Diffusion of water-use innovations
An agent-based model

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Introduction[1]

Climate change scenarios show that in Middle Europe, global rising temperatures might lead to regional dryer climate in some regions and wetter climate with more floods in others (IPCC, 2007). In both ways, the provision of high quality drinking water will be more difficult than today, either because of sinking groundwater levels or because of contaminated water caused by floods. Therefore it is necessary to explore future water use scenarios and assess the impact of interventions.

In this paper the focus is on households to explore how domestic water-use can look like in the future given the water-related large-scale infrastructure. As there are, within that infrastructure, competing water-saving technologies for domestic households, diffusion of innovations serves as theoretical framework. To generate process-driven future scenarios we use a simulation model of the diffusion of water-use innovations.

There already exists a wide variety of models of the diffusion of innovations. Only a few models deal with the diffusion of environmental innovations (e.g. Weisbuch et al., 1996, Jager, 2000, Janssen & Jager, 2002). Because the aims of these studies are mainly to show basic features of models and algorithms, innovations are abstract commodities with only few references to reality. Therefore, there is a huge gap between diffusion models and empirical research concerning the diffusion of innovations and, more specifically, the acceptance of environmental innovations. The main results of previous studies can be summarised by four components:

1. Innovativeness of adopters (Rogers, 2003, Roehrich, 2004), overlapping with sociological lifestyles (Bourdieu, 1984),
2. communication in networks (Valente, 1995),
3. perceived innovation characteristics (e.g. Jeyaraj et al., 2006),
4. other decision processes than utility maximisation (bounded rationality, Simon, 1955), incorporating critics regarding neoclassical economics (summarised by van den Bergh et al., 2000).

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The diffusion model presented in this paper integrates these four components, combining elements of diffusion research (innovation characteristics), social psychology (Theory of Planned Behavior, Ajzen, 1991), sociology (lifestyles, here: the Sinus-Milieus, www.sociovision.com), and decision theory (deliberate decisions versus heuristics).

Empirical data

The first step towards the diffusion model was to empirically analyse the innovations in question. Four water-use innovations were selected: water-saving shower head, rainharvesting system, and dual-flush toilet as environmentally friendly innovations as well as hydromassage shower as a water-squandering technology. The empirical research consisted of a standardised questionnaire (N=272 participants) and a small telephone survey (N=12), both conducted in Southern Germany. Main results were:

1. Five innovation characteristics with high explanatory power for the diffusion of water-use innovations were identified: environmental performance, ease of use, saving of costs, compatibility with existing infrastructure, and investment costs.
2. Differences exist between the considered five lifestyles regarding the amount of relevant innovation characteristics and the relevance of social norm, with environmentally concerned lifestyles evaluating more innovation characteristics and less social norm (summarising the behaviour of peers within the social network, see e.g. Theory of Reasoned Action (Fishbein & Ajzen, 1985) for an overview of the concept).
3. Differences exist between innovations regarding the relevance of innovation characteristics for perceived behavioral control and the estimation of innovation characteristics themselves (Schwarz & Ernst, being prepared).

Integrating empirical data into the agent-based model

As research area, a 13,225 km² large part of Southern Germany around Munich was chosen, incorporating approx. 10 million inhabitants (Figure 1).

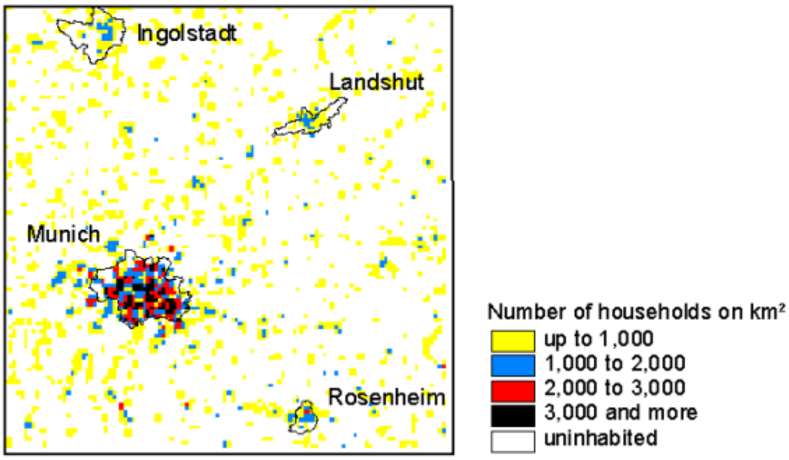

Figure 1: Investigation area represented in the diffusion model

The deciding entity in our diffusion model is a household. Due to the spatial extent of the research area, an agent within the diffusion model symbolises all households of a specific type on one km². Agent types represent – according to the empirical findings – one aggregated lifestyle each. The originally ten Sinus-Milieus® are clustered into five lifestyles:

- Postmaterialists
- Social Leaders (Establisheds, Modern Performers)
- Traditionals (Traditionals, Conservatives, GDR-Nostalgia)

- Mainstream (Modern Mainstream, Consumption-Materialists)
- Hedonistic (Pleasure Seekers, Ground Breakers)

Agents are connected via an artificially generated social network. The agents decide upon competing water-use technologies out of three areas: (a) shower head (standard, water-saving, hydromassage shower), (b) toilet flush (direct flush, standard tank, stop button, dual flush tank), and (c) rainharvesting system. Depending on technology area and agent type, one of two decision algorithms is used to decide upon the technologies (Figure 2).

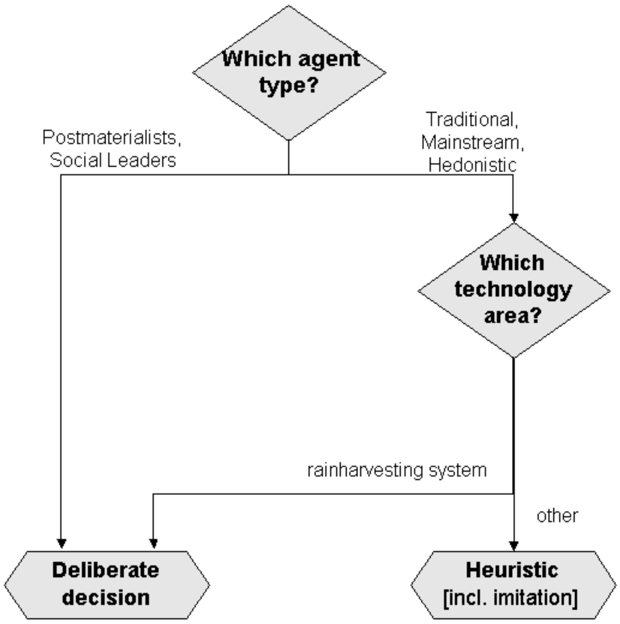

Figure 2: Selection of decision rules according to actor type and technology area

The deliberate decision is a moderate version of rational choice using a multi-attribute utility function. Concepts of bounded rationality are represented by using a heuristic (see Gigerenzer et al., 1999 for an introduction). Here, the so-called "take-the-best" heuristic was chosen: A set of evaluation criteria (here: innovation characteristics and social norm, implemented as behaviour of agents within the social network) is sorted, starting with the most important criterion. All options (here: technologies within a technology area) are evaluated. If there is a clear solution favouring one option, this option is chosen, else the next criterion is evaluated.

Postmaterialists and Social Leaders always decide deliberately because of our own empirical findings: For these two groups a variety of significant variables predicts attitudes in the structural equation models, indicating more complex decision making, while for Traditionals, Mainstream and Hedonistic lifestyles only a few significant variables were found. All agents decide deliberately upon rainharvesting systems because of high investment costs. These conclusions were supported by the telephone survey.

The outcome of the decision process is a decision of each agent for one technology within each technology area. As investments in water-use technologies are quite slow, a so-called "evaluation rate" was implemented: Each agent decides upon all technologies in each time step (one month), but its decisions are only to a certain percentage – the evaluation rate - translated into newly installed technology, representing the fraction of real households represented by that type that install the new technology in the current time step.

To empirically bind parameters of the model, results of our own investigations were implemented, using estimates of structural equation models and linear regression. Comparison of means led to values for innovation characteristics. The model was implemented using a spatially explicit modelling framework described in detail in Janisch et al. (submitted) and is integrated into a general model of water-use behaviour (Ernst et al., submitted).

Results

Results of the agent-based model comprise three steps: validation, sensitivity analysis, and scenarios. Due to limited space, only results for toilet flush will be presented, and results of the sensitivity analysis will not be reported at all.

Validation covers the simulation period of 1980 to 2005 with starting values of 40% (direct flush), 50% (standard flush), 10% (stop button), and 0% (dual flush), respectively. Results on the aggregated (population) level (Figure 3) match overall statistical data for Germany.

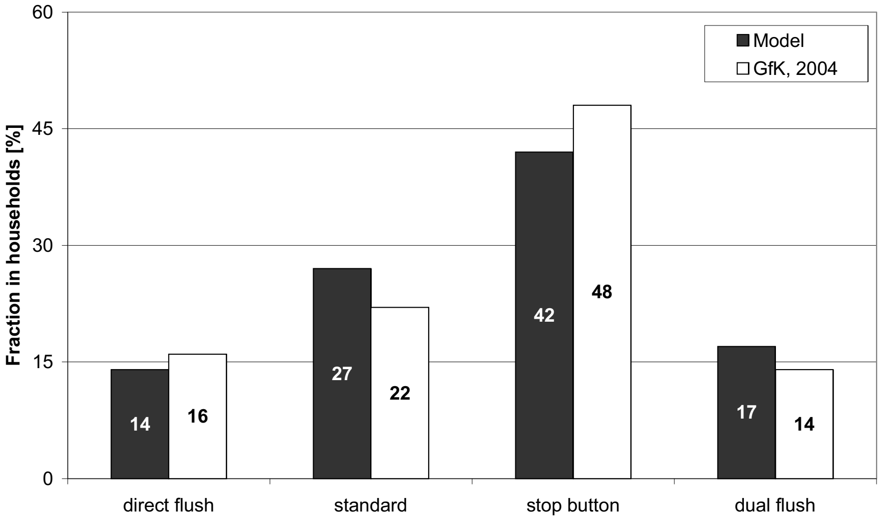

Figure 3: Aggregated results for 2005

Scenario runs were performed with a simulation period from 2006 to 2020 and modelled results for all technologies (2005) as starting values. Two scenarios realise extreme storylines: a scenario without further constraints called "Business as usual" and a scenario called "Environmental regulation" in which – due to environmental regulations on the supply side leading to a market solely dominated by water-saving technologies – agents can only buy the environmental innovation. Furthermore, two moderate policy scenarios have been tested: In the "Information" scenario, an information campaign increases the importance of environmental issues in the decision process, while in the "Finances" scenario, financial support decreases installation costs. Results (e.g. Figure 4) show that

1. due to the slow reinstallation process it takes a long time for an even quite restrictive policy (Environmental regulation scenario) to have an impact on installed technology,
2. even without further promotion, water-saving technologies will further diffuse,
3. there are different promotion strategies according to lifestyles and technologies (not shown here).

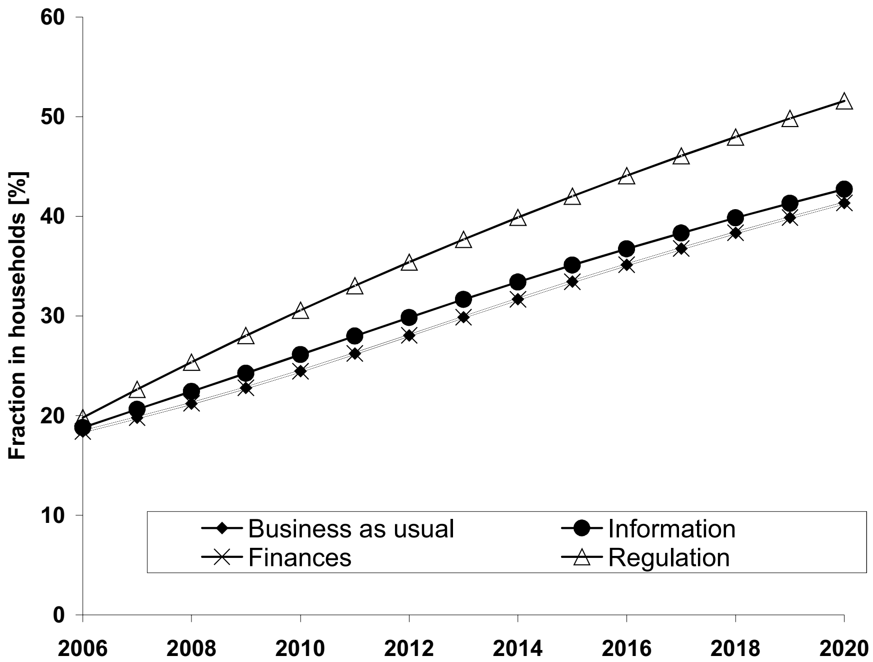

Figure 4: Exemplary scenario results for dual flush toilets.

Conclusions

The approach illustrates that it is feasible to closely link empirical research and agent-based modelling. Due to the nature of the technologies diffusion of innovations is quite slow. Therefore, even in the "Environmental regulation" scenario the diffusion of water-saving innovations does not reach saturation at the end of 2020. This finding implies that environmental policy regarding innovations such as water-saving technologies needs a long time horizon to have a noticeable environmental impact. But even without further promotion, water-saving technologies will further diffuse in German society, leading – if water-related habitual behaviour remains constant – to a further decreasing water demand per capita.

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