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Impact of urban planning on household's residential decisions: An agent-based simulation model for Vienna☆

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ABSTRACT

Interest in assessing the sustainability of socio-ecological systems of urban areas has increased notably, with additional attention generated due to the fact that half the world's population now lives in cities. Urban areas face both a changing urban population size and increasing sustainability issues in terms of providing good socioeconomic and environmental living conditions. Urban planning has to deal with both challenges. Households play a major role by being affected by urban planning decisions on the one hand and by being responsible – among many other factors – for the environmental performance of a city (e.g. energy use). We here present an agent-based decision model referring to the city of Vienna, the capital of Austria, with a population of about 1.7 million (2.3 million within the metropolitan area, the latter being more than 25% of Austria's total population). Since the early 1990s, after decades of negative population growth, Vienna has been experiencing a steady increase in population, mainly driven by immigration. The aim of the agent-based decision model is to simulate new residential patterns of different household types based on demographic development and migration scenarios. Model results were used to assess spatial patterns of energy use caused by different household types in the four scenarios (1) conventional urban planning, (2) sustainable urban planning, (3) expensive centre and (4) no green area preference. Outcomes show that changes in preferences of households relating to the presence of nearby green areas have the most important impact on the distribution of households across the small-scaled city area. Additionally, the results demonstrate the importance of the distribution of different household types regarding spatial patterns of energy use.

1. Introduction

Interest in sustainability assessment for socio-ecological systems of urban areas has increased notably, with additional attention generated due to the fact that by now half the world's population lives in cities (Pagliara et al., 2010). In conceptualizing the biophysical inputs and outputs of a city, the analysis of urban metabolism provides valuable insights into the energy and resource requirements of a given urban area. Departing from energy metabolism as a crucial concept in assessing society–nature interaction and sustainable development (Haberl, 2001a,b), we focus on energy use. Urban energy use can best be understood from a demand perspective, not just for final energy forms, such as electricity or transportation fuels, but for energy services (Lovins, 1977; Jochem, 2000). Research on the factors determining urban energy use is still in its early stages, especially concerning the coupling of different energy systems with each other. Household demand for energy services changes depending on several factors, which can be categorized as economic, demographic and behavioural (Weisz and Steinberger, 2010).

The positive correlation of income and energy use is long established in the traditional energy literature (Vringer and Blok, 1995; Pachauri and Spreng, 2002; Cohen et al., 2005; Wier et al., 2001; Lenzen et al., 2006; Dey et al., 2007; Weber and Matthews, 2008). Demographic factors such as population growth, household size, average household age and migration influence urban energy usage. Household size plays an important role in energy use: above two persons per household, economies of scale can reduce the energy consumed per capita (Pachauri et al., 2004; Lenzen et al., 2004, 2006; Weber and Matthews, 2008). Urban populations may have significantly smaller household sizes than rural populations, due to smaller family sizes and a larger generation gap as well as smaller dwellings, and are thus less likely to shelter extended families or many generations under the same roof. The evidence for age is mixed. The most important impact of age may be through changing household sizes and changing income level.

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In many European cities, demographic growth is rather moderate or even negative and mainly due to migration. The most significant factors affecting urban spatial growth are the growing number of smaller households and the increasing space consumption by households. The composition of household types within European cities changes from a mixture of one-person to more than five-person households to a dominance of single and couple households within the city and an allocation of family households into the suburban area. This process is based on residential location decisions of individual households. Concerning such residential location decisions Dieleman (2001), Coulombel (2010), Knox and Pinch (2010) each give a comprehensive literature overview. Rossi (1980) shifted the focus from an aggregated level to the individual household and its motivation to seek another dwelling and pointed out the influence of the life-cycle on residential decision-making. Wolpert (1965) and Brown and Moore (1970) refined this approach into a stress/resistance model. Various versions of this model exist in the literature e.g. by Robson (1975, p. 33), by Wong (2002) or by Benenson (2004, p. 10). Households may move due to a large number of reasons mainly related to economic, demographic and behavioural causes. Concerning possible classifications of households, Coulombel comes to the conclusion that a "unitary vision of the household keeps on prevailing in the economic literature on housing as well as in applied modelling" (Coulombel, 2010, p. 56).

Residential location modelling is widely acknowledged to be one of the most important challenges in contemporary social science. Urban areas face both a changing urban population size and increasing sustainability issues in terms of providing good socioeconomic and environmental living conditions. Urban planning has to deal with these challenges by considering processes of growth in new areas, decay and abandonment as well as restructuring and rehabilitation. On the one hand households are affected by urban planning decisions. On the other hand households play a major role in urban consumption patterns of energy use mainly depending on the income level (Weisz and Steinberger, 2010). Residential decisions of households may have an impact on the spatial distribution of energy use resulting from the spatial allocation of different household types. In addition, the reaction of individual households in response to urban planning strategies is an important issue in designing a "sustainable" city if we assume that sustainable urban development is among other parameters characterized by a balanced distribution of different socioeconomic structures.

Agent-based microsimulation models have been applied in the past mainly to simulate transportation networks, since it allows for a comprehensive, logically consistent and theoretically sound implementation of two-way interactions between land use/urban form (land development, building supply, location choices, etc.) and transportation (mode choice, travel demand, public transport accessibility, etc.) (Miller et al., 2004, 10). Recently, there have been efforts to extend such models into the area of urban energy modelling (UEM) (Chingcuanco and Miller, 2012).

We here present an agent-based model[1] analysing the effect of residential location decisions of households on the spatial pattern of urban energy use for the city of Vienna. Residential mobility decisions are simulated on the individual household level based on a stress/resistance model considering the residential satisfaction of each household by relating residential preferences of that household to certain attributes of a dwelling and its spatial unit. The main innovations of the model can be considered as the follows: Firstly, the model implements an empirically informed demographic growth model by using existing demographic forecasts. The demographic module simulates event-driven changes in the demography of different household types (e.g. single households, family households, etc). Secondly, the model implements a relocation module which again is empirically informed. Therefore, different studies were used to analyse the motivations of households in Vienna to relocate. Finally, the model integrates the current and planned infrastructure in order to combine population development with the urban development plans of Vienna. Both innovations allow for an empirically based estimation of the city's socioeconomic structure in terms of household type distribution and the resulting energy consumption allocation over the city. The model is able to simulate future scenarios depending on changes in external framework conditions (e.g. urban planning) as well as on internal decisions (e.g. changing preferences of households).

[1] The model is programmed in Java using the Eclipse IDE and cannot be made freely available since it uses non-free licensed data.

2. Study area

Vienna is the capital of Austria with a current population of about 1.7 million (2.3 million within the metropolitan area, which represents more than 25% of Austria's population) living in 23 districts and is located in the north-eastern part of the country, at the easternmost extension of the Alps in the Vienna Basin. The earliest settlement, at the location of today's inner city, was south of the meandering Danube while the city now spans both sides of the river. In the early 1990s, after decades of negative population growth, the population of Vienna grew by about 120,000 inhabitants between 1987 and 1994. The reasons for this rapid population increase may lie in the new geo-political status of Vienna after the fall of the Iron Curtain, as well as Austria's accession to the European Union at the beginning of 1995. This also led to a growing demand for housing and jobs. By the end of the 1980s, construction of subsidized flats had dropped to an annual rate of about 4000. The rising demands on the quality of accommodation and increased housing demand in general, also due to the growing number of (single-person) households, were the main factors for the higher need for new subsidized flats Vienna has seen since the beginning of the 1990s. Given these new framework conditions for Vienna, the Vienna city government at the beginning of the 1990s decided to increase the building rate of subsidized housing to 10,000 new flats annually.

In parallel the settlement structure in suburban areas changed visibly. In the last decades the main development took place in the South. The suburban municipalities and Vienna grew together, which has resulted in a coherent settlement zone. Today the main focus of urban sprawl has shifted from the South to the North. This urban sprawl is entirely based on migration, with birth rates already negative as in the city. While in Vienna the industrial sector is very small, a high aggregation of classical industrial locations in the suburban areas takes place. Additionally, these surrounding areas are facing a strong concentration of trade towards the South and in the meantime also towards the North due to the presence of huge shopping malls.

The population of Vienna is expected to grow from currently 1,686,000 people to more than 2 million people by 2050 (Statistics Austria, 2012a). The main scenario of demographic development for Vienna from 2001 to 2050 by Statistics Austria assumes the persistence of a strong international immigration, which is the single most important factor, expected shaping the demographic development in Vienna during the next decades (Statistics Austria, 2012a,b).

Future demand for new housing units will not depend solely on the quantitative development of the resident population but also on changing expectations regarding the quality of housing in terms of living space per inhabitant, higher quality of the infrastructure and of the environment (e.g. private and public green spaces). Therefore, even if the population were to stagnate, there would still be demand for new housing.

The pattern of household's relocations over a city is based on every-day decision-making processes of single households. In many cases these decisions also affect the distribution of energy consumption over the city. The goal of the decision-making model is to analyse decisions taken by different actors in a city that not only but also affect the average energy use per household (including heating energy and energy use for transport).

3. Model structure and parameterization

The model starts with roughly 770,000 household agents and runs in yearly time steps. Extensive literature about past and current attempts in modelling urban residential mobility exist (for example Wegener and Wagner, 2007; Putman, 2010; Simmonds, 2010; Semboloni, 2007; Waddell, 2010; Benenson, 2004). We observe a trend to develop more detailed models in terms of number of household categories, agent types beside households and fine-grained spatial units (based on grid cell level) as well as more sophisticated technical approaches. Many of these models consist of several modules combining different sectors, activities and preference structures. The need to disaggregate households, primarily on socioeconomic criteria from eight (Putman, 2010) to more than hundred categories (Simmonds, 2010), is a common feature of residential location models. In contrast, we chose to limit our model to categories regarding household types and spatial units that are – in our opinion – relevant, meaningful and yet simple enough to address socio-ecological research issues. We decided to focus on the criteria household size and income as those factors that are most important for energy consumption and to keep the complexity of the model as simple as possible.

The main interaction in the model takes place between households and spatial units. Each household represents an agent in the model and is classified according to household types defined by age and family structure. Household types are characterized by a certain behaviour, which has its own preference profile regarding residential location.

The spatial resolution of the model is based on eight so-called "city area types" ("Stadtgebietstypen") and the 23 administrative districts, which are intersected into a total of 59 spatial units, which we call "small-scaled city areas" (see Fig. 1). The small-scaled city areas are defined by the Viennese spatial planning administration (Stadt Wien, 2007, p.64ff.) using parameters such as density and dominant type and age of buildings. One extra spatial unit for the surrounding region of Vienna is included in the model for simulation of the moves to the suburbs of Vienna.

3.1. Initialisation of the model

The household properties age and family structure taken together define the "household type". We have defined seven household types in the model: Single young, single old, couple young, couple old, single parent, small family and large family. Each of the household types has its own preference profile regarding residential mobility. In contrast to the household type, a household is a concrete representation of a household unit. Households are defined with a household type as an attribute, and are linked to their dwelling and to their household members. During the model run, households change their family structure and thus their household type through the demographic model. The income changes only by rearrangement of the household members, when a household is merged or split.

The spatial units "small-scaled city areas" are characterized by the share of green area and access to infrastructure such as public transport and services. Each small-scaled city area contains a number of dwellings. Each dwelling has a certain size in m^2 and a specific price per m^2.

To initialize the synthetic population (a number of agents) for the model, we follow the procedure developed by Wilson and Pownall (1976). Fig. 2 outlines a flowchart of the procedure steps to initially create households and persons by use of several distributions known from census or micro census data and a pseudo-random number generator. The data sources and the sampling

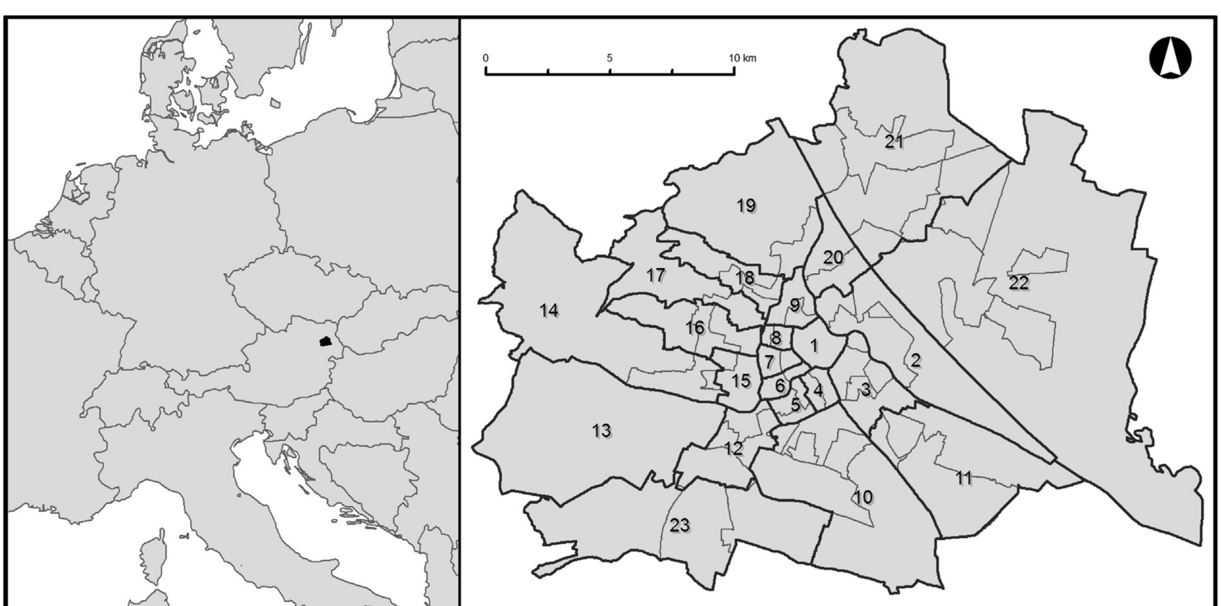

Fig. 1. Left map showing the location of Vienna in the Northeast of Austria in Central Europe; Right map showing the model area consisting of 59 "small-scaled city areas" (thin lines) belonging to the 23 administrative districts (thick lines; indicated by the numbers).

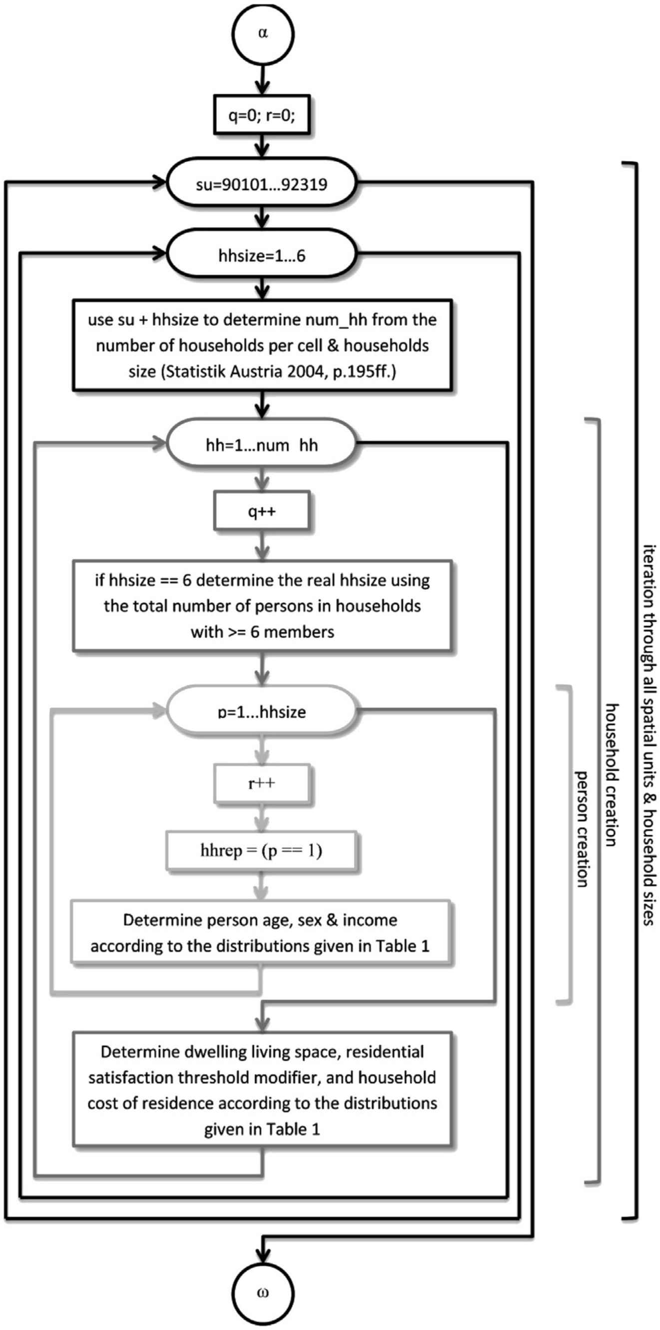

Fig. 2. Steps for creation of the synthetic population in the model.

functions belonging to each procedure step are given in Table 1. Table 2 contains a brief description of variable shortcuts used throughout the flowchart and the formulas describing the sampling process.

Formally, each procedure step can be written,

$$x_s = x_s(P_x(y|...), R_{x_s})$$

where x can be replaced by any of the agent properties on household or person level given in Table 1. The term $P_x(y|...)$ stands for the probability of x of agent s taking the value y conditional on one or more of the parameters specified. This probability is determined using an empirically derived distribution of the respective property. The source of the empirical data is given in the 'Source' column for each step. R_{x_s} is a random number drawn for agent s and their respective characteristic x.

The initial population numbers are taken from the 2001 census data made available by Statistics Austria (2004, p. 1955ff.) in the form of a table of number of households per households size and spatial unit.

A series of statistical data offer the basis for the initialization of the model. The most important source is the micro census 2006–2008. The micro census is performed yearly by Statistics Austria. The nationwide sample contains 22,500 households, of which about 4500 change each year so that each household will be in the sample for five years. Of these 4500 households joining the sample yearly, Statistics Austria made available a sub-sample of about 1000 households selected randomly for each year since 2004 (Statistics Austria, 2008). To estimate the distribution of age and sex of the persons living in a household, we combined the datasets from 2006[2] to 2008 and excluded all households living outside Vienna, resulting in a dataset of 1651 households with 3402 person altogether.

3.2. Demographic sub-module

The number of persons in a household can change due to biographical events, which in turn influences space needs, household income and residential preferences. In the literature (Bauer-Wolf et al., 2003, p. 18; Fontaine and Rounsevell, 2009, p. 1240; Schneider and Spellerberg, 1999, p. 126; I.Z.T.Institut für Zukunftsstudien und Technologiebewertung, 2003, p. 112), strong effects on residential mobility are attributed to biographical events.

Therefore we included a biographical sub model that will calculate the occurrence of the biographical events for each agent each year based on probability distributions taking several agent characteristics as parameters and utilizing a pseudo-random number generator. This process is very similar to that outlined before in the section about generation of the synthetic population. Our residential decision model implements "residential dynamics" as described by Benenson (2004, p. 10).

The following life-course events are considered in our demographic sub model as they appear to influence residential mobility decisions (Bauer-Wolf et al., 2003, p. 19; Hurtubia et al., 2010, p. 8):, (1) Birth of a household member, (2) Death of a household member, (3) Leaving the parental home and (4) Moving together or marriage, foundation of a household, see Table 3. The demographic sub model is strictly based on the probability with which a certain biographic event can occur for certain households. This implies an easy parameterization process of these probabilities through a central database. The data model contains events and their corresponding probability of occurrence for a certain "person-profile". This could be for example the death of a 60-year-old male, who in 2008 had a 1.447% chance to die (Statistics Austria, 2009, p. 26).

3.3. Residential mobility module

After the initialization of the model in terms of distribution of all households to dwellings in different spatial units, the small-scaled city areas, the residential relocation process starts. Some households are affected by demographic events, many are not. However, all households evaluate their current living situation and decide whether to start looking for a new dwelling through a stress/resistance-model (Benenson, 2004, p. 6; Knox and Pinch, 2010).

[2] Because of differences in the variable naming and availability, we decided not to include the datasets for 2004 and 2005.

Table 1
Data sources and input parameters for synthetic population sampling. A legend of the variable names is given in Table 2. Indexes can be found in Fig. 2 ($q = 1\ldots$ total number of households, $r = 1\ldots$ total number of persons).

Description	Formula	Data source
Person age	$\text{age}_r = \text{age}_r(P_{\text{age}}(y\vert\text{su},\text{hhrep}), R_{\text{age}_r})$	Statistics Austria (2008)
Person sex	$\text{sex}_r = \text{sex}_r(P_{\text{sex}}(y\vert\text{su},\text{hhrep}), R_{\text{sex}_r})$	Statistics Austria (2008)
Person income	$\text{income}_r = \text{income}_r(P_{\text{income}}(y\vert\text{su},\text{age},\text{sex}), R_{\text{income}_r})$	Statistics Austria ISIS Database L4C
Household living space	$\text{livsp}_r = \text{livsp}_r(P_{\text{livsp}}(y\vert\text{su},\text{hhsize}), R_{\text{livsp}_r})$	Statistics Austria ISIS Database H0M, Statistics Austria (2004, p. 195ff)
Free dwelling for the household	$\text{dwelling}_q = \text{dwelling}_q(P_{\text{dwelling}}(y\vert\text{su},\text{livsp}), R_{\text{dwelling}_q})$	Statistics Austria ISIS Database H0M
Residential satisfaction threshold modifier	$\text{rtsm}_q = \text{rtsm}_q(P_{\text{rtsm}}(y), R_{\text{rtsm}_q})$	
Household costs of residence	$\text{cor}_q = \text{cor}_q(P_{\text{dwelling}}(y\vert\text{su},\text{livsp}), R_{\text{cor}_q})$	Statistics Austria Micro Census Konsumerhebung 2004/2005

Table 2
Description of variables used for the synthetic population generation.

Variable	Description
age	Age of a person
cor	Household's cost of residence
dwelling	Dwelling of the household
num_hh	Number of households per spatial unit and household size
hhrep	Is the person the household representative?
hhsize	Number of persons in the household
income	Income per person
livsp	Living space of the household
rstm	Residential satisfaction threshold modifier for a household
sex	Sex of a person
su	Spatial unit

In our model the stress to move is implemented by a calculation of residential satisfaction and a fixed threshold.

The only available empirical study on influence factors on residential satisfaction in Vienna is from Zucha et al. (2005). We used these results for two purposes: 1) to determine the most important influence factors for the residential satisfaction/stress to move calculation in our model (see Zucha et al., 2005 p. 50) and 2) to derive the relative weight of these factors in that calculation.

In their study, Zucha et al. (2005) use data from interviews of $n = 8300$ persons in Vienna conducted between May and October 2003 by the Viennese urban planning department (MA18) to carry out a path analysis of the attachment to the neighbourhood in Vienna including residential satisfaction as a main component. The goodness of fit values of this structural equation model are $\chi^2 = 1488.576$, df $= 104$, RMSEA $= 0.05$, GFI $= 0.986$, and AGFI $= 0.980$ (Zucha et al., 2005, p.146).

Given below is a list of the factors that we implemented in our model for residential satisfaction/stress to move calculation:

1. Environmental amenities: share of green area or water bodies in each small-scaled city area.
2. Level of infrastructure: described in the model by the UDP (Urban diversity pattern) indicator[3] (Schremmer et al., 2011a, p. 33ff.) component for accessibility of high-level public transport infrastructure.
3. The centrality of the living area, described in the model by the UDP indicator component for centrality.
4. Social prestige: To measure the social prestige, the relation between the average income in a small-scaled city area and the income of the household is used.

$$\text{STM}_{\text{social prestige}} = 1 - \min\left(1, \frac{\text{avg(income)}}{\text{income}_{\text{hh}}}\right)$$

For a household with lower income than the average income of neighbouring households, the social prestige related stress to move is 0.

5. Satisfaction with the dwelling in terms of costs and size: The satisfaction with the cost-effectiveness of the dwelling is modelled as the deviation from the mean cost-effectiveness of a random sample of dwellings (sample size is controlled via the system parameter “Household comparison sample size”) of the same family structure, the same dwelling size class and the same spatial unit.

$$\text{STM}_{\text{cost-effeciveness}} = \min\left(1, \frac{\text{avg(costs for dwelling)}_{\text{random sample}}}{\text{costs for dwelling}_{\text{hh}}}\right)$$

6. Similarly, the satisfaction with the size of the dwelling is modelled in the same way:

$$\text{STM}_{\text{dwelling size}} = \min\left(1, \frac{\text{size of dwelling}_{\text{hh}}}{\text{avg(size of dwelling)}_{\text{random sample}}}\right)$$

These six factors are used for the stress to move calculation as a percent value that is complemented by a fixed random factor per household to account for unknown parameters. The overall stress to move for a particular household will be calculated with the weighting factors given in Zucha et al. (2005, p. 50).

For each of these factors the stress to move (or residential satisfaction/dissonance) is considered as a thousandth part value. The overall stress to move for a particular household is calculated with weighting factors according to the following formula[4]:

$$\text{STM}_{\text{hh}} = \frac{\sum(\text{STM}_i * \text{pref}_i * \text{weight}_i)}{\sum(\text{pref}_i * \text{weight}_i)}$$

The relative weight of each component is derived from the path coefficients calculated by Zucha et al. (2005, p.50) and are given in Table 4.

[3] The UDP indicator is composed by (1) Accessibility of high-level public transport infrastructure, (2) Centrality (proximity to centre functions) and (3) Diversity (mix of economic and residential functions).

[4] STM = stress to move; pref = household preference weight; weight = weight taken from LISREL model of Zucha et al. (2005, p.50); i is meant to be one of the following: environmental amenities; infrastructure/location; social prestige; size of the dwelling; cost-effectiveness of the dwelling.

Table 3
Detailed description of biographical events.

Biographical event	Affected agents	Residential dissonance calculation	Data source
Birth of a household member	Selected probabilistically through age-specific mortality rate in 2008	Normal relocation procedure	Statistics Austria (2009, p. 16)
Death of a household member	Selected probabilistically through age-specific birth rate in 2008	Normal relocation procedure	Statistics Austria (2009, p. 22)
Leaving the parental home	All households with family children aged 15 and above (Mayer, 2002)	Estimated from Austrian Micro Census 2006–2008 (Statistics Austria, 2008)	Results of a questionnaire of 300 adolescents aged between 15 and 24 years (Mayer, 2002, p.90); Comparison data: Stadt Wien (2007, p. 13)
Foundation of a household (moving together, marriage)	All persons that leave their parental home and all single households	Normal relocation procedure	Statistics Austria (2009, p. 16)

The resulting value for each component (STM_i) will once more be weighted using a "relative importance" that each component has to the respective household based on its household type. These household type-based preferences ($pref_i$), are based on studies by Bauer-Wolf et al. (2003), Hurtubia et al. (2010), Tappeiner et al. (2001), Moser and Stocker (2001) and our own assumptions. The overall stress to move result (STM_{hh}) will then be compared to a fixed threshold deciding whether a household will enter the housing market or not.

When a household searches for a new dwelling, at first the aspiration region is defined by the size and price limits a household can reasonably afford. Also a range of search areas will be defined, depending on the expected residential satisfaction of that area and the maximum number of search areas per household per year configured in the model.

The very same calculation of residential satisfaction is again applied to find a new dwelling by comparing potential residential satisfactions of available dwellings with the current value. Fig. 3 shows a simplified calculation example. On the left-hand side, each household defines its preferences using importance scores for a set of selected criteria. On the right-hand side, each spatial unit offers fulfilment scores for a certain set of properties. Each property reflects exactly one criterion (criteria 1 and property 1 are the same: for example, share of green area). The compliance between these two tables is calculated each year for those households looking for a new residence. Those spatial units that offer the highest residential satisfaction for the particular household will be the aspiration regions in the subsequent search for a dwelling.

The set of vacant dwellings is initialized along household and dwelling data in 2001 from Statistics Austria. 2001 a surplus of free dwellings exists from which only a certain share appears as available at the dwelling market within the model. Additionally, the model uses an urban development scenario that specifies the number of newly constructed dwellings per cell and model year. The numbers currently used are provided by the Austrian Institute for Regional Studies and Spatial Planning (OIR) (Schremmer et al., 2011b, p. 21ff.). These scenarios consist of projects (1) already planned as urban projects until 2025 and (2) projects involving the distribution of population within areas/aces providing good conditions for large urban projects, i.e. assumed as long-term projects from 2026 to 2050. Finally, a stochastic allocation of dwellings completes the number of dwellings needed to accommodate the excess immigrating households.

If a household cannot find a dwelling with a higher satisfaction factor, it will remain at its current living place. Transaction costs in terms of moving costs are included using a stochastic residential satisfaction threshold modifier value on the individual household level. During a model time unit (one year), the household may consider only a certain number of dwellings to reflect the incomplete knowledge of the household (Semboloni, 2007, p. 61). If a more suitable dwelling can be found, the household will relocate and the old dwelling will subsequently be free on the household market for other households.

Table 4
Weights for components of residential satisfaction calculation.

Component	Path coefficients	$weight_i$
Environmental amenities	(0.77 + 0.68) * 0.63/2	0.457
UDP Centrality	0.49 * 0.63	0.309
UDP Public Transport	0.49 * 0.63	0.309
Social prestige	0.68 * 0.63	0.428
Cost-effectiveness	0.62 * 0.15	0.093
Desired living space	0.6 * 0.15	0.090

3.4. Urban development and vacant dwellings sub model

Complementary to the implementation of households, the model also includes dwellings and simulates changes in residential infrastructure through urban development scenarios. These scenarios specify the number of newly constructed dwellings per cell and model year. The numbers currently used in all model scenarios were supplied by the Austrian Institute for Regional Studies and Spatial Planning (OIR) (Schremmer et al., 2011b, p. 21ff.). These scenarios are based on projects already under construction or planned until 2025, on expert assumptions on areas providing good conditions for large urban projects, and on the allocation of additional population/dwellings according to housing/density types, excluding so-called "taboo-zones" in which a further densification cannot be expected for reasons like historic conservation.

A key influence to the urban development scenarios comes from the population estimations of Statistik Austria (2011), specifically from the high estimates on immigration. To accommodate all of these additional households, the model allocates the dwellings still missing after the urban development scenarios stochastically throughout the city area. The decision to resolve the conflict between assumed immigration and dwelling infrastructure this way was taken to adjust closely to the population estimation of Statistik Austria for reasons of comparability.

The census numbers of Statistik Austria in 2001 show an excess of 137,227 dwellings in comparison to the number of households. Of these excess dwellings, about half are known to be non-permanent residences or institutional accommodations. The remaining dwellings without declaration of residence are then put on the housing market by the model.

The matching of dwelling-seekers to available residences is done by a demand-driven first-come, first-serve market model. Households limit their search to affordable and more satisfying dwellings. The rents are provided as exogenous data from Wirtschaftskammer Österreich (2009) and – together with the

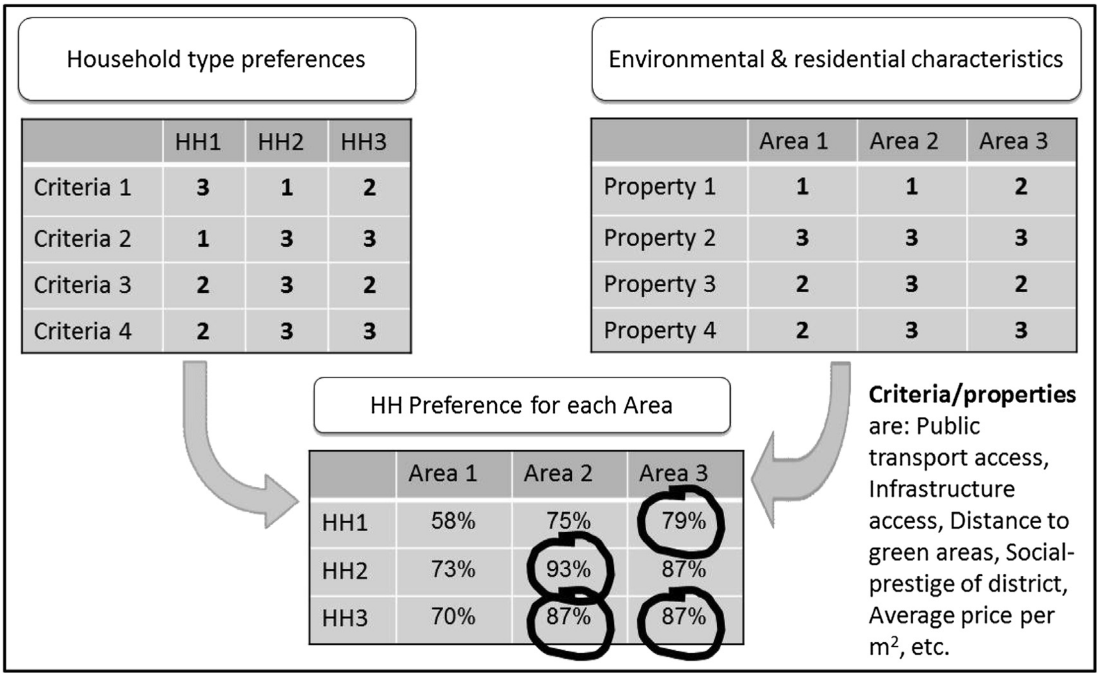

Fig. 3. Simplified sample of implemented procedure for residential location decision-making using weights ranging from 1 to 3: Households have different preferences for criteria 1–4 (depending on household type, income, etc.); areas fulfil these criteria with their properties 1–4 to different degrees (which changes through urban planning actions). This results in specific preferences of each household for each area. Source: own diagram.

income data – are kept on the same level throughout a model run. Based on the classification of land market models given by Parker et al. (2012) there remains room for improvement in the dwelling market module, particularly since no competitive bidding for dwellings is implemented. One option to improve this is outlined in detail by Ettema (2011) where market perceptions by buyers and sellers are used to determine the bid and ask prices for dwellings.

3.5. Scenarios

We used the residential mobility model for Vienna as a tool to simulate future scenarios depending on changes in (1) urban development planning, (2) economic framework conditions in terms of dwelling prices and (3) changes of household's preferences in terms of environmental amenities. We developed assumptions for future developments of external framework conditions in three scenarios, which we contrasted with a reference scenario – the conventional urban planning scenario – that carries forward the initial values as inputs. The scenarios consider the varying recent situations in Vienna as starting points for analysing different urban planning perspectives. The findings in terms of effects describe the distribution of different household types over the city including the surrounding area. Together with the population development until 2050 as the external driver, different story lines (Table 5) are analysed as framework conditions for the future spatial allocation of household types.

The *conventional urban planning scenario* assumes that the conditions of the current planning policies remain constant over the 50 years of the simulation period supporting past spatial development trends (densities and configurations of the urban fabric). For the future city planning those projects that are part of the Urban Development Plan of Vienna were assumed to be realized by 2025 respectively by 2050. The assumptions are based on available planning documents of the city. This scenario demonstrates how the future could unfold if neither external nor internal factors were to change over the next decades.

The *sustainable urban planning scenario* defines a path of more sustainable spatial development – focussing on the interrelations between urban form and the metabolic performance of an urban region, by changing current planning policies towards

Table 5
Framework settings of the four scenarios.

Scenarios	Conventional urban planning	Sustainable urban planning	Expensive centre	No green area
Location of new buildings	Realization of UDP[a] projects	Densification of inner city and areas near to transport routes	Realization of UDP[a] projects	Realization of UDP[a] projects
Density of buildings	Realization of UDP[a] projects	Higher than UDP[a]: 10,000 additional dwellings between 2026 and 2050	Realization of UDP[a] projects	Realization of UDP[a] projects
Dwelling price level in 1st district	No change	No change	Two fold	No change
Dwelling price level in 2nd to 9th district	No change	No change	Four fold	No change
Preference value for green areas	Standard preference values	Standard preference values	Standard preference values	Preference value = 0 for all households

[a] …Urban development plan of Vienna.

a clear guidance of urban development on major transport routes, providing compact and integrated new developments and aiming at densification in areas of good accessibility. The new planning strategy brings in a densification of the inner city as well as localization near transport lines. Additionally, in contrast to the conventional urban planning scenario this scenario allows for a higher density of buildings (Schremmer et al., 2011b, p.B24ff).

The third scenario, the *expensive centre scenario*, is based on the assumptions of the conventional urban planning scenario concerning urban planning strategy, which stays the same as in the past. Drivers in this scenario are the price levels for dwellings in certain areas. The m^2 price of all dwellings in the centre (1st District) rises by 200% of the current price. In the areas around the centre and inside the border of an inner ring-road in Vienna called the "Gürtel" that includes the 2nd to 9th Districts, the average price per m2 increases by about 100%.

Finally, in the fourth scenario, the *no green area preference scenario*, we assume that the preference for green areas in the desired spatial unit is equal for all households, namely zero. The assumption implies that the decision of households for new dwellings is exclusively oriented on the centrality, infrastructure and price level. Even for family households the share of green areas has no relevance in the decision-finding process anymore. The framework conditions stay the same, which means urban planning takes place such as in the conventional planning scenario.

The model outputs indicating scenario dependent patterns of the city's socioeconomic structure serve as basis to assess changes in the energy consumption patterns of the city. We used existing data on average yearly consumption of energy from electricity and natural gas in 2007 in Austria from Wegscheider-Pichler (2009) and data on average yearly energy use for public and individual transport in Austria from Endl (2010). These data are available for different household sizes (from single household to households with more than 6 household members). By combining these per household energy consumption values with the distribution of household types over the small-scaled city areas the yearly consumption of energy of private households in Vienna per small-scaled city area was calculated.

4. Results and discussion

4.1. Scenario analysis

The analysis of the scenario results focuses on the distribution of households in Vienna depending on the age class and income class to which they belong. Therefore, we grouped the two household types of young single households and young couples as the aggregated category of young households (up to an age of 45 years). All family households (small and large families) belong to the second age class and finally old singles and couples represent the third age class of old people. The second type of analysis distinguishes between three income classes – households with less than €20,000 income per year and person, those with a yearly income of €20,000 to 100,000 and finally the class of "rich" people with more than €100,000 yearly income per person. Finally, we clustered along the category 'number of household members' the three family structure types (1) singles, (2) couples and (3) families. We analysed the distribution of households allocated to these categories in the 59 small-scaled city areas in the year 2050 for the four scenarios.

Some results of the model runs can be considered as constant for all scenarios. Above all, the density per small-scaled city area stays almost even in all scenarios as it is mainly defined by the number of available dwellings in each spatial unit (see Fig. 4). Vienna, with its densely populated inner city emanating from the historical old city (1st district), still has a rather mono-centric city structure. Important subordinated centres (the 2nd to 9th districts) are grouped around the original centre and are densely built-up zones containing many buildings designated as cultural heritage. A substantial densification of these areas is not realistic.

As the results show, in any scenario there is continuous population growth both in the densely populated inner city and in the outer districts, i.e. not only in urban development target areas in terms of population/m^2 (Table 6).

Changes in political, economic and planning strategies affect the socioeconomic structure of urban areas, that is, the share of households of different income, age and family structure classes in each urban area, rather than the overall density.

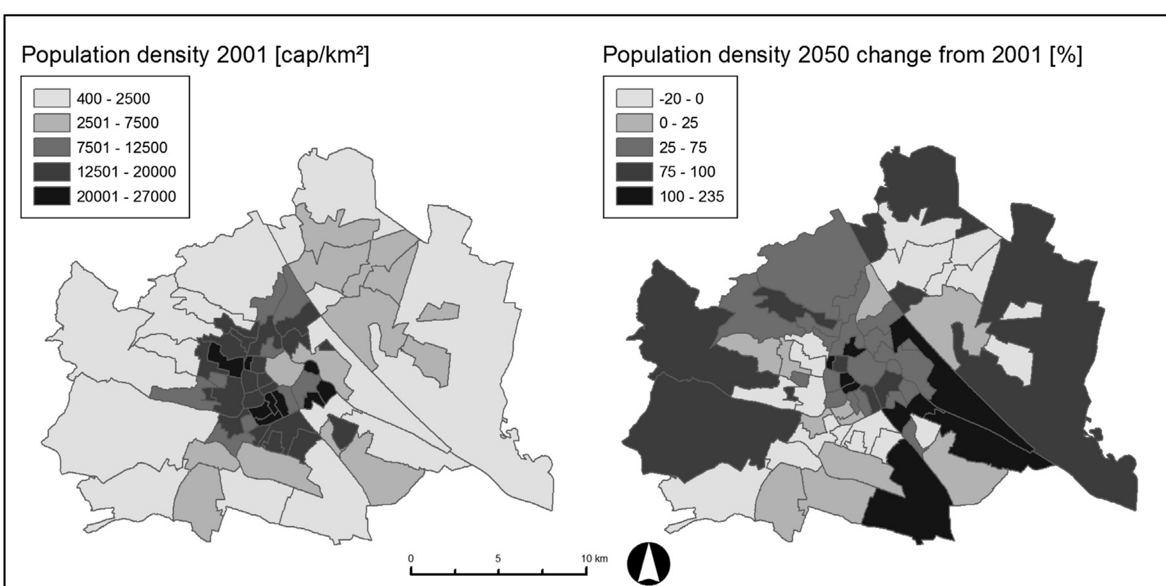

Fig. 4. Population density in 2001 and population density change to 2050 in the conservative urban planning scenario. Authors own diagram.

Table 6
Population increase between 2001 and 2050 in the three city zones: Centre (1st district), dense areas (2nd to 9th districts) and periphery in the conventional urban planning scenario.

Year	Centre	Dense areas	Periphery	Total
2001	8.980	187.950	574.780	771.710
2050	11.130	275.380	786.460	1.072.970

Comparing the distribution of households belonging to different household types (families, couples, singles and others) the results show a general trend in all four scenarios (see Fig. 5). For example the distribution of family households is more or less even across the city areas in all scenarios. Consequently, the share of family households increases not only in the periphery but also in the centre and above all in the dense areas. In contrast, the single households clearly shift from the inner city to the periphery.

One reason is based on the fact that due to the lack of data on the economic status of the immigrating households, we assumed that the distribution of immigrating households across income classes is close to the current income allocation of all households in Vienna. The results show that the middle income class is rather equally distributed over the city, whereas the households belonging to the "poor" households tend to shift to the cheaper districts of the periphery (e.g. North-eastern Vienna). The same phenomenon is true for the single households. These general trends observed for all four scenarios become much more complex as soon as we analyse the results on the level of small-scaled city areas.

In the *conservative urban planning scenario*, young households are concentrated in the west of the city, in the northeast (across the Danube river) and in large parts of the south, mostly in cheaper to mid-priced areas. In contrast, families tend to move to greener and higher income areas in the suburban districts. Those areas that are currently mostly inhabited by the elderly in 2001 are mainly occupied by family households in 2050. The poorest households (yearly household income < €20,000) agglomerate in the cheaper areas just as would be expected and in 2050 tend to concentrate in those areas in contrast to 2001, when they were distributed more evenly across the small-scaled city area. The rich households (yearly household income > €100,000) conversely agglomerate in areas with high rents (except for one area in the 10th district), that is in the inner city districts and the suburban districts in the west of Vienna.

In the *sustainable urban planning scenario*, the distribution of young and old households and families remains almost the same as in the conservative urban planning scenario. This indicates that urban planning strategies aiming at a more sustainable urban development by reducing energy demand only marginally affect the socioeconomic structure of the city. However, the large 22nd district in the northeast of Vienna shows a higher concentration of family households compared to the other scenarios, which may be caused by the additional dwellings available in this scenario. These dwellings are mainly rented by middle-class families seeking cost-effective dwellings in a green area. Obviously, the establishment of secondary city centres in areas like the 22nd district makes these areas attractive for lower- to middle-class family households looking for affordable dwellings in green areas. The concentration of the richest and poorest households remains very similar to those in the conservative urban planning scenario. In general, we can presume that this scenario mainly affects the suburban areas outside the municipal borders of Vienna.

The economically *expensive centre scenario* show that low-income households are largely absent in the affected districts, whereas high-income households are concentrated in the more expensive city centre. The impact of this scenario on young and single households is much greater than on families, couples and old households. Families, couples and the elderly remain present in these inner city areas at more or less the same level as in other scenarios, or even rise slightly. In contrast, young and single households are the household types with the lowest income and consequently have to react to price increases immediately by moving to the periphery.

In the fourth and last scenario – *no green area preference scenario* – the results show that the allocation of families, who would otherwise favour environmental amenities as one of the strongest residential decision criteria, differs clearly from other scenarios. In this scenario, families are more or less evenly distributed across the small-scaled city areas. Families as the biggest group representing middle income households do have a very broad set of satisfying residence locations as soon as the factor of green areas becomes unimportant. In turn, this behaviour of family households allows young, mostly single households with low incomes to move to the outer districts of Vienna, taking up the more affordable space made available by the lower concentration of family households there. In general, the overall picture of this scenario shows a more even distribution of the different household types between the districts, compared with other scenarios. This outcome becomes important, as soon as urban planning measures aim at a thoroughly mixed population structure in socioeconomic terms. If the ignorance of a preference for a high share of green area

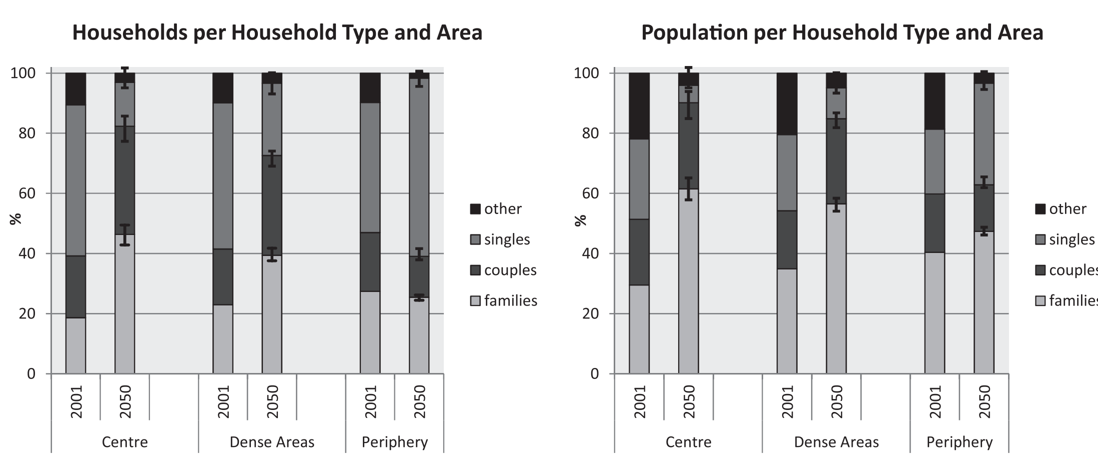

Fig. 5. Comparison between number of households (left) and number of population (right) per household type and area.

allows a mixed socioeconomic structure across the whole city, one can conclude that urban planning strategies supporting the establishment of green spaces even in dense city areas might allow for a "sustainable" well-mixed socioeconomic structure in the city. Environmental amenities seem to be a key criterion in the decision-making process of Viennese households (see Zucha et al., 2005, p. 50).

Based on the spatially explicit distribution of household types (as shown exemplary in Fig. 6), we calculated the energy use for heating, electricity and transportation in the 59 small-scaled city areas for all scenarios based on data for the different household types. Household energy demand depends on many factors. For example, space heating, one of the most important energy use categories of private households, depends on technical factors such as type of dwelling as well as on lifestyle factors that in turn very much depend on income and family structure of a household.

Fig. 7 shows how strongly the spatial pattern of energy use in the city depends on the distribution of household types over the city. Remarkably, the population as well as energy use by households both grew by 38%. Other studies (e.g. Druckman et al., 2008), in contrast, depict a rise in energy use up to three times as much as population growth and argue with an increase of proportion of small households (single, couples and small families). Consequently, the increase of population in Vienna with one third until 2050 must be based on a densification in terms of family structure and living space per person. The big share of migration driven population increase in Vienna might cause an average decrease in m^2 per person. This trend seems to counteract the general trend of increased per capita living space.

By looking at the factor per capita energy consumption per small-scaled city area the importance of the socioeconomic structure for the socio-ecological performance becomes significant. The results show the effect of the common socioeconomic trend of an increasing number of single households living in cities. Single households have the biggest amount of energy use per capita and therefore determine decisively the spatial pattern of energy use.

Even if the current model output represents energy use of households only based on an average factor for energy use per household type – which might not require a spatial representation necessarily – it is nevertheless important for several reasons. The results allow for analysing the effect of different city planning measures in terms of building renovation rates in different city areas. A combination of renovation rates and changes in socioeconomic structures represents an exciting next step. Furthermore, the spatially explicit results of the model allow for including distance and household type dependent use of energy for transportation.

The model version presented here has a set of limitations caused mainly by missing empirical data. For example, numeric empirical

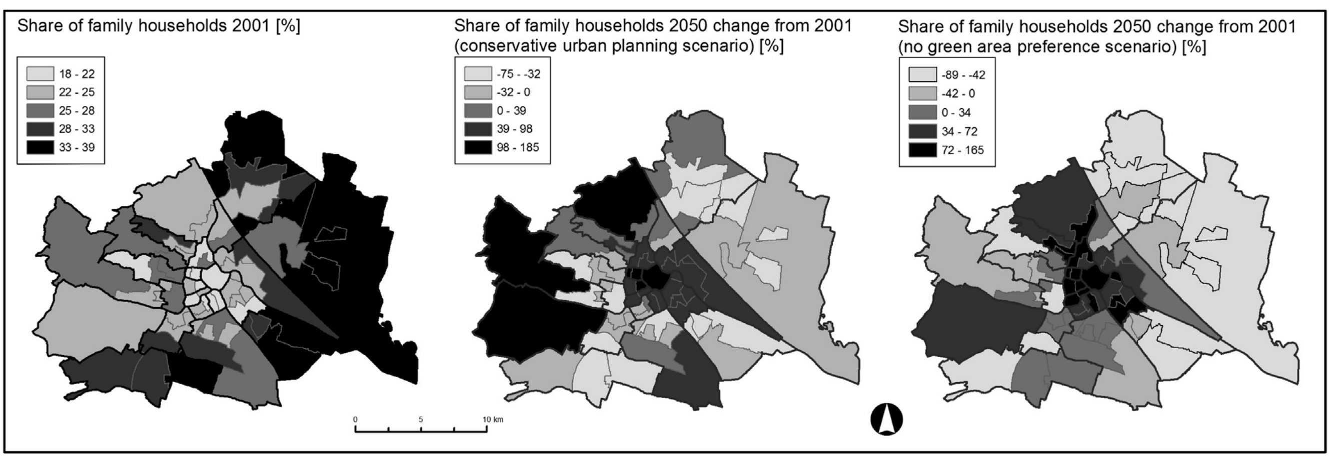

Fig. 6. Example of spatially explicit result representation: Distribution of family households in 2001 and 2050 in the conservative urban planning scenario and the no green area preference scenario. The gradient from light to dark demonstrates the amount of increased share of family households per spatial unit (min 0, max 50–75%), authors' own diagram.

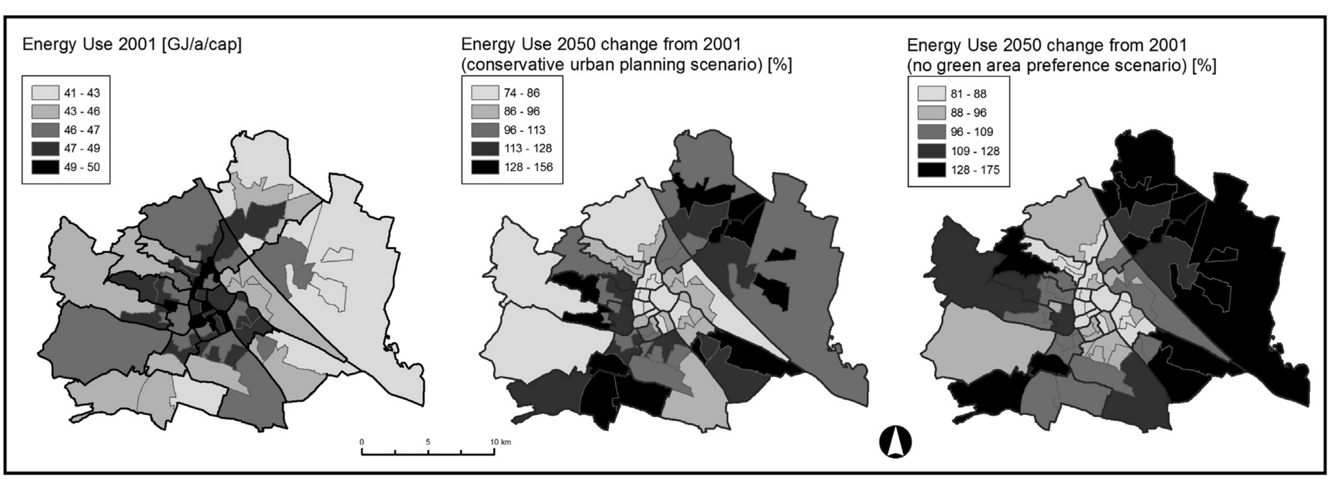

Fig. 7. Distribution of households' energy consumption for heating, electricity and transport.

data on household preferences for properties of districts in Vienna are rarely available (except in Zucha et al., 2005). Therefore the assumptions in our model are based on qualitative information drawn from different studies (Bauer-Wolf et al., 2003, p. 18; Fontaine and Rounsevell, 2009, p. 1240; Schneider and Spellerberg, 1999, p. 126; I.Z.T.Institut für Zukunftsstudien und Technologiebewertung, 2003, p. 112). Further matters such as the reality of three-year fixed-term contracts as rental agreements for new dwellings as well as the issue of ownership of dwellings could be relevant for a next and more advanced version of the model. Nevertheless, the current model represents an empirically based model that allows for a series of applications for future research.

5. Conclusion

The history of modern cities is the result of both planned and spontaneous development. In both cases, the emerging patterns of urban structures are influenced by factors such as available building technologies, urban planning regulations, real estate markets, investment strategies of public and private institutions, public policies (related to, for example, housing, transport, environment and taxation) and institutional traditions as well as individual lifestyle choices and behaviour. Consequently, urban planning is confronted with limited freedom to act restricted by given infrastructure and demographic requirements. The most obvious implication for urban planning principles is that changing the urban form does not necessarily have the desired impact on energy use, for example if people choose to continue to live in household types with a higher per capita energy use pattern. To achieve a more sustainable way of life, the production of sustainable urban planning programmes must take into account the socioeconomic structure of the city. Therefore, sustainable urban planning must be coupled with policies that address the behaviour of users. For example, alongside land use policies promoting high density development, the preferences of users for lower density development must be targeted.

From a methodological point of view we argue that especially in socio-ecological research there are good reasons for developing simpler model approaches. Socio-ecological research questions address social as well as natural issues ideally with the same degree of complexity. The development of agent-based models facilitates an interdisciplinary discourse when adding ecological implications on socioeconomic decisions. To conclude, modelling in general and especially agent-based modelling are therefore important research strategies to foster integrated analysis of society–nature interactions. Nevertheless, efforts should aim at developing models (1) simple in terms of degree of details and technical implications and at the same time (2) complex enough to address socio-ecological issues. In our opinion, this is one of the challenges in using agent-based models for analysing socio-ecological systems.

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