion which walk in green spaces, and the purchasing behaviour to buy a drink and/or food item as described in section 7.3.3.2. The walking characteristics are determined by a probability setting as an initial input. A normal probability curve is used for this purpose where a user can set the mean and standard deviation to vary the population share that walks in the park.

Among those who walk in green spaces the user can further divide these into:

- The proportion that has low walking activity, with 1 walk during work-week of on average 20 minutes, and 1 during weekend of on average 30 minutes
- The proportion that has medium walking activity, with 3 walks during the work-week of on average 30 minutes, and 2 during the weekend of on average 60 minutes.
- The proportion that has high walking activity, with 8 walks during the work-week of on average 40 minutes, and 4 walks during the weekend of on average 80 minutes.

The user can also determine the share of the population that is employed, so as to influence the population that stays at home during the day and thereby has more propensity to walk in green spaces (if that agent does walk in green spaces as described above). Also the number of initial shops can be set by the user and the number of years the model should be run ranging from 1 to 10 years.

7.3.3.1 Agent activities

Population agents in the simulation carry out three main categories of activities:

1. Daily routine activities (sleep, school or work or stay at home, leisure)
2. Walking in greenspace activity
3. Purchase of drink or food

The population is initialised with a set of activities, such that not all agents will have the same activity "set". The switch between activities takes place for each agent across the day based on an activity transition probability. At a set interval during which a transition can occur, such as between 6 and 9 in the morning, a probability roll is made at a 10 minute time-step interval, resulting in 18 probability rolls during the time interval. A normal probability distribution is assumed assuming a symmetrical a distribution.

Varying standard deviations can be provided for each transition. In total the model contains eight transitions:

1. Sleeping to awake at home
2. Awake at home to School (for population members who attend school)
3. School to home (for population members who attend school)
4. Awake at home to work (for population members who work)

5. Work to home (for population members who work)
6. Home to walk in park
7. Walk in park to home
8. At home to sleep

Based on the set of transitions a daily pattern emerges as to at what time residents are in green spaces or elsewhere. Also the difference between weekends and weekdays is taken into account, such that there is to/from work and to/from school transition during weekends.

7.3.3.2 Purchasing behavior, firm financial flows, and firm disappearance

The resident agents are characterized by a daily food status and a daily drink status, which indicates the extent to which for a given day they are in need of a food or drink item. If they already consumed a food or drink item the respective status of consumption is set to saturated and they will no longer seek out to purchase any food or drinks. If a status is not yet saturated there is a probability that a food or drink item is purchased. The occurrence of a purchase is based on a uniform probability roll from 0 to 1, with a 0.90 or higher probability threshold for drinks, and a 0.97 or higher probability threshold for food item purchases. These rolls are made every 10-minute time step, such that the longer a person spends time in an NBS space, the higher the likelihood of a purchase becomes. For example, a 50-minute time spent in an NBS green space results in a $5/10^{th}$ probability of a purchase. In the current version there is no division between people who spend time in green spaces who never purchasing any drinks and/or foods, who rarely purchase drinks and/or foods, and who frequently purchase drinks and/or foods. In a future version such a segmentation can be made if data was available to provide an appropriate distribution.

Once a drink purchase is made it yields additional revenue for the shop where it is made. Prices in the assumption are based on a generic “drink” and a generic “food item” and set to a randomized value per shop. The price value for drinks is set to vary between 2 and 3 euro, and food prices between 4 and 5 euro. Variable costs including food costs and labour cost and other consumables, are assumed as 50% of the price level, and fixed costs are introduced at 20.000 euro per year assuming space rental, financing, taxation, electricity and water charges at 1667 euro per month. As such based on the difference between revenues and costs results in the net profit or loss to the shop which indicates its financial sustainability (or lack thereof)

It is assumed that a purchase is always made at the retail shop that is closest in proximity to the resident agent in terms of spatial distance. To this end the spatial distance is estimated for each purchase that is made to assign the purchase to the closest distance retail shop, which is critical to evaluate which retail shops survive because they make enough purchases, and which close down because of a lack of revenue.

If shops make a sustained loss that is equivalent to half their fixed costs per annum it is assumed that they disappear and are removed from the simulation. Thereby only shops survive over time that make a profit on a sustained basis, based on the number of customers they can get by being in a location close to a large number of customer residents.

7.3.3.3 New firm appearance and location choice

The simulation also allows new shops to appear with similar rules for revenues, costs and profits as described in section 7.3.3.2. The locations in which new firms can appear are fixed as an initial input based on "attractor points". New shops can appear only near these attractor points, which denote either city centre areas or the centre of large green spaces in the simulation. The idea is that companies do not randomly setup, but are attracted to particular locations based on their characteristics such as population density and visitor popularity. The idea behind attractor points has been developed by Arentze (2007) who studied firm location choice in urban settings, based on a specific value per spatial cell for a company.

The probability that a new firm emerges is based on a uniform probability roll between 0 and 10, with a 5% probability that a new firm establishes itself per probability roll. The periodicity at which a probability roll is made for a new firm to emerge can be varied such as on a daily, weekly, or monthly basis.

7.3.4 Model Results Interpretation

The model provides insights in the number of retail shops that can be sustained for the population that visits parks, based on a demographically representative simulated number of people as agents. It also provides insights in the locations in which these shops appear based on choice selection by people when they are walking assuming the closest distance shops are selected. The results can as such be interpreted to be valid for larger NBS park spaces which are visited by a substantial number of citizens. Insights are thereby created for such spaces on how much revenue can be generated locally be allowing for retail places within or close to NBS park spaces.

The main limitation of the model relates to the absence of data on the preferences of park visitors in terms of frequency of purchases, and the amount spent on purchases. At present the model assumes a standard probability that does not change over time, whilst purchases in reality will differ depending on the type of visitor, week or weekend-day, weather, and other factors. To build a real world model investigations of the conditions under which purchases are made are needed. The influence on the results are that the number of purchases is in error in the simulations, which in reality will be lower or higher given actual purchasing behavior. A survey among park visitors and/or observational results on purchases if existing retail establishments are in place would be required to fill this data gap.

The second limitation of the model is that more factors can play a role next to closest distance, such as price and type of drink or food available at a retail shop, versus the generic drink and food item now provided in the model. This is especially relevant for foods in cases where there are different dietary segments of the population, as non-alcoholic drinks are relatively universally available across retail shops.

A third limitation is the selection of the number of locations where shops can be established which was constrained to a limited few, so as to understand differences between establishing shops in NBS park spaces or in city centers near or further away from NBS park spaces. In reality the number of areas where retail shops can establish is much larger, and a much more complex locational option model would be needed if the aim is to predict specific locations. For purposes of understanding the number of shops and the extent to which additional revenues can be generated by NBS green parks this level of locational detail is unnecessary.

8 Results and overall findings

Each of the three models were run for the four use case cities in the project. Results are presented for Szeged in section 8.1, for Alcalá de Henares in section 8.2, for Città Metropolitana di Milano in section 8.3, and for Çankaya Municipality in section 8.4. The same sub-set area as described in chapter 6 was consistently selected across each of the three models to obtain model results.

The models were also run with the same input data variations. In case of "*Water runoff and catchment improvement by NBS promotion in private gardens*" twelve model runs were established for each city, based on variation in two population segments with either 100% of the population allocated as "proud gardeners" or 100% of the population allocated as backyard barbeques. Furthermore, variation was added for each of these two groups. First, the results were simulated twice for both groups with no interventions. Second, four intervention combinations were simulated for each group, only 80 gardening workshop organising municipal agents, only 100 gardening network groups organiser municipal agents, only 1000 annual financial subsidies per year for garden transformation, and a combination of all three interventions occurring at the same time.

In case of *"Urban heat mortality impact reduction through NBS"* a total of 360 model runs were made for each city. First, a no heatwave baseline model run were the mortality effects from heatwaves were "turned off" so as to only capture baseline non-heatwave mortality for comparative purposes. Second, based on variations between five simulated temperature years: 2016, 2030, 2050, 2070 and 2090. Third, for each of these years with heatwave effects seven variants were simulated, without green roofs, with 30%, 60%, and 100% of the elderly population houses covered by green roofs, and with 1.5°- and 3°-degree temperature reduction impact due to green roofs. Finally, these 36 different model runs were each simulated ten times to obtain a min-max range and average value to establish variation due to probability variation as incorporated in the model.

For the last model, "*Socio-economic and commercial development resulting from NBS changes"* a total of six model runs were established for each city. Each of these runs covered a five-year period for which daily population activities at 10-minute intervals were simulated, including park walking for weekdays and weekends. The input variations were the number of initial shops at the start of each model runs, set 1, 5, or 10 retail shops randomly allocated across the city. Each run was carried out twice to give a course understanding of variability across model runs.

8.1 Szeged

The simulation area was selected to cover the center of Szeged with surrounding areas and satellite peri-urban areas (See Figure 11). The area includes the green waterfront NBS use case in the Nature 4 Cities project as a green space. The same area was used across all the three simulations described in the next sections.

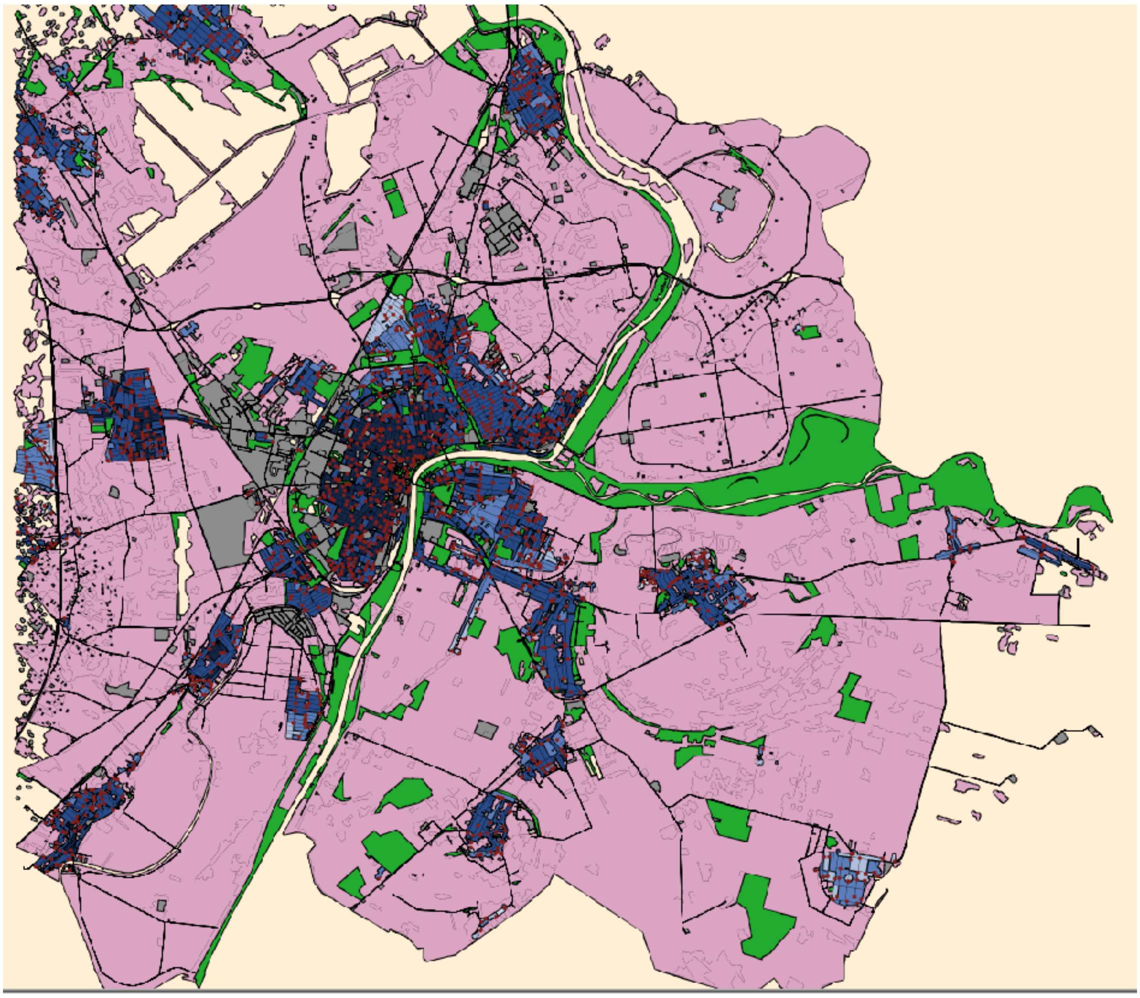

Figure 11. Area of Szeged simulated in model as per Netlogo initialization display. NBS areas in green colour, commercial areas in grey, household areas in blue, agricultural areas in pink, and population agents displayed as red dots.

8.1.1 Water runoff and catchment improvement by NBS promotion in private gardens

The simulation shows a substantial difference between the proud gardener and backyard barbeque segments in terms of transitions from paved to NBS based green gardens, due to differences in gardening related motivation and ability between these segments. In both cases at the start of the simulation the number of paved gardens ranges from about 350 to 380. In case of proud gardeners 120 to 150 paved gardens are transformed into partially green and green NBS based gardens, whereas in case of backyard barbeques only about 30 paved gardens are transformed. Also, the majority of transformed gardens become green NBS based gardens for proud gardeners, whereas the majority of transformed gardens for backyard barbeques become partially green gardens (see Table 27).

Table 27. Szeged simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	No gardening knowledge workshop influencers	No gardening Group Organiser influencers	No financial subsidies per year for garden transformation	No. Paved Gardens		No. Partially Green Gardens		No. Green Gardens		Cumulative Runoff 10 years (m³)	Cumulative Runoff final year (m³)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	354	216	165	207	119	215	253,300,000	25,725,000
2	100% proud gardeners	0	0	0	383	230	184	243	91	185	259,000,000	26,220,000
3	100% backyard barbeques	0	0	0	380	353	162	181	104	112	265,200,000	27,860,000
4	100% backyard barbeques	0	0	0	359	338	174	187	104	112	265,110,000	27,943,000
5	100% proud gardeners	80	0	0	367	219	172	200	92	212	243,900,000	24,567,000
6	100% proud gardeners	0	100	0	367	188	168	193	91	245	248,770,000	25,100,900
7	100% proud gardeners	0	0	1000	385	94	178	65	97	501	245,500,000	24,769,000
8	100% proud gardeners	80	100	1000	367	47	170	53	94	531	226,900,000	22,750,000
9	100% backyard barbeques	80	0	0	368	346	155	161	106	122	270,000,000	28,460,000
10	100% backyard barbeques	0	100	0	405	369	150	168	108	126	273,000,000	28,630,000
11	100% backyard barbeques	0	0	1000	388	365	173	184	91	103	269,200,000	28,310,000
12	100% backyard barbeques	80	100	1000	366	304	198	198	97	159	267,090,000	27,810,000

The effect of gardening knowledge workshops and gardening network group organisers, and subsidies as individual measures is non-existent for backyard barbeques. In case of proud gardeners, the effect is non-existent for gardening knowledge influencers, small for gardening group organisers, with 35 more transformed paved to green gardens over the modelled period, and large for subsidies with close to 130 additional gardens transformed from paved to green gardens (see Table 27). Interestingly, in case of combined interventions there is a medium sized effect on backyard barbeques, with an additional 50 gardens transformed from paved to green, demonstrating that combining measures can be more effective for particular segments than others.

The garden transformation has a non-measurable impact on total private garden water runoff for backyard barbeque segment model runs. In case of proud gardeners, the growth in green NBS based gardens reduces water runoff by over 10% in the case where close to 300 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby 5% to 10% of the water runoff that can be reduced by private garden based NBS promotion.

8.1.2 Urban heat mortality impacts reduction through NBS

A total of 1600 citizens were simulated in the model run. The background mortality impact for Szeged was estimated for 2016 at 73 mortalities during the year, or close to 5% per year. The impact of a simulated heatwave in 2016 increased the mortality to 122 per year, or close to 8% of the elderly population above 65+ of age (see Table 28). Green roofs can if rolled out across all buildings with elderly people reduce heatwave mortality by over 80% in case of a 3˚C indoor temperature reduction from green roofs. In comparison a 1.5˚C indoor temperature reduction results in a 50% reduction in heatwave mortality deaths, when achieved across all buildings.

The heatwave mortality reduction impact for future years in Szeged remains significant although it is increasingly reduced due to increasing temperatures. In case of 100% green roof coverage with a 3˚C indoor temperature reduction, the mortality reduction in 2030 is 63% versus the background mortality rate, in 2050 it is 65%, in 2070 it is 64%, and in 2090 it is 47%. In case of 100% green roof coverage with a 1.5˚C indoor temperature reduction, the mortality reduction in 2030 is 47% versus the background mortality rate, in 2050 it is 45%, in 2070 it is 34%, and in 2090 it is 25%. As such the reduced indoor temperatures are insufficient to fully mitigate the effects of growing temperatures across the century due to climate change, but still can reduce the impact by half in case of 3˚C indoor temperature reductions (see table 28 and Figures 12 to 14).

Table 28. Szeged simulation model results comparison for heatwave mortality based on eight different scenarios

Run Set	Description	Temperature Year	Green Roofs Temperature impact	Share of People living under green roof	Highest Mortality of 10 runs	Lowest Mortality of 10 runs	Difference	Mean mortality for 10 runs
1	No heatwave	2016	-	0	73	56	17	66
2	0% green roof	2016	-	0	122	93	29	109
3	30% green roof - 1.5˚C impact	2016	1.5 ˚C	30%	122	92	30	105
4	30% green roof - 3˚C impact	2016	3 ˚C	30%	127	82	45	103
5	60% green roof - 1.5˚C impact	2016	1.5 ˚C	60%	115	92	23	99
6	60% green roof - 3˚C impact	2016	3 ˚C	60%	111	74	37	92
7	100% green roof - 1.5˚C impact	2016	1.5 ˚C	100%	107	57	50	86
8	100% green roof - 3˚C impact	2016	3 ˚C	100%	84	61	23	73
9	No heatwave	2030	-	0	73	56	17	66

10	0% green roof	2030	-	0	124	94	30	109
11	30% green roof - 1.5˚C impact	2030	1.5 ˚C	30%	131	95	36	110
12	30% green roof - 3˚C impact	2030	3 ˚C	30%	123	87	36	99
13	60% green roof - 1.5˚C impact	2030	1.5 ˚C	60%	106	80	26	93
14	60% green roof - 3˚C impact	2030	3 ˚C	60%	114	76	38	89
15	100% green roof - 1.5˚C impact	2030	1.5 ˚C	100%	102	76	26	89
16	100% green roof - 3˚C impact	2030	3 ˚C	100%	94	73	21	82
17	No heatwave	2050	-	0	73	56	17	66
18	0% green roof	2050	-	0	157	115	42	135
19	30% green roof - 1.5˚C impact	2050	1.5 ˚C	30%	146	120	26	130
20	30% green roof - 3˚C impact	2050	3 ˚C	30%	124	91	33	108
21	60% green roof - 1.5˚C impact	2050	1.5 ˚C	60%	127	102	25	112
22	60% green roof - 3˚C impact	2050	3 ˚C	60%	115	93	22	107
23	100% green roof - 1.5˚C impact	2050	1.5 ˚C	100%	121	82	39	104
24	100% green roof - 3˚C impact	2050	3 ˚C	100%	102	77	25	90
25	No heatwave	2070	-	0	73	56	17	66
26	0% green roof	2070	-	0	179	142	37	165
27	30% green roof - 1.5˚C impact	2070	1.5 ˚C	30%	176	140	36	157
28	30% green roof - 3˚C impact	2070	3 ˚C	30%	170	133	37	144
29	60% green roof - 1.5˚C impact	2070	1.5 ˚C	60%	189	134	55	153
30	60% green roof - 3˚C impact	2070	3 ˚C	60%	143	105	38	127
31	100% green roof - 1.5˚C impact	2070	1.5 ˚C	100%	154	120	34	131
32	100% green roof - 3˚C impact	2070	3 ˚C	100%	121	88	33	102
33	No heatwave	2090	-	0	73	56	17	66
34	0% green roof	2090	-	0	226	182	44	201
35	30% green roof - 1.5˚C impact	2090	1.5 ˚C	30%	217	182	35	200
36	30% green roof - 3˚C impact	2090	3 ˚C	30%	196	166	30	185
37	60% green roof - 1.5˚C impact	2090	1.5 ˚C	60%	199	145	54	182

38	60% green roof - 3˚C impact	2090	3 ˚C	60%	166	141	25	156
39	100% green roof - 1.5˚C impact	2090	1.5 ˚C	100%	192	150	42	167
40	100% green roof - 3˚C impact	2090	3 ˚C	100%	163	114	49	138

Figure 12. Results for eight scenarios for model runs for 2016 (top) and for 2030 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

Figure 13. Results for eight scenarios for model runs for 2050 (top) and for 2070 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

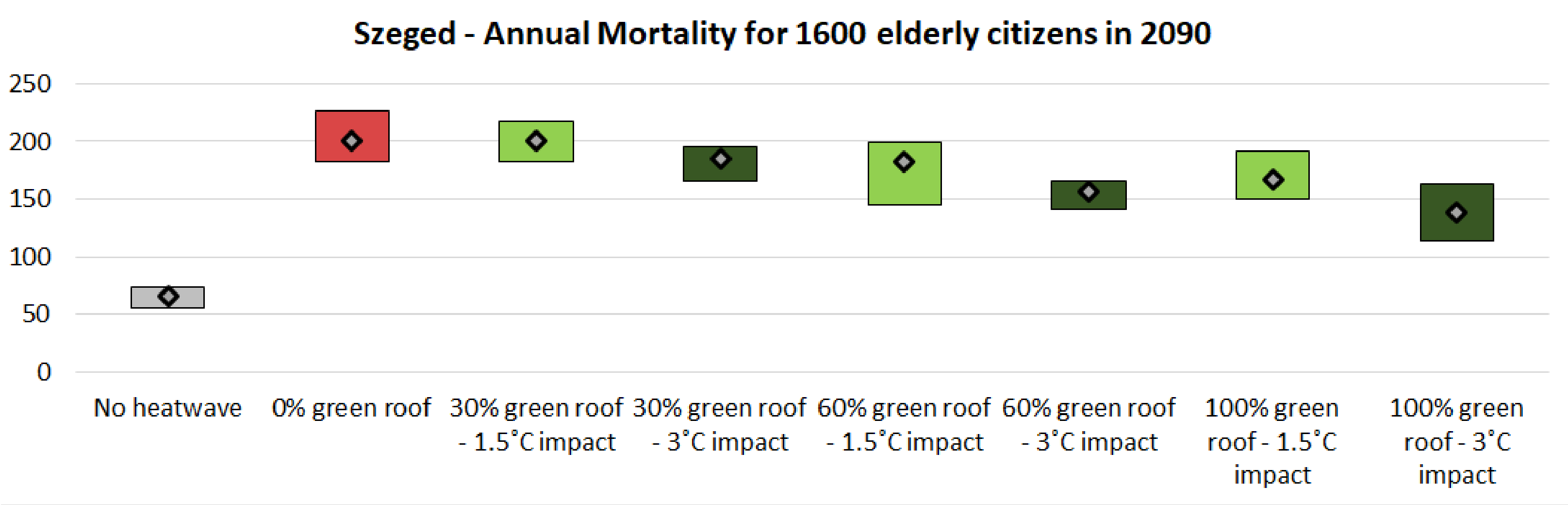

Figure 14. Results for eight scenarios for model runs for 2090 based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

8.1.3 Socio-economic and commercial development resulting from NBS changes.

The model runs for Szeged showed that for a simulated population of about 800 citizens, that walks in parks out of 1583 citizens, a total of 5 to 6 retail shops can be supported based on drink and food purchases associated with time spent in green spaces (Table 29). The final number of shops at the end of the five-year simulation varied substantially between 3 and 8. No substantial difference was found for different initial number of retail shops. The location of the shops was found to be closely related to green spaces. At least half of the shops was located within greenspace areas or at the edge of it, and in the majority of cases three quarters of shops were located in green spaces. In one simulation run all retail shops were in greenspaces (see figure 15).

Table 29. Szeged simulation model results for Socio-economic and commercial development resulting from NBS changes

Run set	Population	Population that walks in parks	Number of retail shops		
			At start of model run	At end of model run	Average across model run
1	1583	827	1	8	6
2	1583	783	1	3	5
3	1583	818	5	7	6
4	1583	873	5	6	5
5	1583	810	10	3	5
6	1583	845	10	5	5

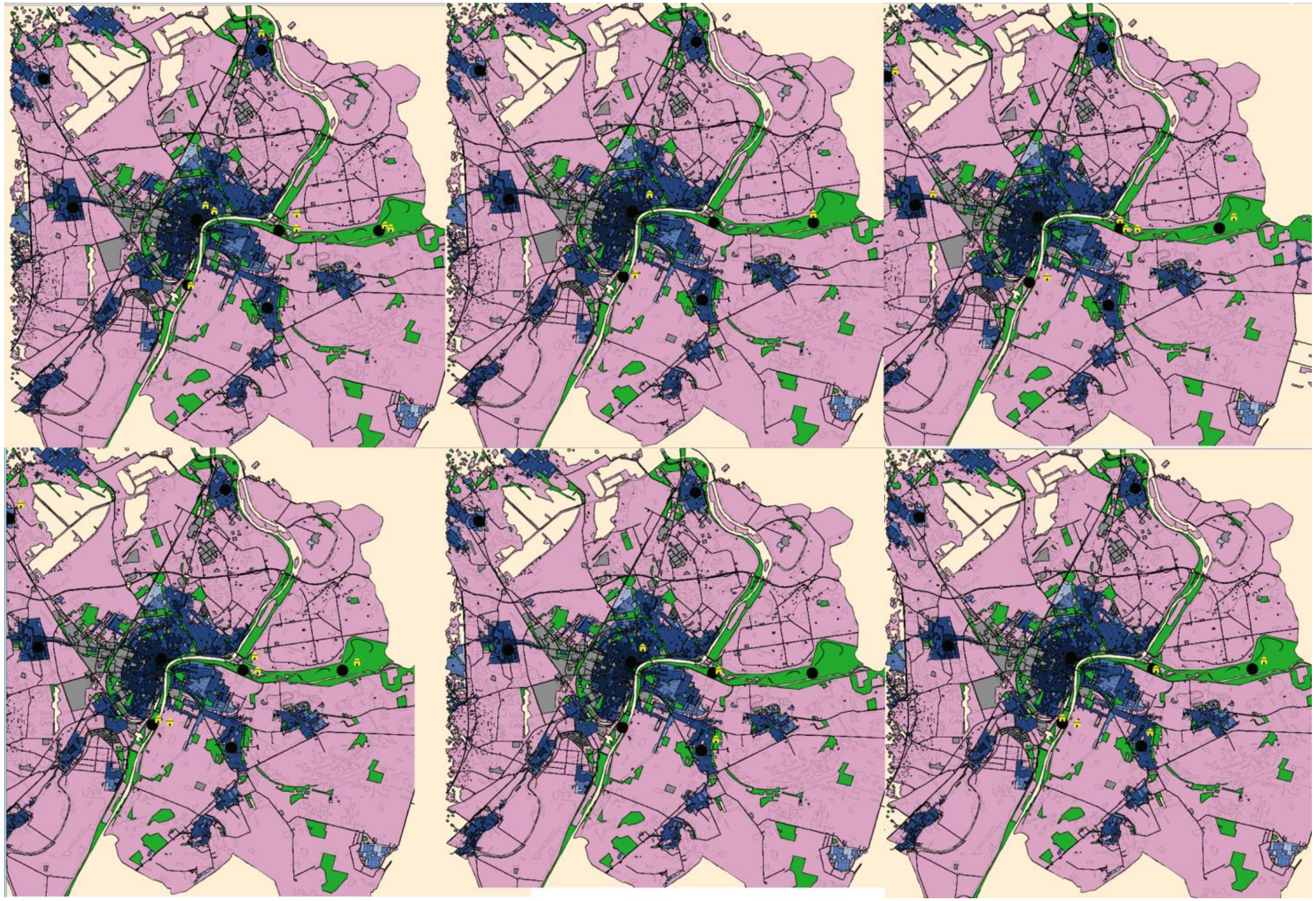

Figure 15. Final map location results for Szeged of retail shops across six model runs. Initial retail shops (if still existing) in orange, new retail shops are coloured yellow. Land use is depicted based on green spaces (green), households (blue), agriculture (pink) and commercial spaces (grey).

8.2 Alcalá de Henares

The simulation area was selected to include the center area of Alcalá de Henares with surrounding areas and satellite peri-urban areas (See Figure 16). The area includes the edible forest NBS use case in the Nature 4 Cities project as a green space. The same area was used across all the three simulations described in the next sections.

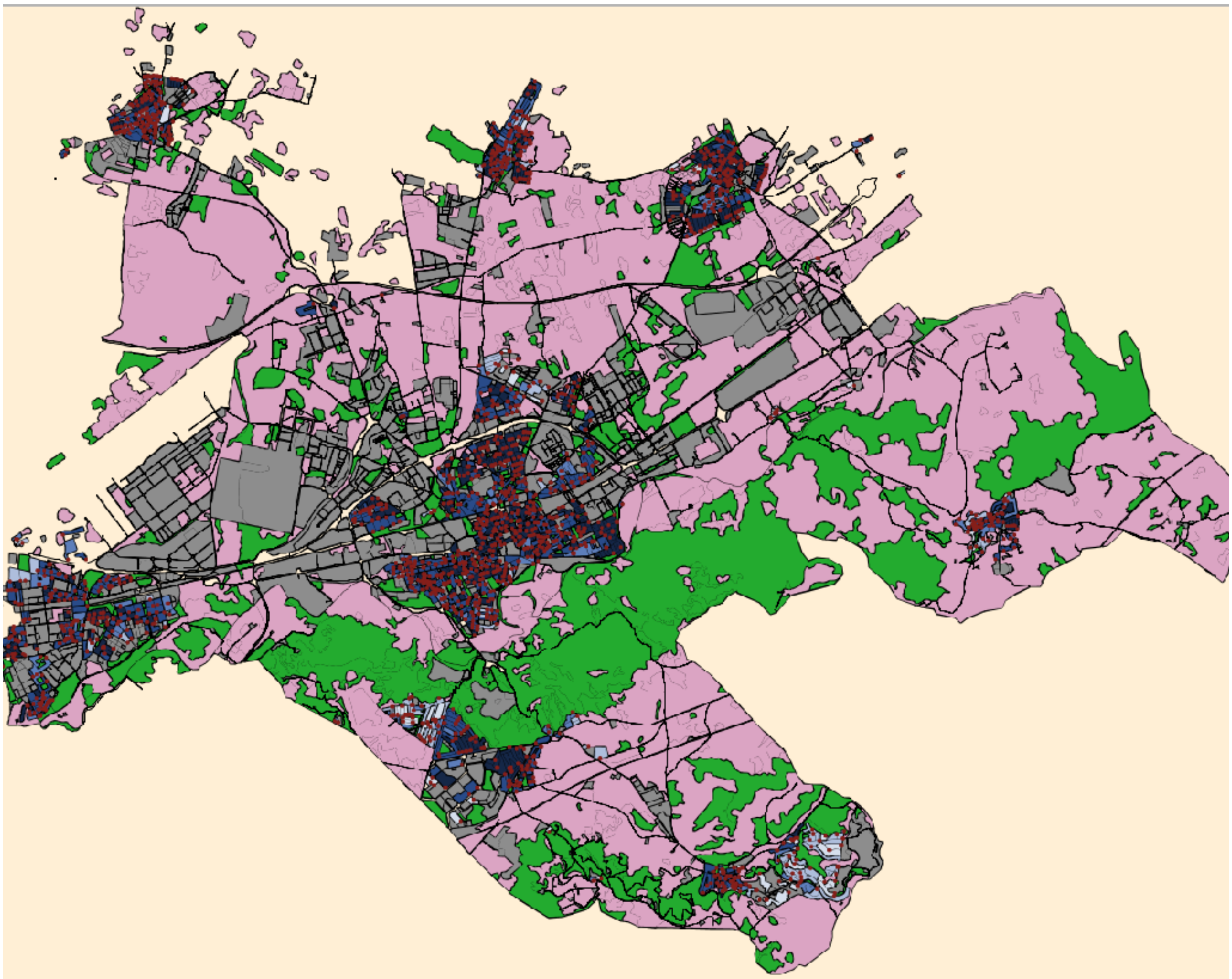

Figure 16. Area of Alcalá de Henares simulated in model as per Netlogo initialization display. NBS areas in green colour, commercial areas in grey, household areas in blue, agricultural areas in pink, and population agents displayed as red dots.

8.2.1 Water runoff and catchment improvement by NBS promotion in private gardens

The simulation shows limited changes for backyard barbeque segments and substantial changes for proud gardeners in terms of transitions from paved to NBS based green gardens, due to differences in gardening related motivation and ability between these segments. At the start of the simulation the number of paved gardens range between 670 and 800. In case of proud gardeners 240 to 300 paved gardens are transformed into partially green and green NBS based gardens, whereas in case of backyard barbeques only about 30 to 40 paved gardens are transformed. Also, about half of transformed gardens become green NBS based gardens for proud gardeners and the other half partially green gardens. The majority of transformed gardens for backyard barbeques become partially green gardens (see Table 30).

Table 30. Alcalá de Henares simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	No gardening knowledge workshop influencers	No gardening Group Organiser influencers	No financial subsidies per year for garden transformation	No. Paved Gardens		No. Partially Green Gardens		No. Green Gardens		Cumulative Runoff 10 years (m^3)	Cumulative Runoff final year (m^3)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	801	516	211	337	177	336	122,443,876	13,157,346
2	100% proud gardeners	0	0	0	709	461	222	334	223	359	126,219,000	13,724,784
3	100% backyard barbeques	0	0	0	673	632	205	236	198	208	131,859,470	15,318,105
4	100% backyard barbeques	0	0	0	709	679	230	249	223	234	139,723,138	16,319,339
5	100% proud gardeners	80	0	0	694	413	223	327	146	323	117,229,700	12,578,218
6	100% proud gardeners	0	100	0	756	465	217	321	224	411	128,962,056	13,916,964
7	100% proud gardeners	0	0	1000	672	135	233	118	238	890	112,762,481	12,364,437
8	100% proud gardeners	80	100	1000	668	141	223	94	175	831	100,678,370	11,151,138
9	100% backyard barbeques	80	0	0	719	685	246	265	175	190	135,234,450	15,678,575
10	100% backyard barbeques	0	100	0	771	734	225	246	191	207	136,389,930	15,857,002
11	100% backyard barbeques	0	0	1000	690	654	205	226	210	225	136,660,000	15,921,648
12	100% backyard barbeques	80	100	1000	726	654	249	288	226	258	136,421,300	15,609,300

The effect of gardening knowledge workshops and gardening network group organisers, and subsidies as individual measures is non-existent for backyard barbeques. In case of proud gardeners, the effect is not measurable for gardening knowledge influencers and gardening group organisers, and large for subsidies with around 350 additional gardens transformed from paved to green gardens (see Table 30). In case of combined interventions there is a negligible effect for all interventions on additional garden transformations, such that in case of Alcala de Henares it is shown that for particular segments combining measures does not yield additional transformations over individual interventions.

The garden transformation has a non-measurable impact on total private garden water runoff for backyard barbeque segment model runs, given the limited change from paved to green gardens. In case of proud gardeners, the growth in green NBS based gardens reduces water runoff by close to 20% in the case where over 500 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby 10% to 20% of the water runoff that can be reduced by private garden based NBS promotion.

8.2.2 Urban heat mortality impacts reduction through NBS

A total of 2900 citizens were simulated in the model run. The background mortality impact for Alcalá de Henares was estimated for 2016 at 117 mortalities during the year, or at 6% per year. The impact of a simulated heatwave in 2016 increased the mortality to 284 per year, or close to 10% of the elderly population above 65+ of age (see Table 31). Green roofs can if rolled out across all buildings with elderly people reduce heatwave mortality by 76% in case of a 3˚C indoor temperature reduction from green roofs. In comparison a 1.5˚C indoor temperature reduction results in a 56% reduction in heatwave mortality deaths, when achieved across all buildings.

The heatwave mortality reduction impact for future years in Alcalá de Henares remains significant although it is increasingly reduced due to increasing temperatures. In case of 100% green roof coverage with a 3˚C indoor temperature reduction, the mortality reduction in 2030 is 100% versus the background mortality rate, in 2050 it is 97%, in 2070 it is 83%, and in 2090 it is 66%. In case of 100% green roof coverage with a 1.5˚C indoor temperature reduction, the mortality reduction in 2030 is 49% versus the background mortality rate, in 2050 it is 62%, in 2070 it is 51%, and in 2090 it is 36%. The reduced indoor temperatures effect improves in the 2030 and 2050s because the temperature datasets for Spain improve (e.g. it is cooler in those decades then today) based on the IPCC average temperature forecasts. As such green roofs, if they can reduce the impact by half in case of 3˚C indoor temperature reductions, can provide substantial mortality reductions, consistently over half for the 21st century and close to zero for the first half of the century (see table 31 and Figures 17 to 19).

Table 31. Alcalá de Henares simulation model results comparison for heatwave mortality based on eight different scenarios

Run Set	Description	Temperature Year	Green Roofs Temperature impact	Share of People living under green roof	Highest Mortality of 10 runs	Lowest Mortality of 10 runs	Difference	Mean mortality for 10 runs
1	No heatwave	2016	-	0	131	104	27	117
2	0% green roof	2016	-	0	305	255	50	284
3	30% green roof - 1.5˚C impact	2016	1.5 ˚C	30%	284	235	49	259
4	30% green roof - 3˚C impact	2016	3 ˚C	30%	271	230	41	247
5	60% green roof - 1.5˚C impact	2016	1.5 ˚C	60%	275	217	58	244
6	60% green roof - 3˚C impact	2016	3 ˚C	60%	229	190	39	215
7	100% green roof - 1.5˚C impact	2016	1.5 ˚C	100%	235	193	42	211
8	100% green roof - 3˚C impact	2016	3 ˚C	100%	199	150	49	172

9	No heatwave	2030	-	0	131	104	27	117
10	0% green roof	2030	-	0	181	144	37	160
11	30% green roof - 1.5˚C impact	2030	1.5 ˚C	30%	190	134	56	155
12	30% green roof - 3˚C impact	2030	3 ˚C	30%	164	139	25	152
13	60% green roof - 1.5˚C impact	2030	1.5 ˚C	60%	163	116	47	143
14	60% green roof - 3˚C impact	2030	3 ˚C	60%	146	106	40	132
15	100% green roof - 1.5˚C impact	2030	1.5 ˚C	100%	165	122	43	139
16	100% green roof - 3˚C impact	2030	3 ˚C	100%	123	99	24	112
17	No heatwave	2050	-	0	131	104	27	117
18	0% green roof	2050	-	0	206	175	31	194
19	30% green roof - 1.5˚C impact	2050	1.5 ˚C	30%	208	164	44	185
20	30% green roof - 3˚C impact	2050	3 ˚C	30%	185	158	27	173
21	60% green roof - 1.5˚C impact	2050	1.5 ˚C	60%	187	155	32	171
22	60% green roof - 3˚C impact	2050	3 ˚C	60%	164	139	25	151
23	100% green roof - 1.5˚C impact	2050	1.5 ˚C	100%	167	131	36	146
24	100% green roof - 3˚C impact	2050	3 ˚C	100%	136	96	40	119
25	No heatwave	2070	-	0	131	104	27	117
26	0% green roof	2070	-	0	281	238	43	261
27	30% green roof - 1.5˚C impact	2070	1.5 ˚C	30%	250	209	41	231
28	30% green roof - 3˚C impact	2070	3 ˚C	30%	246	204	42	221
29	60% green roof - 1.5˚C impact	2070	1.5 ˚C	60%	246	201	45	216
30	60% green roof - 3˚C impact	2070	3 ˚C	60%	201	178	23	188
31	100% green roof - 1.5˚C impact	2070	1.5 ˚C	100%	199	175	24	188
32	100% green roof - 3˚C impact	2070	3 ˚C	100%	155	121	34	142
33	No heatwave	2090	-	0	131	104	27	117
34	0% green roof	2090	-	0	347	289	58	315
35	30% green roof - 1.5˚C impact	2090	1.5 ˚C	30%	325	276	49	293
36	30% green roof - 3˚C impact	2090	3 ˚C	30%	303	256	47	280

37	60% green roof - 1.5˚C impact	2090	1.5 ˚C	60%	294	266	28	280
38	60% green roof - 3˚C impact	2090	3 ˚C	60%	265	210	55	239
39	100% green roof - 1.5˚C impact	2090	1.5 ˚C	100%	265	226	39	244
40	100% green roof - 3˚C impact	2090	3 ˚C	100%	196	167	29	185

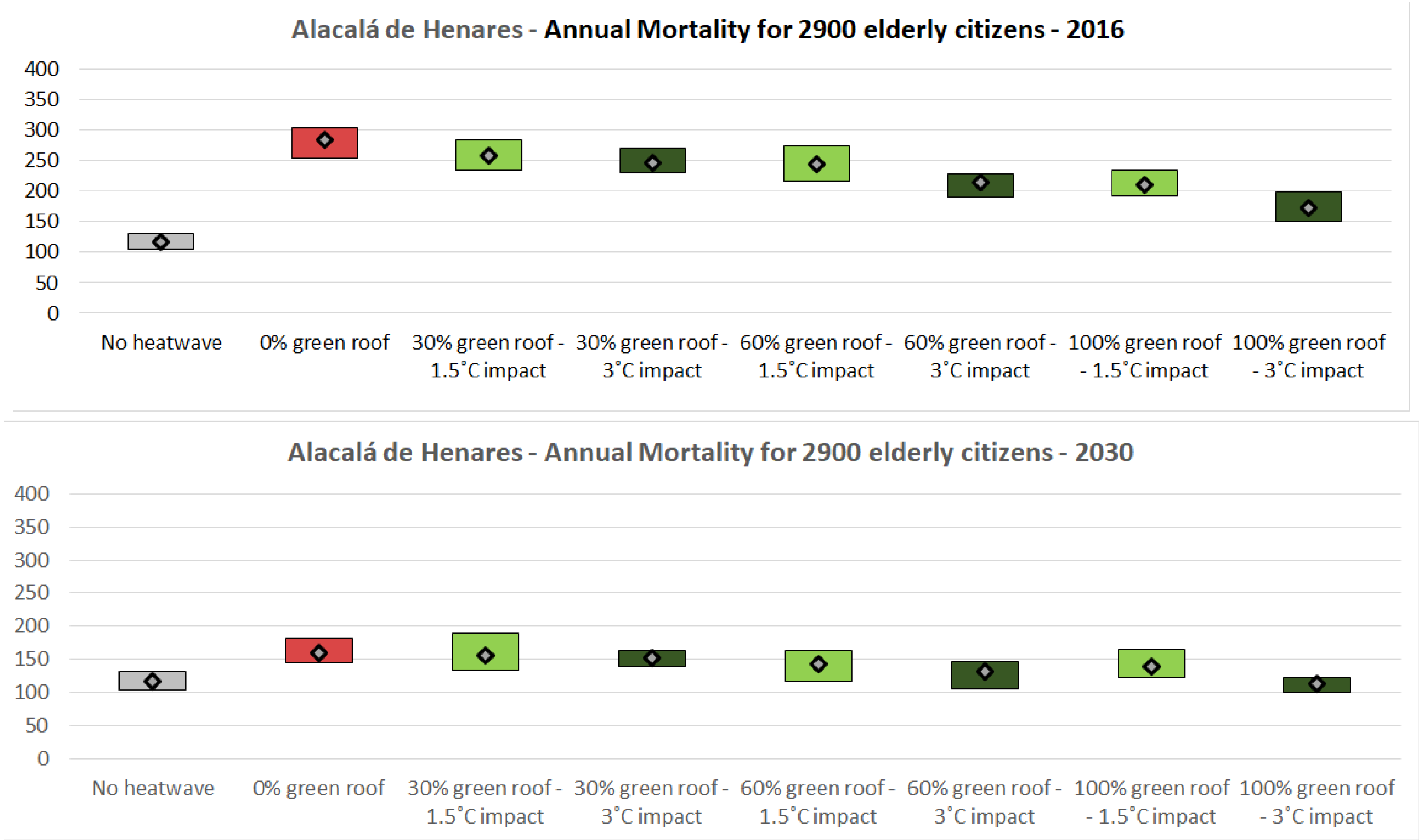

Figure 17. Results for eight scenarios for model runs for 2016 (top) and for 2030 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

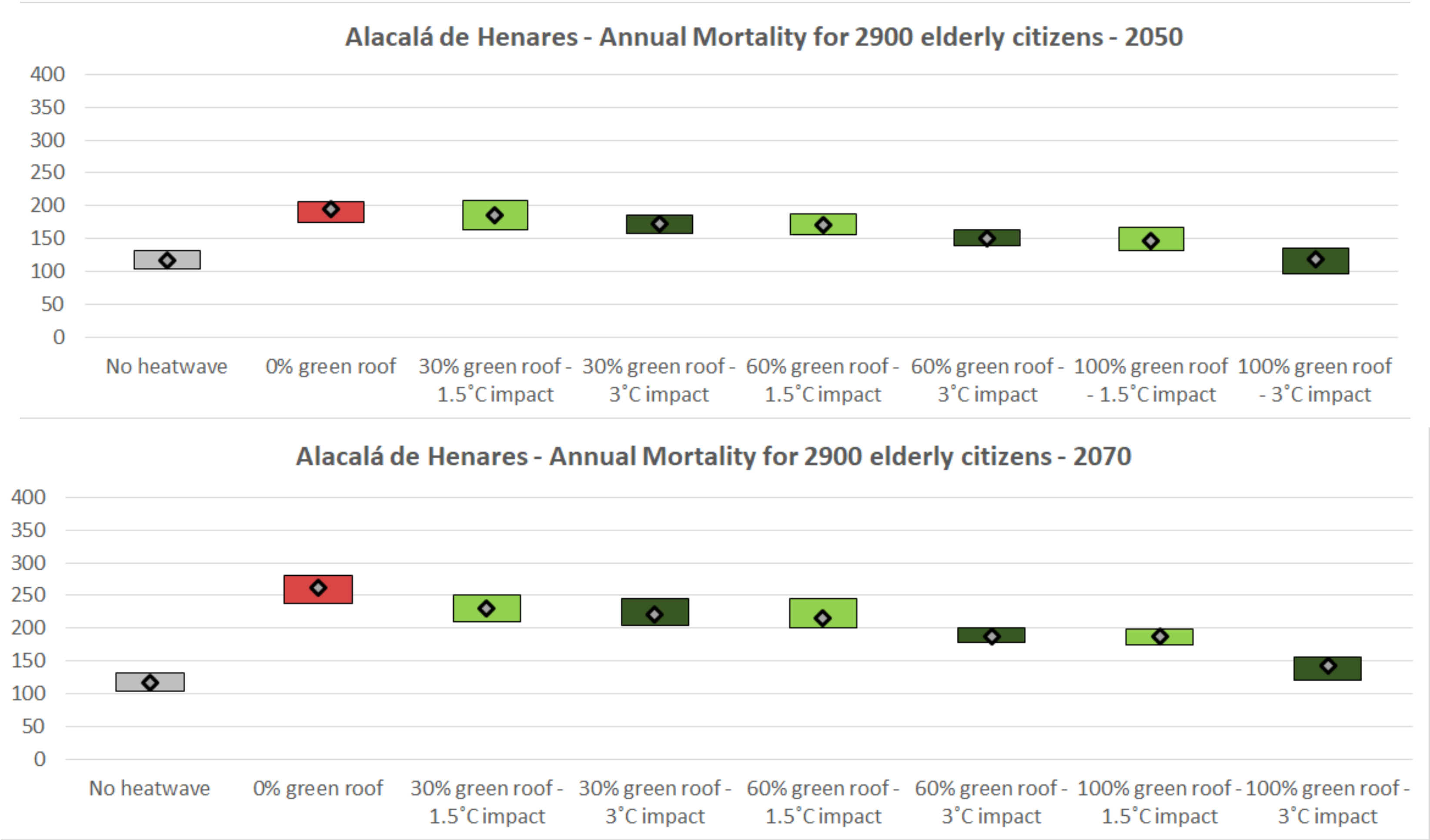

Figure 18. Results for eight scenarios for model runs for 2050 (top) and for 2070 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

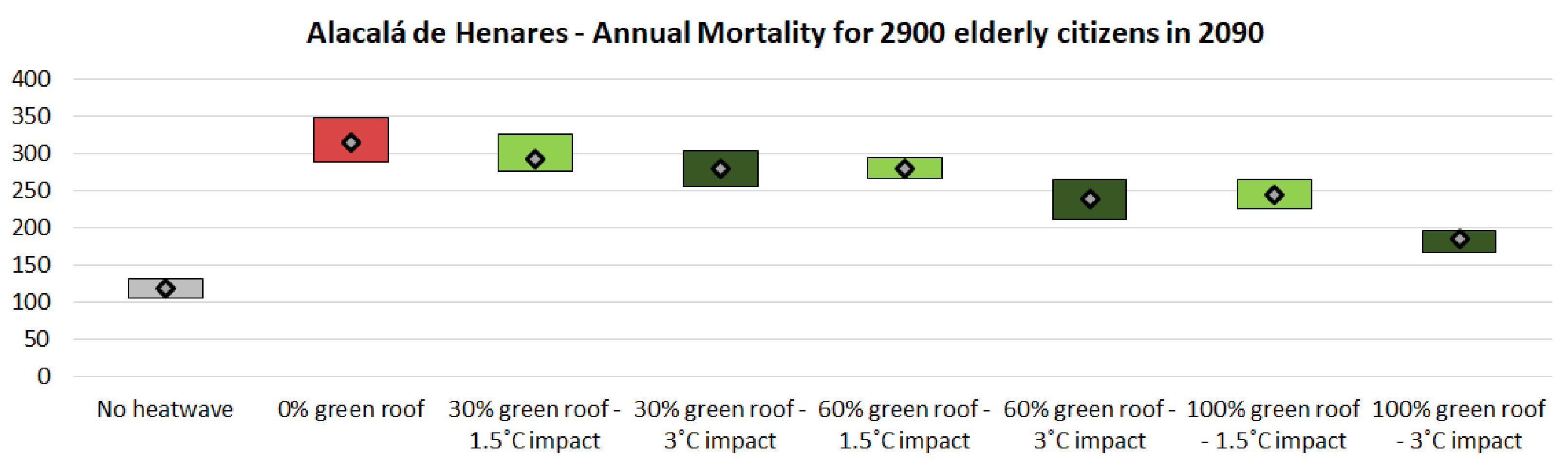

Figure 19. Results for eight scenarios for model runs for 2090 based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

8.2.4 Socio-economic and commercial development resulting from NBS changes.

The model runs for Alcalá de Henares showed that for a simulated population of about 1500 citizens, that walks in parks out of 2900 citizens, a total of 7 to 9 retail shops can be supported based on drink and food purchases associated with time spent in green spaces (Table 32). The final number of shops at the end of the five-year simulation was quite stable at 7 or 8. No substantial difference was found for different initial number of retail shops which was varied between 1 and 10 across the six model runs. The location of the shops was established mostly in residential centers further away from larger greenspaces. About a quarter to half of the shops was located within greenspace areas or at the edge of it. At maximum half of all retail shops were in greenspaces (see figure 20).

Table 32. Alcalá de Henares simulation model results for Socio-economic and commercial development resulting from NBS changes

Run set	Population	Population that walks in parks	Number of retail shops		
			At start of model run	At end of model run	Average across model run
1	2868	1559	1	8	9
2	2868	1498	1	8	9
3	2868	1511	5	7	6
4	2868	1440	5	7	8
5	2868	1448	10	8	7
6	2868	1461	10	8	7

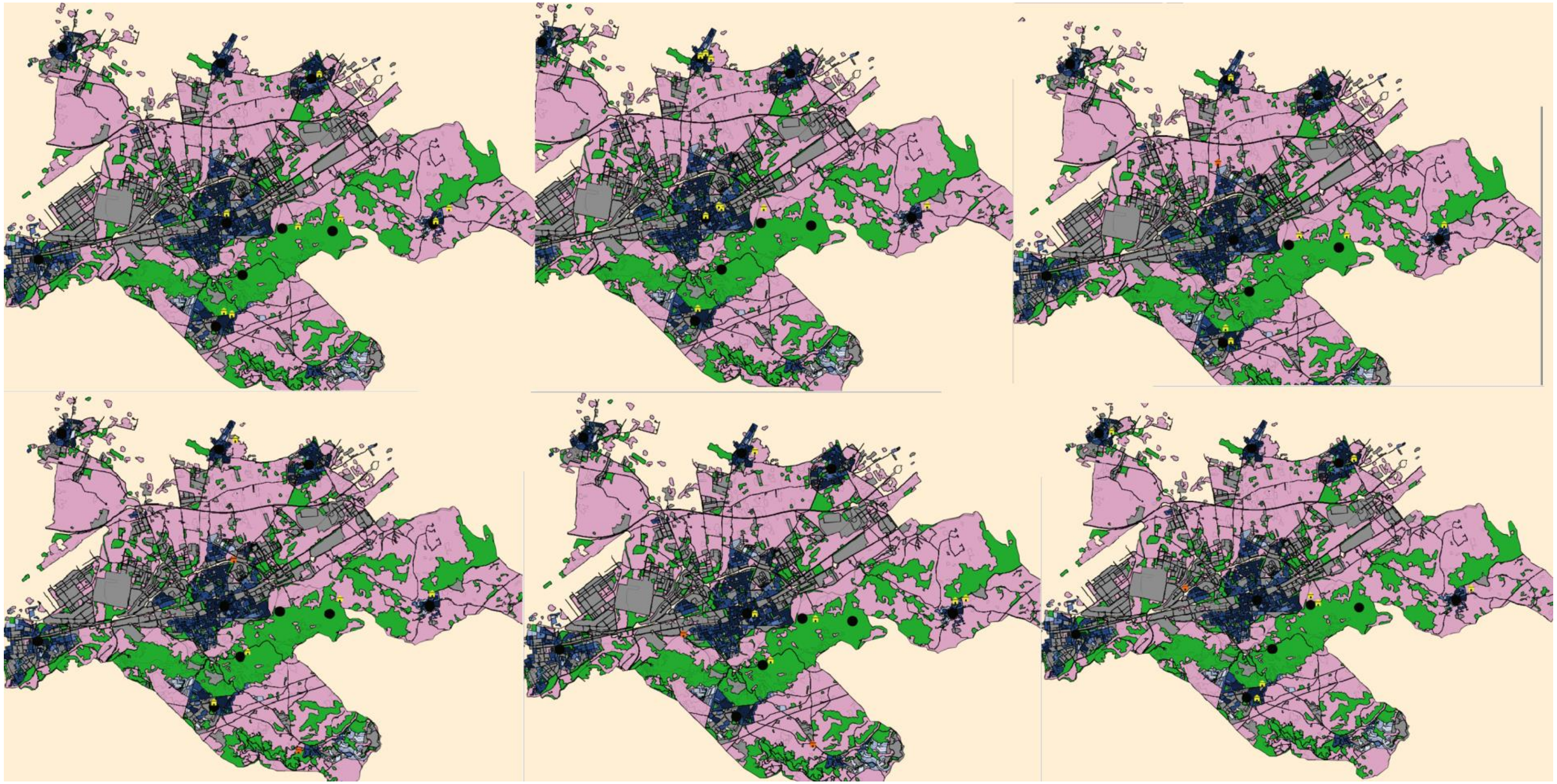

Figure 20. Final map location results for Alcalá de Henares of retail shops across six model runs. Initial retail shops (if still existing) in orange, new retail shops are coloured yellow. Land use is depicted based on green spaces (green), households (blue), agriculture (pink) and commercial spaces (grey).

8.3 Città Metropolitana di Milano

The simulation area was based on a portion of the North of the Milan Metropolitan Area centering on the quarry restoration site in Parco Lago Nord selected with surrounding neighbourhoods (See Figure 21). The same area was used across all the three simulations described in the next sections.

Figure 21. Neighbourhoods in North Milan Metropolitan Area simulated in model as per Netlogo initialization display. NBS areas in green colour, commercial areas in grey, household areas in blue, agricultural areas in pink, and population agents displayed as red dots.

8.3.1 Water runoff and catchment improvement by NBS promotion in private gardens

The simulation shows a transformation of about 80 to 90 paved gardens into partially green and green gardens for backyard barbeque segment, relative to a transformation of close to 500 paved gardens into both partially green and green gardens for proud gardeners. In both cases at the start of the simulation the number of paved gardens ranges from 1350 to 1400 (see Table 33).

Table 33. Città Metropolitana di Milano simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	No gardening knowledge workshop influencers	No gardening Group Organiser influencers	No financial subsidies per year for garden transformation	No. Paved Gardens		No. Partially Green Gardens		No. Green Gardens		Cumulative Runoff 10 years (m^3)	Cumulative Runoff final year (m^3)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	1373	874	502	711	373	663	1,153,782,700	118,912,091
2	100% proud gardeners	0	0	0	1390	917	488	656	385	690	1,191,479,000	122,381,000
3	100% backyard barbeques	0	0	0	1404	1322	463	502	380	423	1,217,212,257	128,300,480
4	100% backyard barbeques	0	0	0	1410	1334	491	540	396	423	1,206,933,500	127,273,740
5	100% proud gardeners	80	0	0	1356	828	448	653	373	696	1,167,484,600	119,423,008
6	100% proud gardeners	0	100	0	1344	887	514	665	401	707	1,155,100,000	118,499,250
7	100% proud gardeners	0	0	1000	1405	393	459	262	355	1564	1,122,606,470	113,974,702
8	100% proud gardeners	80	100	1000	1355	300	490	268	403	1680	1,119,285,721	113,404,603
9	100% backyard barbeques	80	0	0	1355	1299	503	520	368	407	1,201,793,500	126,945,900
10	100% backyard barbeques	0	100	0	1312	1251	491	531	376	397	1,204,644,599	127,176,382
11	100% backyard barbeques	0	0	1000	1371	1293	508	560	364	390	1,246,314,209	131,399,937
12	100% backyard barbeques	80	100	1000	1393	1290	495	552	388	434	1,210,696,790	127,365,850

The influence of gardening knowledge workshops, gardening network group organisers, and subsidies does not lead to additionally transformed gardens for backyard barbeques, showing the lack of influence of additional motivational and ability factors. In case of proud gardeners, the effect is not measurable for gardening knowledge influencers and small for gardening group organisers, and large for subsidies with close to 500 additional gardens transformed from paved to green gardens (see Table 33). Interestingly, in case of combined interventions there is a medium sized effect on proud gardeners with an additional 100 gardens transformed from paved to green versus only providing subsidies, showing that combining measures can lead to better results.

The garden transformation has a non-measurable impact on total private garden water runoff for backyard barbeque segment model runs as there is a limited transformation from paved to green gardens. In case of proud gardeners, the growth in green NBS based gardens reduces water runoff by about 5% in the case where close to 1000 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby up to 5% of water runoff that can be reduced by private garden based NBS promotion.

8.3.2 Urban heat mortality impacts reduction through NBS

A total of 5600 citizens were simulated in the model run. The background mortality impact for Città Metropolitana di Milano was estimated for 2016 at 227 mortalities during the year, or 4% per year. The impact of a simulated heatwave in 2016 only marginally increased the mortality to 254 per year, or close to 4.5% of the elderly population above 65+ of age (see Table 28). Green roofs if rolled out across all buildings with elderly people do not have a substantial effect on heatwave mortality reduction, even in case of a 3˚C indoor temperature reduction from green roofs. This is also the case for future temperatures (see table 34 and Figures 22 to 24) The reason is that heatwaves in the simulation do not have a substantial mortality impact, due to a very high temperature threshold found in the literature at which mortality starts to increase. As such increased temperatures do not have increased mortality impacts, and thereby green roofs do not reduce such mortalities as they do not occur.

Table 34. Città Metropolitana di Milano simulation model results comparison for heatwave mortality based on eight different scenarios

Run Set	Description	Temperature Year	Green Roofs Temperature impact	Share of People living under green roof	Highest Mortality of 10 runs	Lowest Mortality of 10 runs	Difference	Mean mortality for 10 runs
1	No heatwave	2016	-	0	251	203	48	227
2	0% green roof	2016	-	0	248	210	38	228
3	30% green roof - 1.5˚C impact	2016	1.5 ˚C	30%	250	204	46	232
4	30% green roof - 3˚C impact	2016	3 ˚C	30%	240	211	29	226
5	60% green roof - 1.5˚C impact	2016	1.5 ˚C	60%	247	217	30	232
6	60% green roof - 3˚C impact	2016	3 ˚C	60%	262	220	42	238
7	100% green roof - 1.5˚C impact	2016	1.5 ˚C	100%	250	204	46	227
8	100% green roof - 3˚C impact	2016	3 ˚C	100%	252	198	54	232
9	No heatwave	2030	-	0	251	203	48	227
10	0% green roof	2030	-	0	274	199	75	233
11	30% green roof - 1.5˚C impact	2030	1.5 ˚C	30%	250	217	33	238
12	30% green roof - 3˚C impact	2030	3 ˚C	30%	250	206	44	228
13	60% green roof - 1.5˚C impact	2030	1.5 ˚C	60%	249	206	43	229
14	60% green roof - 3˚C impact	2030	3 ˚C	60%	257	201	56	235

15	100% green roof - 1.5˚C impact	2030	1.5 ˚C	100%	260	206	54	234
16	100% green roof - 3˚C impact	2030	3 ˚C	100%	255	198	57	224
17	No heatwave	2050	-	0	251	203	48	227
18	0% green roof	2050	-	0	248	206	42	227
19	30% green roof - 1.5˚C impact	2050	1.5 ˚C	30%	250	198	52	225
20	30% green roof - 3˚C impact	2050	3 ˚C	30%	253	215	38	233
21	60% green roof - 1.5˚C impact	2050	1.5 ˚C	60%	242	204	38	225
22	60% green roof - 3˚C impact	2050	3 ˚C	60%	260	200	60	229
23	100% green roof - 1.5˚C impact	2050	1.5 ˚C	100%	272	211	61	232
24	100% green roof - 3˚C impact	2050	3 ˚C	100%	262	222	40	242
25	No heatwave	2070	-	0	251	203	48	227
26	0% green roof	2070	-	0	258	231	27	241
27	30% green roof - 1.5˚C impact	2070	1.5 ˚C	30%	261	230	31	247
28	30% green roof - 3˚C impact	2070	3 ˚C	30%	265	216	49	237
29	60% green roof - 1.5˚C impact	2070	1.5 ˚C	60%	259	205	54	236
30	60% green roof - 3˚C impact	2070	3 ˚C	60%	256	185	71	232
31	100% green roof - 1.5˚C impact	2070	1.5 ˚C	100%	271	205	66	229
32	100% green roof - 3˚C impact	2070	3 ˚C	100%	266	216	50	234
33	No heatwave	2090	-	0	251	203	48	227
34	0% green roof	2090	-	0	283	234	49	254
35	30% green roof - 1.5˚C impact	2090	1.5 ˚C	30%	271	227	44	253
36	30% green roof - 3˚C impact	2090	3 ˚C	30%	286	220	66	247
37	60% green roof - 1.5˚C impact	2090	1.5 ˚C	60%	268	235	33	249
38	60% green roof - 3˚C impact	2090	3 ˚C	60%	259	221	38	241
39	100% green roof - 1.5˚C impact	2090	1.5 ˚C	100%	257	213	44	234
40	100% green roof - 3˚C impact	2090	3 ˚C	100%	253	203	50	225

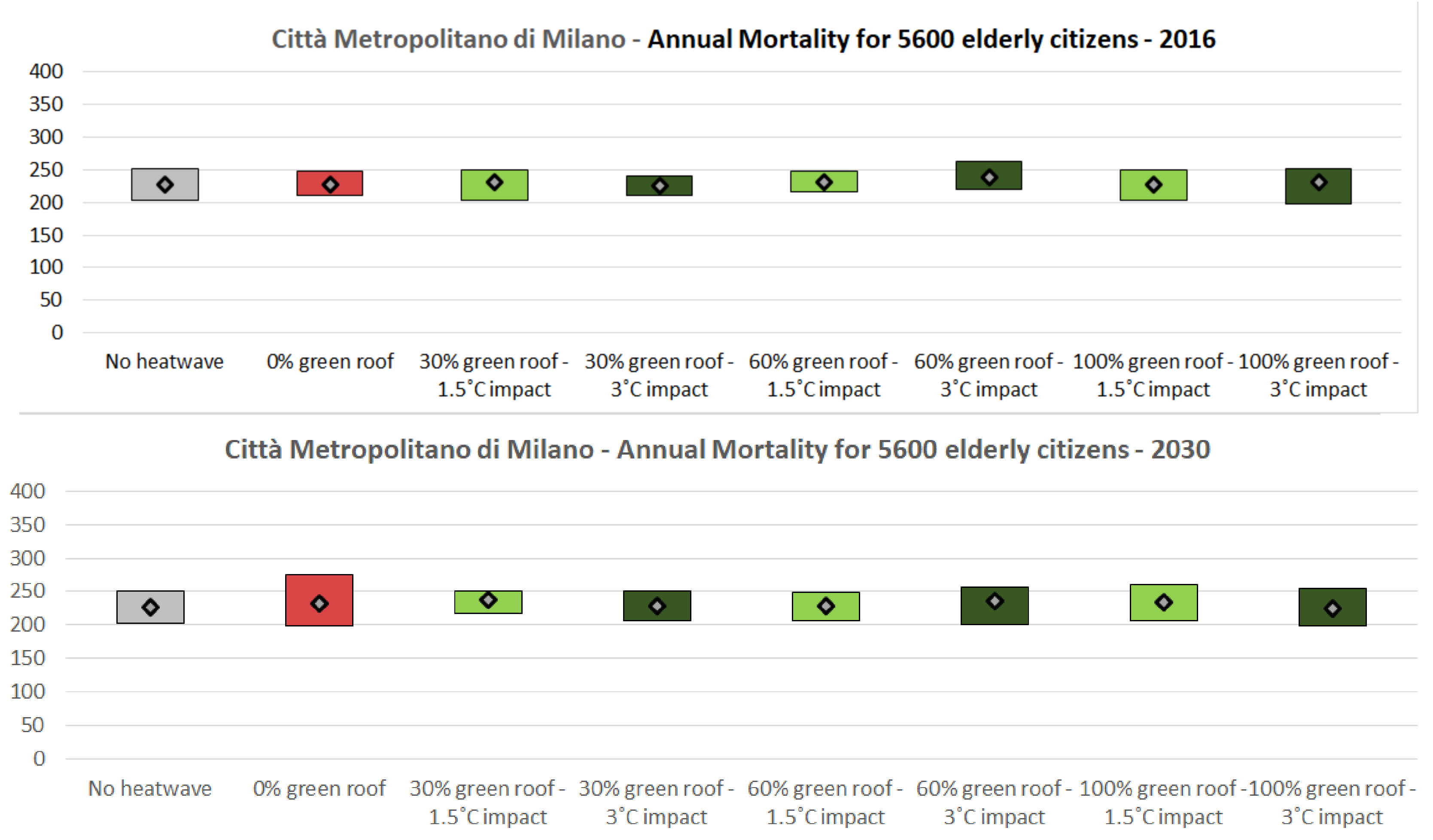

Figure 22. Results for eight scenarios for model runs for 2016 (top) and for 2030 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

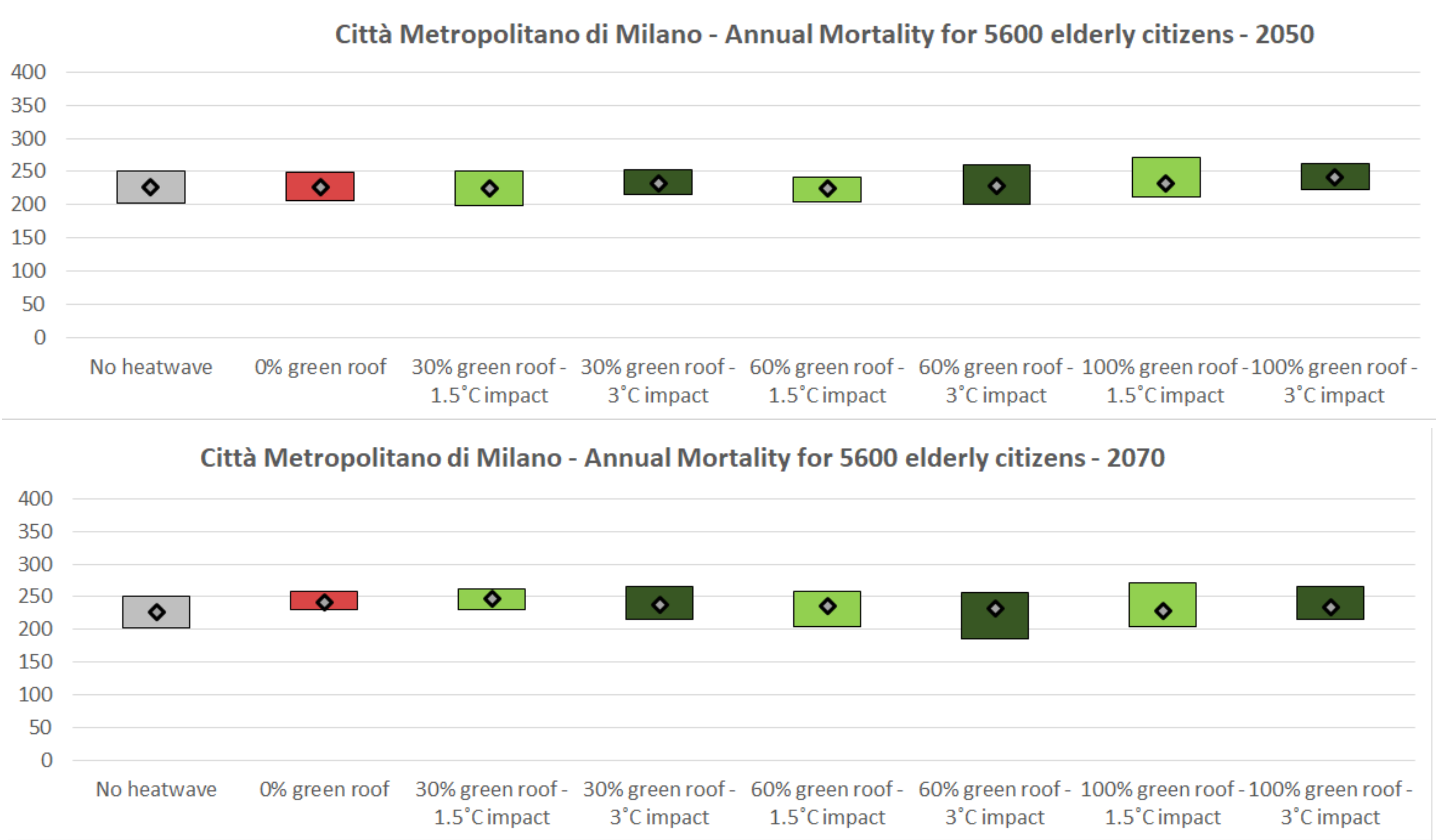

Figure 23. Results for eight scenarios for model runs for 2050 (top) and for 2070 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

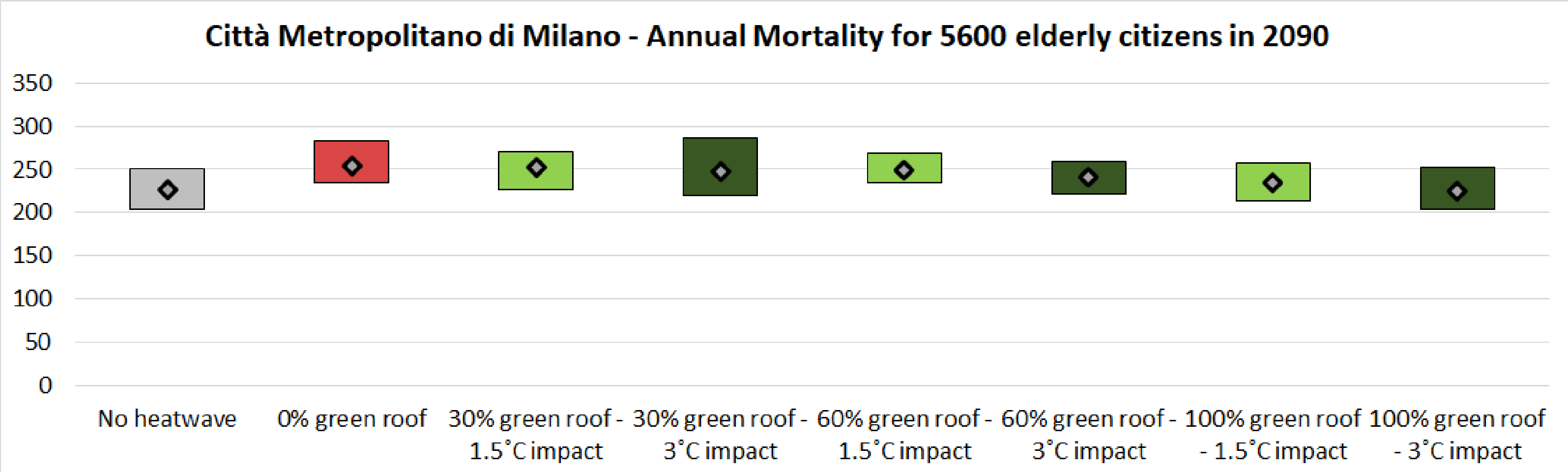

Figure 24. Results for eight scenarios for model runs for 2090 based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

8.3.3 Socio-economic and commercial development resulting from NBS changes.

The model runs for Città Metropolitana di Milano showed that for a simulated population of about 5600 citizens, about 3000 walks in parks, and as a result a total of 12 to 14 retail shops can be supported based on drink and food purchases associated with time spent in green spaces (Table 35). The final number of shops at the end of the five-year simulation was quite stable at 13 or 14. No substantial difference was found for different initial number of retail shops which was varied between 1 and 10 across the six model runs. The location of the shops was established mostly in residential centers at reasonable distance from larger greenspaces. About one third to two fifth of the shops was located within greenspace areas or at the edge of it. At maximum half of all retail shops were in greenspaces (see figure 25).

Table 35. Città Metropolitana di Milano simulation model results for Socio-economic and commercial development resulting from NBS changes

Run set	Population	Population that walks in parks	Number of retail firms		
			At start of model run	At end of model run	Average across model run
1	5592	2929	1	14	14
2	5592	2950	1	13	12
3	5592	2919	5	14	13
4	5592	2943	5	13	13
5	5592	2921	10	14	13
6	5592	2815	10	14	12

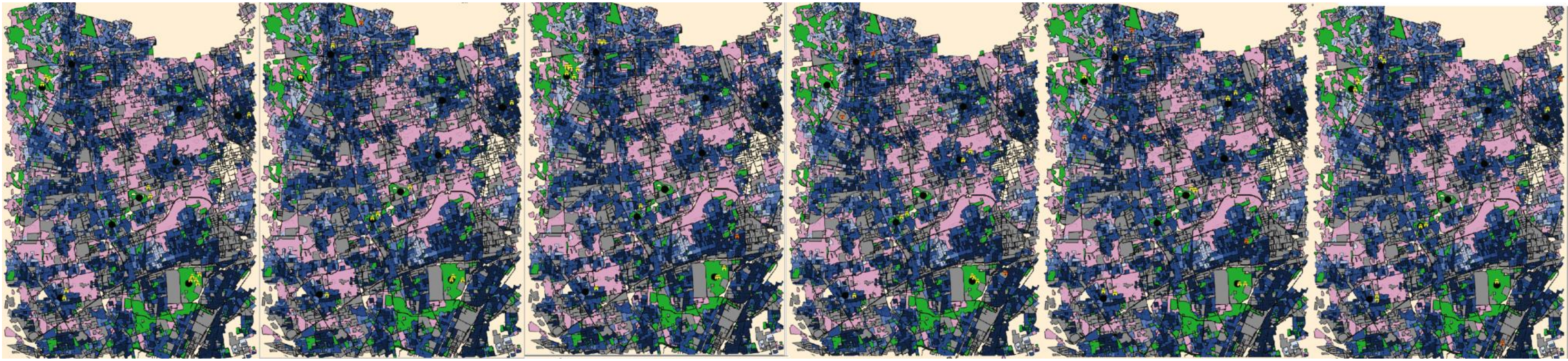

Figure 25. Final map location results for Città Metropolitana di Milano of retail shops across six model runs. Initial retail shops (if still existing) in orange, new retail shops are coloured yellow. Land use is depicted based on green spaces (green), households (blue), agriculture (pink) and commercial spaces (grey).

8.4 Çankaya Municipality

The simulation area was based on the south-east portion of Ankara where Çankaya Municipality is located inclusive of the METU forest NBS use case, which is identified as a green space in the model (See Figure 26). The same area was used across all the three simulations described in the next sections.

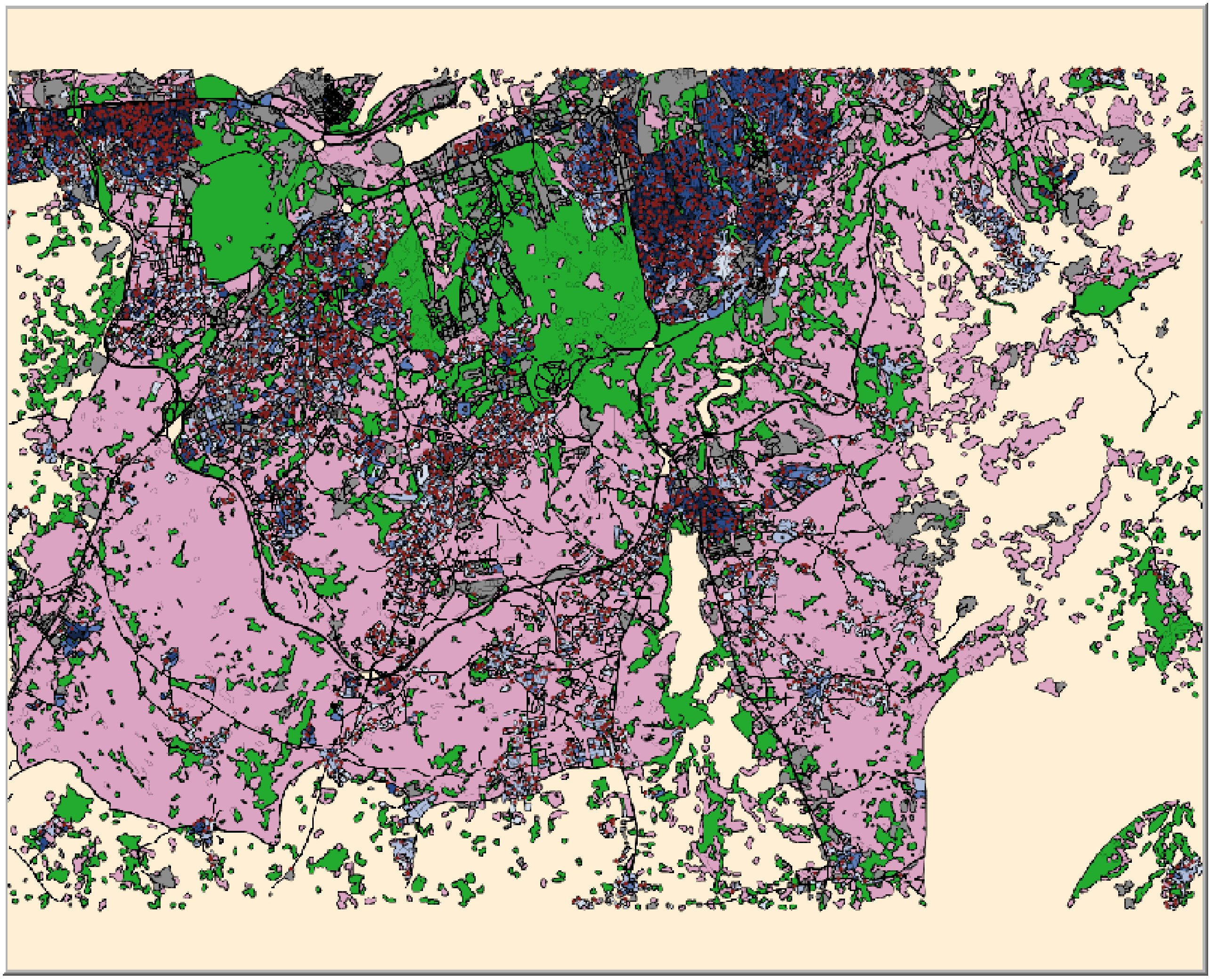

Figure 26. Neighbourhoods in and around Çankaya Municipality simulated in model as per Netlogo initialization display. NBS areas in green colour, commercial areas in grey, household areas in blue, agricultural areas in pink, and population agents displayed as red dots.

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

8.4.1 Water runoff and catchment improvement by NBS promotion in private gardens

The simulation shows a substantial difference between the proud gardener and backyard barbeque segments in terms of transitions from paved to NBS based green gardens, due to differences in gardening related motivation and ability between these segments. The number of paved gardens at the start of the simulation ranges from 190 to 270, whilst the number of initial partially green gardens ranges from 160 to 220, and the number of NBS green gardens from 700 to 800. Thereby the households in the municipality already have mostly green gardens as opposed to paved gardens. During the simulations in case of proud gardeners close to 70 to 100 paved gardens are transformed into green NBS based gardens. In case of backyard barbeque segments only about 15 paved gardens are transformed. Of the transformed gardens, nearly all become green NBS based gardens for proud gardeners (see Table 36).

Table 36. Çankaya Municipality simulation model results for water runoff and catchment improvement by NBS promotion in private gardens

Run set	Household mix	No gardening knowledge workshop influencers	No gardening Group Organiser influencers	No financial subsidies per year for garden transformation	No. Paved Gardens		No. Partially Green Gardens		No. Green Gardens		Cumulative Runoff 10 years (m³)	Cumulative Runoff final year (m³)
					Start	End	Start	End	Start	End		
1	100% proud gardeners	0	0	0	241	147	159	147	787	893	278,875,680	28,806,589
2	100% proud gardeners	0	0	0	198	125	170	167	787	863	282,621,000	29,182,840
3	100% backyard barbeques	0	0	0	233	218	201	208	752	760	293,545,000	30,865,200
4	100% backyard barbeques	0	0	0	234	226	181	177	796	808	294,414,000	31,043,860
5	100% proud gardeners	80	0	0	213	135	173	160	751	842	279,634,000	28,922,090
6	100% proud gardeners	0	100	0	258	179	187	176	795	885	287,024,000	29,654,200
7	100% proud gardeners	0	0	1000	225	57	179	64	795	1078	270,198,000	27,816,820
8	100% proud gardeners	80	100	1000	252	49	163	58	792	1100	271,416,800	27,963,900
9	100% backyard barbeques	80	0	0	255	244	197	195	765	778	297,173,290	31,319,940
10	100% backyard barbeques	0	100	0	249	229	216	221	761	776	294,381,057	30,916,457
11	100% backyard barbeques	0	0	1000	270	259	171	173	718	727	297,249,331	31,278,000
12	100% backyard barbeques	80	100	1000	193	179	158	150	791	813	294,819,370	31,039,300

In case of the backyard barbeque segment the effect of gardening knowledge workshops, gardening network group organisers, and subsidies as individual measures are negligible. In case of proud gardeners, gardening knowledge influencers, small for gardening group organisers, with 35 more transformed paved to green gardens over the modelled period, and large for subsidies with close to 130 additional gardens transformed from paved to green gardens (see Table 27). Interestingly, in case of combined interventions there is a medium sized effect on backyard barbeques, with an additional 50 gardens transformed from paved to green, demonstrating that combining measures can be more effective for particular segments than others.

The garden transformation has a non-measurable impact on total private garden water runoff for backyard barbeque segment model runs. In case of proud gardeners, the growth in green NBS based gardens reduces water runoff by over 10% in the case where close to 300 paved gardens are transformed into partially green and green gardens. The order of magnitude as estimated is thereby 5% to 10% of the water runoff that can be reduced by private garden based NBS promotion.

8.4.2 Urban heat mortality impacts reduction through NBS

A total of 3000 citizens were simulated in the model run. The background mortality impact for Çankaya Municipality was estimated for 2016 at 119 mortalities during the year, or close to 4% per year. The impact of a simulated heatwave in 2016 increased the mortality to 122 per year, or 4.2% of the elderly population above 65+ of age (see Table 37). Green roofs in 2016 across all buildings with elderly people have a negligible result on heatwave mortality reduction both in case of a 1.5˚C and 3˚C indoor temperature reduction from green roofs. The reason is that the heatwave impact is limited in 2016 based on temperature estimates for that year.

The heatwave mortality reduction impact for future years in Çankaya Municipality becomes increasingly prominent as the temperature increases across the century. In case of 100% green roof coverage with a 3˚C indoor temperature reduction, the mortality level in 2030 is 4 versus the 14 additional deaths without the green roofs under the heatwaves, in 2050 it is 6 versus 47 additional deaths, in 2070 it is 3 versus 98, and in 2090 it is 47 versus 189. In case of 100% green roof coverage with a 1.5˚C indoor temperature reduction, the mortality level in 2030 is 12 versus 20, in 2050 it is 11 versus 41, in 2070 it is 46 versus 93, and in 2090 it is 107 versus 172. As such the reduced indoor temperatures can substantially up to 75% mitigate the effects of growing temperatures across the century due to climate change, especially in case of 3˚C indoor temperature reductions (see table 37 and Figures 27 to 29).

Table 37. Çankaya Municipality simulation model results comparison for heatwave mortality based on eight different scenarios

Run Set	Description	Temperature Year	Green Roofs Temperature impact	Share of People living under green roof	Highest Mortality of 10 runs	Lowest Mortality of 10 runs	Difference	Mean mortality for 10 runs
1	No heatwave	2016	-	0	129	108	21	119
2	0% green roof	2016	-	0	139	118	21	128
3	30% green roof - 1.5˚C impact	2016	1.5 ˚C	30%	147	103	44	120
4	30% green roof - 3˚C impact	2016	3 ˚C	30%	140	107	33	126
5	60% green roof - 1.5˚C impact	2016	1.5 ˚C	60%	142	115	27	130
6	60% green roof - 3˚C impact	2016	3 ˚C	60%	146	112	34	126
7	100% green roof - 1.5˚C impact	2016	1.5 ˚C	100%	136	103	33	117
8	100% green roof - 3˚C impact	2016	3 ˚C	100%	147	109	38	128
9	No heatwave	2030	-	0	129	108	21	119

10	0% green roof	2030	-	0	147	118	29	133
11	30% green roof - 1.5˚C impact	2030	1.5 ˚C	30%	157	122	35	139
12	30% green roof - 3˚C impact	2030	3 ˚C	30%	150	103	47	130
13	60% green roof - 1.5˚C impact	2030	1.5 ˚C	60%	147	123	24	134
14	60% green roof - 3˚C impact	2030	3 ˚C	60%	138	117	21	128
15	100% green roof - 1.5˚C impact	2030	1.5 ˚C	100%	153	108	45	131
16	100% green roof - 3˚C impact	2030	3 ˚C	100%	132	109	23	123
17	No heatwave	2050	-	0	129	108	21	119
18	0% green roof	2050	-	0	181	148	33	166
19	30% green roof - 1.5˚C impact	2050	1.5 ˚C	30%	178	143	35	160
20	30% green roof - 3˚C impact	2050	3 ˚C	30%	165	128	37	150
21	60% green roof - 1.5˚C impact	2050	1.5 ˚C	60%	159	134	25	148
22	60% green roof - 3˚C impact	2050	3 ˚C	60%	159	126	33	140
23	100% green roof - 1.5˚C impact	2050	1.5 ˚C	100%	148	121	27	130
24	100% green roof - 3˚C impact	2050	3 ˚C	100%	148	111	37	125
25	No heatwave	2070	-	0	129	108	21	119
26	0% green roof	2070	-	0	237	201	36	217
27	30% green roof - 1.5˚C impact	2070	1.5 ˚C	30%	223	197	26	212
28	30% green roof - 3˚C impact	2070	3 ˚C	30%	217	177	40	193
29	60% green roof - 1.5˚C impact	2070	1.5 ˚C	60%	205	170	35	189
30	60% green roof - 3˚C impact	2070	3 ˚C	60%	183	137	46	158
31	100% green roof - 1.5˚C impact	2070	1.5 ˚C	100%	181	137	44	165
32	100% green roof - 3˚C impact	2070	3 ˚C	100%	135	108	27	122
33	No heatwave	2090	-	0	129	108	21	119
34	0% green roof	2090	-	0	346	286	60	308
35	30% green roof - 1.5˚C impact	2090	1.5 ˚C	30%	321	273	48	291
36	30% green roof - 3˚C impact	2090	3 ˚C	30%	291	257	34	269
37	60% green roof - 1.5˚C impact	2090	1.5 ˚C	60%	294	238	56	268

38	60% green roof - 3˚C impact	2090	3 ˚C	60%	232	211	21	221
39	100% green roof - 1.5˚C impact	2090	1.5 ˚C	100%	263	198	65	226
40	100% green roof - 3˚C impact	2090	3 ˚C	100%	176	152	24	166

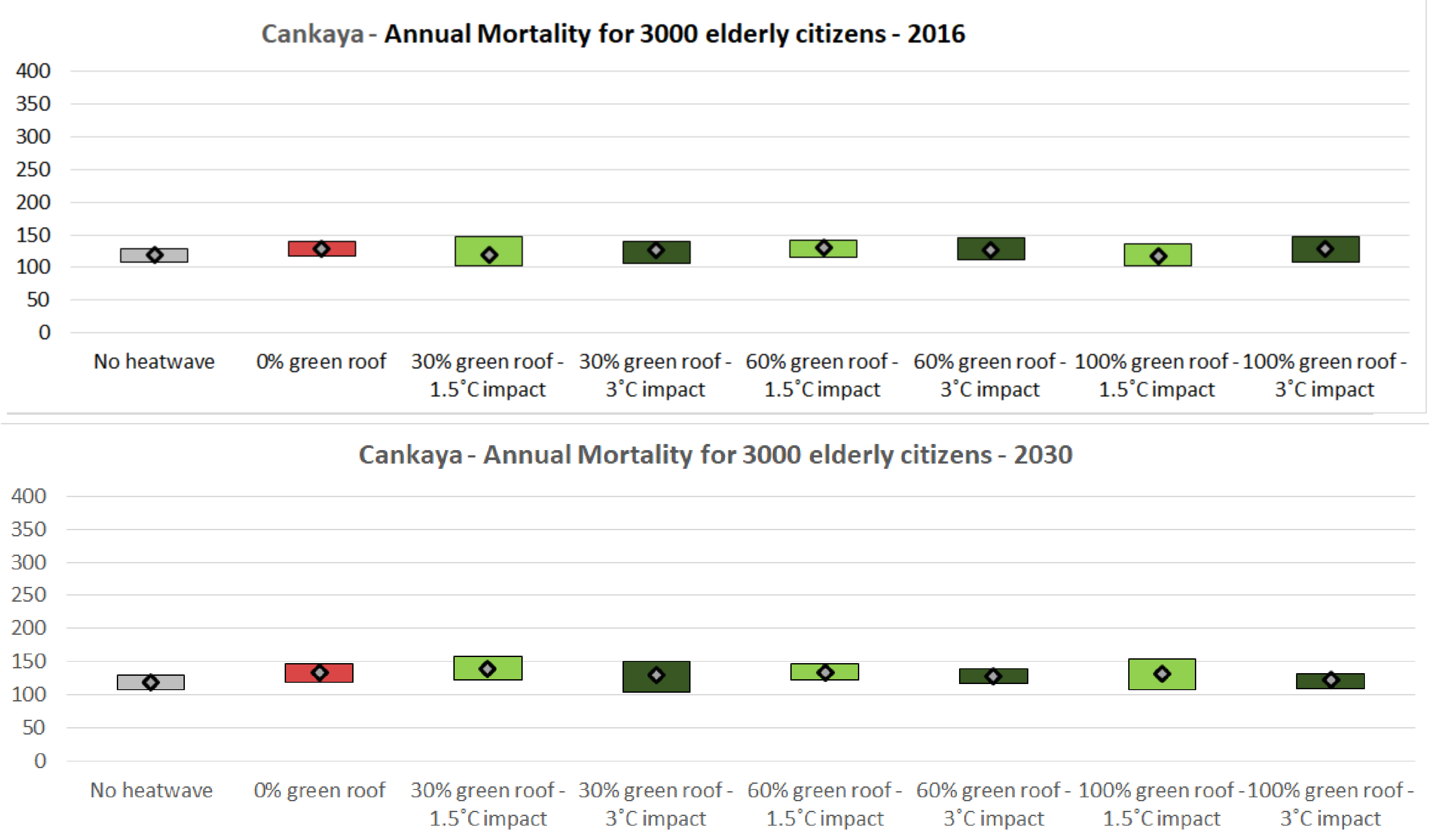

Figure 27. Results for eight scenarios for model runs for 2016 (top) and for 2030 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

 This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730468

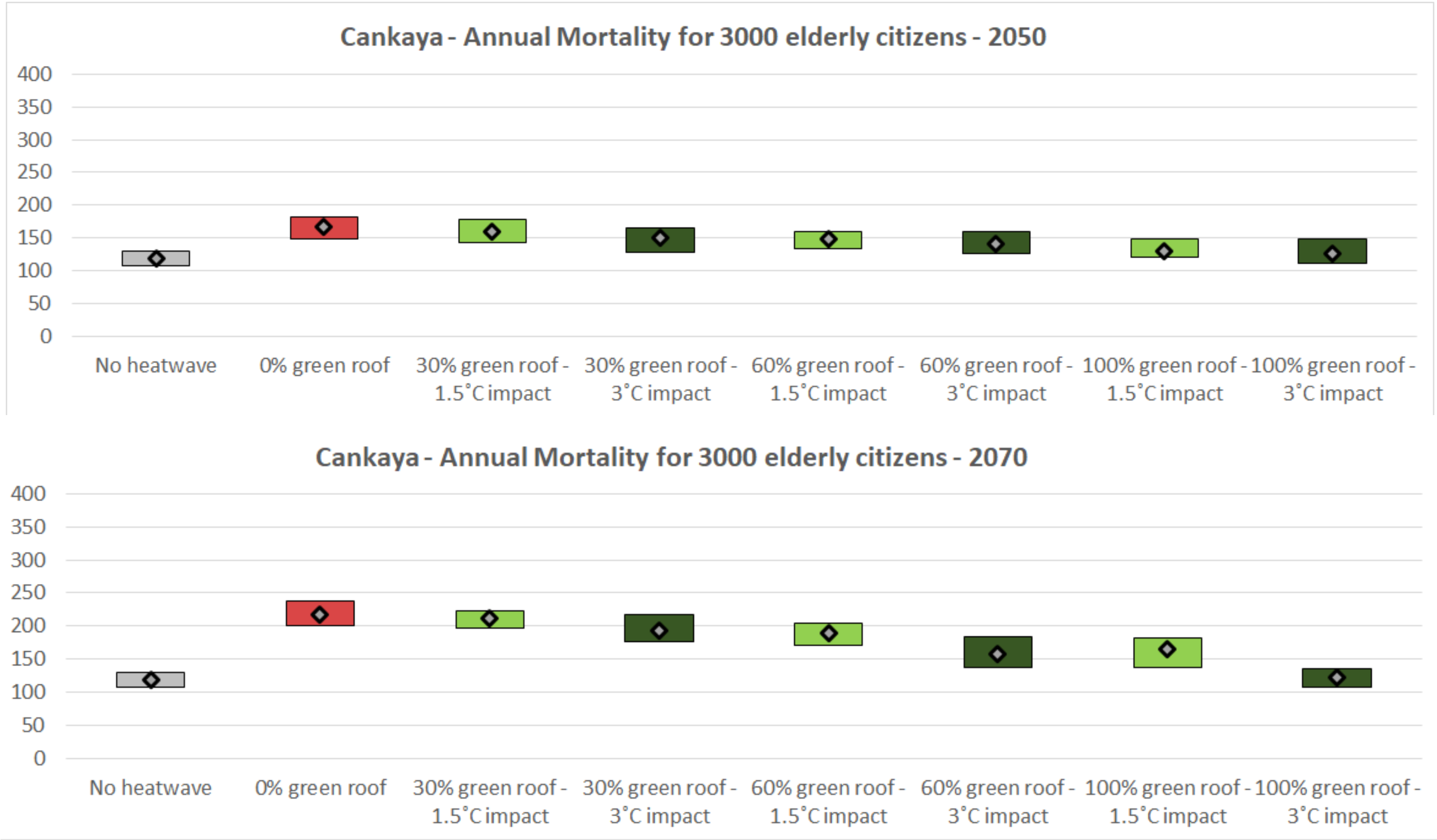

Figure 28. Results for eight scenarios for model runs for 2050 (top) and for 2070 (bottom) based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

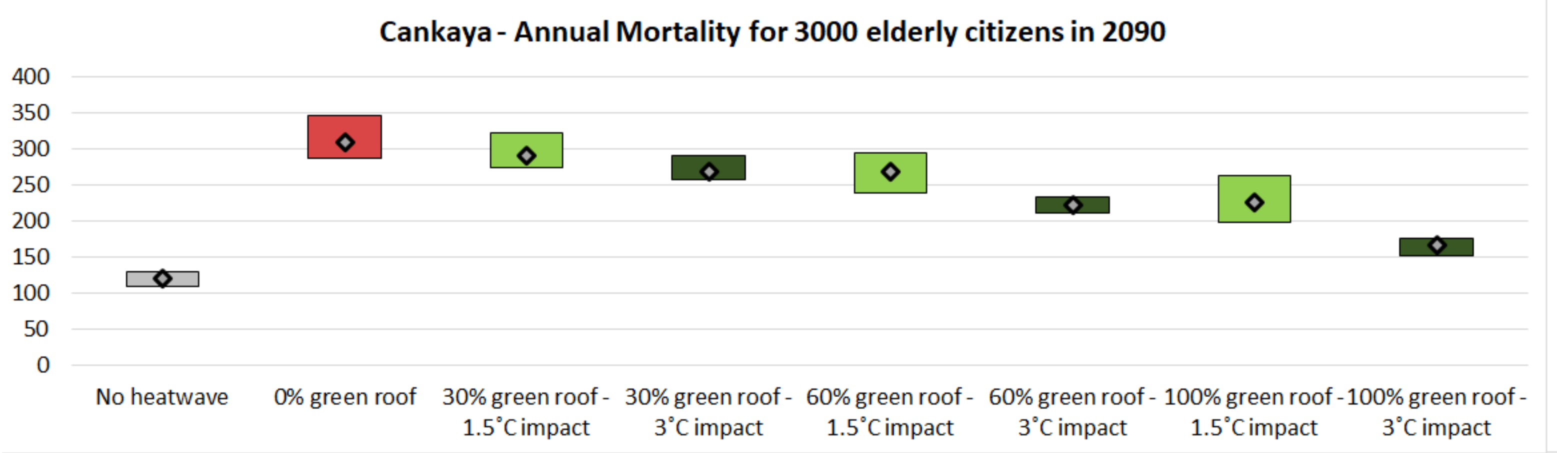

Figure 29. Results for eight scenarios for model runs for 2090 based on variations in green roof cover and impact range from 1.5°C to 3°C temperature reduction due to green roofs

8.4.4 Socio-economic and commercial development resulting from NBS changes.

The model runs for Çankaya Municipality showed that for a simulated population of about 3000 citizens, close to 1600 walks in parks, and as a result a total of 7 to 9 retail shops can be supported based on drink and food purchases associated with time spent in green spaces (Table 38). The final number of shops at the end of the five-year simulation varied significantly between 5 and 11. No substantial difference was found for the average number of retail shops, based on the initial number of retail shops which was varied between 1 and 10 across the six model runs. The location of the shops was established primarily in residential centers quite far away from larger greenspaces. Only about one eight of the shops was located in five out of six model runs within greenspace areas or at the edge of it. At maximum a quarter of retail shops were in greenspaces (see figure 30).

Table 38. Çankaya Municipality simulation model results for Socio-economic and commercial development resulting from NBS changes

Run set	Population	Population that walks in parks	Number of retail shops		
			At start of model run	At end of model run	Average across model run
1	3000	1569	1	8	9
2	3000	1596	1	11	8
3	3000	1545	5	7	7
4	3000	1553	5	6	8
5	3000	1608	10	5	8
6	3000	1610	10	11	8

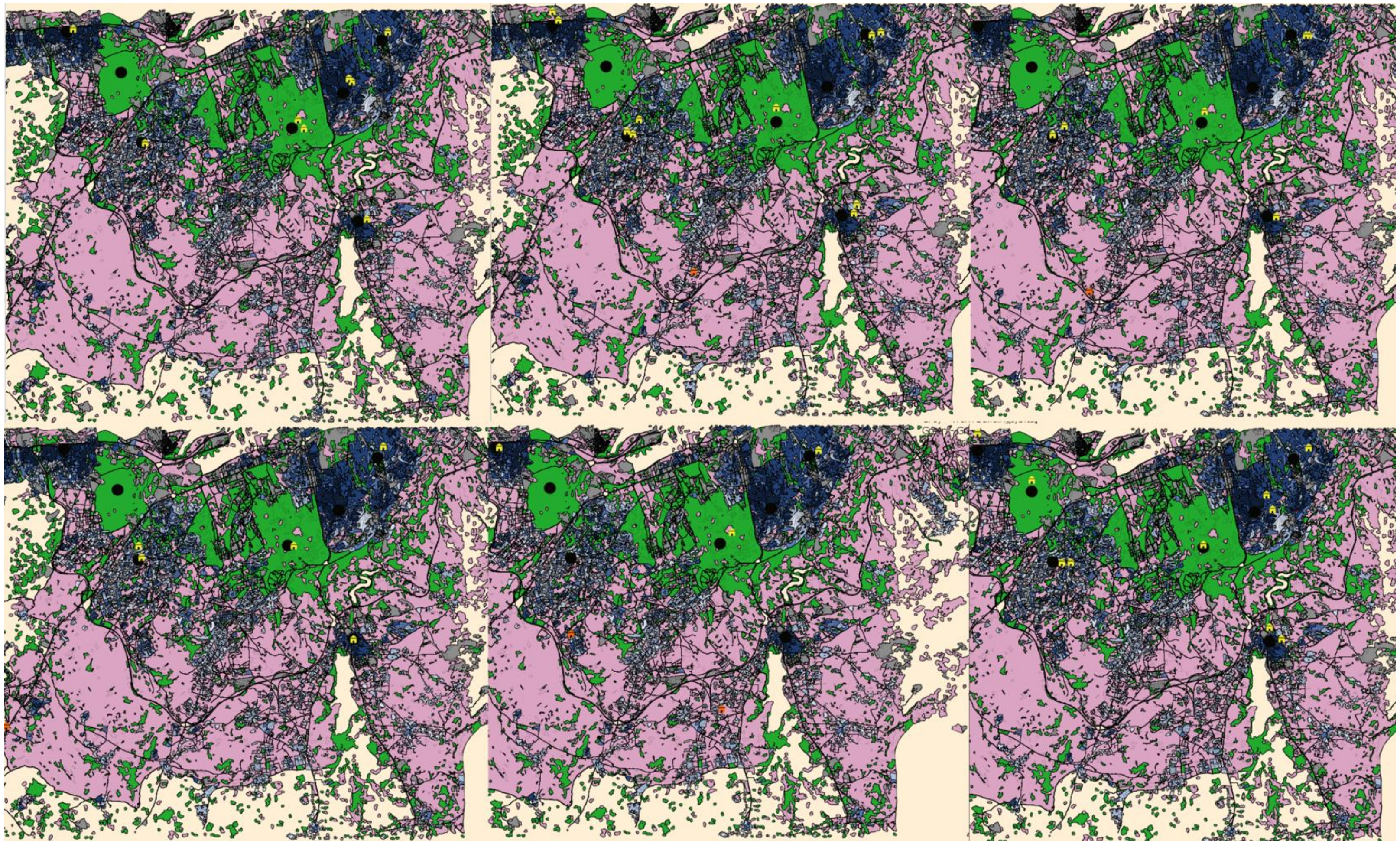

Figure 30. Final map location results for Çankaya Municipality of retail shops across six model runs. Initial retail shops (if still existing) in orange, new retail shops are coloured yellow. Land use is depicted based on green spaces (green), households (blue), agriculture (pink) and commercial spaces (grey).

9 Conclusions and Recommendations for future NBS Agent Based Modelling assessments

9.1 Conclusions on Task Results

The purpose of the task was to evaluate the usability of Agent Based Modelling (ABM) for evaluating NBS projects covering a wide variety of citizen behaviours and linkages to environmental assessments. A review of past work in this area in Chapter 3 showed that to present the use of ABM is absent in the sphere of NBS, but there are models developed for studying specific behaviours that relate to green spaces. Especially for land use development, human-wellbeing and quality of life, and rainwater catchment. The use of ABM as a methodology to provide key decision-making insights to NBS planners and stakeholders thereby is an innovative new research and development area.

The reasons for using ABM for studying NBS were discussed in the background on ABM in Chapter 2. In general ABM allows for a fine representation of the real world based on its object oriented approach, where individual people can be simulated with their individual characteristics, as well as group behaviours from interactions between people. As such ABM allows for easily simulating hetereogeneity among societal groups, due to socio-economic factors such as age, lifestyle, preferences, motivational factors and so forth. That makes it a good methodology to study a wide range of behavioural and socio-economic factors relevant for NBS decisions, such as health, quality of life, social cohesion, environmental justice, economic value, and so forth. Other advantages of ABM as a unique methodology for studying real world phenomena is that it can easily bridge micro to macro phenomena from individual people to groups to the dynamics of a population in an entire municipality. Moreover, spatial information of the urban environment and its relationship to people can be readily incorporated based on Geographical Information Systems (GIS) collated data, which is meaningful for purposes of evaluating heterogeneity between NBS spaces, buildings with NBS, and other structures associated with urban NBS networks. Finally, relationships between people and spaces can be incorporated as ABM allows for simulating network structures, which is helpful in case information exchange between people within a specific context, such as related to social acceptance, needs to be simulated.

The starting point to showcase the ABM capabilities for NBS purposes was to develop a conceptual level assessment of possible model arrangement (Chapter 5). In total ten different applications of ABM were made that allowed for exploring particular behavioural insights like building utilization changes due to NBS building improvements or inclusivity effects of NBS in neighbourhood planning or transformation of private gardens into NBS gardens for water runoff and catchment improvements, particular projects such as transforming a motorway into a tunnel and the surface area into a NBS space, or wide boundary costs and benefits of NBS at a wide level associated with a particular factor such as property value changes, climate extreme events, or urban heat mortality.

The ten conceptual areas were compared for how they could potentially provide insights across the ten different performance indicator domains built in the Nature4Cities project under WP2.1. It was found that ABM can assist with gaining insights in qualitative non-financial areas and environmental-human dynamics that are usually difficult to assess. For example, quality of life, health status, air quality, climate mitigation and adaptation, and urban food, energy and water flows.

Especially of relevance in using the ABM methodology is to establish the dynamics between these indicator domains, such as the influence of air quality on health, or climate adaptation on urban water flows.

Based on the comparison of the ten scenario concepts that were developed three concepts were selected for implementation in showcase ABM models. Subsequently, each of the models were defined technically as per Chapter 7, prior to their implementation, so as to provide a grounding for model development. The three selected models covered "*Water runoff and catchment improvement by NBS promotion in private gardens*" as per section 7.1, "*Urban heat mortality impact reduction through NBS"* as per section 7.2, and finally in section 7.3 the ABM model for "*Socio-economic and commercial development resulting from NBS changes".* The scope was set to enable exploring of the concept based on a series of input parameters, processes and desired outputs. With the aim to gain an understanding for NBS practitioners of how such ABM models of NBS could assist with decision making support by gaining insights in particular indicators and overall areas. For example, the urban heat mortality impacts reduction through NBS was developed to showcase how simulation of the urban built environment with and without green roofs could assist with understanding the impact of the green roofs on human health and mortality focusing on elderly population.

Without such a simulation one could gain insights based on background literature on the degree of the mortality effect in terms of proportion, but it would miss a number of key areas for decision maker relevance. The simulation helps to make the results localized to a city and particular scenarios therein, and help with additional insights such as future scenarios in terms of future temperature scenarios under climate change and how green roofs not only today but also in the future can assist with mortality reduction. Furthermore, the simulation enables a way to easily gain insights in a plug and play manner on the benchmark temperature reduction that is needed for a particular city to have a maximum impact, such as 1.5 ˚C or 3 ˚C indoor temperature reduction as simulated (see Chapter 8).

Result Conclusions for Water runoff and catchment improvement by NBS promotion in private gardens

The simulation results demonstrated that changing the make-up of private gardens can have up to a 20% impact on water run-off and catchment in cities with mostly paved gardens and large private garden areas, but that the typical impact of such changes is in the order of 5% to 10%. These results are based on averages, however, such that they are not representative for peak flows that may result in flash-floods. The linkage between promotion of changing paved into NBS gardens, and how this affects the water balance was thereby showcased in terms of how it could be effectuated in a simulation, and be shown that such micro-level impacts can have a macro-outcome change within an urban NBS context.

The approach to positively influence social behavioural changes in relation to transforming private gardens was demonstrated based on a framework grounded in both social-psychological theoretical perspectives with elements of social practice theory (see sections 2.2.2 and 2.2.3). The framework showed that various qualitative factors of relevance can be incorporated easily within a complex framework of decision making. In the simulation including environmental, social, financial and knowledge related aspects. Also such aspects can be grounded in local views to make a locality specific simulation, by use of using Likert scale ratings or other common social science qualitative-quantitative approaches.

In the simulation two different opposing segments of the population were simulated: "*Proud Gardeners*" and "*Backyard Barbeques*". The former with high motivation on environmental values and social preferences, and the latter with low motivation for gardening on all motivational factors. And the former with high ability in time but lower in finances, and the latter with higher ability in finances. A substantial variation between the two different segments emerged, primarily due to the low motivations of the backyard barbeque segment. Whereas in case of "*backyard barbeques*" very few to a limited 5% saw garden transformations in the base case scenarios, in case of "*proud gardeners"* the transformations ranged up to 40% of paved gardens transformed into fully green NBS gardens.

The simulations also showcased how different qualitative and quantitative programmes that could be setup by the municipality can be simulated, in terms of their potential impact of people's socio-economic factors such as motivation and the ability to implement green NBS gardens. Three such interventions were simulated, organisation of garden workshops that increases knowledge available, establishment of gardening networks that increased motivation, and gardening subsidies that increased finances available as an ability. The simulations established that based on the loadings that were included, limited improvements were established due to garden workshops and gardening networks, but that making gardening subsidies available had a significant impact in the order of an additional 20% to 40% of gardens transformed from paved to green gardens. The results also showed that combinations of interventions can have an impact even if individual interventions do not, because they can lift multiple barriers. The reason is that it is assumed that motivational factors relate to probabilities which are multiplicative, such that when increasing motivation for multiple factors, the overall probability of transforming a garden grows. In other words, if there is more environmental motivation and social motivation, the combined effect is greater than the effect of these motivations alone. The results indicate that by using such simulations to evaluate actual segments based on local surveys, insights can be gained into how combined facilitation of NBS changes can work best together.

Result Conclusions for Urban heat mortality impact reduction through NBS

The simulation results showed substantial variation of the impacts of green roofs across cities on heatwave mortality. In case of Szeged, Alcalá de Henares, and Çankaya Municipality a substantial reduction in mortality was found to occur in case of green roofs for the present and more so for future especially as it becomes hotter across the 21st century. The reduction impact was established for these three cities in the order of 75% for a 3 ˚C indoor temperature reduction, and 50% for a 1.5 ˚C indoor temperature reduction caused by green roofs for today's situation. In case of future years at the end of the century the mortality reduction was found to be 25% - 35% for the 1.5 ˚C indoor temperature reduction case, and 50% - 70% for the a 3 ˚C indoor temperature reduction case.

This contrasted with Città Metropolitana di Milano where green roofs had little mitigating impact, because heatwaves had little additional mortality effects in the first place in the simulations. The reason for this difference is the temperature threshold above which heatwave mortality occurs being substantial higher in Città Metropolitana di Milano than for other cities, according to the literature on which the model was built.

The potential impacts on mortality showed that green roofs and other temperature impacting NBS can have a substantial impact that also provides climate resilient infrastructure relative to future temperature scenarios, especially if their impact is on the higher end of the estimated spectrum in the literature, or can be engineered for greater temperature impacts. As such it is of key importance to take into account the degree of temperature reductions in the design of NBS that also have a temperature mitigating impact like green roofs. The limitations of the results for the "*Urban heat mortality impact reduction through NBS"* simulation include the limited ability to look at location specific aspects, which was signalled to be a useful feature as per the model usefulness assessment with the cities (section 9.1). If location specific details could be incorporated, in terms of where vulnerable people such as elderly of 65+ years of age and people with mental or physical health conditions are located on a building or area by area, more targeted infrastructure options could be evaluated for more effective mitigation.

Result Conclusions for Socio-economic and commercial development resulting from NBS changes

The simulations provide insights in the number of retail shops that can be sustained based on the purchasing behaviour of citizens that walk in parks. The simulations were constrained by a number of design choices. A limited number of locations were fixed where retail shops could emerge in the situation, either in the centre of built environment/towns across the map boundary, or within large urban green NBS spaces such as parks. Also a fixed ratio between profits, operational costs, and a fixed investment cost per shop was assumed, to allow focus entirely on how many shops emerged per size of the population that is walking and their location.

The number of shops scaled based on the sized of the population was simulated using a five year simulation with a 10 minute periodic interval. In case of Szeged about 5-6 retail shops emerged on average for about 800 walking citizens, with no variation if there were differences in starting retail shops. In case of Alcalá de Henares as well as Çankaya Municipality about 7 to 9 retail shops emerged for around 1500 walking citizens. The simulation with Alcalá de Henares showed a lower number of shops in case of 10 initial shops (about 7 on average across the simulation) and higher in case of 1 initial shops (9 across the simulation) which may be a random result given the limited number of simulations of 5 years, and that this result did not emerge in the simulations for other municipalities/cities. The simulation for Città Metropolitana di Milano provided an average number of retail shops of 12 to 14 for a simulated population of 2900 that walks in parks.

The results are caused by the combination of the number of people that walks in parks, the probability of a purchase, the number of purchases that need to be made to run breakeven given investment cost, and the ratio between revenues and operational costs. Since these were chosen based on informed estimates and not local evaluations, the results assist with demonstrating the potential of such models only. If the model would be built for a real decision making case, it would need to be informed based on surveys of people in parks to better understand the actual frequency of people who walk in parks and the segments (in the simulation set as low, medium, and high park walkers), as well as their purchasing behaviour in relation to socio-economic factors such as income. The simulation then allows for testing different variations in segments and their changes over time, in terms of how many retail shops can be sustained.

The other result that was established was the location of the retail shops in the simulations as a consequence of the proximity to where the person is walking when the purchase happens. The result shows that the layout of the municipality and location of green spaces matter substantially for where retail shops emerge and are maintained because they make sufficient profit to survive. The simulation showed that in case there are limited large continuous green spaces, such as in case of Szeged it is more likely that retail shops can be sustained in a concentrated green area, than in situations where there is a large fairly continuous area of green NBS space across the city centre, such as in case of Alcalá de Henares and Çankaya Municipality. In the latter case the walking behaviour is more dispersed and it is more likely that retail shops will emerge at the edge or closer to built-up residential areas. However, the simulations did not take into account whether there are particular green space NBS areas that are frequented more often than others for walking purposes, which could have a substantial influence on the outcome.

9.2 Discussion on Usefulness of Model Insights

The simulation methods developed for Task 3.2 provide a State-of-the-Art contribution to ABM methodology as a decision-support tool within the context of assess NBS benefits. The aim of the work package is to experiment with Agent Based Modelling of citizens and the interaction with the city environment and Nature Based Solutions (NBS), so as to see how it can be of use in understanding agent behaviour in relation to NBS interventions (or the absence of). The idea is that Agent Based Modelling could be a valuable support tool for decision-makers. Simulations presented here are explorative showcases that (aim to) demonstrate the potential use of agent-based modelling for the implementation of NBS. Hence, this report presents a requirements overview that contributes to the further development and uptake of ABM in the implementation of NBS.

To validate the assumption that agent-based modelling can be used as a decision-support tool, a review meeting with the policymakers from the four partners cities Alcalá de Henares (SP), Çankaya (TR), Città Metropolitana di Milano (IT) and Szeged (HU) involved in the Nature4Cities project was organised to showcase the scenarios as presented Chapter 7. After the presentation, the policymakers were interviewed. For the review we presented the three scenarios and associated simulation results: "*Water runoff and catchment improvement by NBS promotion in private gardens*" *"Urban heat mortality impact reduction through NBS", and* "*Socio-economic and commercial development resulting from NBS changes"*. These three ABM concepts have been developed differently both in terms of city challenge, as well as the technical implementation, as described in Chapter 7. By providing three different approaches, illustrated in the three scenarios, a rounded assessment is made of how Agent Based Modelling methodology can be utilized and how it may fit the needs of policy makers and decision-makers for NBS project evaluation purposes.

The review round served to talk about the following aspects:

1. **Impressions**, their first impression of the model (is it understandable, can they relate to it);
2. **Usefulness**, how the model could be of help and for which specific problems it may be particularly useful (in the city planning context);
3. **Timing**, at which stage of the planning and decision-making process the presented simulation models could possibly be useful;
4. **Limitations,** the challenges the interviewee sees with using the results that impose a limitation on the usefulness;
5. **Recommendations**, the kind of adjustments and improvements needed to increase its usability.

Based on the five aspects described above we developed an interview guide that can be found in Appendix A. Here we briefly present the Nature4Cities city partner responses per scenario.

Scenario 1: ***Water runoff and catchment improvement by NBS promotion in private gardens***
Three out of the four interviewees mentioned that their cities experience issues with flooding and/ or rain water excess, but in all four cities there are hardly any private gardens in the city area (but mainly on the outskirts). High buildings (ranging from low- to high-rise buildings) dominate these

densely populated areas. Greening gardens is thus not considered a suitable strategy to deal with water excess. Nevertheless, a model that runs data on rain water runoff enables city planners to identify problem areas and simulate potential interventions that would fit in the urban context e.g. rain harvesting or water retention in (critical) public areas. The behavioural depiction of agents in this scenario was positively evaluated in the sense that it could support more effective policies and interventions to engage citizens to adopt NBS. However, engaging citizens does not always fit in the political culture of the partner cities. Some of the interviewees mentioned that it is more common to either opt for (greening) regulations or top down interventions in public spaces rather than private spaces.

Scenario 2: *Urban heat mortality impact reduction through NBS*
This scenario was evaluated positively because it shows that green roofs have a substantial impact on reducing heat in buildings, which in effect reduce the chances of heatwave mortality. The scenario thereby illustrates a solid relation between heat, health and NBS. This could be used to create more support for NBS (i.e. 'hard numbers' are more convincing) and to ensure that investments (e.g. finances, human resources) are well spend. One interviewee mentioned that green roofs are not considered as viable option, but when a scenario in which census data and heat island effect are combined to identify pocket areas where interventions are urgently needed, the municipality may take this into consideration.[6] Despite the positive feedback, the interviewees were generally hesitant to consider green roofs as a suitable NBS intervention within their context. Green roofs are expensive, residential buildings are not public but in private ownership, some buildings have monumental or architectural status, or the roofs are too steep and thus not suitable for greening and in some cases there is a lack of expertise to create green roofs. Nevertheless, the model set-up offering the quantifiable results makes it usable and interesting for further exploration.

Scenario 3: *Socio-economic and commercial development resulting from NBS changes*
The third scenario was the most interesting according to the interviewees because economic activity is high on the agenda. In each of these cities there have been debates about the extent to which economic activities should be allowed in or near green spaces, how the benefits and burdens will turn out and for whom, and what purposes the intervention serves (to increase 'green activities', such as walking in the park and sports activities, or to generate more economic activity by making the area more attractive). One of the interviewees mentioned that the scenario could be improved by including data on the impact of sports activity and sports facilities in the park.

This third scenario allows to compare different options and could thus help to establish a benchmark for what would be sufficient in terms of economic activity, (sports) facilities and green space. The interviewees thought this to be useful for the designing stage of new projects because it supports them to better understand the synergy between the environmental and socio-economic benefits. The scenario could also be used to present to citizens and to create social acceptance for (project) plans.

In all four presentations it became first of all clear that for practitioners, the topic of the simulation (heat, green roofs and garden, economic activity) received more attention than the technical aspects of the simulation (e.g. the assumptions behind the model, methodology and agent representation).

[6] E.g. when the data shows that elderly people live in critical areas such as old buildings with flat roofs

This was probably more the result of the stage in which the interviewees are in developing NBS interventions and the information they currently seek, rather than their capacity to understand the showcase presentations. As a result, some time was spent on discussing the usefulness of different typologies of NBS in relation to their context besides discussing scenario's itself. While this may seem less relevant, it is important to mention because the perspective of 'the receiver' (e.g. policymakers, practitioners) will steer how information is interpreted. In the case of agent-based modelling we know already that the threshold of understanding and ability to interpret the data/output is quite high, in the sense that one needs extensive skills in IT and data-analytics. In practice, not many policymakers and practitioners possess these skills (especially when multiple departments are involved) hence a 'user-translation' is always necessary. Being aware of this knowledge gap and understanding the information need of the receiver may prevent misinterpretations and miscommunication.

The showcases were developed to see if agent-based modelling has the potential as modelling tool for NBS planning processes. It is important to bear this in mind because in practice a better alignment between 'the receiver' and developer will take place before and in the early stages of model development, whereas the scenarios presented here were not developed to model specific cases within real-life contexts. Despite this absence of alignment, the policymakers that were interviewed could relate to the three different scenarios, and are convinced that this type of modelling is usable for different stages and for different purposes in the planning process, especially when the scenario is flexible enough to compare how different alternatives will turn out.

The review furthermore demonstrated that agent-based modelling could contribute to the social acceptance of NBS, in the sense that the scenarios provide evidence-based information on the impact of NBS interventions in a comprehensive manner. The social acceptance of NBS is an important step to take in mainstreaming the uptake of NBS. As depicted in Figure 31, the Triangle Model of Social Acceptance (Wüstenhagen et al., 2007), there are basically three areas in which social acceptance can accumulate: community, political/institutional and the market:

Figure 31: The Triangle Model of Social Acceptance, Wüstenhagen et al. (2007)

Socio-political acceptance concerns the acceptance of NBS both by the 'general public' as well as the key stakeholders and policymakers (EWEA, 2007). Whereas community acceptance concerns the acceptance of local interventions by local communities that are either affected by the effects of climate change and who thus have 'a stake' in the solutions that are adopted and/ or who are affected by the adopted NBS. Besides citizens, these communities also include a broader range of local stakeholders and local authorities. Market acceptance refers to the adoption and uptake of NBS practices by consumers, citizens as well as municipalities or others who purchase NBS products and services.

Scenario 2, *Urban heat mortality impact reduction through NBS,* and 3, *Socio-economic and commercial development resulting from NBS changes,* in particular offer 'hard numbers' which could be used to build confidence and create general support for NBS amongst politicians and broader audiences. Which could eventually result in the socio-political acceptance of NBS. Community acceptance entails the local acceptance of NBS which could be established through local dialogue sessions with local stakeholders. Information from scenario 2 and 3 can be used to inform stakeholders and feed into the discussion e.g. by pointing out potential risk areas, the impact of NBS interventions and potential alternatives. Scenario 1 *Water runoff and catchment improvement by NBS promotion in private gardens* is somewhat different in the sense that the scenario itself models if citizens accept, are willing and actually adopt NBS and is thus best to gain an insight in the market acceptance of NBS.

One important limitation in the usability of ABM that was mentioned during the showcase review concerns the organisational structure of the municipality, where departments operate in silos. This does concerns both access to data and information necessary to develop ABM-models, as well as the day-to-day responsibilities inpolicymaking. Communication and collaboration between the different departments is (often) limited which hampers cross-data analysis and integral interventions that transcend policy domains which is necessary for ABM-NBS modelling.

Lastly, it must be noted that developing ABM requires specific expertise (in IT) which is generally not present in public administration and thus requires hiring external advisors. Although the technology may be not as expensive, for municipalities with (very) limited financial resources the cost effectiveness of this type of modelling should be taken into account.

In sum, the interviewees regard agent-based modelling as a useful and complementary decision-support tool. Especially when the model allows for flexibility in adjusting certain elements, or a comparison between alternative interventions (and thus policy options) is possible. Despite the barriers that might hamper the uptake of NBS (e.g. financial, knowledge, organisational) and the practical usage of agent-based modelling, the decision-support tool would certainly help to generate more support for NBS.

9.3 Recommendations for future modelling efforts

The showcase models demonstrated that different impacts of NBS in the urban environment can be successfully simulated, inclusive of socio-economic factors, health impacts, economic effects, and climate mitigation impacts. The showcase models provided relatively course insights for two reasons. First, given the large number of assumptions made that were not based on local data as it was outside of the scope of the task to carry out local surveys for particular model parameters. Second, given the absence of specific data for particular buildings or built areas, generalised assumptions based on land use data were made. If more localised data and survey based data would be available, both deeper insights can be gained as well as more specific localised and valid data. For example, the areas or buildings in which 65+ year or older population typically live, could provide a spatial periodization of buildings where green roofs can have the highest mortality impact. Similarly, data on the actual instead of inferred type of garden that is privately owned by citizens, could provide for a more accurate assessment of the potential for rainwater management through NBS transformation of paved gardens. As such, in case of further developing the existing models, or other models, for purposes of feeding into NBS development decision making, a data collection exercise would need to be programmed in that combines local surveys with observational data which can draw from WP1.7 on urban data collection methodologies that is under development as of the writing of this report.

The questionnaires with city partners indicated that the simulations were indicatively useful in terms of the topics explored and what type of insights were provided (section 9.2) but that further work would be required to provide meaningful mechanisms in terms of feeding into NBS decision making. A key element that was found critical is to improve on the uncertainty found in the modelling results in relation to decision making. A first key step would be to quantitatively characterise the uncertainty in a standardised manner, so as to put forward possibilities to narrow the uncertainty for key decision making. Critical is also to take into account the organisational hierarchy of responsibilities within the municipality and partner organisations, and how different model information is useful for different stakeholders. Thereby further understanding is needed on what particular insights would be needed to further the implementation of NBS. To this end the implementation models typology used in WP1.2, that will be furthered in T5.4 within the context of socio-economic assessment will be of use to provide further alignment with municipal stakeholder processes. Also the output layer in this task will provide inputs in the data interrogation time series development in T3.5 for purposes of improving the comparison and providing continuous dashboard based insights into NBS performance. In future modelling efforts a better grounding of decision making processes would be of help, preferably by inclusion of municipalities and/or other decision makers in the conceptual model decision (as per Chapter 7) instead of only technical partners.

The tool used for developing the showcase models, Netlogo, was found to be highly suitable for rapid model development and testing of the conceptual ideas. Both by enabling quick adjustments based on partner suggestions, as well as providing a visual interface with no additional coding required to obtain results in a versatile manner including spatial maps. However, the main limitation was found in two aspects. First, the limited ability of the platform to carry out many simulation runs in sequence an automated manner as opposed to having manually log the results of every run, and start every new run manually. Because of this limitation substantial time needed to be spent on running the models. Especially in case of *Socio-economic and commercial development resulting from NBS changes* a model run takes over an hour as five years were simulated with 10 minute period intervals, because of which the number of model runs was limited to six per city. Second the limited ability of the platform to link with web and data streaming architecture, which is possible in case of other ABM packages such as MEAS, MASON and Repast-Simphony (section 2.4) as these utilise cross-platform programming languages including Java and Python, that can be readily linked to web and data platform architecture. When developing such models for replicability purposes within simulation platforms for recurring use, one of these different platforms would thereby be selected for programming. The downside is that these languages have more complexity and also do not come with similar in-built visualisation automation, thereby requiring substantially more coding time to provide a working model. However, in case of extensive familiarity with such programming languages that would not provide a barrier to deployment.

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Annex A. Interview Guide

Table 1: Questionnaire (before interview)

Questions	Who
1. Describe your role at the municipality / metropole (Milan) in relation to NBS interventions (what are your tasks and responsibilities)	
2. Rate your top 3 knowledge gaps regarding NBS interventions. How are you dealing with these knowledge gaps currently?	
3. Rate your top 3 knowledge problems with relation to the types of NBS-related challenges that the models addresses (Heatwave mortality impacts today and in the future, potential for economic retail/tourism development around parks and green spaces, and water management in cities by greening of private gardens0.	

Table 2 Questionnaire Skype interview

Questions	Who
1 by 1 presentation of the three scenarios	Rembrandt. Questions 1 and 2 need to be asked after each scenario
1. For each scenario: what is your first impression of the scenario	Yvette/ Sylvia
2. For each scenario: to what extent and how is this scenario applicable to your situation (challenges connected to NBS)? If not, do you think the scenario can be translated to your context? **- Considering the challenges you have with regard to this area/topic, which elements or parts of the scenarios are interesting and useful and in what manners?** **- Could you explain how exactly this**	Present Step-by-Step Guide when addressing the planning process

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scenario can be useful? (for what, when/in which phase of the planning process, for whom else next to yourself, etc.) - **What would need to be addressed/included in this scenario in order to make is more useful to your specific situation/ context?**	
After the three presentations	
3. Considering the three scenarios discussed, which one do you find most interesting? And is this one also the most useful one? Why and how?	
4. Now you have seen three examples (very different ones) of how the ABM can be used for NBS interventions, what is your general impression of Agent-based modelling? Is it useful for your planning practice (e.g. other scenarios)?	•
5. What kind of improvements are needed? (e.g. design, content, jargon, structure, additional information needed for interventions). Can you identify limitations (data-sets available, outcomes, level of understanding, etc.)	