Sustainable Urbanizing Landscape Development (SULD) decision support tool: report on frontrunner Aqua Cases

Aqua-Add Technical Report nº.03, prepared by:

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Aqua-Add project

June 2014

Citation:

Roebeling, P.C., Teotónio, C., Alves, H. and Saraiva, M., 2014. Sustainable Urbanizing Landscape Development (SULD) decision support tool: report on frontrunner Aqua Cases. Aqua-Add project, Aqua-Add Technical Report nº.03, Centre for Environmental and Marine Studies (CESAM), Department of Environment and Planning (DAO), University of Aveiro (UA), Aveiro, Portugal. 33pp.

Executive summary

This report has been developed in the context of the international co-operation project Aqua-Add (Deploying the added value of water in local and regional development), aiming at the sharing of knowledge and experience between project partners as to better deploy the potential of 'water' (economically, socially and environmentally) in urbanised landscapes and to improve the implementation of water measures in local and regional spatial development. Aqua-Add not only collects, analyses, disseminates and promotes the specific functions, services and values of green/blue spaces, but also develops and applies a Decision Support Tool (DST) that: i) demonstrates the (potential) social, environmental and economic impacts of different water management scenarios, and ii) facilitates the planning process and better informed decision making across stakeholders.

The objective of this report is to present, not only, the theory and methodology underpinning, but also, the application of the Sustainable Urbanizing Landscape Development decision support tool (SULD; Roebeling et al., 2007). Case studies are presented for the two frontrunner Aqua Cases (Aveiro PT; Eindhoven NL), to assess the impact of location-specific green/blue space and socio-economic scenarios on the location of residential development, housing quantity, residential development density, population density, population composition, household living space and real estate values.

For the Aveiro case study, assessed scenario simulations include: i) the establishment of the Polis urban park, ii) an economic crisis scenario where expendable incomes decrease by 10%, and iii) the combination of the Polis urban park and economic crisis. Results for the Polis urban park scenario show that the establishment of this park leads to a more condensed city with higher real estate values – resulting in a net increase in total real estate value. Households are willing to accept a smaller living space when able to live in the vicinity of the Polis urban park and, at the same time, are willing to pay higher real estate (rental) values. The economic crisis scenario leads to a smaller city and mixed impacts on real estate values – leading to a net and significant decrease in total real estate value. Medium income households move from the city's periphery to the urban centres, and high income households move into desirable areas that become available. Finally, the combined Polis urban park and economic crisis scenario shows that the impacts of the economic crisis are somewhat dampened by the Polis urban park. The contraction of the urban residential area is less strong and the decrease in total real estate value less severe. The net increase in total real estate value due to the establishment of the Polis urban park is similar in the situation with or without economic crisis.

For the Eindhoven case study, scenario simulations include the realization of: i) the Emmasingel-kwadrant project, ii) the Genderpark project, and iii) all five projects (i.e. the Genderpark, Frederika van Pruisenweg, Willemstraat, Emmasingelkwadrant and Stationsgebied projects). Results for the Emmasingelkwadrant scenario show that the establishment of the park attracts medium and high income households to the centre of Eindhoven, where urban parks are currently absent. Households are willing to accept a somewhat smaller living space and, simultaneously, are willing to pay slightly higher real estate (rental) values – resulting in a net increase in total real estate value. The Genderpark requalification scenario attracts and benefits mainly high income households, that are willing to accept a somewhat smaller living space and, simultaneously, willing to pay somewhat higher real estate (rental) values. Overall this leads to a small net increase in total real estate

value. Finally, the combined scenario shows that the establishment of all projects leads to an increase in population. Medium and high income households are attracted to the new green/blue spaces in the centre of Eindhoven (Emmasingelkwadrant and Stationsgebied projects), and high income households to the requalified green/blue spaces (Genderpark, Frederika van Pruisenweg and Willemstraat projects). All households benefit from these interventions through an increase in real estate (rental) values, while accepting a smaller living space in the vicinity of these green/blue spaces – leading to a net increase in total real estate value.

Based on these results, the following three main lessons can be derived regarding the value-added of green/blue spaces in urban and urbanizing landscapes.

1. First, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces brings value-added to residents in urban areas – reflected by an increased willingness-to-pay for housing and appreciation of real estate values in the area surrounding the intervention;
2. Second, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces leads to more condensed cities – reflected by an increase in population (in particular medium and high income households) and population density surrounding the intervention area;
3. Finally, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces dampens the negative impacts of economic crises – reflected by reduced urban land abandonment and real estate value depreciation.

In all abovementioned cases, the value added of green/blue space is dependent on the location, size and type of intervention relative to existing urban residential areas, urban centers and environmental amenities.

The SULD decision support tool can be used by Aqua-Add partners and stakeholders in a spatial development process with a 'water challenge'. In these participatory processes, the social, environmental and economic impacts of water challenge scenarios is quantified and illustrated to all stakeholders in the form of tables, graphs and/or maps. Use of this information, but also the joint collection of data as input, creates an open setting and invites stakeholders to discuss and express new ideas and insights. Consequently, it encourages stakeholders to reflect about their reality and future possibilities – effectively engaging them in the design of urban development plans where the value of water and green spaces may assume a forefront position.

Acknowledgements

This report has been developed in the context of Aqua-Add (Deploying the added value of water in local and regional development), a 3-year co-operation project of 11 partners from 8 EU regions. The project aims to share knowledge and experience between the project partners, to better deploy the potential of 'water' (economically, socially and environmentally) in urbanised landscapes and to improve the implementation of water measures in local and regional spatial development. The project is co-financed by the European Regional Development Fund (ERDF) along with each of the 11 partners and made possible by the INTERREG IVC programme. The Interregional Cooperation Programme INTERREG IVC helps Regions of Europe work together to share experience and good practice in the areas of innovation, the knowledge economy, the environment and risk prevention.

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1. Introduction

European regions and cities face important challenges related to water, including water storage and discharge after (heavy) rainfall events, water quality and the impact of summer droughts on water supply. This sense of urgency is getting larger in the face of climate change. To address these challenges, it is evident that 'water' must become an integrated part of spatial development policies and their implementation. Unfortunately, until now, water management issues are often secondary. Although dealing with water does not seem urgent in the short term, it is clear that implementing measures in the medium term is necessary to prevent problems in the long term.

There are, however, many obstacles to achieving medium-long term water management goals. First, water issues compete with other public concerns, resulting in insufficient public and political support. Second, stakeholders in the public domain are often not aware of the added value that effective water management can bring to spatial development. Finally, efficient water management will avoid high costs in the long term and, in turn, result in higher housing/real estate values.

The objective of the Aqua-Add project is to "better deploy the potential of 'water' (economically, socially and environmentally) in urbanised landscapes and to improve the implementation of water measures in local and regional spatial development". To this end, Aqua-Add builds on exchange of experiences and good practices – including soft testing on:

1. Stakeholder involvement;
2. The added value of green/blue space in urbanised landscapes;
3. Practical and successful business models for 'water-projects'.

Knowledge on the functions, services and values of green/blue spaces is incomplete and not easily accessible for policymakers, spatial planners, developers, entrepreneurs and other stakeholders – especially when it comes to economic and social values. Aqua-Add not only collects, analyses, disseminates and promotes the specific functions, services and values of green/blue spaces, but also develops and applies a decision support tool that: i) demonstrates the (potential) social, environmental and economic impacts of different water management scenarios, and ii) facilitates the planning process and better informed decision making across stakeholders. The decision support tool is developed and applied to eight Aqua Case studies (two frontrunner Aqua Cases[1] and six other Aqua Cases[2]), with input from partners that are knowledge institutions and based on the needs of the partners that are regional/local authorities.

The objective of this report is to present, not only, the theory and methodology underpinning, but also, the application of the Sustainable Urbanizing Landscape Development decision support tool (SULD; Roebeling et al., 2007). Case studies are presented for the two frontrunner Aqua Cases (Aveiro PT; Eindhoven NL), to assess the impact of location-specific green/blue space and socio-economic scenarios on the location of residential development, housing quantity, residential development density, population density, population composition, household living space and real estate values. Stakeholders have been involved in the development and application of SULD from an early stage,

[1] Frontrunner Aqua Cases include Aveiro (Portugal; PT) and Eindhoven (Netherlands; NL).

[2] Other Aqua Cases include Bremerhaven (Germany; DE), Copenhagen (Denmark; DK), Debrecen (Hungary; HU), Imperia (Italy; IT), Lyon (France; FR) and Sofia (Bulgaria; BU).

providing input on the type and format of information to be produced as well as scenarios to be assessed.

The structure of the report is as follows. In the next chapter a review of urban land use change approaches is presented, thereby differentiating between non-economic and economic models of land use change. In Chapter 3 the modelling approach underlying the SULD decision support tool is presented, with emphasis on the Input, Model and Output components. Chapter 4 provides a short description of the Aveiro and Eindhoven frontrunner Aqua Cases and, in turn, respective results for various green/blue space projects and socio-economic scenarios are presented in Chapter 5. Finally, Chapter 6 provides conclusions and recommendations.

2. Literature review: urban land use change approaches

Changes in land use patterns can be attributed to a wide range of factors, including economic development, population growth, changes in demographics, and modifications in landscape features. Different modelling approaches have been used for explanatory, forecasting and simulation purposes. However, not one explicit classification for land use change models exist in the urban economic and geographic literature. Overlap in characteristics of different models and the convergence of models to a more integrated approach (see for example Ward et al., 2003) has led to plural typology within the literature. In discussing the approaches used in describing and explaining urban land use change we follow the broad distinction made by Irwin and Geoghegan (2001) and Eppink et al. (2004), which differentiates between non-economic and economic models of land use change.[3]

2.1. Non-economic models of land use change

Non-economic or non-optimisation models are generally characterised by large scale exogenous forces, describing land use patterns at the regional, national or even global level. These models start from the viewpoint of a geographical entity or unit and are, therefore, very efficient in spatial representation of land use change. With improved spatial modelling techniques, such as GIS, and better and more remote sensing data available, these models have received considerable attention in recent studies. Rather than relying on micro-economic theory, however, these models use heuristic decision rules, cellular automata and multi-agent systems to generate land use patterns (Parker et al., 2003; Eppink et al., 2004).

Hueristic models

Heuristic decision rules, based on expert knowledge regarding historical land use patterns, are used to represent the complex decision process of which the actual land use pattern is the result (Baker, 1989; Eppink et al., 2004). An example of heuristic models is the Markov chain model, which focus on a geographical unit as do Cellular Automata (CA) models (see below). Cell states depend upon the probabilistically and temporally lagged cell state values of its surrounding cells. The calculation of a cell's probability to transform to a different state (or its land use) is based upon a set of criteria that is evaluated in each time period (Anderson et al., 2002; Deal and Schunk, 2004).

Cellular automata

Cellular Automata (CA) are spatially explicit discrete cell-based models. A CA-model consists of four components: cells, neighbourhoods, states and transition rules (Parker et al., 2003; Deal and Schunk, 2004; Eppink et al., 2004). The geographical area under investigation is represented by a regular spatial grid of cells. Fundamental to this grid is that cells have some adjacency to each other and that they can possess one of a finite number of states (Ward et al., 2003). The state of a cell (or its land use) is determined by the state of its neighbouring cells in the previous time period and a set of transition rules that govern the behaviour of the system. These transition rules express the probability or likelihood that a cell will change from one state to another, given the current land use distribution and the cell specific

[3] In addition to these extremes of land use change models, so called hybrid models of land use change are mentioned in literature. Hybrid models combine the characteristics of non-economic and economic models of land use change and, thus, include exogenous forces as well as micro-economic decision variables (Eppink et al, 2004).

characteristics (Deal and Schunk, 2004). In a standard CA-model cell spaces tend to be of uniform shape and size, however, several studies have incorporated heterogeneity among cells (White and Engelen, 2000). Despite the simplicity of the transition rules that represent the micro-level behaviour, CA-models can produce complex macro-level outcomes and land use patterns. CA models can be used for simulation, estimation or a combination of both (Irwin and Geoghegan, 2001).

Multi-agent systems

Multi-Agent Models (MAMs) are, frequently, considered a special type of CA (White and Engelen, 2000). What distinguishes MAMs from CA is that they focus more on human actions and interactions, whereas CA focus more on landscape entities and their transition. Central to MAMs is that they combine a landscape (represented by a cellular grid) and a decision making framework. All agents are assumed to make autonomous decisions that are linked to the environment, the latter being shared by all agents through communication and interaction (Parker et al., 2003; Ligtenberg et al., 2004; Brown et al., 2004). Because of this complex dynamic system, a MAM is able to show how individual micro-level actions aggregate up over scales and time to form certain land use patterns. The macro-level outcome of such interactions among individual agents is also referred to as "emergent" phenomena (Parker and Metersky, 2004).

2.2. Economic models of land use change

Economic or optimisation models are generally characterised by small scale processes, ranging from the level of individuals or households to the level of local areas. An individual agent or public decision maker optimises decision variables, such as volume, spatial allocation or timing of development, in order to maximize an objective function representing, for example, utility, profit or income (Eppink et al., 2004). This provides the opportunity to assess and understand an individual's response to incentive changes and, hence, enables policy evaluation. Economic models of urban land use change are used to investigate urban sprawl (Irwin and Bockstael, 2002; Wu and Plantiga, 2003; Wu, 2006), optimal city size and urban concentration (Henderson, 2003), timing of land development (Irwin and Bockstael, 2004), and land management policy measures (Bento et al., 2006).

The traditional economic model used to explain land use and land rent patterns is the Alonso-Muth-Mills model or bid-rent model (see Mills and Hamilton, 1994; O'Sullivan, 2000). The central idea behind this model is that households optimize their residential location by trading off commuting costs to the urban centre versus land rent costs, subject to a budget constraint. The maximum rent a household is willing to pay for a unit of land will adjust for difference in accessibility to the urban centre so as to maintain a given level of utility.

Although considerable extensions have been made to make this model more sophisticated, its main shortcoming (the lack of spatial explicitness) has remained focal point of much criticism (see Mills and Hamilton, 1994; O'Sullivan, 2000). In many studies the area under consideration is treated as a "featureless" plane, with the purpose of increasing analytical tractability, thereby, however, failing to explain the impact of heterogeneous landscape features on the resulting land use pattern. More recent studies have been able to incorporate some spatial heterogeneity into their models.

Brueckner et al. (1999) use an amenity-based model to explain why western European city centres tend to be populated by rich households and the urban fringe by the poor, while the reverse pattern holds true for typical American cities. Although in urban economic literature there is extensive attention for environmental amenities, this is a rare example of a study that includes urban composition as an amenity. The historical centre of many European cities is, for instance, regarded as an amenity that attracts rich households to the city.

Wu and Plantinga (2003) take into account spatial features by developing a model to explain the influence of amenities on urban development patterns. In a static two-dimensional spatially explicit model, they examine the impact of exogenously determined geographic features (such as a shore-line or a scenic hill) on land development patterns. Wu (2006) extends this model to examine the interaction between endogenous social amenities (e.g. provision of public services) and different income groups, while Wu and Irwin (2003) and Roebeling et al. (2007) extended this model to develop a dynamic spatially explicit model to explore the interaction between land use pattern and water quality.

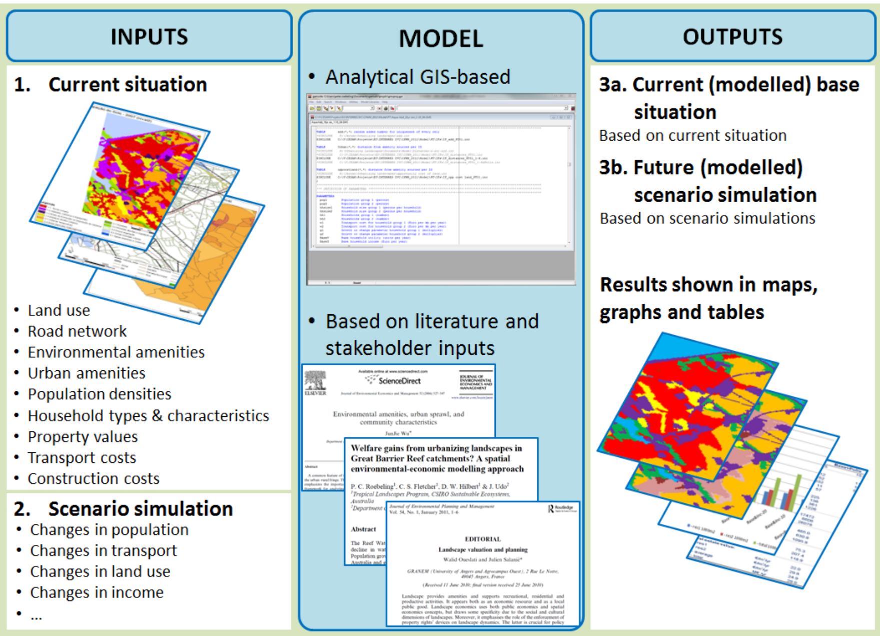
Besides landscape heterogeneity, several studies have also been able to incorporate spatial interactions among households as an endogenous process that results in the formation of a specific urban spatial structure or pattern (Irwin and Geoghegan, 2001; Irwin and Bockstael, 2002). More recent studies also investigate the efficiency and distributional impacts of alternative policy measures designed to protect a certain amount of land from conversion into residential use (Irwin and Bockstael, 2004; Bento et al., 2006). They assess smart growth policies (e.g. clustering and urban boundaries) and economic policy instruments (e.g. development, property and gasoline taxes) within a framework somewhat similar to Wu and Plantiga (2003).

3. Methodology: the SULD modelling approach

The Sustainable Urbanizing Landscape Development decision support tool (SULD; Roebeling et al., 2007) is a GIS-based model, based on an analytical urban economic model with environmental and urban amenities (see Mills, 1981; O'Sullivan, 2000; Wu & Plantinga, 2003), that allows for the assessment of sustainable landscape development patterns and/or scenarios. Based on scientific and stakeholder input (e.g. scenarios for climate change adaptation, population growth, household characteristics and economic development), the model assesses the economic and quality-of-life benefits of green/blue space development and/or rehabilitation. It provides information that is normally not available to stakeholders in the urban planning process (e.g. added value in terms of household welfare, land value, preferred locations and cost-benefit indicators), and is tailored to be used by regional/local authorities and stakeholders in spatial development processes with a 'water challenge'.

Stakeholders are involved in the development and application of SULD, providing input on the scale, type and format of information to be produced. In this participatory process, the social, environmental and economic impacts of green/blue space scenarios is determined and illustrated to stakeholders, and scenario simulation results may be used as input for the development of urban plans. This involvement facilitates the identification and communication of different views and interests, and will encourage their effective engagement in a participative design of urban development plans.

Figure 1 Structure of the SULD decision support tool



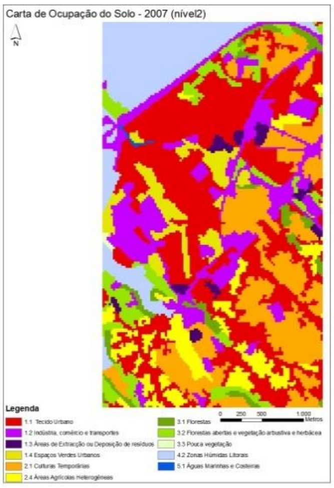
SULD contains three components (see Figure 1). The **Inputs** component contains the data for the current situation as well as the scenario simulations. The **Model** component contains the mathematical equations that transpose relevant input data into corresponding indicator values. Finally, the **Outputs** component presents the simulated results (indicator values) for the current situation and scenario simulations. The following sections provide a brief description for each of these components.

3.1. Inputs: Data requirements

For SULD to be applied to each case study, it is essential to define the study area – i.e., the area to be shown/discussed with stakeholders (X by Y km). Note, however, that the model area (the area used for model calculations) corresponds to a larger area (e.g. 1.25*X by 1.25*Y km) so that amenities close to the study area, but not covered by it, can be considered in the analysis as they may influence households' location preferences.

Accordingly, for each of the case studies the following spatial data for the model area (1.25*X by 1.25*Y) is retrieved:

Figure 2 Land use map



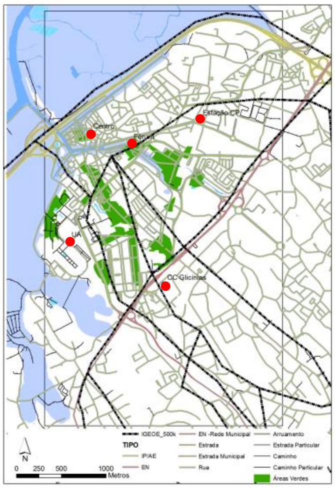
a. Land use: The land use map identifies the following land use types (see Figure 2):
   - Forest areas;
   - Water;
   - Open space / Agricultural areas;
   - Urban commercial / Industrial areas;
   - Urban green/blue spaces;
   - Urban residential areas.

   Sources of land use data include the Municipal Master Plan (GBK in The Netherlands; PDM in Portugal) and/or land use and cover maps like the COS2007 (IGP, 2008) or CLC2006 (EEA, 2009).

b. Road network: The road network map identifies the major road connections (black lines in Figure 3), including the following road types:
   - Highway;
   - Provincial;
   - Main.

   Sources of road network data include the National, Regional or Municipal Road Network maps. Complementary to these sources, road networks are checked and corrected using Google Earth (http://www.google.com/earth/index.html).

Figure 3 Road network and amenities



c. Environmental amenities: The environmental amenity map (green shapes in Figure 3) includes the following:
   - Green/blue space location;
   - Green/blue space type or quality (e.g. urban park, neighbourhood park or local park);
   - Other relevant environmental amenities in the model area (e.g. lagoon, lake or ocean).

   Sources of environmental amenity data include the Municipal Master Plan (GBK in The Netherlands; PDM in Portugal), land use and cover maps (COS2007 - IGP, 2008; CLC2006 - EEA, 2009) and Google Earth (http://www.google.com/earth/index.html).

d. Urban amenities: The urban amenity map (red dots in Figure 3) can include the following urban amenities:
   - City centre location(s);
   - Shopping centre location(s);
   - Railway station location(s);
   - Metro station location(s);

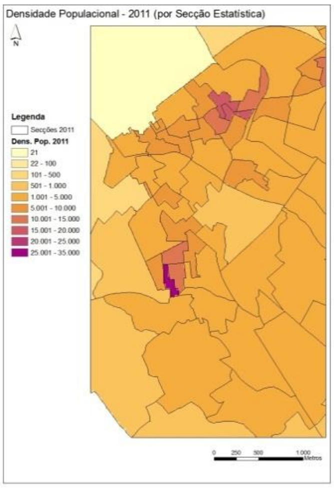
- Business centre location(s);
- Location of other relevant urban amenities in model area.

Sources of urban amenity data include the Municipal Master Plan (GBK in The Netherlands; PDM in Portugal) in combination with information from Google Earth (http://www.google.com/earth/index.html).

e. Population densities: The population density map includes the following information (see Figure 4):
   - Neighbourhood location (shape);
   - Neighbourhood size (km^2);
   - Neighbourhood population (persons);
   - Neighbourhood population density (persons/km^2).

   Sources of population (density) data per neighbourhood include the National Bureau of Statistics (CBS in The Netherlands; INE in Portugal). The neighbourhood shape file is, generally, available at the demographics and/or cadastral department of the municipalities.

Figure 4 Population density



Similarly, for each of the case studies the following non-spatial data for the model area (1.25*X by 1.25*Y) is retrieved:

a. Household types: To characterize households in the best possible way, the following household survey) information is needed:
   - Age of the head of household (years);
   - Persons per household (number of residents);
   - Expendable income (€/month) and expenditure distribution (%) per household;
   - Household composition (single; single parent; couple; couple w/ children);
   - Education per household (none; primary; secondary; higher; university);
   - Type of residence per household (apartment; terraced; semidetached; detached);
   - Living space per household (m^2);
   - Real estate value (€/m^2).

   This type of information is typically obtained through household surveys, in which households are asked to provide information on all of these variables. In turn, households are stratified/clustered on the basis of one or more of these variables and corresponding household type characteristics calculated (age; household size; income; etc.). In case this type of information is not available, the following (minimum) information is required:
   - Persons per household (number of residents);
   - Expendable household income (annual net income in €/yr, according to the equivalised income quintiles);
   - Household expenditure distribution (% food; % clothing; % housing; % furniture; % health; % transport; % communications; % recreation/culture; % education).

   Sources of household characteristics data include the National Bureau of Statistics (CBS in The Netherlands; INE in Portugal) – typically census data and household budget surveys.

b. Property value: The average property value per neighbourhood (€/m^2) is, generally, obtained from the cadastral data base.

c. Transport costs: The average transport costs (€/km) can be obtained for private (car) and public (bus; metro) transport options. Figures can be obtained from various sources.

d. Construction costs: The average construction costs (€/m^2 or €/m^3) will depend on the number of floors of the building – generally, the larger the number of floors the larger the building costs. These figures are obtained from, for example, builders, construction companies and/or real-estate developers. Note that the construction costs do not include the value of land.

3.2. Model: Sustainable Urban Landscape Development (SULD)

The SULD decision support tool (Roebeling et al., 2007) builds on the classic urban economic model with environmental amenities, based on the Alonso-Muth-Mills bid-rent model (Mills, 1981; O'Sullivan, 2000; Wu & Plantinga, 2003). In essence the model determines the value of housing given its' location relative to urban centres and environmental amenities – i.e. the equilibrium price for which demand for and supply of housing are equal.

The **demand side** is represented by households, characterized by their preferences for a certain set of goods and services: residential space *S*, other goods and services *Z*, and environmental amenities *e*. The utility/welfare obtained by households in each location is a function of their preferences, distance to environmental amenities and income. Households maximize their utility/welfare *U* at location *i* subject to the budget constraint *y*, which is spent on housing *S*, other goods and services *Z*, and transportation from the residential area to the urban centre ($p_x x$):

$$\underset{S_i,Z_i}{Max}\,U_i(S_i,Z_i)=S_i^{\mu}Z_i^{(1-\mu)}e_i^{\varepsilon}$$

$$\text{subject to } y=p_i^h S_i+Z_i+p_x x_i$$

U_i = household utility
S_i = residential space
Z_i = other goods and services
e_i = environmental amenity value (1)
y = household income
p_i^h = rental price housing
p_x = commuting costs
x_i = distance to urban centre

The environmental amenity value e_i that the household experiences at location *i* is decreasing with distance from the amenity source, and is determined by:

$$e_i = 1 + a \cdot \exp^{-\eta z_i} \tag{2}$$

where *a* is the environmental amenity, *η* is the amenity distribution factor, and where z_i is the distance from location *i* to the environmental amenity *a*. The household's bid-rent price for housing p_i^{h*} at location *i* can now be derived (see Roebeling et al., 2007), and is given by:

$$p_i^{h*} = \left(\frac{\mu^{\mu}(1-\mu)^{(1-\mu)}e_i^{\varepsilon}(y-p_x x_i)}{u}\right)^{\frac{1}{\mu}} \tag{3}$$

where *u* denotes a given utility level *U*. This equation gives the household's maximum willingness to pay for housing (p_i^{h*}) at location *i*, and represents the demand side of the housing market. Consequently, households optimize their residential location by trading off utility from environmental amenities (e_i), residential space (S_i) and other goods and services (Z_i) versus land rent ($p_i^h S_i$) and commuting costs ($p_x x_i$), subject to a budget constraint (y).

Considering that households face a given rental price (they are “price-takers”), they can select the faced rental price and obtained utility/welfare from the environmental amenities and other goods by choosing the residential location *i*.

The **supply side** is represented by developers, who maximize their profit by trading off returns from housing development density net of associated development costs, subject to households’ willingness to pay for housing. Developers aim to maximize their profit π at location *i*, which is given by the revenue of construction (p^hD) net of incurred development costs ($l + c_0 + D^\eta$):

$$\underset{D_i}{Max}\,\pi_i(D_i) = p_i^h D_i - (l_i + c_0 + D_i^\eta)$$

with $D_i = n_i S_i$

π_i = developer’s profit
D_i = development density
p_i^h = rental price housing
l_i = opportunity cost land (4)
$c_0 + D_i^\eta$ = construction costs
n_i = household density
S_i = residential space

The developers bid-price for land r_i^{**} at location *i*, can now be derived (see Roebeling et al., 2007), and is given by:

$$r_i^{**} = \left(mp_i^{h**}\right)^{\frac{\eta}{\eta-1}} - c_0 \tag{5}$$

with $m = [(\eta-1)^{(\eta-1)/\eta}]/\eta$. This equation determines the minimum rental price for housing the developer is willing to accept (p_i^{h**}) at location *i*, and represents the supply side of the housing market. Thus, developers will develop when residential land rents ($p_i^hD_i$) are larger than the opportunity cost of development ($l_i + c_0 + D_i^\eta$) – which is equal to the forgone land rents (l_i; e.g. revenues from agriculture or payments from ecosystem services) and the value of the capital invested in converting the land ($c_0 + D_i^\eta$).

Finally, **equilibrium** occurs where supply for housing equals demand for housing and, thus, $p_i^{h*} = p_i^{h**}$. The land rent price r_i at location *i* can now be derived using Equation (3) and (5) (see Roebeling et al., 2007), and is given by:

$$r_i = \left(\frac{ke_i^{\varepsilon}\left(y - p_x x_i\right)}{u}\right)^{\frac{\eta}{\mu(\eta-1)}} - c_0 \tag{6}$$

with $k = (\mu m)^\mu (1-\mu)^{(1-\mu)}$. The corresponding optimal household density n_i at location *i* is now given by:

$$n_i = \frac{D_i}{S_i} \tag{7}$$

with $S_i = \dfrac{\mu\left(y - p_x x_i\right)}{p_i^{h*}}$ (necessary condition for optimality U_i)

$D_i = (\eta-1)^{-\frac{1}{\eta}}\left(r_i + c_0\right)^{\frac{1}{\eta}}$ (necessary condition for optimality π_i)

and where p_i^{h*} and r_i are given in Equation (3) and (6), respectively.

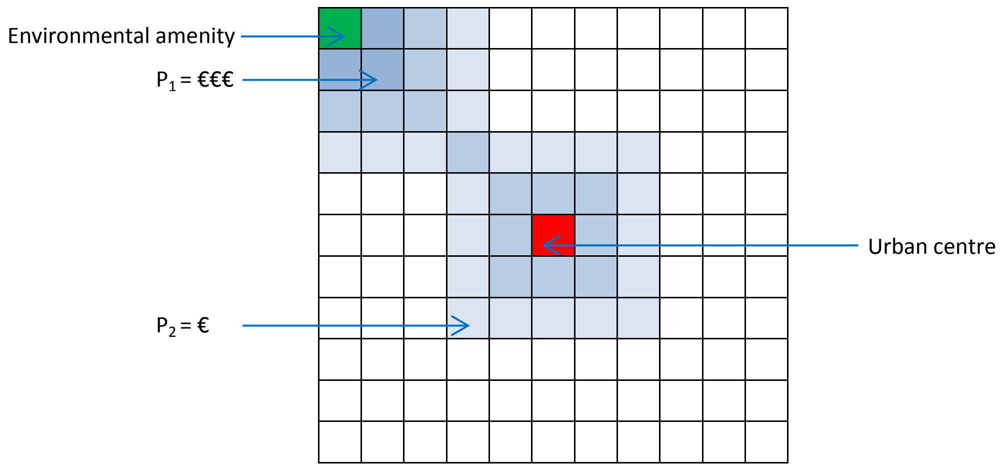
The SULD decision support tool (Roebeling et al., 2007) builds on a numerical application of the above described classic urban economic model with environmental amenities, using GAMS 21.3 (Brooke et al., 1998). The objective function maximizes, for a given household population Q_t, benefits B from residential land uses L_i^{res} and non-residential land uses L_i^{nres} net of development costs (l_i+c_0+D_i^{η}) over all locations i, so that:

$$\underset{L_i}{Max}\, B(L_i) = \sum_i \left(l_i L_i^{nres} + (r_i - l_i - c_0 - D_i^{\eta}) L_i^{res} \right) \tag{8}$$

subject to $Q_t = \sum_i n_i$ and $L_i^{res} + L_i^{nres} = a_i$, and where l_i is the opportunity cost of land, r_i is the land rent price, and a_i is the area of location i. Note that land use conversion can take place between residential and user-defined non-residential land uses – the remaining land uses are fixed.

Hence, residential development patterns and values for a specific population size are determined given the distance to the urban centres and the location of environmental amenities (see Figure 5). Each location i has a specific value as a function of distance to the urban centres and environmental amenities as well as demand for and a supply of housing.

Figure 5 Residential development patterns and values relative to amenities



Thus, the model calculates the equilibrium price for housing as a function of demand and supply. It determines the location of residential development, the residential development density, the population density, the housing quantity, the living space and the real estate value, taking into account households' willingness to pay as well as the opportunity cost of land.[4] Consequently, SULD is not a static calculator of real estate values as a function of proximity to urban and environmental amenities like Zizabi (http://zizabi.com/) or TEEB.stad (http://www.teebstad.nl/). Instead, it allows to assess the impact of location-specific green/blue space, infrastructure and socio-economic scenarios on the location of residential development, housing quantity, residential development density, population density, population composition, household living space and real estate values.

[4] In this case, the opportunity cost of land corresponds to the rent that land owners give up when they decide to urbanize an area instead of keeping its former use (e.g. if it was formerly used for agriculture, its opportunity cost would correspond to the agricultural rent owners would not gain due to its conversion in urban area).

3.3. Outputs: Results presentation

SULD model simulation results are presented in different ways. Depending on the public to be addressed, results presentation formats include tables, graphs and maps.

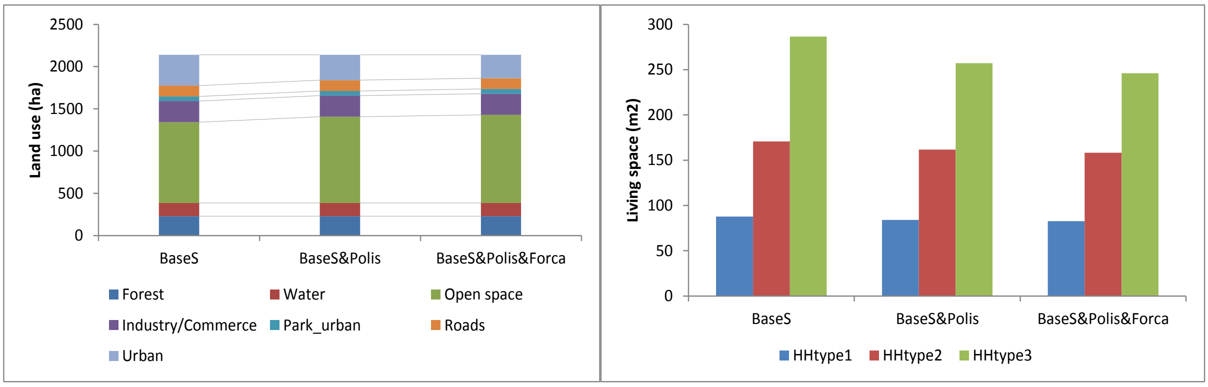
A summary overview of key scenario simulation results is given in tabular format, including information on land use, population, housing quantity, development density, living space and real estate value (see Table 1). 'Land use' provides information on seven different types of land use in the study area (in ha). 'Population' gives the number of residents in the study area (in #), which are grouped in three different social classes – i.e. low, medium and high income households. 'Housing quantity' provides information about the total built area (in m^2), 'Development density' refers to the total floor space (in m^2) and 'Living space' refers to the average living space (in m^2/hh) per household type. Finally, 'Real estate value' provides information on the annual rental value of living space (in €/m^2/yr) per household type.

Table 1 SULD tabular information provided for scenario simulations

	Unit	Description
Land use		
- Forest	ha	Forest, open forest, shrub and herbaceous vegetation
- Water	ha	Ocean, lakes, reservoirs, ponds, pools, rivers and canals
- Open space / Agriculture	ha	Brownfields / Annual, perennial and heterogeneous agriculture
- Industry / Commerce	ha	Industry, commerce and transport infrastructure
- Park_urban	ha	Urban green/blue space (e.g. urban, neighbourhood or local park)
- Roads	ha	Road network
- Urban	ha	Urban residential fabric
Population		
- per type of household	#	Resident population per household type
Housing quantity		
- per type of household	1000 m^2	Square meters of built area per household type
Development density		
- per type of household	1000 m^2	Square meters of floor space per household type
Living space		
- per type of household	m^2/hh	Square meters of living space per household type
Real estate value		
- per type of household	€/m^2/yr	Annual rental value of living space per houshehold type

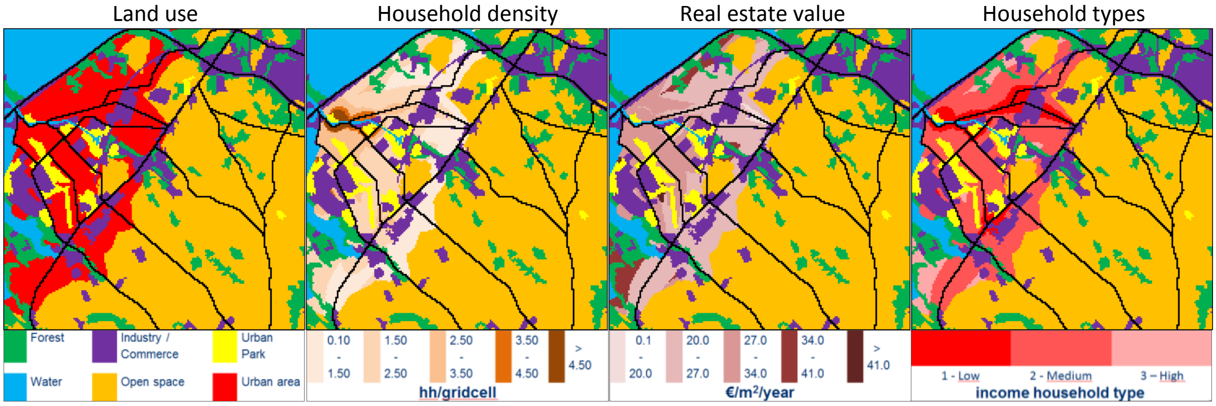
To allow for easy comparison between scenario simulations, results are presented in graphical format (column charts) for selected areas of information presented in the tabular format (see Table 1). Figure 6 provides an example for land use (stacked column chart) and household living space (clustered column chart) across the base scenario (BaseS) and two scenario simulations (BaseS&Polis; BaseS&Polis&Forca).

Figure 6 SULD graphical information provided for scenario simulations



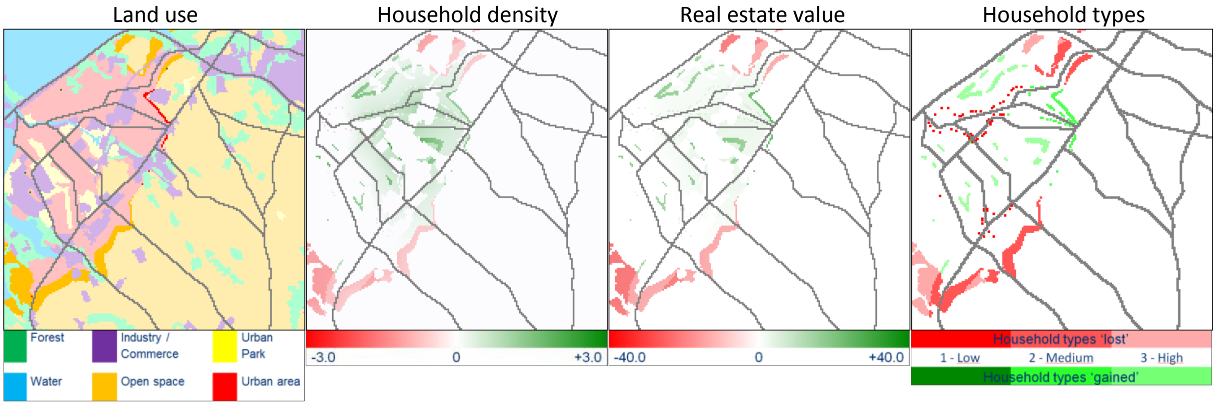
Finally, results are presented in cartographic format to visualize and assess the spatial implications of scenario simulations, including information on land use, household density, real estate value and household type distribution patterns (Figure 7). The 'Land use' map shows the land use in the study area, the 'Household density' map indicates the number of households at a specific location (in #/grid cell), the 'Real estate value' map indicates the annual rental value of living space at a specific location (in €/m^2/yr), and the 'Household types' map identifies the type of household living at a particular location (low, medium and high income households).

Figure 7 SULD cartographic information provided for scenario simulations



To allow for better comparison of the spatial implications between scenario simulations, difference maps are created – i.e. maps that indicate the location and extent of change relative to the base scenario (Figure 8). The 'Land use' difference map shows the land use change in the study area (bright colours corresponding to the different land uses). The 'Household density' difference map indicates the decrease (red) or increase (green) in the number of households at a specific location (in #/grid cell) and, similarly, the 'Real estate value' difference map indicates the decrease (red) or increase (green) in annual rental value of living space at a specific location (in €/m^2/yr). In both cases, the brighter colours correspond to the largest changes. Finally, the 'Household types' difference map identifies the types of household lost (red shades) or gained (green shades) at a particular location.

Figure 8 SULD cartographic information provided for scenario simulation comparison



4. Frontrunner Aqua Case study descriptions

The SULD decision support tool will be developed and applied to eight Aqua Case studies, including two frontrunner Aqua Cases (Aveiro PT; Eindhoven NL) and six other Aqua Cases (Bremerhaven DE; Copenhagen DK; Debrecen HU; Imperia IT; Lyon FR; Sofia BU). This chapter provides a short description of the Aveiro (Section 4.1) and Eindhoven (Section 4.2) frontrunner Aqua Cases – for a more detailed description of the Aqua Cases, please refer to Roebeling et al. (2012).

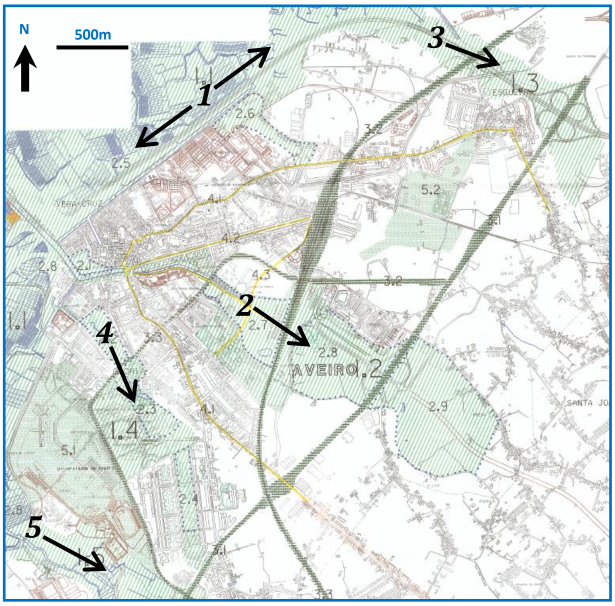
4.1. Aveiro (PT)

The city of Aveiro (~26,078 inhabitants and ~1,219 inhabitants/km^2), underwent severe urbanization and industrialization over the last decades – in particular along the margins of the Ria de Aveiro lagoon. This resulted in an increase in floods and flooding risk, affecting economic activities, biodiversity, people and infrastructures. Despite the measures implemented to protect Aveiro from inundations, the city has had severe floods over the last 100 years. These floods were caused by high water levels in the Ria de Aveiro in combination with large river flows, and affected mainly the historical city centre.

4.1.1. Problem setting and objective

Continued urbanization in Aveiro will increasingly enter into conflict with green/blue space preservation/rehabilitation requirements for flood and storm-water control. To resolve this problem and within the scope of the 1997 urban development plan, the Municipality of Aveiro developed the so-called '5-Finger Plan' which envisaged the establishment of five green/blue strips ('Fingers'; see Figure 9). However, due to the lack of financial resources as well as continuous urbanization pressure, only 'Finger-4' got fully implemented.

Figure 9 The Aveiro 5-Finger Plan (Municipality of Aveiro, 1997)

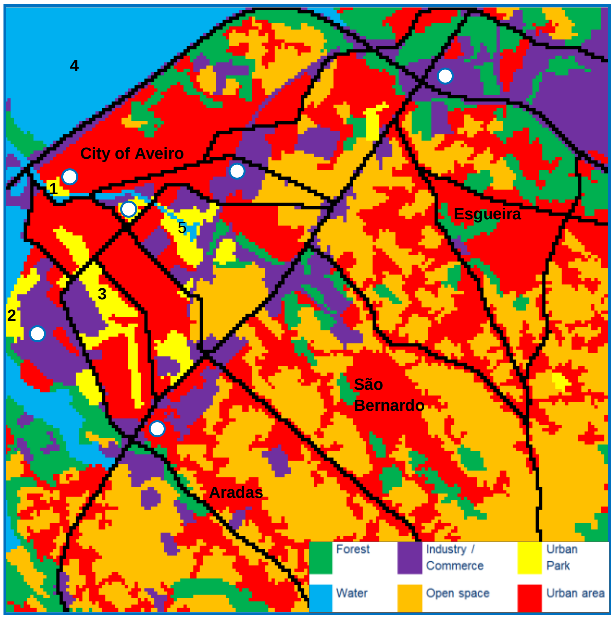


Later, in the 2009 urban plan, the 'Finger Plan' was re-introduced – now containing the remaining four fingers. Finger-2 is considered of key importance for flood control, recreation, tourism and cultural activities, as the area forms part of an 8 km^2 catchment area (generating peak flows during storm events), is at the centre of major residential areas and is close to the historical city centre. The development of an urban green/blue park as part of Finger-2 is, therefore, expected to reduce flood risks in Aveiro as well as to provide additional social, environmental and economic benefits (Polis, 2004). The objective of this Finger-2 case study is to assess what combination of green/blue space preservation/rehabilitation components best conciliate urbanization needs/preferences and flood/storm-water control.

4.1.2. Bio-physical characteristics

The Aveiro case study focusses on the city of Aveiro, which is surrounded by the Ria de Aveiro lagoon (to the North), three satellite villages (Aradas, São Bernardo and Esgueira) and agricultural areas (see Figure 10). The city is serviced by one highway (A25), one provincial road (N109), and a railway with intercity railway station.

Figure 10 Land use in and around the city of Aveiro (CLC, 2007)



The city of Aveiro has four environmental amenities, including three urban parks (Jardim do Rossio (#1), the University of Aveiro campus gardens (#2) and the Parque de Santo Antonio (#3)) and water (#4). There are six urban centres, including the historical city centre, three shopping centres (Forum, Glicínias and Taboeira), the railway station and the University of Aveiro (see white dots in Figure 10).

4.1.3. Socio-economic characteristics

For the Aveiro case study, the definition of household socio-economic characteristics was carried out using available statistics on population, household size, expendable income and expenditure distribution (Table 2). The total population living in the study area is 26,078 and the total number of households equals 10,911 (INE, 2012), resulting in an average household size of 2.39 persons/household.

Based on income data for the Centro region in Portugal (INE, 2012), we distinguish three income groups: low, medium and high income households. The low income household type (HHtype1) corresponds with the 1st quintile of income, the medium income household type (HHtype2) corresponds with the 2nd to 4th quintile of income, and the high income household type (HHtype3) corresponds with the 5th quintile of income. The number of households per type is calculated using data about the percentage of households per quintile of income. Consequently, HHtype1 corresponds to 19% of the population that earns 8% of total income, HHtype2 corresponds to 69% of the population that earns 64% of total income, and HHtype3 corresponds to 12% of the population that earns 27% of total income.

Table 2 Household characteristics for the Aveiro case study area (based on INE, 2012)

	Unit	Household type 1	Household type 2	Household type 3	Total
Demographics					
Population	#	4,929	18,046	3,103	26,078
Household size	#/household	2.39	2.39	2.39	2.39
Households (*Q*)	#	2,062	7,551	1,298	10,911
Household budget					
Expendable income (*y*)	€/yr	9,473	19,849	49,155	$233.2*10^6$
Housing expenditures (μ)	%	23.5%	23.0%	21.4%	22.6%

Finally, housing expenditures are obtained for the identified household types based on household expenditure data for the Centro region in Portugal (INE, 2012). Households spend on average 22.6% of their income on housing, with low income households spending relatively more (23.5%) and high income households relatively less (21.4%) than average.

4.2. Eindhoven (NL)

The city of Eindhoven (~215,000 inhabitants and ~2,500 inhabitants/km^2) is the main city of the Eindhoven metropolitan area (~750,000 inhabitants), and is situated at the confluence of various small rivers and streams. The Eindhoven metropolitan area and city have grown fast since industrial companies, like Philips, settled there in the 1920s.

4.2.1. Problem setting and objective

Eindhoven is facing some problems related to water quality and quantity, as the urban water system did not keep track with the city's growth. The main issues are:

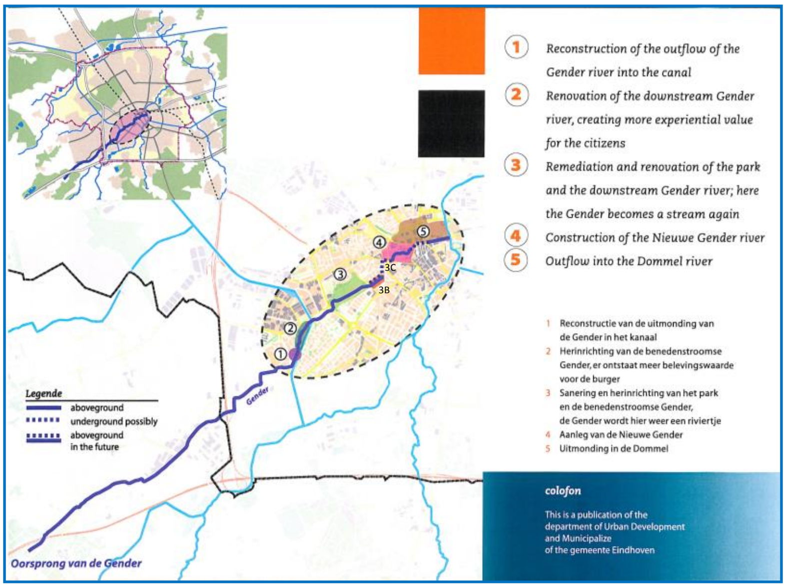
- Water on streets after heavy rainfall due to insufficient urban drainage capacity;
- Combined sewer outlets polluting vulnerable surface waters with higher ecological functions and values;
- Malfunctioning of the remaining surface waters due to closing of former streams or connecting these to combined sewer systems;
- A large waste water treatment plant, serving 750,000 inhabitants, discharging effluent on a small surface water area, with insufficient biological treatment capacity in periods of large sewage supply;
- Groundwater entering basements of houses due to building in former wetlands, combined with reductions in groundwater extractions.

A long term programme has been developed to tackle these problems. The measures envisaged include: i) changing the sewer system from combined to separate sewers, and ii) the (re-) opening of various watercourses throughout the city. Most of these measures will be implemented until 2015; the date by which abovementioned problems will have been reduced significantly.

In particular, one of the measures is the reopening of the Gender watercourse (which has been closed down in the 1950s) in various parts of the city centre. The reopening of the "Nieuwe Gender" aims to:

- Provide a technical optimal contribution to the water goals, including space for maximum storage and discharge capacity;
- Add maximum value to the public space (e.g. recreation and visibility).

Figure 11 Overview of (re-) opening the Nieuwe Gender

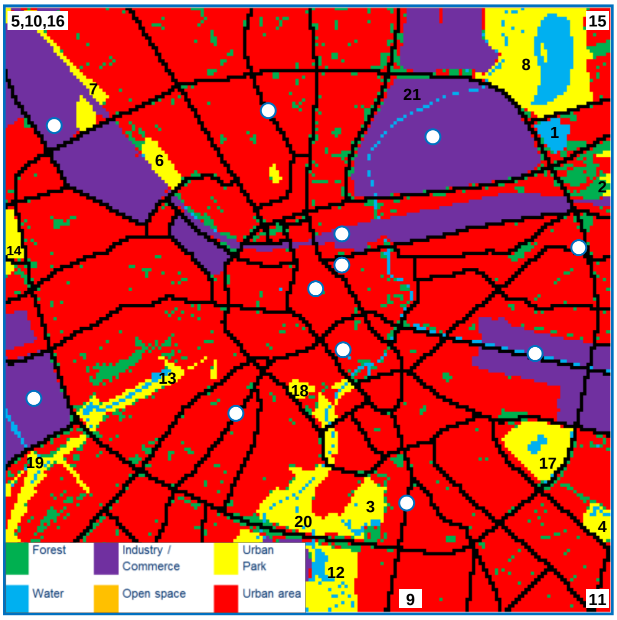


The section of the watercourse to be studied includes de last 3 kilometres of the Nieuwe Gender, before it discharges into the Dommel river (see Figure 11). Within this section, there are five parts to be studied in more detail: Genderpark (Section 3), Frederika van Pruisenweg (Section 3B), Willemstraat (Section 3C), Emmasingelkwadrant (Section 4) and the Stationsgebied (Section 5).

4.2.2. Bio-physical characteristics

The Eindhoven case study focusses on the inner-ring of the city of Eindhoven, which comprises 23 neighbourhoods and is surrounded by a ring road (see Figure 12). The city is

Figure 12 Land use in and around the city of Eindhoven (based on GeoInfo, 2013)



serviced by 4 highways (A2, A58, A67 and A270), 8 provincial roads, a major railway station (in the centre) and an international airport (on the West).

The city of Eindhoven has 21 environmental amenities, including 6 urban parks (Stadwandelpark (#3), Karpendonkse Plas (#8), Gijzenrooi Stratum Heide (#11), Gennep (#12), Eckart (#15) and the Dommelplantsoen (#20)), 4 neighbourhood parks (Genderrplantsoen (#13), Evoluon (#14), Catharina Kerkhof (#18) and the TU Grounds (#21)), 10 local parks (Wasven (#2), Sint Bonifatius park (#4), Philips De Jongh park (#5), Stadium park (#6), Philips park (#7), Kotonjo (#9), Groote Beek (#10), De Wielewaal (#16), De Burgh (#17) and the Beatrix canal (#19)) and water (#1). There are 12 urban centres, including the central shopping centre, five local shopping centres, three industrial areas, railway station, town hall and the Technical University of Eindhoven (see white dots in Figure 12).

4.2.3. Socio-economic characteristics

For the Eindhoven case study, the definition of household socio-economic characteristics was carried out using population statistics and household survey data (Table 3). The total population living in the study area is 88,023 and the total number of households equals 40,751 (BioInfo, 2013), resulting in an average household size of 2.16 persons/household.

Based on household survey data (N=3,297) for the city of Eindhoven (BioInfo, 2013), we identified the following three income groups using cluster analysis: low, medium and high income households. The low income household type (HHtype1) can be characterised as relatively young households (~40 years) with lower levels of education and an average expandable income of ~11.5k€ per year. The medium income household type (HHtype2) can be characterised as retirees (65+ years) with lower levels of education and an average expandable income of ~22.3k€/yr. Finally, the high income household type (HHtype3) can be characterised as middle-aged (~50 years) with high levels of education and an average expandable income of ~35.3k€/yr. The number of households per type in the case study area is based on the relative household distribution from the household survey.

Table 3 Household characteristics for the Eindhoven case study area (based on BioInfo, 2013)

	Unit	Household type 1	Household type 2	Household type 3	Total
Demographics					
Population	#	15,240	29,092	43,692	88,023
Household size	#/household	2.16	2.16	2.16	2.16
Households (Q)	#	7,056	13,469	20,228	40,751
Household budget					
Expendable income (y)	€/yr	11,576	22,333	35,362	$1{,}098.8*10^6$
Housing expenditures (μ)	%	29.8%	28.7%	28.2%	28.5%

Finally, housing expenditures are obtained for the identified household types based on household expenditure data from the survey for the city of Eindhoven (BioInfo, 2013). Households spend on average 28.5% of their income on housing, with low income households spending relatively more (29.8%) and high income households relatively less (28.2%) than average.

5. Frontrunner Aqua Case study results

The SULD decision support tool can be used to assess the socio-economic impacts of location-specific green/blue space projects, road/railway infrastructure developments and socio-economic scenarios. This chapter presents the results for the Aveiro (Section 5.1) and Eindhoven (Section 5.2) frontrunner Aqua Cases, assessing various green/blue space projects and socio-economic scenarios.

5.1. Aveiro (PT)

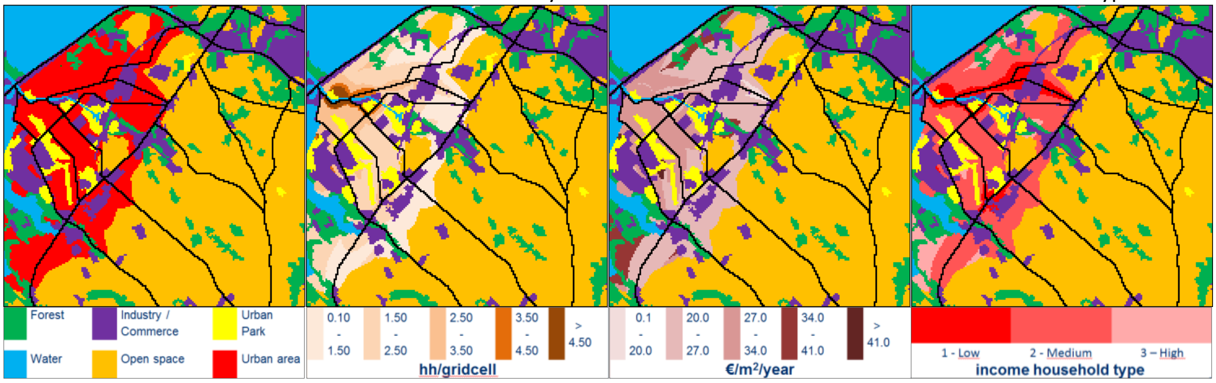
The numerical application of SULD to the Aveiro case study is based on a population comprising three household types (low, medium and high income households), differentiated by number of households (Q), levels of expendable income (y) and shares of housing expenditures (μ; see Table 2 in Section 4.1.3) as well as levels of utility (u=3,175 for HHtype1, u=6,652 for HHtype2 and u=16,475 for HHtype3). All household types share the same appreciation for environmental amenities (ε=0.08; a=10.0; η =1.0), annual commuting costs (p_x=250 €/km), opportunity cost of land (l_i=1,000 €/yr) and development costs (c_0=0 and η=1.5). The study area encompasses an area of 4.625km by 4.625km (=21.39km^2), covered by a grid layer of 185 by 185 (=34,225) cells of 25m by 25m. It includes four environmental amenities (three parks and one water with equal amenity value; a=10.0) and six urban centres (see Section 4.1.2), with distances to environmental amenities and urban centres based on straight-line and road-network distances, respectively.

This section presents the results for the base run (Section 5.1.1) and scenario simulation (Section 5.1.2) results, with numerical results presented in Table 4 and cartographic results presented in Figure 13 to 16. Results are based on available data for 2007-2009, and assessed scenario simulations include: i) the establishment of the Polis urban park, ii) an economic crisis scenario where expendable incomes decrease by 10%, and iii) the combination of the Polis urban park and economic crisis.

5.1.1. Base run results

As mentioned in Section 4.1, the Aveiro case study focusses on the city of Aveiro – hence excluding the three satellite villages Aradas, São Bernardo and Esgueira (see Figure 10). The city of Aveiro covers an urban residential (364ha) and industry/commerce (250ha) area of almost 615ha, and is surrounded by open-space/agricultural, forest and water areas.

Figure 13 Base run simulation results for the Aveiro case study



The total population of 26,078 persons comprises 19% low income, 69% middle income and 12% high income households. Low income households live close the urban centres (in particular along the axis from the historical city centre to the railway station), while high income households live in attractive areas close to the waterfront and urban parks.

Table 4 Base run and scenario simulation results for the Aveiro case study

	Unit	Base	Polis		Inc-10%		Polis & Inc-10%	
Land use								
- Forest	ha	230	230	0.0%	230	0.0%	230	0.0%
- Water	ha	156	156	0.0%	156	0.0%	156	0.0%
- Open space / Agriculture	ha	955	1020	6.8%	1000	4.7%	1056	10.6%
- Industry / Commerce	ha	250	250	0.0%	250	0.0%	250	0.0%
- Park_urban	ha	56	56	0.0%	56	0.0%	56	0.0%
- Roads	ha	128	128	0.0%	128	0.0%	128	0.0%
- Urban	ha	364	299	-17.8%	319	-12.3%	263	-27.7%
Total	ha	2139	2139	0.0%	2139	0.0%	2139	0.0%
Population								
- HHType1	#	4929	4929	0.0%	4929	0.0%	4929	0.0%
- HHType2	#	18046	18046	0.0%	18046	0.0%	18046	0.0%
- HHType3	#	3103	3103	0.0%	3103	0.0%	3103	0.0%
Total	#	26078	26078	0.0%	26078	0.0%	26078	0.0%
Housing quantity								
- HHType1	1000 m^2	63.8	51.7	-18.9%	53.1	-16.8%	42.6	-33.2%
- HHType2	1000 m^2	800.6	620.4	-22.5%	620.3	-22.5%	480.2	-40.0%
- HHType3	1000 m^2	189.4	122.2	-35.5%	144.0	-23.9%	96.2	-49.2%
Total	1000 m^2	1053.8	794.3	-24.6%	817.5	-22.4%	619.1	-41.2%
Development density								
- HHType1	1000 m^2	180.8	173.4	-4.1%	163.7	-9.5%	156.7	-13.4%
- HHType2	1000 m^2	1289.4	1220.2	-5.4%	1149.4	-10.9%	1087.9	-15.6%
- HHType3	1000 m^2	371.9	334.0	-10.2%	329.1	-11.5%	298.7	-19.7%
Total	1000 m^2	1842.1	1727.6	-6.2%	1642.1	-10.9%	1543.2	-16.2%
Living space								
- HHType1	m^2/hh	87.7	84.1	-4.1%	79.4	-9.5%	76.0	-13.4%
- HHType2	m^2/hh	170.8	161.6	-5.4%	152.2	-10.9%	144.1	-15.6%
- HHType3	m^2/hh	286.5	257.2	-10.2%	253.4	-11.5%	230.0	-19.7%
Average	m^2/hh	168.8	158.3	-6.2%	150.5	-10.9%	141.4	-16.2%
Real estate value								
- HHType1	€/m^2/yr	24.0	25.4	5.8%	23.8	-0.8%	25.3	5.3%
- HHType2	€/m^2/yr	25.3	27.0	7.0%	25.5	1.1%	27.3	8.2%
- HHType3	€/m^2/yr	35.7	39.9	11.8%	36.3	1.5%	40.2	12.6%
Average	€/m^2/yr	26.3	28.1	6.9%	26.5	0.8%	28.3	7.8%
Total	m€/yr	50.2	50.7	1.0%	45.2	-10.0%	45.7	-8.9%

The total built area (housing quantity) equals ~$1.0*10^6 m^2$, distributed over low (6%), medium (76%) and high (18%) income households. The total floor space (development density) covers almost double this area (~$1.8*10^6 m^2$), distributed somewhat similar over low (10%), medium (70%) and high (20%) income households. Consequently, household density is highest in low income areas (up to well over 4.5 households per grid cell), lower in attractive high income areas (up to 3.5 households per grid cell) and lowest in medium income areas on the outskirt of the city of Aveiro (up to 2.5 households per grid cell). Available living space equals, on average, almost 170m^2 per household, while noting large differences between household types: about 88m^2, 171m^2 and 287m^2 for low, medium and high income households, respectively.

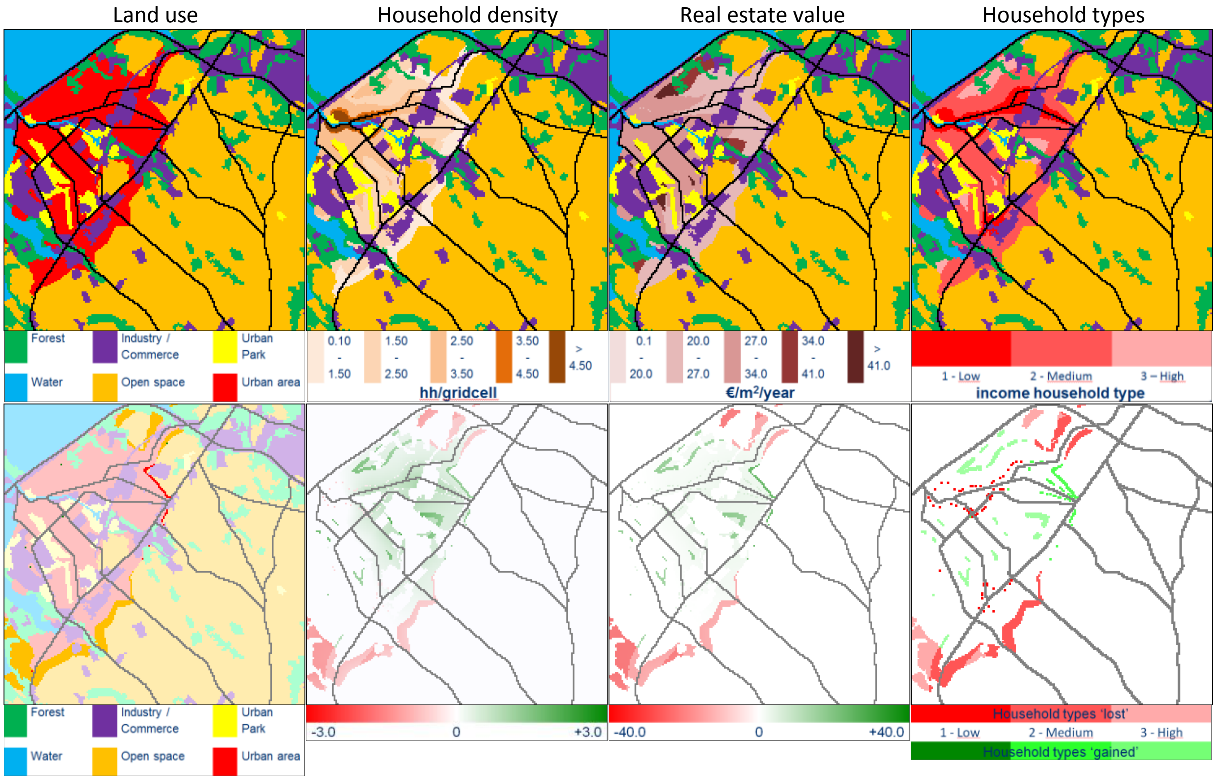
Real estate (rental) values equal, on average, about 26€/m^2/yr, varying between 24.0€/m^2/yr for low, 25.3€/m^2/yr for medium and 35.7€/m^2/yr for high income households. Largest values can be observed in attractive high income areas (up to well over 41€/m^2/yr) and lowest values can be observed in low income areas close to urban centres and, in particular, the railway station (up to 20€/m^2/yr). The total real estate (rental) value for the city of Aveiro equals 50.2 million Euros per year.

5.1.2. Scenario simulation results

Polis urban park

The establishment of the Polis urban park (Parque da Fonte Nova; #5 in Figure 10) is considered to be of key importance for flood control, recreation, tourism and cultural activities, as the area forms part of an 8km^2 catchment area (generating peak flows during storm events), is at the centre of major residential areas and is close to the historical city centre (Polis, 2004). At a later stage the supplementary Forca urban park (Parque dos Galitos) will be established.

Figure 14 Polis scenario simulation results for the Aveiro case study



Establishment of the Polis urban park results in an overall decrease in urban residential area of about -18%, in particular in the North and South of the city of Aveiro. Medium and high income households are attracted from these areas to the area surrounding the Polis urban park, leading to an increase in population density as well as a small (local) increase in urban residential area.

Housing quantity and development density decrease with -25% and -6%, respectively. In particular, the built area (housing quantity) decreases with between -19% for low income households and -35% for high income households, while floor space (development density) as well as living space decrease with between -4% for low income households and -10% for high income households. Consequently, household densities increase in the area surrounding the Polis urban park, in particular to the North and East where urban parks are currently absent. To the South household densities increase to a lesser extent, given the existence of the Parque de Santo Antonio (#3 in Figure 10).

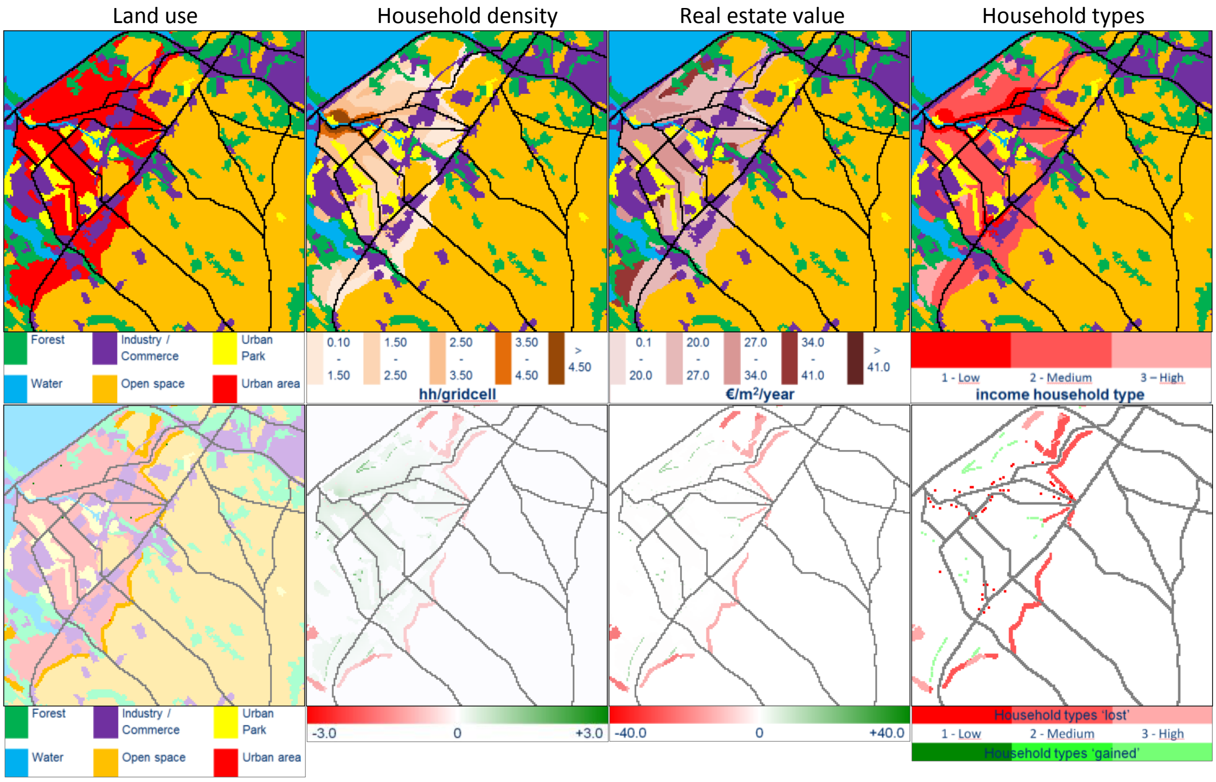
Real estate values, on the other hand, increase with almost 7%, varying between +6% for low income households and +12% for high income households. Again, largest increases in real estate values can be observed to the North and East of the Polis urban park, while smaller increases can be observed to the South. The total real estate (rental) value for the city of Aveiro increases with 1%, to 50.7 million Euros per year.

Summarizing, the establishment of the Polis urban park leads to a more condensed city with higher real estate values – resulting in a net increase in total real estate value. Households are willing to accept a smaller living space when able to live in the vicinity of the Polis urban park and, at the same time, are willing to pay higher real estate (rental) values.

Economic crisis

The economic crisis in Portugal started in 2009, resulting in an increase in income and value added taxes and a subsequent decrease in household expendable income. This scenario simulation assesses the medium to long-term impacts of a sustained decrease in expandable income of -10% across all households.

Figure 15 Income-10% scenario simulation results for the Aveiro case study



The decrease in expendable income of -10% results an overall decrease in urban residential area of about -12%, in particular along the edges of the city of Aveiro. Medium income households living in these areas aim to move closer to the urban centres (as to save on transport costs), leading to an increase in population density in the areas surrounding these urban centres.

Housing quantity and development density decrease with -25% and -6%, respectively. In particular, the built area (housing quantity) decreases with between -17% for low income households and -24% for high income households, while floor space (development density) as well as living space decrease with between -10% for low income households and -12% for high income households. Consequently, household densities increase in the areas surrounding the urban centres – in particular along the axis from the historical city centre to the railway station.

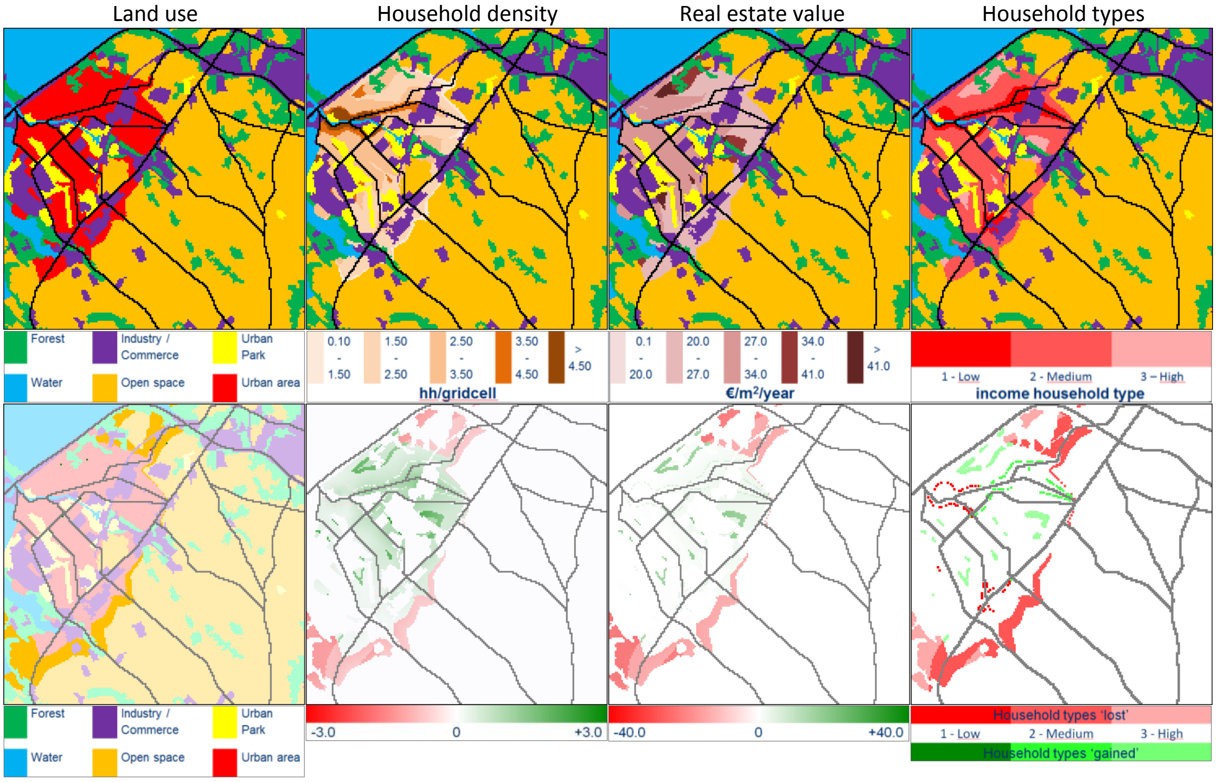
Real estate values show, on average, a small increase (+0.8%), varying between -0.8% for low income households and +1.5% for high income households. Due to the concentration of, in particular, low and medium income households surrounding the urban centres, more desirable residential areas become available for high income households – e.g. along the waterfront on the North-Western edge of the city of Aveiro. Overall, however, the total real estate (rental) value for the city of Aveiro decreases with 10%, to 45.2 million Euros per year.

Summarizing, the economic crisis leads to a smaller city and mixed impacts on real estate values – leading to a net and significant decrease in total real estate value. Medium income households move from the city's periphery to the urban centres, and high income households move into desirable areas that become available.

Polis urban park and economic crisis

This scenario combines the previous two scenarios (the establishment of the Polis urban park and the decrease in expandable income of -10% across all households), as to assess the extent to which green/blue spaces contribute the resilience of cities in times of economic downturn.

Figure 16 Polis & Income-10% scenario simulation results for the Aveiro case study



This scenario results, to a degree, in the combined cumulative effect of the previous two scenarios. The urban residential area decreases with about -28%, which is less than the cumulative decrease of the previous two scenarios separately (-30%). Medium and high income households on the North and South of the city are attracted to the area surrounding the Polis urban park, and medium income households on the city's edges are attracted to the areas surrounding the urban centres. This results in an overall increase in population density in the areas surrounding the Polis urban park and urban centres.

Housing quantity and development density decrease with -41% and -16%, respectively, which is less than the cumulative decrease of the previous two scenarios separately (-47% and -17%, respectively). The built area (housing quantity) decreases with between -33% for low income households and -49% for high income households, while floor space (development density) as well as living space decrease with between -13% for low income households and -20% for high income households. Household densities increase in the areas surrounding the Polis urban park and urban centres, in particular along the axis from the historical city centre to the railway station and, to a minor extent, to the South and East of the Polis urban park.

Real estate values increase with almost 8%, varying between +5% for low income households and +13% for high income households. Largest increases in real estate values can be observed to the North and East of the Polis urban park, as well as along the waterfront on the North-Western edge of the city. The total real estate (rental) value for the city of Aveiro decreases with 9% (to 45.7m€/yr), which is similar to the cumulative decrease of the previous two scenarios separately.

Summarizing, the impacts of the economic crisis are somewhat dampened by the Polis urban park. The contraction of the urban residential area is less strong, and the decrease is in housing quantity and development density less severe. The net increase in total real estate value due to the establishment of the Polis urban park is similar in the situation with or without economic crisis.

5.2. Eindhoven (NL)

The numerical application of SULD to the Eindhoven case study is based on a population comprising three household types (low, medium and high income households), differentiated by number of households (Q), levels of expendable income (y) and shares of housing expenditures (μ; see Table 3 in Section 4.2.3) as well as levels of utility (u=2,350 for HHtype1, u=4,534 for HHtype2 and u=7,179 for HHtype3). All household types share the same appreciation for environmental amenities (ε=0.08; η =1.0), annual commuting costs (p_x=375 €/km), opportunity cost of land (l_i=1,000 €/yr) and development costs (c_0=0 and η=1.665). The study area encompasses an area of 4.070km by 4.070km (=16.56km^2), covered by a grid layer of 185 by 185 (=34,225) cells of 22m by 22m. It includes 21 environmental amenities (20 parks and one water with amenity value ranging from a=5.0 for local, a=7.5 for neighbourhood and a=10.0 for urban parks) and 12 urban centres (see Section 4.2.2), with distances to environmental amenities and urban centres based on straight-line and road-network distances, respectively.

This section presents the base run (Section 5.2.1) and scenario simulation (Section 5.2.2) results, with numerical results presented in Table 5 and cartographic results presented in Figure 17 to 20. Results are presented for the inner-ring area and based on available data for 2010-2011. Assessed scenario simulations include the realization of: i) the Emmasingel-kwadrant project, ii) the Genderpark project, and iii) all five projects (i.e. the Genderpark, Frederika van Pruisenweg, Willemstraat, Emmasingelkwadrant and Stationsgebied projects; see Section 4.2.1).

5.2.1. Base run results

As mentioned in Section 4.2, the Eindhoven case study focusses on the inner-ring of the city of Eindhoven – hence excluding the surrounding city and metropolitan area (see Figure 12). The inner-ring covers an urban residential (625ha) and industry/commerce (164ha) area of almost 790ha, and forms the centre of the larger surrounding city.

Figure 17 Base run simulation results for the Eindhoven case study

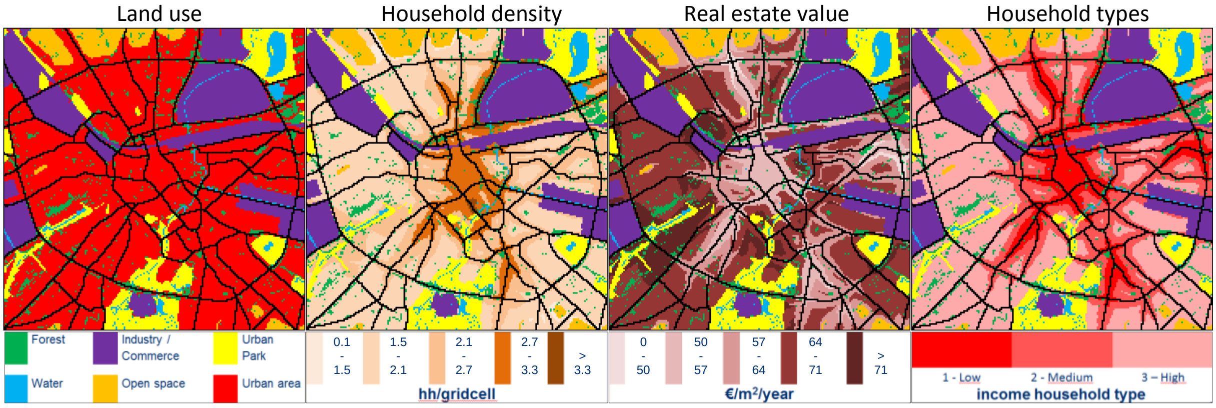


Table 5 Base run and scenario simulation results for the Eindhoven case study

	Unit	Base	Emmasingelkwadrant		Genderpark		All projects	
Land use								
- Forest	ha	41	41	0.0%	41	0.0%	41	0.0%
- Water	ha	11	11	0.0%	11	0.0%	11	0.0%
- Open space	ha	1	2	45.5%	0	-86.4%	1	18.2%
- Industry / Commerce	ha	164	164	0.0%	164	0.0%	164	0.0%
- Park_urban	ha	49	49	0.0%	49	0.0%	49	0.0%
- Roads	ha	133	133	0.0%	133	0.0%	133	0.0%
- Urban	ha	625	625	-0.1%	626	0.1%	625	0.0%
Total	ha	1024	1024	0.0%	1024	0.0%	1024	0.0%
Population								
- HHType1	#	14424	14430	0.0%	14425	0.0%	14436	0.1%
- HHType2	#	24106	24217	0.5%	24137	0.1%	24276	0.7%
- HHType3	#	24741	25113	1.5%	24972	0.9%	25714	3.9%
Total	#	63272	63760	0.8%	63534	0.4%	64426	1.8%
Housing quantity								
- HHType1	1000 m^2	151.3	147.5	-2.5%	151.2	-0.1%	145.8	-3.6%
- HHType2	1000 m^2	458.5	454.7	-0.8%	457.8	-0.2%	449.0	-2.1%
- HHType3	1000 m^2	889.5	896.4	0.8%	891.7	0.2%	904.0	1.6%
Total	1000 m^2	1499.3	1498.6	0.0%	1500.7	0.1%	1498.8	0.0%
Living space								
- HHType1	m^2/hh	64.2	63.7	-0.7%	64.1	0.0%	63.4	-1.1%
- HHType2	m^2/hh	98.3	98.0	-0.4%	98.3	-0.1%	97.5	-0.8%
- HHType3	m^2/hh	144.2	143.9	-0.2%	143.9	-0.2%	143.3	-0.6%
Average	m^2/hh	108.5	108.3	-0.2%	108.5	0.0%	108.2	-0.3%
Real estate value								
- HHType1	€/m^2/yr	53.1	53.6	0.8%	53.2	0.0%	53.8	1.2%
- HHType2	€/m^2/yr	63.5	63.7	0.4%	63.5	0.1%	64.1	0.9%
- HHType3	€/m^2/yr	69.4	69.5	0.2%	69.5	0.2%	69.8	0.7%
Average	€/m^2/yr	64.3	64.6	0.5%	64.4	0.2%	65.0	1.0%
Total	m€/yr	207.0	209.0	1.0%	208.1	0.6%	212.1	2.5%

The total population of 63,272 persons comprises 23% low income, 38% middle income and 39% high income households. Low and middle income households live close to the urban centres (in particular around the central shopping centre, the railway station and the university), while high income households live in more attractive areas close to urban and neighbourhood parks.

The total built area (housing quantity) equals ~$1.5*10^6 m^2$, distributed over low (10%), medium (31%) and high (59%) income households. Available living space equals, on average, almost $110m^2$ per household, with large differences between household types: about $64m^2$, $98m^2$ and $144m^2$ for low, medium and high income households, respectively. Consequently, household densities are highest in centrally located low income areas (up to 3.6 households per grid cell), lower in medium income areas (up to 3.0 households per grid cell) and lowest in peripheral high income areas (up to 2.2 households per grid cell).

Real estate (rental) values equal, on average, about 64€/m^2/yr, varying between 53.1€/m^2/yr for low, 63.5€/m^2/yr for medium and 69.4€/m^2/yr for high income households. Largest values can be observed in attractive high income areas (up to over 75€/m^2/yr) and lowest values can be observed in low income areas close to urban centres and, in particular, peripheral industrial and shopping areas (up to less than 50€/m^2/yr). The total real estate (rental) value for the city of Eindhoven equals almost 210 million Euros per year.

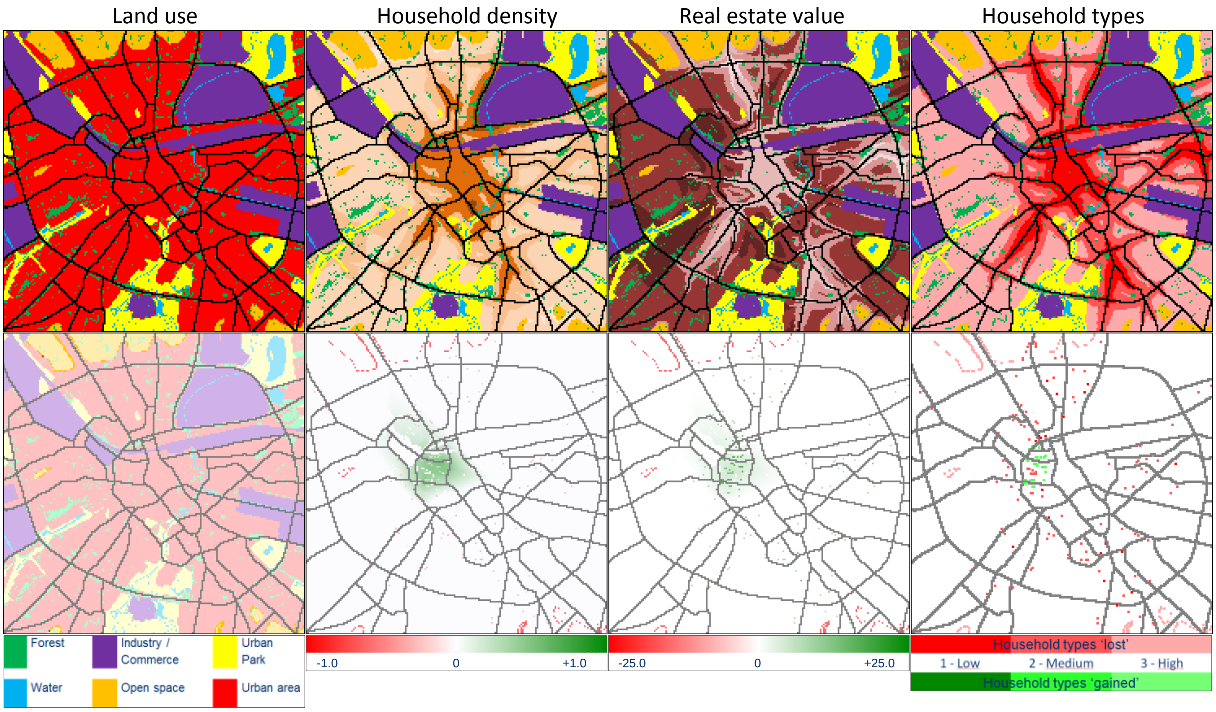
5.2.2. Scenario simulation results

Emmasingelkwadrant

Before presenting the results from the Emmasingelkwadrant project, it needs to be mentioned that these results are fairly similar to those obtained for the Stationsgebied project. Although the geographical location is different, the general tendencies and values that hold for the Emmasingelkwadrant project also hold for the Stationsgebied project.

The establishment of the Emmasingelkwadrant project (#4 in Figure 12) entails the redevelopment of a former industrial area into a residential area with housing, shopping and leisure functions. Out of three possible project options (see Roebeling et al., 2012), here we consider the option of the Gender as an open watercourse in a spatial green setting.

Figure 18 Emmasingelkwadrant scenario simulation results for the Eindhoven case study



The establishment of the Emmasingelkwadrant project leads to an increase in population (+0.8%) and population density surrounding the Gender watercourse and green space. In particular medium and high income households are attracted by this intervention, given the current absence of green/blue space surrounding the central shopping centre.

Housing quantity is, on average, hardly affected. Across household types, however, we see that the built area (housing quantity) decreases for low income households (-2.5%) and increases for high income households (+0.8%) – indicating that low income households are crowded-out by, in particular, high income households. Household living space decreases with between -0.7% and -0.2% for low and high income households, respectively. Consequently, household densities increase in the area surrounding the Emmasingelkwadrant project – in particular to the East and South where urban parks are currently absent. To the North household densities increase to a lesser extent given the interference of the railway track.

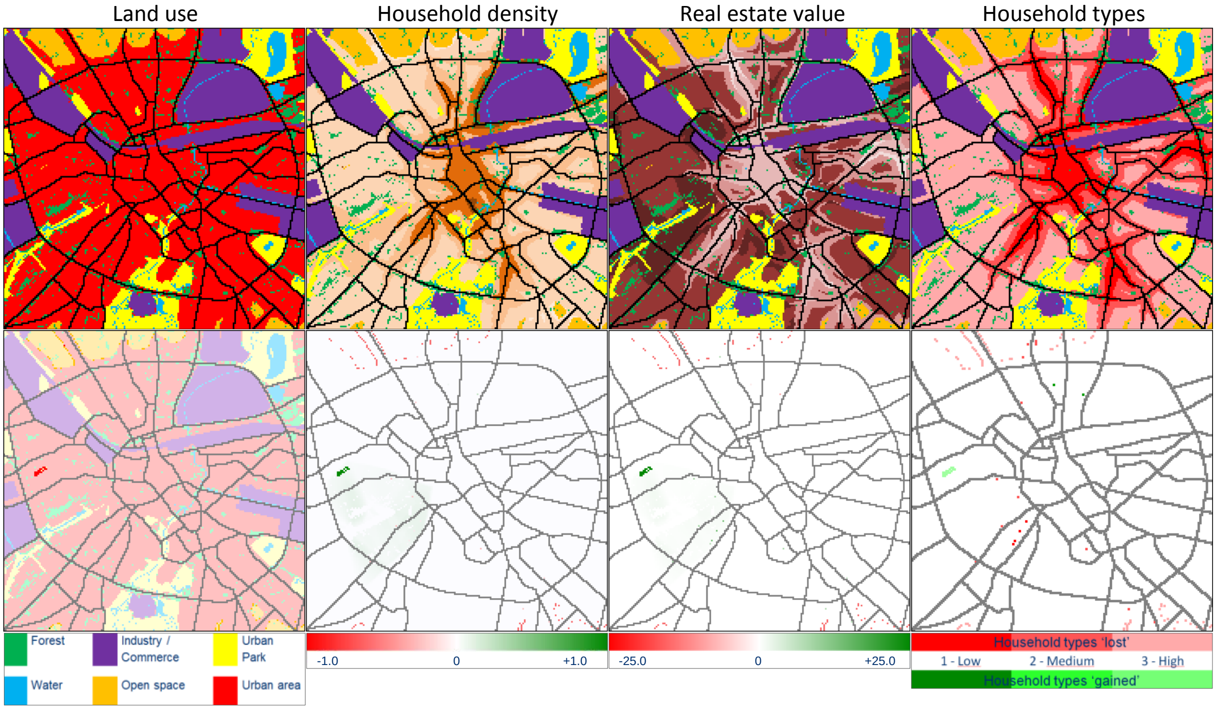
Real estate values increase with, on average, 0.5% – varying between +0.8% for low income households and +0.2% for high income households. Again, largest increases in real estate values can be observed to the East and South of the Emmasingelkwadrant project, while smaller increases can be observed to the North. The total real estate (rental) value for the city of Eindhoven increases with 1%, to 209.0 million Euros per year.

Summarizing, the establishment of the Emmasingelkwadrant project attracts medium and high income households to the centre of Eindhoven, where urban parks are currently absent. Households are willing to accept a somewhat smaller living space and, simultaneously, are willing to pay slightly higher real estate (rental) values – resulting in a net increase in total real estate value.

Genderpark

The Genderpark project (#3 in Figure 12) entails the requalification of the park and pond in

Figure 19 Genderpark scenario simulation results for the Eindhoven case study



combination with a flexible weir and water retention system. Two variations to the project are considered: restoration to a more natural watercourse or maintaining the present configuration (see Roebeling et al., 2012).

The Genderpark project leads to a small increase in population (+0.4%) and population density surrounding the already existing Genderpark. In particular high income households are attracted by this requalification intervention, given its remoteness relative to the main urban centres.

Housing quantity is, again, hardly affected, while noting that the built area (housing quantity) decreases for low and middle income households (up to -0.2%) and increases for high income households (up to +0.2%). Hence, specifically high income household are attracted by this requalification intervention. Household living space decreases with -0.2% for high income households. As a consequence, household densities increase slightly in the area surrounding the Genderpark project – in particular to the South in the direction of the local shopping centre.

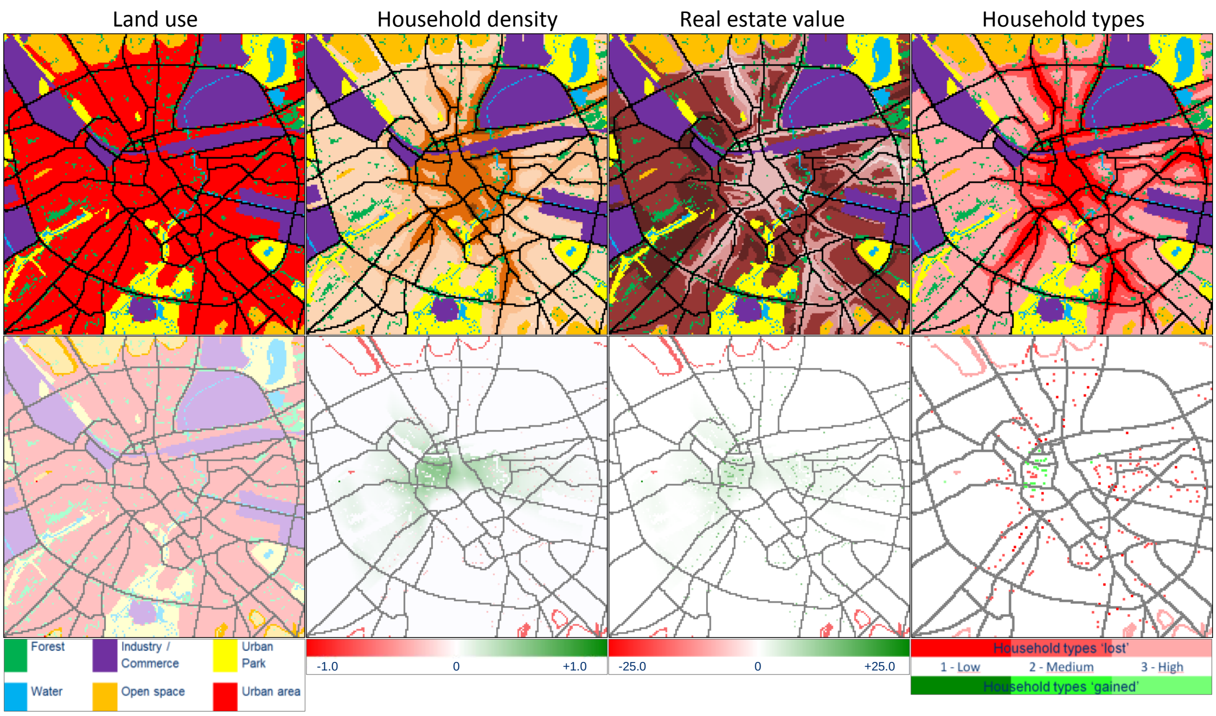
Real estate values increase with up to +0.2% for high income households, thereby noting that, again, largest increases in real estate values can be observed to the South of the Genderpark project. The total real estate (rental) value for the city of Eindhoven increases with 0.6%, to 208.1 million Euros per year.

In sum, the Genderpark project attracts and benefits mainly high income households. These are willing to accept a somewhat smaller living space and, simultaneously, willing to pay somewhat higher real estate (rental) values. Overall this leads to a small net increase in total real estate value.

All projects

The establishment of all envisaged projects along the Nieuwe Gender (see Figure 12) entails the reopening of the Gender watercourse in various parts of the city centre. This

Figure 20 All projects scenario simulation results for the Eindhoven case study



corresponds to the integrated approach proposed by the Municipality of Eindhoven to tackle existing water management issues and linking it with the planning of other activities in the public space (see Roebeling et al., 2012).

The establishment of all project leads to an increase in population (+1.8%) and population density surrounding the areas where the Gender resurfaces and/or is requalified. In particular medium and high income households are attracted by these interventions, given the current absence of green/blue space surrounding the central shopping centre (the Emmasingelkwadrant and Stationsgebied projects) as well as requalification of existing green/blue spaces (the Genderpark, Frederika van Pruisenweg and Willemstraat projects).

The built area (housing quantity) decreases for low and middle income households (-3.6% and -2.1%, respectively) and increases for high income households (+1.6%), indicating that low and middle income households are crowded-out by high income households. Household living space decreases with between -1.1% and -0.6% for low and high income households, respectively. Consequently, household densities increase particularly in the areas surrounding the Emmasingelkwadrant and Stationsgebied projects (mainly to the East and South where urban parks are currently absent), and somewhat less in the areas surrounding the green/blue space requalification projects (the Genderpark, Frederika van Pruisenweg and Willemstraat projects).

Real estate values increase with ~1.0%, varying between +1.2% for low income households and +0.7% for high income households. Largest increases in real estate values can be observed to the East and South of the Emmasingelkwadrant and Stationsgebied projects, while smaller increases can be observed in the areas surrounding the Genderpark, Frederika van Pruisenweg and Willemstraat projects. The total real estate (rental) value for the city of Eindhoven increases with 2.5%, to 212.1 million Euros per year.

Summarizing, the establishment of all projects attracts medium and high income households to the new green/blue spaces in the centre of Eindhoven (Emmasingelkwadrant and Stationsgebied projects), and high income households to the requalified green/blue spaces (Genderpark, Frederika van Pruisenweg and Willemstraat projects). All households benefit from these interventions through an increase in real estate (rental) values, while accepting a smaller living space in the vicinity of these new or requalified green/blue spaces. Overall this results in a net increase in total real estate value.

6. Conclusions and recommendations

In this report we presented the theory and methodology underpinning, as well as, the application of the Sustainable Urbanizing Landscape Development (SULD) decision support tool. To this end, we performed a literature review on non-economic and economic models of land use change, and provided a detailed description of the modelling approach underlying the SULD decision support tool (Roebeling et al., 2007). In turn, the frontrunner Aqua Cases (Aveiro PT; Eindhoven NL) were described, and results for green/blue space projects and socio-economic scenarios presented – with particular focus on the impact of location-specific green/blue space projects and socio-economic scenarios on the location of residential development, housing quantity, residential development density, population density, population composition, household living space and real estate values.

For the Aveiro case study, results for the Polis urban park scenario show that the establishment of this park leads to a more condensed city (decrease in urban residential area of about -18%) with higher real estate values – resulting in a net increase in total real estate value of +1%. Households are willing to accept a smaller living space (up to -10%) when able to live in the vicinity of the Polis urban park and, at the same time, are willing to pay higher real estate (rental) values (up to +12%). The economic crisis scenario (decrease in expandable income of -10%) leads to a smaller city (-12%) and mixed impacts on real estate values – leading to a net and significant decrease in total real estate value (-10%). Medium income households move from the city's periphery to the urban centres, and high income households move into desirable areas that become available. Finally, the combined Polis urban park and economic crisis scenario shows that the impacts of the economic crisis are somewhat dampened by the Polis urban park. The contraction of the urban residential area is less strong (-28%) and the decrease in total real estate value less severe (-9%). The net increase in total real estate value due to the establishment of the Polis urban park is similar in the situation with or without economic crisis (+1%).

For the Eindhoven case study, results for the Emmasingelkwadrant scenario show that the establishment of the park attracts medium and high income households to the centre of Eindhoven (increase in population of +0.8%), where urban parks are currently absent. Households are willing to accept a somewhat smaller living space (up to -0.7%) and, simultaneously, are willing to pay slightly higher real estate (rental) values (up to +0.8%) – resulting in a net increase in total real estate value (+1%). The Genderpark requalification scenario attracts and benefits mainly high income households (+0.4%). These are willing to accept a somewhat smaller living space (-0.2%) and, simultaneously, willing to pay somewhat higher real estate (rental) values (+0.2%). Overall this leads to a small net increase in total real estate value (+0.6%). Finally, the combined scenario shows that the establishment of all projects leads to an increase in population (+1.8%). Medium and high income households are attracted to the new green/blue spaces in the centre of Eindhoven (Emmasingelkwadrant and Stationsgebied projects), and high income households to the requalified green/blue spaces (Genderpark, Frederika van Pruisenweg and Willemstraat projects). All households benefit from these interventions through an increase in real estate (rental) values (+1.2%), while accepting a smaller living space (-1.1%) in the vicinity of these green/blue spaces – leading to a net increase in total real estate value (+2.5%).

Based on these results, the following three main lessons can be derived regarding the value-added of green/blue spaces in urban and urbanizing landscapes. First, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces brings value-added to residents in urban areas – reflected by an increased willingness-to-pay for housing and appreciation of real estate values in the area surrounding the intervention. Second, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces leads to more condensed cities – reflected by an increase in population (in particular medium and high income households) and population density surrounding the intervention area. Finally, the establishment of new and, to a minor extent, the requalification of existing green/blue spaces dampens the negative impacts of economic crises – reflected by reduced urban land abandonment and real estate value depreciation. Note that, in all cases, the value added of green/blue space is dependent on the location, size and type of intervention relative to existing urban residential areas, urban centers and environmental amenities.

The SULD decision support tool is not an aim in itself but the starting point of a process. It facilitates participatory planning and scenario development, creating confidence in and familiarity with the model and its outputs. Also, it enriches public discussion and adds transparency to the urban planning decision-making processes. Consequently, it encourages stakeholders to reflect about their reality and future possibilities – effectively engaging them in the design of urban development plans where the value of water and green spaces may assume a forefront position.

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