# A Regional, Spatially Explicit Agent-Based Model of Individual Acceptance of Climate Change Adaptation Measures

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**Abstract.** Climate change and its consequences are to attract much attention on many levels. Understanding the processes of individual adaptation as well as public reaction to and evaluation of policy defined adaptation strategies in this matter is a challenging field of research.

We address this issue by developing a spatially explicit multi-agent simulation model for the Northern Hesse region located in the centre of Germany. Agents represent households that are grouped according to their social differentiation by lifestyles. In addition to geographically differentiated, demographical-economic data, simulations are based on empirically gained data on individual's perceptions of both local opportunities and restrictions that are derived from several scenarios of climate change.

We focus on an explicit representation of the individual perceptions of climate change impacts through e.g. immediate climate perception or its media coverage, opinion formation by exchange through social networks or experienced limitations in personal behavioural options and achievable goals. These perceptions differ in their impact on an actor's overall satisfaction also depending on its lifestyle. Several domains of behaviour like individual transportation, health and compliance with legal and informational instruments are integrated.

As a result we expect the identification of anxious or dissatisfied population groups that require additional adaptation measures and such where current and planned strategies perform well. Results will be used to inform policy makers and stakeholders about the interplay of barriers and incentives regarding the individual action of adaption to climate change and their trajectories until 2030.

**Keywords.** climate adaptation, agent-based simulation, individual perception and acceptance, scenario analysis, social networks

# 1 Motivation

The goal of our research project is to simulate the population's satisfaction with respect to their freedom of action when facing the impacts of climate change, and to possible adaptation measures. Impacts of climate change vary across local topology and show temporal dynamics. Furthermore, we expect differences among households in terms of media perception, social network influence and climate change vulnerability, depending on their location, lifestyle, and age structure. Thus, in order to estimate such effects and to evaluate adaptation measures that need to be integrated like a flexible approach to care for heat-fragile people [5], an integrated modelling approach is required.

This paper is organised as follows: First, we review some applications of agent-based modelling to climate change issues and discuss key aspects of our approach. We continue with a description of the research project KUBUS and present an empirical approach to collecting data about the psychological processes and characteristics of social structure. We also give a short introduction to the so called Sinus-Milieus® as a differentiation of lifestyles and the way we apply these. Chapter three describes the input data of our agent-based model, which are census data, the spatial distribution of Sinus-Milieus® and climate scenarios. Then, our modelling approach to simulating the population's perception and satisfaction is introduced in detail. We conclude with an outlook for the ongoing research project.

## 1.1 Agent-Based Modelling and Climate Change

Agent-based modelling is a valuable tool to represent the heterogeneity of actors along with their social and spatial embeddedness. In particular, agent-based models are a suitable way to address cognition issues in adaptation, since vulnerability to environmental change depends on a number of individual cognitive capabilities such as perceiving risks, exchanging information, identifying and weighting of behavioural options, deciding upon them, acting and evaluating the outcome [1]. As Jager and Janssen [9] state, an explicit representation of interacting agents is intuitively understandable and thus appropriate to explore and communicate possible effects of policy strategies. Even combinations of activities could be explored without false estimation of the competing effects of single measures.

Recently, agent-based models were applied to explore regional impacts of climate change. Berman, Nicolson, Kofinas, Tetlichi and Martin [3] explored in a number of scenarios the effects of climate and economic change on deployment, household income and subsistence harvests in a small arctic community. They found that subsistence alleviates economic pressure in most scenarios, but climate impacts on caribou herds are difficult to mitigate. Links to psychosocial health and social capital for implementing beneficial scenarios to respond to this challenge were not integrated in the model but could be discussed directly with the community.

Acosta-Michlik and Espaldon [1] present an agent-based spatial model of four types of farmer households on an island of the Philippines. The adoption rate of proposed measures to secure yield under conditions of economic and climate change were investigated. They found that social connectivity is a crucial factor for successful adaptation.

### 1.2 Socially Embedded Super Agents

Unlike the approaches of Acosta-Michlik and Espaldon and Berman et.al. we focus on people's perception and satisfaction instead of economic success. Similar to the model of Philippine farmers we geo-reference agents to capture spatial heterogeneity.

Since the number of households within our model region is quite large (approx. 500,000) our agents are a kind of super-agents similar to super-individuals, a concept very common in ecological modelling [15; 8]. Super-agents were also applied to households in the past by Schwarz and Ernst [16], but implications from such aggregation were not investigated in depth.

Relations between individuals have different impacts on opinion formation and behaviour, depending on several characteristics like tie strength, for instance [6]. To adequately represent interaction among households regarding social support, information exchange, social comparison and social influence we model a social network, which is challenging because of super agents. Furthermore, we focus on interaction dynamics that originate from time-dependent tie strengths and frequencies, or peer-specific information exchange. That is, players of the same soccer team do not meet during winter, and people do not tell their neighbours the secrets they share with best friends. We also consider cutting off relations and establishing new ones, as Sobkowicz [19] suggests in his critical review of modelling social networks. Such alteration may happen in case of dispute (cutting off) or harmonisation (establishment) that exceed a certain threshold and is likely to cause meaningful dynamics within the social network that are not yet investigated in detail.

### 1.3 Assessing Agent's Satisfaction

A major element of our framework is a boundedly rational approach that reifies the identification and evaluation of possible actions from which the agent finally chooses one to execute. Thereto, every agent is assigned a preference structure comprising values that quantify its preference for specific goals. Current environmental conditions may influence these values in a way that a goal's priority is raised or decreased. Inexpensiveness is an example for the domain of transportation that is less crucial in prosperous situations and more important in times of limited liquidity. Compliance with the predominant opinion within the network of friendship represents an important goal related to social acceptance.

Furthermore, for every behavioural option the extents to which it fulfils the goals are given. For instance, for the goal "compliance with friends" is calculated how many of connected agents in the social network of friends support the option how strongly. A cumulative measure of an option's appropriateness is given by summarizing the products of current personal preferences and the option's contribution to a goal for every such goal.

The satisfaction of people depends to a large extent on their freedom and quality of available options. That is, an agent is satisfied in case there are some highly assessed options he may choose from and is dissatisfied if there is only one action that is expected not to meet his goals. The evaluations of available behavioural options may be interpreted towards the agent's satisfaction. Depending on the agent's lifestyle, comparisons to the behavioural options of connected agents may influence his evaluation.

## 2 Empirical Foundation

The research project "KUBUS" is part of the climate change adaptation network Klimawandel zukunftsfähig gestalten (KLIMZUG) in the region Northern Hesse [10]. The transdisciplinary research project started in October 2008 and shall develop and test new structures, institutions, products and services that are sustainable with respect to a successful adaptation to climate change. To ensure successful implementation of results the KLIMZUG project stresses exchange among science, economy, administration and society as part of a specific governance innovation strategy. Findings shall be transferred to similar regions in Germany and beyond.

Northern Hesse is located in the middle of Germany with its regional centre, the major city Kassel, being a meaningful node for both railway and car traffic. Its topology is characterized by low mountain ranges largely covered by woods and the river Fulda. One million people live on approx. 6,900 km², which means the area apart from Kassel is rather sparsely populated and organised at a small scale. Main future challenges of the region are ageing combined with decline of population in the rural areas, expected increased precipitation during autumn, winter and spring seasons and extreme weather situations like heat periods, storms, and flooding.

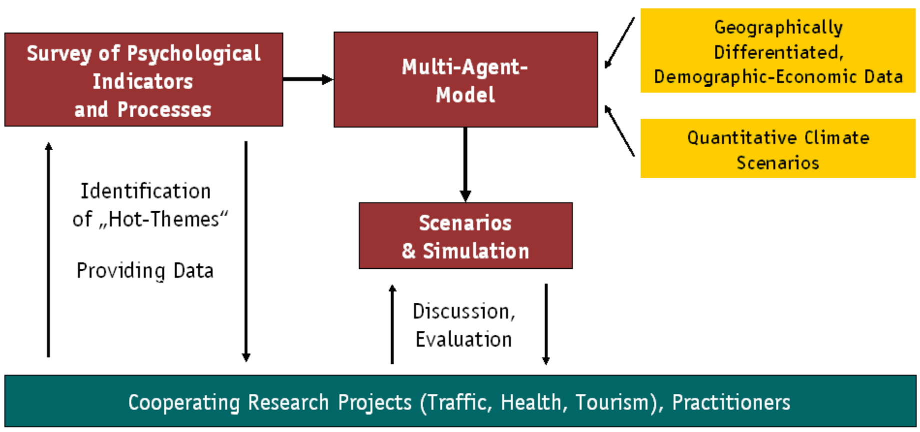


**Fig. 1.** Multiple socio-scientific surveys and a multi-agent model that incorporates survey results as well as climate and demographic data are the two components of the KUBUS project.

The KUBUS project strives to qualitatively and quantitatively represent individual perceptions of regional impacts of climate change, individual attitudes and options of action accordingly, comprising some of their trajectories. Uncertainties, fears as well as opportunities and potentials of conflict need to be considered. Possible adaptation of individual behaviour like change of habit or preventative measures is then investigated including their acceptance among the socially interacting population. The identification of crucial topics is done in cooperation with other research projects of the KLIMZUG network concerning legal and informational instruments, individual traffic, local recreation and health care issues.

Therefore, empiric surveys are conducted which focus on psychological indicators and processes as well as on sources of influence, i.e. media consumption and characteristics of social networks. Moreover, the spatial multi-agent-based computer simulation of scenarios of societal adaptation processes is developed to map the population's satisfaction with respect to climate change processes. Thus, the model might support decision makers in identifying areas that need action and to evaluate possible measures. As figure 1 shows, the simulation is based on empirically gained data as well as on geographically differentiated, demographical-economic data to capture individual perceptions of both local opportunities and restrictions derived from several scenarios of climate change. Agents represent spatially distributed households that are grouped according to their lifestyle, and that are embedded into their social network.

## 2.1 Empirical Approach

To investigate psychological processes and indicators of individuals in the light of climate change we conduct a long-term-study that employs a three-wave panel design, with a one-year interval between waves. The surveying methods mainly consist of a questionnaire, which is consigned by mail to at least 1000 households in Northern Hesse. For further information about this questionnaire we might carry out interviews and supposedly also a survey via internet.

The questionnaire is divided into two parts. The first part consists of variables concerning the adaptation to climate change in different fields like health, traffic and legal instruments. It mainly discusses the courses of action in the fields mentioned and also how important other variables are (like e.g. volunteer work, media perception and social networks) for showing a certain action and for effects on satisfaction.

The second part comprises the questions relating to sociological lifestyles by using the Sinus-Milieus® [18]. Because of societal liberalisation social norms based on social classes decay and individuals experience more autonomy. Lifestyles seek to capture perceivable patterns of behaviour, symbolic integration and underlying orientations as expressions of that autonomy. Lifestyles are meant to be a more relevant grouping of individuals and households [20]. The Sinus-Milieus® are commonly used in commercial market research, but also in environmental research [16]. The questionnaire contains items to identify the respondent's milieu in order to map results to other representatives of that lifestyle.

As a result, we expect that different behaviour in connection with adaption to climate change results from someone's lifestyle and from the importance attached to a specific action. Finding out to what kind of weather conditions (e.g. heavy rain versus heat) a person can adapt more easily and which climate circumstances lead to a disaster or to restrictions experienced in those lifestyles, constitutes an interesting element of our research

## 2.2 Data Drivers and Scenarios

Besides the empirical studies our simulations are based on geographically differentiated, demographical-economic data as well as on several scenarios of climate change. The Microm® corporation raised demographic data of the composition of Sinus-Milieus® within so-called market cells that comprise up to several hundred households. As figure 2 demonstrates this data provides the number of households differentiated by Sinus-Milieu® and size of household for each of 1133 Microm® market cells within our model region at four points in time.

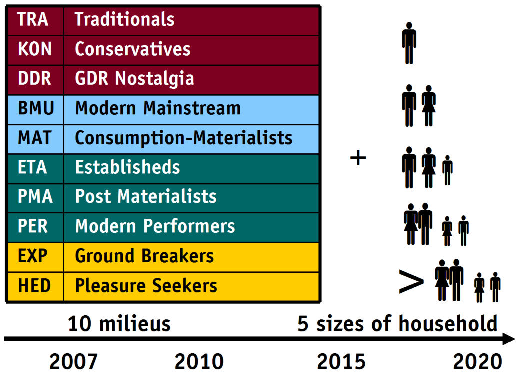


**Fig. 2.** Numbers of households per Microm® market cell are available for each of ten milieus and five household sizes for the year 2007 and three projections for 2010, 2015, and 2020. Colour coding indicates similarity of milieus: traditional lifestyles (*dark red*), mainstream (*light blue*), societal guiding lifestyles (*dark green*) and hedonistic (*yellow*).

Thus, we consider shifts of certain Sinus-Milieus® which are obvious for some parts (figure 3). For instance, traditional milieus are expected to decline substantially while hedonists are going to increase. With respect to sizes of household there is a trend towards smaller households. Furthermore, we evaluate census data to get information about the population's age distribution.

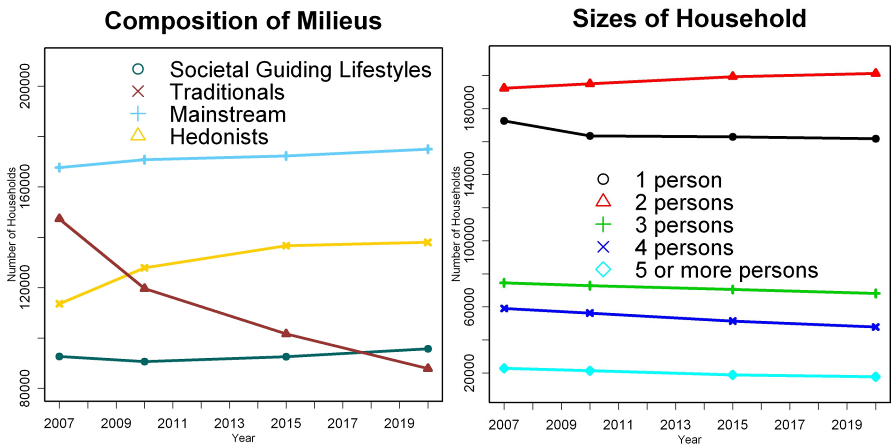


**Fig. 3.** The *left* figure shows the development of Sinus-Milieu®'s composition until 2020 in Northern Hesse. The *right* figure displays the development of sizes of household.

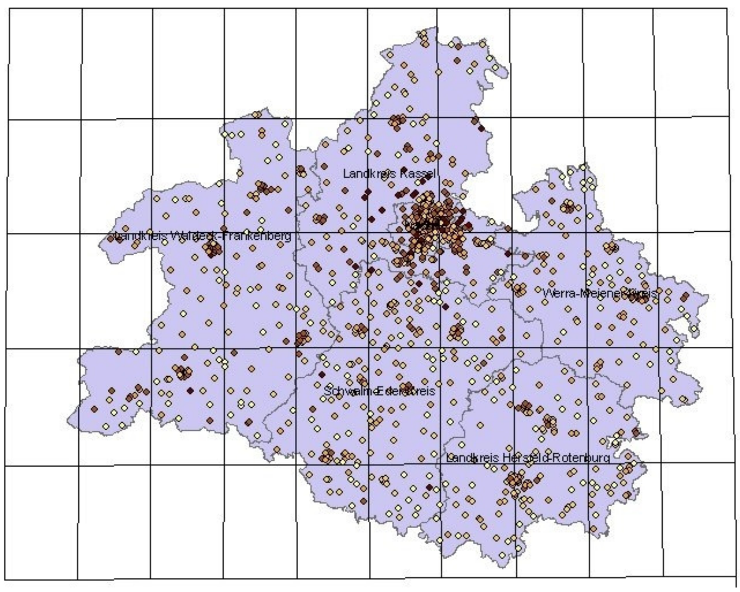


**Fig. 4.** This figure represents the population of Northern Hesse by its distribution as Microm® market cells. Darker points indicate cells with many households. The grid demonstrates allocation of available climate scenario data.

The climate scenario data is generated by the CLM-model and based on the IPCC scenario A1B [7]. Available values comprise air temperature, wind speed, rainfall, snowfall and cloud cover and are calculated for time intervals of 1 or 3 hours. The grid cells that are visible in figure 4 and for which data is computed are approx. 14 kilometres wide and 22 kilometres high. Since for better accuracy it is recommended to average over several neighbouring cells, the spatial resolution of climate scenarios is rather coarse. Attempts to adapt these climate data to regional topology are undertaken by another KLIMZUG project.

## 3 A Spatial Agent-Based Model of Population's Satisfaction

Simulating the population's satisfaction within a complete region is challenging. We focus on handling large numbers of households by super-agents and on initializing social networks as plausible as possible. Furthermore, considerations are given to a flexible architecture to implement diverse domains of climate change.

### 3.1 Super Agents

We aggregate households according to their Sinus-Milieu® in every Microm® market cell to one or more agents, depending on the number of represented households that may vary from 0 to 430. For reasons of computational efficiency the available 10 Sinus-Milieus® are aggregated to 4 lifestyles (see figure 2). If there are many agents and the differences of represented households are small, agents may not need to be weighted according to the number of represented households with respect to their influence on overall satisfaction, for instance. However, the level of grouping depends on the computational effort and on the level of individuality that is necessary to represent processes accurately.

Parry and Evans [14] considered the challenge of adapting super agents when the number of individuals change – an issue we need to address since composition of lifestyles changes over time (see figure 3). Again, in case of many agents representing fewer households single agents could be added or removed. Otherwise a factor accounting for the varying number of households per agent need to be introduced to capture according affects. For example, empirical results may show that older Traditionals in rural areas whose number exceeds a certain threshold need additional nurse support to be satisfied.

Because every agent is assigned to a fixed position within the GIS, computational demands are likely to be reduced by super-individuals without distorting effects of spatial interaction from coarsening that Parry and Evans found out to be problematic for moving individuals.

### 3.2 Social Networks

Individuals are part of many social networks that vary in their kind of relationship. They maintain ties to more or fewer alters which differ in their frequency and closeness of contact. To survey complete data of these relationships for a whole region is practically impossible, and even detailed information of some individuals is hard to achieve. Furthermore, reported ties may differ substantially from actual ones, although these deviations are often systematic, as Marsden [11] finds in his review of methods for gathering network data: Relations of long duration are more likely to be reported, and data is more accurate when close ties are asked prior to acquaintances.

Consequently, based on some plausible assumptions we need to identify a few items to gain valuable information on how to initialize the social networks. Name or resource generators [12] in combination with name interpreters are appropriate to investigate personal network size and further information like residence of selected alters. Patterns of homophily could be observed in many social networks and give hints on who to connect with whom: People tend to form relations with others of same race, religion, sex, age and with similar education, often because they are married with, live next to, work with and engage in organizations with people who have a similar background. Additionally and maybe as a reason, ease of communication and shared cultural taste are forces to tend to interact with related individuals [13].

The empirical results will be scaled up to the population of the entire region according to the respondent's lifestyle and type of location (i.e. rural, suburban or urban). Projecting personal networks on super agents is especially challenging. Regarding super agents as super nodes in the network that capture all incoming and outgoing links of the represented households leads to unrealistic high degrees. Therefore, we determine the average network characteristic of underlying households and apply it to the super agent, with respect to lifestyle and location of alters.

Findings of homophily will be operationalised especially with respect to preferential and discriminating attachment between certain lifestyles following an approach of Schwarz [17]. Based on milieu characteristics she defined the number of ties and probabilities for connections between certain lifestyles (for instance, hedonists build up 50% of their connections to the guiding milieus and 50% to other hedonists). Starting with relations between neighbours, randomly chosen ties were rewired to more distant agents, applying an algorithm similar to Watts and Strogatz [21]. Additionally, we consider multiplex relations and network changes. That is, we include separately social influence as well as information exchange and dynamically create ties in case of emerging homophily and dissolve relations in case of heterogeneity. Links are attributed with frequency and tie strength that affect the influence an alter's opinion or knowledge has on the agent at a given point in time.

### 3.3 A Flexible Framework Approach

With respect to concrete processes that influence the population's satisfaction we cooperate with other research teams of the KLIMZUG project network. One of these investigates impacts of extreme weather events like storms and flooding on individual traffic. Thus, we model mobility within the GIS on a meso level, that is representing main targets like job location and explore the influence of road closures. What will people do in case they cannot drive along a certain road? Does a planner find an alternative routeing? Does it not bother them since they choose railway transportation?

With respect to our approach of boundedly rational agents, for every domain of activity each agent is assigned a list of possible behavioural actions. Agents then evaluate the effectiveness of each action, which is adapted by the current impact of environmental factors, according to their general goals. If commuting by train a priori has maximum potential to achieve the agent's goals he is satisfied despite a road closure. Behavioural options are activated or disabled according to current conditions. A car being repaired excludes this option, and the overall satisfaction may be less than in the case this driving option could be included. Furthermore, the agents may learn about how well a certain action reached their general goals and may adapt the action's matrix entries accordingly. The reasoning is boundedly rational because of limits of perception and memory, the occasional use of heuristics, and possibly irrational postprocessing of decisions. For further details on the approach on evaluation of behavioural options see Ernst, Krebs, Elbers, Holzhauer and Klemm [4].

The variety of topics makes it plausible to use a framework approach that helps to represent several domains like mobility, health care and legislation in a sound way. As Barthel, Janisch, Schwarz, Trifkovic, Nickel, Schulz and Mauser [2] found, an abstract model structure in fact simplifies model development, validation as well as documentation.

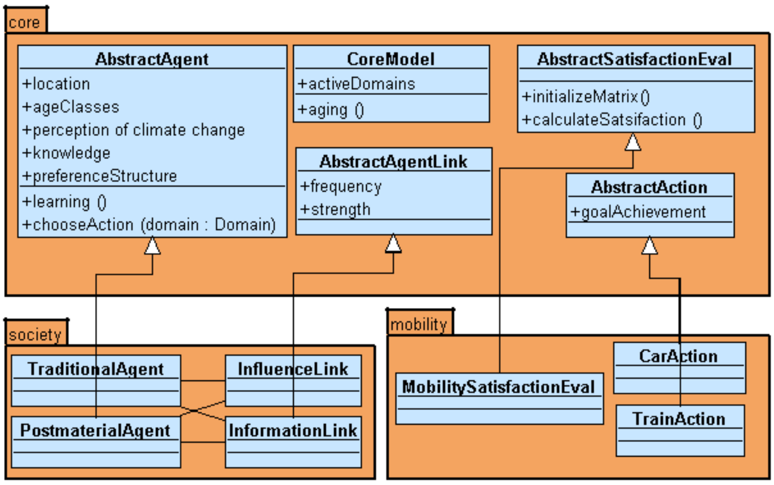


**Fig. 5.** UML class diagram of the general agent-based model architecture: Agents have different properties according to lifestyle, location and age. Several domain-classes implement methods to initialise and evaluate the action matrix. Domains are separated from each other in packages and may be enabled or disabled by the CoreModel class.

We implement several modules for the domains listed above that all follow the same architecture. This way, it is possible to investigate implications of climate change and adaptation isolated or in combination. For instance, for the domain of leisure availability of nearby open air pool becomes important during periods of heat. In combination with mobility, traffic options to visit the bath may be evaluated as well. Additionally, it is possible to run the model for a specific part of the region.

## 4 Conclusions and Outlook

We presented our agent-based modelling approach for simulating the population's satisfaction with respect to their freedom of action facing impacts of climate change and possible adaptation measures. Key aspects are the super-agent method that helps to adequately represent a large number of households based on lifestyles and the advanced representation of social networks which influences exchange of information and opinion. Besides, a flexible architecture allows to integrate and to isolate certain domains for investigation.

Result of the KUBUS research project will be a deepened knowledge about the interplay of barriers and incentives regarding the individual action of adaption and their developments until the year 2030. Individual perceptions will be presented with appropriate spatial resolution. The results will be provided to the other KIMZUG research projects and stakeholders, but will also be integrated into curricula for advising the public.

However, there are some issues that need further investigation in the course of modelling and simulation. Impacts from grouping households to super-agents have not been studied in detail, especially with respect to adequately representing the social network among these agents. The network itself might be a source of uncertainty, and different approaches to initialize and alter relations among agents should be evaluated.

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