Integrating urban built and green structures to improve climate change mitigation and adaptation: The approach of a recently initiated centre

Philipp Geyer, Jan Tigges, Teresa Zölch, Daphne Gondhalekar, Johannes Maderspacher, Julia Brasche, Werner Lang[1], Stephan Pauleit,
Zentrum Stadtnatur und Klimaanpassung (ZSK) - Centre for Urban Ecology and Climate Adaptation, Technische Universität München, Germany

ABSTRACT

Climate change mitigation and adaptation increasingly become urgent issues for planning in urban agglomerations. Although plans for either mitigation or adaptation have been developed, only few integrated approaches and strategies can be found. The hypothesis is that for both, for mitigation and adaptation measures at urban planning level can be implemented far more effective if both are considered integratively. Therefore, the Centre for Urban Ecology and Climate Adaptation (ZSK) at Technische Universität München was initiated to deliver integrated approaches for addressing climate protection and climate change adaptation. ZSK examines both, the built environment and urban ecology, and their interaction at the neighbourhood scale. On this basis, integrative planning strategies are developed. This development is based on energy and microclimate simulation including a coupling of both. The strategies are developed at neighbourhood scale for types of urban structures in close cooperation with case study partner cities in the State of Bavaria, southern Germany.

Introduction

Climate change is a major challenge for cities that is potentiated by the ongoing urban heat island effect. This affects an increasing number of urban dwellers, such as an aging and more sensitive population. Few research projects tackle the development and realization of integrated climate change mitigation and adaptation plans at an urban scale. However, urban policy making and administration will require further knowledge for the development of effective countermeasures. There is a particular need for creating and implementing integrative planning approaches for built and green structures that would support synergies to mitigate and adapt for climate change impacts, as well as identifying and minimizing planning conflicts in early stages.

The Centre for Urban Ecology and Climate Adaptation (*Zentrum Stadtnatur und Klimaanpassung*) (ZSK), which was founded in mid-2013 with support of the Bavarian State Ministry of the Environment and Consumer Protection (StMUV), addresses this need for integrative planning strategies. In its research, ZSK aims to develop integrative strategies at the scale of urban neighbourhoods. Rising temperatures and the increase in strong rain events are the major climate change impacts expected in Bavaria in the coming decades. Therefore, the emphasis is placed on the one hand on regulatory ecosystem services such as the cooling effect with regard to the outdoor environment and buildings and the absorption of rainwater by green infrastructure. On the other hand, a further focus lies on the retrofitting of the building stock to improve energy efficiency and reduce greenhouse gas emissions. In addition, potentials of the use of renewable energies will be explored. Selected Bavarian cities will serve as case studies in order to derive and apply strategies in real urban contexts. The aim of the centre is not only to provide information on the potential of ecosystem

[1] w.lang@tum.de, +49 89 289-23990.

services and options of actions for the buildings stock but also to put emphasis on actions having effect on both, mitigation and adaptation and to develop integrative strategies that are realisable under the conditions of Bavarian towns and cities. This includes the initiation of first implementations of such actions. Furthermore, ZSK will compile information on this topic and transform the results of the research projects into guidelines for integrated urban plans for the reduction of GHG emissions and for climate change adaptation. Finally, ZSK aims to establish a platform promoting the dissemination and implementation of appropriate strategies in Bavarian municipalities.

State of the art

At present strategies and options of actions for climate change mitigation and adaptation are developed and implemented by the cities separately. This is the result of a survey of activities in German cites done by ZSK including all major cities with more than 100,000 inhabitants. Policy documents, plans and other publication on strategies and options of actions are examined and comparatively compiled. This survey revealed that most cities have mitigation strategies, but only a few cities have adaptation plans. Furthermore, they are even less cities which consider integrated strategies to interconnect both sides; this integration mostly takes place at the project level. This section provides an overview of the activities that are relevant for mitigation and adaptation at an urban planning level and provides a literature review about the state of the art in both fields and their integration.

A result of this survey is that Germany is internationally not in a leading position regarding vulnerability and resilience-related (V&R-related) climate actions in cities (Spiekermann 2013). Our review of city practice showed that strategies and approaches recommended by the government are mostly qualitative and not legally binding. There is so far little integration of climate change mitigation and adaptation approaches to address climate change risk reduction. The Rockefeller foundation (2014) claims that existing studies place the focus either physical properties or on subsystems aggravating the sectoral approach. According to UNEP (2013), an integrative approach however is the key to reducing vulnerability. Kilper, Christmann and Ibert (2013) state that the focus is on catastrophes neglecting continuous changes. Neighbourhood-focused examinations of the vulnerability and resilience of urban structures to climate change are rare.

The review of strategic documents of the cities shows that it is common for German cities to have integrated climate mitigation plans that include all relevant sectors, such as private housing, public buildings, commercial buildings, transport etc. Usually, these plans deal with a time horizon between 2020 and 2050 to reduce GHG emissions. Often the long-term plans have ambitious objectives, such as reducing emissions by 50%, some aiming at zero emissions, such as Frankfurt and Berlin. Besides a lot of exemplary projects at building level, such as passive houses and zero emission houses, the cities increasingly realize exemplary low-energy and low-emission districts or retrofit districts following these paradigms. Examples are Freiham in Munich and the Solarsiedlung Köln-Niehl. To achieve the aims of the climate mitigation plans, different instruments are used by the cities. A distinction can be made between planning and controlling. One planning tool for example is a “heat map” which shows the energy consumption of all houses on a district or city level. Another instrument for planning is so called solar maps, which assess the potential of installing PV systems on the roof of private buildings. For the implementation of the mitigation strategies almost every city tries to develop new or to adapt existing networks for district heating with a focus on the production of heat with renewable energy such as biomass in combination with a combined heat and power (CHP) plant. Many cities have programs which provide subsidies for the improvement of the energy efficiency of the building stock, mainly focusing on residential buildings that complement the national program. These programs include retrofitting, decentral use of renewable energy, exchange of outdated building service systems and the installation of district heating networks. On the policy level, some cities set up guidelines for retrofitting and energy efficient districts in addition to the national standard for buildings (Energieeinsparverordnung EnEV, regulation for energy saving). Further activities aim at communication of climate mitigation. This includes brochures and guidelines for building owners, free advice centres and commissionable services, actions, competitions, education activities, exhibitions and tours etc.

For climate change mitigation by the buildings stock, it is required to consider retrofitting cycles between 30 and 60 years (Nemeth et al. 2011), which delays the impact of measures. Furthermore, a decrease of energy demand for heating and cooling in North and Middle Europe caused by climate change has significant effect in future; heat demand will decrease between 35 and 45 % (Nik und Sasic Kalagasidis 2013; Frank 2005; Weller et al. 2012; Weller et al. 2013) and cooling demand will increase between 35 and 60 % (Frank 2005). Hacker et al. (2005) examine measures to adapt buildings to climate change considering thermal comfort in summer. Although these studies take climate change into account at a global level, none of them considers local heat island effects and cooling loads or deterioration at a neighbourhood level.

Among all cities that have been reviewed not even one third has adopted a strategy for climate adaptation and only one fifth has dedicated a section on climate adaptation within their mitigation strategies. Among the objectives for having an adaptation strategy are adapting the urban population and increasing their quality of life as well as the integration of adaptation into urban planning and development. The most frequently mentioned climate change impacts, which require adaptation, are urban overheating and flooding. The strategies further aim at establishing adaptation as important second pillar next to mitigation. Looking at the existing adaptation plans they show large differences in terms of structure and level of detail. When planning green infrastructure for adaptation the following measures are named most often in the strategies: increase of the proportion of green and blue spaces within the city, use of climate adapted vegetation, preservation and development of urban air exchange, de-sealing of impermeable surfaces and the creation of a green network within the city. Green roofs are considered as a way to increase the green cover in cities and plans for assessing the green roof potential are part of many adaptation strategies. Technical measures, such as sun protection, increase of albedo by light materials and ventilation during the night to reduce the climate impacts on buildings, are not as commonly named in the plans in comparison to green measures.

The consideration of climate adaptation measures at urban level gain in importance as climate change effects are no longer avoidable (IPCC 2007). The ecosystem services have the potential to support inhabitants in a sustainable climate change adaptation (Jones, Hole et al. 2012). Regulating Ecosystem services can significantly contribute to climate change adaptation (TEEB 2011); green infrastructures predominately provides these services (EEA 2014). However, for the realization of such infrastructures, information on their benefit are of major importance (Tröltzsch et al. 2012). Simulation, such as Envi-Met (Bruse and Environmental Modelling Group 2014), helps to quantify the benefit for microclimate. However, other criteria, such as costs and side effects, are crucial for the realisation of the measures (Altvater et al. 2011). Side effects are biodiversity, climate change mitigation and outdoor qualities for cities (TEEB - The Economics of Ecosystems and Biodiversity 2011). For realization, furthermore, the location and the identified vulnerability play a role (Perks 2011). Quantitative information and evaluations of these synergies could support decision-making processes in urban planning significantly; however, this knowledge is rarely available (Naumann et al. 2011).

There are some cities that establish projects exploiting the potential of synergies between climate change mitigation and adaptation, which is for example the case of Hamburg (KLIMZUG Nord Verbund, 2014), Jena (Kurmutz et al. 2012) or Dresden (REGKLAM 2013). However, most of these projects are unique solutions that work only in the environment of the specific environment of the city and are not transferable to other cities. For instance, Hamburg practices sustainable densifying by considering urban ventilation, solar shading at buildings, green roofs and water retention; further projects of the city combine geothermal power and costal protection. In addition, the city of Hamburg is one of the few that has obtained expert advice of adaption costs (HWWI 2012).

Furthermore, approaches and guidelines also tend to contain few references between the areas of mitigation and adaption, because mitigation aims are enshrined more detailed in municipal law whereas the implementation of climate adaptation measures tends to be overruled by implementation of measures that are easily quantifiable. So far, only very few studies have analysed the need for legal action in adapting to climate change. (Reese et al. 2010) and ever fewer can offer cost-benefit analysis for adaption strategies (Umweltbundesamt 2012). Quantitative assessments, in terms of costs or CO2 reductions, are urgently needed to support the implementation of innovative integrated urban planning approaches.

Approach of the Centre

The objective of ZSK is to develop integrated climate change mitigation and adaptation strategies at neighbourhood level. Particular focus will be on the role of urban ecology as a “green infrastructure” for climate change mitigation and adaptation via ecosystem services. Such an approach should also improve quality of life. The following research questions structure the research of the ZSK:

1. What are the effects of climate change on Bavarian cities or urban agglomerations depending on their location, size and structure, and how are these to be assessed?
2. How vulnerable are cities or urban agglomerations in Bavaria as well as their population, housing stock and infrastructures, urban open spaces and biodiversity?
3. What are possible approaches to integrated climate protection and adaptation strategies in Bavarian cities and which of these can be developed at the various levels of planning (regional and urban planning, city planning, and urban neighbourhood planning)? This includes presentation of strategies for reduction of carbon emissions and on the use of renewable energies in the building sector.
4. What are the present benefits of urban green structures for the ecosystem and which ones could be better identified and used for the adaptation of the cities to climate change?
5. Which strategies are suited for the development and successful implementation of climate-adapted green infrastructures in newly developed areas and in existing urban spaces?
6. How can these strategies be devised and implemented in ways that also improve conservation of urban ecology including the animals and plants living in urban areas?

Urban District Types, Case studies, and Options for Actions

ZSK will draw on case studies of selected municipalities to investigate the possible effects of climate change on Bavarian cities and to develop and implement strategies for an integrated approach to research and action. Currently three case studies have been selected, which represent typical situations of the three main urban district types identified for the Bavarian residential building stock:

1. Maxvorstadt in Munich, which includes to a large degree building blocks,
2. Neuaubing in Munich, which represents row type urban structures, and
3. Heidingsfeld in Würzburg, which is a historic village centre with high density and few green structures.

The case studies serve to examine potential for energy-efficiency improvements at municipal and building levels as well as ecosystem benefits and urban ecology in connection with integrated climate protection and climate adaptation strategies. 22 options for actions have been defined as the basis to develop strategies. These actions include, i.e. improvement of the building service systems and building envelopes, decentral renewable energy systems, use of biomass for heating, heat networks, solar shading, densification / breaking up of urban structures, integration of green on roofs and at façades, green networks, planning of wetland, change of Albedo etc. A workshop with key stakeholders from the three case study districts in June served to prioritize actions for each district. The identification of the urban district types and their use in the case studies is the basis for transferability. The selection of types that are representative for Bavarian cities provides the basis for the transfer to other urban areas in Bavaria. It is intended that the quantified interactions and the derived mitigation and adaptation strategies can at least be transferred in a qualitative way in the form of guidelines.

Research Fields

Improving Urban Ecosystems services for Climate Change Adaptation

Green infrastructure, which is a strategically planned network of green spaces, has the potential to effectively support climate change adaptation in the urban environment (e.g. Gill et al. 2007). It has a particular role for moderating the urban heat island and increasing events of extreme heat days and heavy rain, as indicated by climate change scenarios Bavarian cities by the year 2050. Urban densification and the consequent increase of building mass and impervious surfaces will exacerbate potentiating effects of the urban heat island and storm water runoff. Continuing urbanization and demographic changes will further require effective countermeasures against such climate change risks (EEA 2012). Green infrastructure can provide services that help to reduce these effects, so called regulating ecosystem services (TEEB 2011). Therefore, main research questions that will be analysed in the case studies are: What is the potential of urban green infrastructure to reduce the phenomenon of local overheating considering an increase of extreme heat events, and how can micro scale climate modelling and analysis of storm water runoff help to set up urban green infrastructure in the future?

First, the current situation will be analysed in the selected neighbourhoods as a base reference. The main input variables are set to be transferred to other regions of the city and characterize typical urban structures, their respective degree of sealed-surface, vegetation types and fraction of vegetation. The case study areas focus on urban district types of densely built-up areas as they are representing high climate change risk due to high heat emissions, heat storage capacity and surface run off as Hennersdorf and Lehmann (2014) argue. Existing urban climate maps for the cities further help to identify areas with particular exposure to climate change related risks, which are suitable for the study. Climate change scenarios like REMO serve as a basis for climate modelling (KLIWA 2005).

Micro scale models will be applied in selected different urban district types within the neighbourhoods concerning the outdoor thermal environment and storm water runoff under current and climate change scenario conditions (KLIWA 2005). The model output will also be used for analysis of the effects of outdoor climates on the built infrastructure. Cooling by evapotranspiration and shading of vegetation will be input to modelling energy consumption of the housing stocks. The microclimate model (EnviMet) will consider an extreme heat event of the last years (90^{th} percentile values of daily maximum summer temperatures from local weather data base) as a test condition. Vegetation and built infrastructure are the main input of the micro-scale model (Huttner, Bruse and Dostal 2008). Both data sets are based on 3D-models of the city administration or derived by remote sensing data. First, the microclimatic processes within the case area and their influence on air temperature and the thermal comfort of human outdoors will be modelled under current conditions (Huttner, Bruse and Dostal 2008). Second, future scenarios of green and built infrastructure will be developed and modelled. Scenarios will not consider an increase of vegetation cover but also a decrease in order to assess the potential effects of urban densification. The cooling potential of different options of actions of urban green space planning will be assessed. Options of actions will include, for instance, roof greening, planting street trees and greening facades. Suitable options of actions for implementation in the different case areas will be identified in cooperation and by involving the stakeholders of the city administration. Results are expected to show the potential of implementing the different options of actions in distinctive urban structural types, which might be transferred to similar urban structural types in other cities.

Mitigating Emissions and Adapting the Building Stock

In urban areas, the building stock accounts for a major share of CO_2 emissions. Therefore, the reduction of CO_2 emissions from the building stock is one main objective of ZSK. The potentials to mitigate emissions are first explored under current climatic conditions. In a second step, change of these potentials under the modified conditions of climate change will be assessed in a long-term perspective. This study will focus on residential buildings as they account for the major part of the Bavarian building stock. Two strategies serve to accomplish this aim: on the one hand, the reduction of energy demand of the building stock and, on the other hand, the usage of renewable energy. The most important parameters, which are related to energy consumption of buildings and options of actions to reduce their consumption, will be identified. Studies state a high potential for the reduction of the energy demand in building retrofitting (e.g. Erhorn et al. 2008). Further, options for decentral production of renewable energy at urban scale will be assessed. With this information, it is possible to identify the potential of reducing CO_2 emissions in the building stock.

Furthermore, taking climate change into account, different approaches of reducing overheating of buildings will be analysed as both urban heat island effect and climate change exacerbate such overheating. Overheating results in discomfort or in further energy demand for ventilation and air conditioning. Due to typical consumer behaviour climate in Bavaria, the share of residential buildings with air conditioning is very low under current climatic conditions. Therefore, a significant increase of discomfort is to be expected under climate change. Special attention will be given to the implementation of green countermeasures improving ecosystem services to reduce the energy demand and discomfort. Three green options of actions will be considered in particular. First, the effect of vegetation on the microclimate is a means to reduce overheating in the neighbourhood. Second, shading by trees and green façades can reduce the required heat energy input of buildings. Third, green roofs or similar techniques for integration of vegetation into buildings have the potential to reduce heat loads by thermal mass and by evaporation.

To determine the potential of reduction of the GHG emissions from buildings, two research methods will be applied. First, studies determining the improvement of energy-efficiency and the potential of the renewable energies in urban structures will be compiled and examined with respect to their applicability to the Bavarian building stock. In this context, the comparison by climate and by types of urban structures plays an important role. However, these studies mainly focus on potentials of technical solutions and do not consider the effect of climate change on the building stock's behaviour and the benefit available by ecosystem services. Therefore, in the second step the effect of change of the surrounding climate conditions on the buildings emissions and the benefit of ecosystem services will be determined. In contrast to conventional options of actions, such as insulation, the effect of microclimate and of ecosystem services requires the examination of one or a few buildings in their environment by detailed analysis and simulation. For this purpose, representative exemplars for the aforementioned urban district types will be selected in the case study cities. Simulation models will be calibrated with available data; e.g. energy consumption data shall serve to gain a valid thermal performance model of the buildings. These models first serve to study the effects of conventional energy-efficiency options of actions in detail. Second, they allow the evaluation of ecosystem services on the buildings and the changes energetic performance and comfort caused by climate change.

The results of all these reviews and research activities for the built environment will be compiled in a matrix. This matrix describes the potential effect of options of actions on emissions and thermal comfort first assuming today's conditions and second conditions of climate change and intensified heat islands and further categorized by urban structural types as the suitability of options of actions is different for each structural type, such a matrix will be developed for each structural type. The matrix will allow the comparison of traditional options of actions, such as air conditioning, with innovative options of actions, such as green infrastructure planning.

Development of Integrative Strategies

A special focus of the centre is set on the integration of sectors, mitigation and adaptation, with its respective models and options of actions. Integrative modelling and simulation provides a means to achieve this. Defined coupling of models will help to achieve this. Such coupled models form the basis for the development of integrated strategies and their implementation in planning. In addition, the method of system modelling described in Geyer and Buchholz (2012) will optionally be applied with the aim to capture and to quantify the inner-sectoral and inter-sectoral dependencies.

The structure and method of the models and their coupling are described in Figure 1. For selected representative urban district types in the case studies both sectoral simulation models, the energy model of the built environment and the microclimate model were defined. The data for these models origin from the cooperation with the partner cities. In these models, besides the district types, the options for actions are modelled leading to respective variants of the base models in order to evaluate the effect of the options. Furthermore, the interaction between the sectors needs consideration already during the setup of the sectoral models. There are three major interactions to consider: First, shading of buildings by vegetation as green countermeasure against overheating needs implementation; second, microclimate is a central interaction to be linked by parameters; third, for some types of interaction, such as green roofs and façades, a modelling of physical direct contact interaction is required, as shown in Figure 1. The first interaction needs to derive specific dynamically changing three-dimensional structures of vegetation configurations casting shadow in the building simulation. The second interaction is realized by modified weather data file; the challenge of this interaction is that the building simulation runs over one or more years whereas the micro climate simulation computes only one to a few days. Currently, coupling strategies for this purpose are developed. The third interaction requires modelling of the thermal mass as well as the evaporation performance attached to the buildings model; this is part of future work.

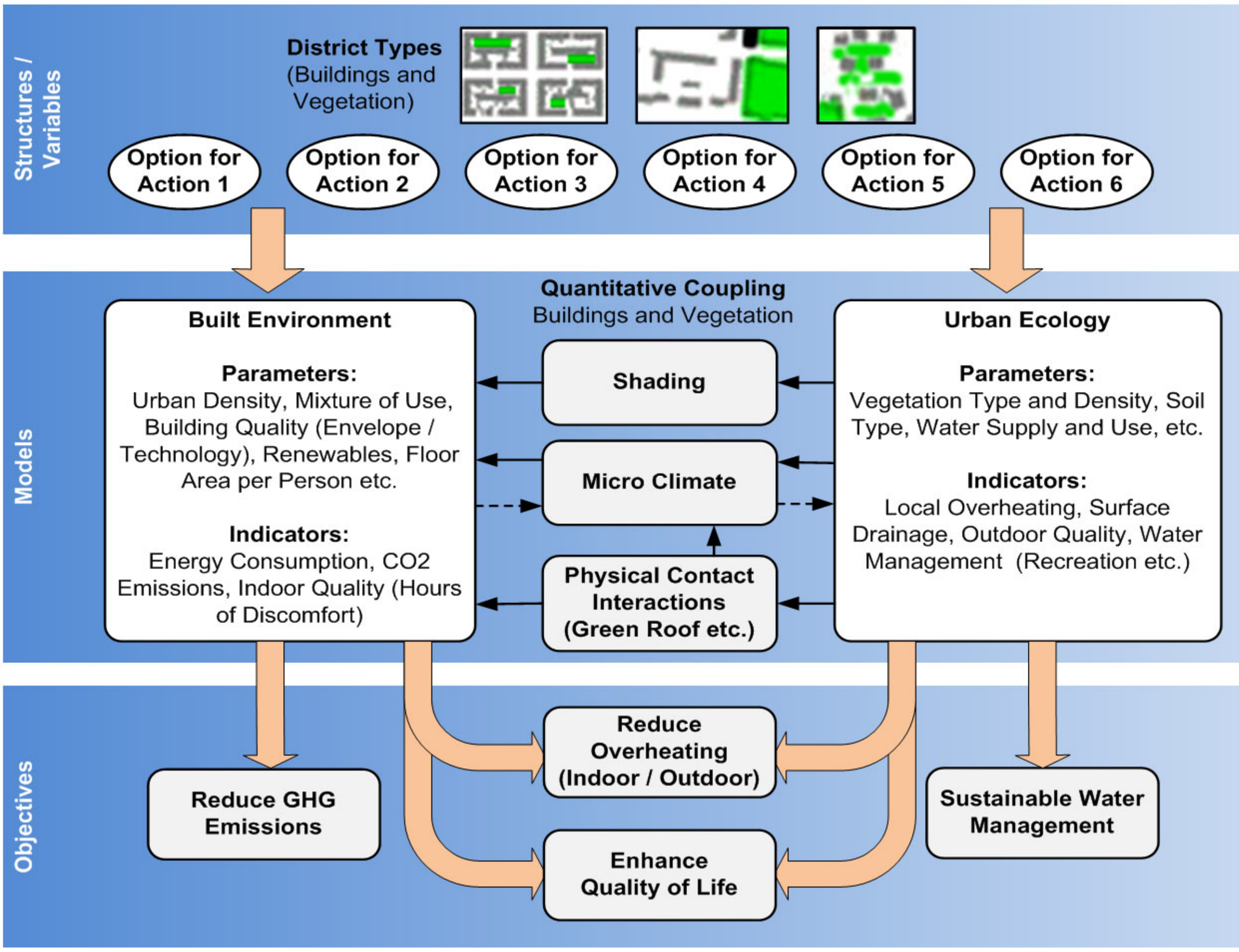

Figure 1. Integrative modelling for both parts of the project, the urban ecology and the built environment (information flows are shown, thin black arrows = pure data flows, orange broad arrows = information flows requiring modelling / evaluation by scientists).

For the evaluation of the simulation results for defining integrative strategies, there are two options in future: First, a qualitative interpretation of the results forms the basis for the development of integrative strategies selecting best combinations of options. Second, the optional development of a systems model as mentioned before allows a quantitative interpretation of interdependencies between sectors and options of actions. This quantitative superordinate model allows the quick determination of effects for variants of options and their combinations as well as for similar other districts than the case studies. To develop this model, quantitative interdependencies need to be calculated on basis of the simulation results. For this purpose, a controlled experimentation set needs to be conducted, such as described by the Design of Experiments (DoE) method (Antony 2003, Cox and Reid 2000). The subsequent quantification for the systems model will use methods of metamodelling (surrogate modelling) developed for a quick responding model in design and planning (Geyer and Schlüter 2014). The mathematical substitute models have two advantages: First, they allow the quick exploration of solutions in the design and planning process without simulation. Second the strength of dependencies in these models provides a means of analysing the structure of dependencies crossing the boundaries of the sectors. The both features allow the well-informed development of integrated planning strategies.

Developing Scenarios and Implementing Integrative Planning Strategies

As indicated in an earlier section of this paper, climate change mitigation and adaptation are often treated as two separate areas of research. However, in terms of urban planning neighbourhoods are increasingly recognized by academia and practitioners as a promising level for integrated approaches to climate change mitigation and adaptation which create synergies between.

While the goals of energy and climate strategies are set at the (inter-)national level, it is the regional and local level that needs to translate these goals into action. Framed by climate and energy targets adopted at EU and national level, over the past years, regional and local governments have defined their own strategies to reduce CO2 emissions (climate change mitigation) and to adapt to the changes brought about by global warming (climate adaptation). To date however, it has not been explored how these local strategies are actually implemented. Do local governments have sufficient capacities and competencies to manage this energy transition? How much room does the legal framework leave to city planning? How can measures targeting climate protection and adaptation be integrated into general strategies for local development? With a comparative analysis of cases in three Bavarian communes mentioned above, the aim is, to identify the opportunities and challenges that the local government level faces in the context of implementing climate actions. The main questions are: (1) Do local governments actually have sufficient capacities and room for manoeuvre when implementing climate strategies? (2) If so, what are critical conditions for a successful implementation?

Moreover, as cities densify, space is becoming more limited, and conflicts of interests may increase. Development of integrated approaches needs to be supported by quantitative assessment of the benefits and disadvantages of different planning options to enable implementation of alternatives to “business as usual” options. Due to the lack of such information, relatively few integrated urban approaches have been implemented at the neighbourhood scale so that little monitoring on the impacts of implementing such approaches exists. For prioritisation of strategies, ZSK aims to assess the vulnerabilities of its case study cities and of the selected neighbourhoods to climate change related risks. ZSK focuses on the vulnerabilities and risks related to the city system such urban heat island effect and strong rain events. In terms of V&R-related literature, there is comparatively little research on such climate risks as opposed to the volume of existing studies on catastrophes e.g. caused by riverine flooding. ZSK assesses V&R predominantly in terms of: (1) vulnerable population groups (aged people and small children) and (2) types of urban infrastructure (particularly residential buildings, green and water infrastructures). In order to research the V&R of the case study cities, ZSK will conduct a socio-economic questionnaire survey of a representative portion of the population in each case study neighbourhood, as well as an interview survey with key representatives of urban municipal governments.

Next, the developed integrative strategies discussed in the section above need to be translated into scenarios that visualize the innovative urban strategies to various stakeholders and actors involved in the decision-making process surrounding the conceptual development, design and implementation of urban planning projects. Stakeholder workshops form a part of the participative process needed in order to transfer the developed strategies to the decision-making process and allow their implementation. The expected outcome is applicable guidelines for municipal governments as well as the different sectors that allow their key actors to realise the strategies in urban planning and policy making. At the same time, uncertainty of energy demand will increase as in the next decades under climate change-induced rising temperatures a large portion of energy demand namely for heating may decrease but energy will be in demand increasingly for cooling. Under such uncertainty, the energy sector may be interested in investing in innovative urban planning approaches that can render energy demand in the next decades more predictable. Urban planning approaches integrating climate change mitigation and adaptation may be able to contribute significantly to reduce climate change-related energy demand uncertainty. Potential synergies include planning of green infrastructures, passive heating and cooling and others.

Concluding Remarks

ZSK is developing an integrated approach to consider potential synergies between climate change mitigation and adaptation approaches and develop these into planning strategies and scenarios at the neighbourhood scale. ZSK assesses options of actions and best practice in green infrastructure planning and the built environment and as a particularly innovative feature, examines potential synergies between these with regard to specific options of actions, for instance, in terms of ecosystem services that reduce indoor and outdoor overheating, such as shading or microclimate improvement. Results concerning the developed options of actions and planning strategies are disseminated in Bavarian cities in form of planning strategy guidelines. Workshops and conferences support the involvement of stakeholders and dissemination of results. The implementation of strategies in exemplary city planning projects and the realization of options of actions are planned in order to assess and monitor the real-time effect of the developed integrated planning strategies.

Acknowledgements

The Centre for Urban Ecology and Climate Adaptation (ZSK) is funded by the Bavarian State Ministry of the Environment and Consumer Protection (StMUV) under the project number TLK01U-63929.

LEBENSMINISTERIUM BAYERN.DE
finanziert durch
Bayerisches Staatsministerium für
Umwelt und Verbraucherschutz

References

Altvater, S., B. Görlach, D. Osberghaus, S. McCallum, T. Dworak, J. Klostermann, K. van de Sandt, J. Tröltzsch and A. Frelih Larsen. 2011. *Recommendations on priority measures for EU policy mainstreaming on adaptation - task 3 report*. E. Institute. Berlin.

Antony J. 2003. *Design of experiments for engineers and scientists*. Amsterdam: Butterworth-Heinemann. http://www.sciencedirect.com/science/book/9780750647090.

Bruse, M. and Environmental Modelling Group. 2014. *ENVI-Met.* Retrieved 2014/06/18. from http://envi-met.com/.

Cox DR. Reid N. 2000. The theory of the design of experiments - Monographs on statistics and applied probability. 86. Boca Raton: Chapman & Hall/CRC.

EEA. 2012. Urban adaptation to climate change in Europe. Challenges and opportunities for cities together with supportive national and European policies. EEA report, EEA. 2/2012.

EEA. 2014. Spatial analysis of green infrastructure in Europe. Copenhagen. EEA Technical Report.

Erhorn H, Hauser G, Nast PM, Schmidt D. 2008. Energetische Potenziale im Gebäudebestand. FVEE Themen. http://www.fvee.de/fileadmin/publikationen/Themenhefte/th2008-1/th2008_04_01.pdf. accessed May 2014.

Frank, Th.. 2005. „Climate change impacts on building heating and cooling energy demand in Switzerland." *Energy and Buildings* 37 (11): S. 1175-1185. DOI: 10.1016/j.enbuild.2005.06.019.

Geyer P, Buchholz M. 2012. „Parametric systems modeling for sustainable energy and resource flows in buildings and their urban environment." *Automation in Construction* 22. pp. 70-80. http://dx.doi.org/10.1016/j.autcon.2011.07.002.

Geyer P, Schlüter A. 2014. „Automated metamodel generation for Design Space Exploration and decision-making - A novel method supporting performance-oriented building design and retrofitting". *Applied Energy* 119 (0). pp. 537 -556. http://dx.doi.org/10.1016/j.apenergy.2013.12.064.

Hacker, J. N., Holmes, M., Belcher, S., Davies, G. 2005. *Climate change and the indoor environment: impacts and adaptation*. London.

Hamburgisches Weltwirtschaftsinstitut (HWWI), Ecologic Institut. 2012. Gutachten zu den ökonomischen Folgen des Klimawandels und Kosten der Anpassung für Hamburg - für die Behörde für Stadtentwicklung und Umwelt der Freien und Hansestadt Hamburg, Berlin und Hamburg.

Hennersdorf, J. and I. Lehmann. 2014. Grünausstattung von Städten und Regionen und klimatische Wirkungen von Stadtgrün. *Grundlagen für eine klimawandelangepasste Stadt- und Freiraumplanung*. W. Wende, S. Rößler and T. Krüger. Berlin, RHOMBOS-Verlag Heft 6.

Huttner, S., M. Bruse and P. Dostal. 2008. „Using ENVI-met to simulate the impact of global warming on the microclimate in central European cities." *5th Japanese-German Meeting on Urban Climatology*, Japan, Mayer, Helmut.

IPCC. 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.). Geneva, Switzerland. IPCC.

Jones, H. P., D. G. Hole and E. S. Zavaleta. 2012. „Harnessing nature to help people adapt to climate change." *Nature Climate Change* 2: 504-509.

Kilper, H., Gabriela Christmann, Oliver Ibert. 2013. „Der State of the Art der Resilienzforschung." *IRS Aktuell: Magazin für sozialwissenschaftliche Raumforschung*. 74: 5-8.

KLIMZUG Nord Verbund (Hrsg.). 2014. *Kursbuch Klimaanpassung: Handlungsoptionen für die Metropolregion Hamburg*. Hamburg.

KLIWA. 2005. *Der Klimawandel in Bayern für den Zeitraum 2021-2050* - Kurzbericht. K.-K. u. Wasserwirtschaft. München: Bayerisches Landesamt für Wasserwirtschaft.

Kurmutz, U., Gude, M. et al. 2012. *Handbuch Klimawandelgerechte Stadtentwicklung für Jena*. im Auftrag der Stadt Jena. Jena.

Naumann, S., G. Anzaldua, P. Berry, S. Burch, M. Davis, A. Frelih Larsen, H. Gerdes and M. Sanders. 2011. *Assessment of the potential of ecosystem-based approaches to climate change adaptation and mitigation in Europe*. D. E. Final report to the European Commission. Contract no. 070307/2010/580412/SER/B2. Ecologic Institute and Environmental Change Institute. Oxford University Centre for the Environment.

Nemeth, I., Lindauer, M., Schneider, P., Windeknecht, M., Elbel, K., Hoppe, M.. 2012. *Energetische Gebäudesanierung in Bayern*. München: Studie der Vereinigung der Bayerischen Wirtschaft e.V.

Nik, Vahid M., Sasic Kalagasidis, Angela. 2013. „Impact study of the climate change on the energy performance of the building stock in Stockholm considering four climate uncertainties." *Building and Environment* 60. S. 291-304. DOI: 10.1016/j.buildenv.2012.11.005.

Perks, J. 2011. *Adaptation Strategies for European Cities - Final Report*. Ricardo-AEA. European Commission - Directorate General for Climate Action.

Reese, M., Möckel, S., Bovet, J, Köck W. 2010. *Adapting Environmental Law to the impacts of climate change – Analysis, development and innovation of legal instruments*. Helmholtz Centre for Environmental Research (UFZ). Department of Environmental and Planning Law. Berlin.

REGKLAM-KONSORTIUM (Hg.). 2013. Integriertes Regionales Klimaanpassungsprogramm für die Region Dresden. Grundlagen. Ziele und Maßnahmen. *REGKLAM Publikationsreihe. Heft 7*. Rhombos-Verlag. Berlin

Rockefeller Foundation. 2014. *City Resilience Index*, ARUP: London. GB. p. 24.

Spiekermann, E. 2013. Resilienz als Paradigma der Stadtentwicklung - Nutzen und Chancen für Städte in Deutschland und der Welt. in Policy Brief. Stiftung neue verantwortung e. V.: Berlin, Deutschland. p. 20.

TEEB - The Economics of Ecosystems and Biodiversity. 2011. *TEEB Manual for Cities: Ecosystem Services in Urban Management*.

Tröltzsch, J., B. Görlach, H. Lückge, M. Peter and C. Sartorius. 2012. *Kosten und Nutzen von Anpassungsmaßnahmen an den Klimawandel - Analyse von 28 Anpassungsmaßnahmen in Deutschland*. Dessau-Roßlau: Umweltbundesamt. Climate Change 10/2012.

Umweltbundesamt. Hrsg. Autoren: Tröltzsch, Jenny, Benjamin Görlach, Helen Lückge, Martin Peter, und Christian Sartorius. 2012. *Kosten und Nutzen von Anpassungsmaßnahmen an den Klimawandel - Analyse von 28 Anpassungsmaßnahmen in Deutschland*. Berlin.

UNEP. 2013. *Research Priorities on Vulnerability, Impacts and Adaptation, in Programme of Research on Climate Change Vulnerability. Impacts and Adaptation (PROVIA).* United Nations Environment Programme (UNEP): Nairobi, Kenya: UNEP. p. 52.

Weller, Bernhard, Naumann, T., Jakubetz, S. (Hg.). 2012. „Gebäude unter den Einwirkungen des Klimawandels." *Publikationsreihe des BMBF-geförderten Projektes REGKLAM - Regionales Klimaanpassungsprogramm für die Modellregion Dresden, Heft 3.* Berlin: Rhombos-Verl.