Strengthening Risk-Informed Decision-Making: Scenarios for Human Vulnerability and Exposure to Extreme Events

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Content

1 Key Messages

- Risk-informed decision making in the context of climate change requires – in addition to scenarios about climatic changes – also scenarios for exposure and vulnerability.
- Scenarios of human vulnerability to heat stress provide important additional information for risk management and urban planning compared to pure exposure maps.
- Scenarios of vulnerability can encompass both, qualitative and/or quantitative approaches. These methods can be combined in order to capture tangible and intangible aspects.
- The case study of Ludwigsburg - a growing medium-sized city in Germany – shows that the city center is highly exposed to heat stress, but the share and growth of the elderly population is particularly high in other districts that need to be considered priority areas for building urban resilience and for implementing urban renewal programmes.
- Data for exposure and vulnerability scenarios can be derived from downscaled global models, however, also statistical offices at state and local level already often operate with different scenarios (e.g. for population growth) that can be used for local scenario development.
- Spatial and temporal scale mismatches emerge when trying to link data of future human vulnerability or exposure with climate scenarios. Socio-demographic information is often provided for a time span of 15 to 20 years into the future, while climate scenarios also focus on much longer horizons for example on the situation in 2050 or 2100.
- Urban planning and risk management are important endusers of exposure and vulnerability scenarios.
- City-specific scenario approaches can complement global approaches, such as the Shared Socioeconomic Pathways (SSPs), since they can account for context specific issues as well as for local risk management and urban development tools. This can enhance the applicability and usefulness of such scenarios for practical decision-making.

2 Introduction: problem statement and scope of the paper

Enhancing the resilience of cities and implementing risk-informed sustainable development are defined as key within the Global Agenda 2030, particularly in the Sustainable Development Goals (UN 2015a), the Sendai Framework (UN 2015b), the Paris Agreement (UN 2015c) and UN Habitat III (UN Habitat 2016, UN 2017). Up to now, various risk assessments at national, sub-national and local level in the context of climate change consider climatic changes in the future and their impacts on specific hazards, such as heat stress, droughts or forest fires. However, implementing risk-informed decision making also requires the consideration of scenarios of exposure and vulnerability. Various risk assessments in the context of climate change examine changes in climatic conditions and

respective hazards e.g. for the year 2030, 2050 and 2100, but juxtapose this information with data on vulnerability referring to the present. This is a major mismatch, since not only climatic conditions are changing in the future, but also socio-economic and demographic conditions of people within cities or regions. Consequently, scenarios of climatic changes have to be complemented with scenarios regarding the potential status and development of human vulnerability (IPCC 2014, Birkmann et al. 2014a/b, Greiving et al. 2016). The necessity to consider scenarios of human vulnerability for risk-informed decisionmaking can be illustrated in terms of heat stress risks in cities. Heat stress related risks are not solely a result of local temperature extremes, but also determined by the present and future exposure and vulnerability patterns of people that are affected by the urban heat island effects due to climatic changes and changes in the urban fabric. Hence, risk as the product of the interaction between hazard, exposure and vulnerability is largely socially constructed. Considering changes in future population and particularly changes in the vulnerability of people is quite essential in order to provide an appropriate information base for risk-informed urban planning and emergency management. Against this background, the paper presents selected scenario approaches and illustrates preliminary findings on how such vulnerability scenarios can look like for specific indicators and how they can inform decision making, particularly in the context of urban planning. Based on the BMBF funded research project ZURES (future-oriented vulnerability and risk assessment as a tool to support urban resilience), the paper focuses on medium-sized cities in Germany – particularly the city of Ludwigsburg - that have to deal with population growth requiring the development of new urban areas, while at the same time these cities are also highly exposed to heat stress already due to urbanization and climate change. In this regard, the paper addressed especially the following research questions:

Vulnerability scenarios are methods and ways to characterize hypothetical states of a system or indicator in the future. They can support decision-making under uncertainty, since these scenarios describe and illustrate different future development trends of a phenomena or characteristic of vulnerability.

- What are key elements, core indicators and criteria of vulnerability and exposure scenarios at the local level to heat stress?
- Why are scenarios of human vulnerability and exposure important?
- Which typologies of scenarios exist?
- What are qualitative and quantitative scenarios?
- Which data is needed and available at the local level to illustrate future vulnerability?

- Which timeframes can be addressed?
- How can information derived from such scenarios be applied in decision making?

3 Scenarios in risk and adaptation research

Various methods to develop scenarios emerged in different scientific disciplines, ranging from simplistic to complex, qualitative to quantitative, expert versus non-expert oriented approaches (Glenn and Gordon 2009). In the field of climate change adaptation and disaster risk reduction, most approaches that deal with scenarios have been developed in the domain of physical changes to the climate system (climate change scenarios, SRES scenarios etc.), while less work has been done on scenarios for vulnerability or societal adaptation processes (e.g. Giannini et al, 2011). Vulnerability is to be understood, for example, in the climate change community as "the propensity or predisposition to be adversely affected." (IPCC 2012: 560). In addition, UNISDR (2016) defines vulnerability as "conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards." That means vulnerability encompasses different thematic dimensions (physical, social, economic, etc.) and causal factors (susceptibility, capacities to cope, etc.) that shape the ability of a society or system to deal with hazards and extreme events and to recover from such impacts (see Wisner et al. 2004; Birkmann 2013 and 2006). Consequently, scenarios for vulnerability should consider these multi-dimensional phenomena, however, at the same time scenario data is often limited and therefore has to be based on selected indicators that can capture specific characteristics of vulnerability. However, also qualitative data and qualitative scenarios can be very useful to present information on vulnerability. Overall, a scenario characterizes a hypothetical state of a system in the future (Scholz and Tietje, 2002). Hence, scenarios are a mechanism for describing future trends and/or conditions for a specific point in time, despite some degree of irreducible uncertainty with respect to the future (see e.g. Kok et al., 2006; Kok et al. 2011). Scenarios allow us to illustrate and discuss potential evolutions and different directions that development processes might take, drawing attention to the consequences for decision making and management strategies (see e.g. Glenn et al. 2009; van Vuuren et al. 2012a/b). Scenarios developed for the IPCC encompass emission scenarios (SRES scenarios) as well as scenarios that aim to inform adaptation policies, such as the Shared Socioeconomic Pathways (SSPs). Scenarios have been developed particularly to:

- make the future(s) more real and understandable for decision makers
- understand the significance of uncertainties
- illustrate different potential development pathways and therewith to underscore what might be possible and impossible development directions

- identify which policies and measures might work across a range of possible scenarios, which is highly relevant also for adaptation to climate change

(see Glenn et al. 2009; van Vuuren et al. 2012b; Hallegatte et al. 2011).

Scenarios can help researchers and decision makers to think of different pluralistic futures in order to support the development of policies today that anticipate different futures and potential development pathways. Today different types and methods to develop scenarios can be found. Various approaches are based on quality criteria, such as a) they should be plausible, making a rational route from here to there that makes causal processes and decisions explicit; b) they should be internally consistent; and c) they should be sufficiently interesting and exciting to make the future "real" enough to elicit strategic responses (see Glenn and Gordon 2009; Hallegatte et al. 2011; Gordon 2009). In this context, scenarios have an *analytic and explorative function* in that they facilitate a systematic discussion of current conditions and potential future development trends. Secondly, scenario development also has a *normative function* in that it allows for a discussion of desirable or non-desirable development patterns and futures (see Birkmann et al. 2014a). Participatory scenario methods can help to identify underlying normative assumptions, development trends and their role within specific framings. Hence, scenario development in participatory or transdisciplinary processes can also strengthen trust building and mutual learning (see Garschagen et al., 2016). The climate change research and integrated modelling communities have developed a new framework of Shared Socioeconomic Pathways (SSPs) for improving the assessment of climate change, its impacts, and response options (see Moss et al., 2010; Kriegler et al., 2012; O'Neill et al., 2011; van Vuuren et al., 2012b). One of the key aims of the SSP architecture is to facilitate research and assessment that can inform policy makers about the challenges in *mitigation* efforts as well as to provide information about potential ranges of *adaptation* efforts. SSPs consist of three elements: 1) a narrative, 2) a set of traditional drivers for Integrated Assessment Models (GDP, population, urbanization) and several indicators that are relevant for research on impacts, adaptation and vulnerability, such as poverty and governance (van Ruijven et al. 2014). The narratives of the five SSPs explore the different potential combinations of high and low challenges to climate change adaptation mitigation (see O'Neil et al. 2015). While some indicators used in global models refer indirectly or directly to issues of human vulnerability (e.g. poverty, governance), other trends such as urbanization might imply more nuanced and ambiguous effects on vulnerability (Garschagen and Romero-Lankao 2015).

In risk management, hazard scenarios are quite common as a tool to design risk reduction measures or to define specific areas that should be treated as buffer zones against certain hazards, such as flooding or coastal

inundation. These scenarios often encompass a very specific design and aim to enhance the capacities of disaster managers to deal with an extreme event, rather than focusing on shifts and trends.

Finally, also in the context of natural hazard research and risk management at the local level, different approaches are currently emerging that focus for example on future changes of land-use patterns or urban growth. These approaches, however, still need more research.

Table 1 provides a short overview of the different scenario approaches, their core characteristics, focus and application context.

Concept	**Characteristics**	**Focus on**	**Context**
Hazard Scenarios	Identify changes and future status of hazards, in terms of intensity and magnitude, e.g. floods, droughts or heat waves	Changes in hazard profiles and changes in physical events	Hazard assessments inform sectoral policies, e.g. water management
Event or Disasters Scenarios /Crises management	Exercise that deals with a specific disaster or crises	Crises and disaster management capacities for specific events	Civil Protection
Shared Socioeconomic Pathways (SSPs)	Development indicators and potential futures at the global and national level	Socio-economic and demographic development based on global models	Integrated Assessment Modelling Community and IPCC (e.g. AR6 outline)
Local vulnerability scenarios	Quantitative and qualitative criteria and indicators that represent general and local specific aspects of vulnerability	Indicators, criteria and story lines, assessment of development patterns for entire cities or in specific areas/ sectors	Urban planning, local risk management,

Table 1: Different types of scenario approaches in risk management and adaptation (source: own table)

In contrast to quantitative emission scenarios, vulnerability scenarios often encompass both: tangible and intangible aspects due to the multi-faceted nature of vulnerability (see Birkmann et al. 2017; Birkmann et al. 2013). Tangible aspects of vulnerability include e.g. parameters such as the percentage of people living in extreme poverty or the percentage of elderly - used as proxies for assessing most susceptible population groups. Other examples would be access to infrastructure and social vulnerabilities towards disaster-related infrastructure failures (Garschagen and Sandholz 2018). In contrast, intangible aspects of vulnerability are linked to aspects of governance (e.g. issues of corruption) or the strength of social networks. In general semi-quantitative and qualitative vulnerability scenarios allow capturing intangible aspects more comprehensively compared to quantitative approaches. However, qualitative scenarios - similarly to quantitative once - face difficulties when trying to develop scenarios for e.g. governance or risk awareness conditions, since changes in such areas are difficult to estimate – but can have profound impacts. Extreme events - such as the European heatwave in 2003 - can function as catalysts of societal changes and transformations and are hard to predict. Overall, there is a need to triangulate different methods and data in order to be able to capture intangible and tangible characteristics of vulnerability in scenarios. While the importance of capturing vulnerability as a multi-dimensional phenomenon (social, economic, ecological and institutional vulnerability) has been underpinned, the practical assessment and development of scenarios is often constraint by limited data to monitor and assess such aspects in the medium- and long-term future. Some newer examples encompass approaches that were developed for selected megacities (Birkmann and Welle 2016).

4 Scenarios for vulnerability and exposure to heat stress at the local level

The following section presents the research steps that have been conducted to develop scenarios for human vulnerability and exposure to heat stress at the local level (see Fig. 1) using qualitative and quantitative approaches. In addition, a short description of the city of Ludwigsburg is provided, where the research was conducted. Overall, the research process encompassed particularly the following phases: a) a literature analysis regarding scientific papers that deal with heat stress vulnerability, urban development and climate change, b) discussion of important trends, indicators and criteria for assessing risks and vulnerabilities to heat stress at the local level with local stakeholders, c) development of qualitative scenarios using a participatory scenario approach, d) identification of relevant and available data that would allow to illustrate selected indicators and criteria in quantitative ways and identification of

additional parameters and the validation of the indicators and criteria identified before using a household survey to capture risk awareness and responses to heat stress of the local population.

Figure 1: Overview of research steps that informed the development of scenarios of vulnerability and exposure to heat stress (Source: own figure)

These research activities were conducted in the city of Ludwigsburg. The city is a medium-size city - according to German standards - with a population of about 93.000 inhabitants and more than 50.000 jobs located in the city. The city is part of the Region of Stuttgart, which is one of the most economically prosperous city-regions with a relatively high GDP and is still characterized by a large portion of industrial production, particularly the automotive sector. The entire region of Stuttgart – including Ludwigsburg – is highly exposed to heat stress and therefore, the conservation and improvement of open space is an important aspect in urban and regional development. At the same time the city and the entire region are characterized by an ever-increasing population and a lack of affordable housing. In this context, the city is urgently searching for space for the development of new housing and industrial areas. This often leads to tensions between the general goal of preserving open space (green spaces) and the need of future urban growth. Hence, risk reduction regarding and adaptation strategies regarding increasing heat stress are a hot topic and highly relevant with respect to the definition of future urban growth and urban renewal strategies.

A) Results of the literature analysis

The literature analysis encompassed the examination of scientific papers that contained the key words “heat stress”; “urban heat island”, “urban climate”, “vulnerability”, “urban development” and “climate change”. The search was carried out in SCOPUS database, without any limitations regarding publication dates, covering publications until 2017. The survey found that more than 590 scientific papers exist on these topics; however, the more in-depth analysis focused on 144 papers that seem to be most relevant. The analysis revealed that present studies on heat stress vulnerability focus on attributes of “health” and “problematic pre-existing health conditions”, particularly cardiovascular diseases and respiratory diseases as factors that increase the likelihood to be adversely affected by heat stress. In addition, chronic diseases in general, immobility, and obesity were mentioned in this broader category of health related factors. Secondly, age, particularly the number and percentage of elderly were named as parameters that show heat stress related vulnerability. Some papers, also identified children as a vulnerable group. On the third rank, issues of the living conditions, such as the type of building and the limited access to green space were mentioned as criteria that characterize vulnerability to heat stress at the local level (see Sandholz et al. 2018). Interestingly, these parameters can be directly influenced by urban planning that falls into the responsibility of municipalities and cities in many countries. Moreover, various papers also mentioned the economic status of people and the population density as factors that influence human vulnerability to heat stress. Economic status and income can serve as a proxy for adaptation capacities, e.g. low income might show limited coping and adaptive capacities. Population density is, in our view, not an appropriate indicator for vulnerability, but rather relates to issues of exposure. Furthermore, several papers mention that social capital, such as the availability of social networks or the lack thereof and the phenomenon of social isolation of elderly can be seen as an important issue characterizing vulnerability to heat stress because isolated individuals are less often checked upon and/or lack a social network that supports them when problems occur (Johnson et al. 2009, Laverdière et al. 2015, Reid et al. 2009).The access and availability of infrastructures, such as air-conditioning and the issue of risk perception (as precondition for behavioural change) were named various times in the examined scientific literature (see Sandholz et al. 2018). Education, sex, ethnicity and occupation were mentioned only in few papers and these aspects seem not to be as important as the parameters outlined before. The results of the literature survey served to inform the following steps of the research process.

B) Results of the local stakeholder workshop

A stakeholder workshop, with representatives of different city departments was conducted in the city of Ludwigsburg that aimed to gather criteria and parameters seen as most important to describe and assess issues of human vulnerability and urban risk to heat stress. Since not all practitioners were experts in vulnerability, exposure, hazard and risk, the workshop results contain criteria that mainly refer to issues of vulnerability, but in part also to exposure and risk. Nevertheless, the identification of these parameters is important, since the further development of scenarios can consider these aspects. In this case, the workshop particularly served as base for the participatory scenario development and the identification of potential indicators that can also be part of the quantitative scenario development process. In addition, the local stakeholders also named already tools that might help better managing the risks associated with extreme heat at present and in the future. For example, the workshop identified concepts, such as climate change adaptation concepts and the open space/green space plan of Ludwigsburg that are important for future risk management. Table 2 provides an overview of the core results of the stakeholder workshop also assessing the priority of each parameter and the data availability at city scale.

City of Ludwigsburg

with about 93.000 inhabitants and more than 50.000 jobs Ludwigsburg is clearly a medium sized city in Germany. The city is relatively young with about 300 years and is today part of the larger urban metropolitan area of Stuttgart. This region is economically booming with world leading industries, such as Bosch, Porsche and Mercedes. About 47 percent of the city is settlement space. According to national standards the region and the city are highly exposed to heat stress in the summer – particularly the urban center of Ludwigsburg also due to the additional impacts of the urban heat island effect. The city is nationally known for its activities in the area of sustainable urban development.

List of relevant criteria and their priority	Priority		Data availability	
	Low	high	Available	Not-available
Urban development/ open space				
Percentage of forest in the city (Ludwigsburg, city with no urban forest)		X	X	
Accessibility and interconnectivity of urban green (e.g. green paths, cycle- and foot paths; accessibility of green belts or bodies of water)		X	X	
Implementation of the climate adaptation concept of the city (KLIK) in different areas		X	X	
Securing urban and developing new urban green through the implementation of the space development concept (FEK)		X	X	
Supply and access to free drinking water		X		X
Buildings and physical conditions of housing				
Year of construction		X	X	
Current state of restoration and insulation		X		X

Availability of air-conditioning	X			X
Economic aspects				
Unemployment		X	X	
Available income of residents (to afford adaptation)		X		X
Loss of job due to ongoing digitalization	X			X
Health, age and societal structures and behaviour				
Age of residents, children, elderly		X	X	
Social capital/social network, including single people and elderly (over 67)				
Healthcare and pre-existing medical conditions at the local level (e.g. density of physicians)		X		X
Changed leisure-time behaviour due to livelihood changes				
Risk awareness and behaviour patterns	X			X

Table 2: Selected results of the stakeholder workshop focusing on criteria that characterize represent and future vulnerability to heat stress in Ludwigsburg

C) Data for local and spatial specific scenarios

The development of vulnerability scenarios is often hindered by limited data about the future developments of key indicators, particularly at the local level. While progress has been made in downscaling global scenarios that can inform exposure and vulnerability assessments at national and local scale based on the SSP approach and global assessment models, for example in terms of the future population (see Jones and O'Neil 2016) or poverty patterns (see Byers et al. 2018), the development of context specific local approaches is still in its initial development. Globally derived and downscaled scenario data is still relevant also for local assessments in order to explore whether and how future local conditions might be linked to national or international developments. However, local approaches that aim

to inform risk management and urban development at the city scale, need to also account for the specific risk and development contexts. Hence, the approaches presented in this paper aim to inform risk management and urban planning at the local level. Consequently, these scenario approaches should also represent local specific trends and configuration of vulnerability to heat stress. Against this background, important trends and indicators were identified together with local stakeholders and through the analysis of existing strategies and tools in the city. In this regard, the local approaches presented in this paper can complement global and globally downscaled scenarios. The identification of different parameters to characterize vulnerability and exposure to extreme heat in the city underscores the broad range of topics that need to be addressed within a comprehensive risk management. However, the quantitative scenario development revealed significant shortcomings of quantitative data, for key aspects of vulnerability to heat stress, such as the pre-existing medical or health conditions and their potential development. It was also found that various cities in Germany (Ludwigsburg, Munich etc.) already apply different population scenarios in their work, for example in terms of future urban planning, housing policies or mobility management (see Maeding and Schmitz-Veltin 2018; Schmitz-Veltin 2011). Nevertheless, for various characteristics of vulnerability to heat stress the present official data is very thin.

D) Household survey to enhance and validate criteria and indicators

In order to enhance data on how people cope and adapt to heat stress as well as to assess whether some of the criteria identified in the literature and stakeholder workshops are also seen as relevant by local households, a household survey was conducted in particular in city districts that face already high exposure to heat stress. The household survey aimed to provide additional information and a kind of validation of parameters pre-selected before, such as issues of health and the availability, accessibility and use of green space. The latter serves as a mean to better cope with heat stress in the city of Ludwigsburg. The survey was conducted from 25th of June until 27th of July 2018. It included 16 heat prone city quarters in Central and East Ludwigsburg. The survey encompassed 3000 households that were chosen randomly (inhabitants of these households were 18 years and older) and received the questionnaire per post. A high response rate of more than 20% allowed a statistically valid sample size and also stressed that the topic is highly relevant for the respective citizens in Ludwigsburg. The household questionnaire encompassed aspects of risk awareness and the ranking of importance of different hazards, as well as questions regarding the ability to implement risk mitigation and adaptation measures at present and in the future in the light of increasing heat stress. The household survey confirmed for example, the relevance of heat stress mitigation and the already felt effects of heat stress, particularly in terms of sleeping problems in the night and exhaustion during the day. The evaluation of

adaptation measures already implemented or planned in the future revealed for example, that shifts in the mode of transport or changes in working hours are already conducted, while in terms of the future respondents indicated that they would like to have air-conditioning installed or even considered moving to heat adjusted flats or neighbourhoods.

5 Linkages: trends, drivers of human vulnerability and vulnerability complexes

Improving the understanding on how present trends influence differential vulnerabilities of people requires in the first place a preliminary overview of key trends, their link to aspects that influence human vulnerability and phenomena that largely represent vulnerability challenges, such as social isolation, socio-economic segregation and declining health conditions, etc. (see Fig. 2). The results from the local stakeholder workshop and the findings of the literature analysis and household survey underscored the fact that trends, such as economic growth, population growth or aging of the population can have different effects on social groups and societal structures. Fig. 2 illustrates the dynamics that can be observed in the economically booming medium-sized city of Ludwigsburg. While the population growth and a booming economic situation are resulting in a low unemployment rate, thus signalling a positive development, this boom also results in and might intensify problems, such as shortages of affordable housing, the increase of urban heat stress due to further urbanization and also socio-spatial segregation. The shortage of affordable housing as well as the booming economic situation particularly increase the pressure on the city to identify new areas for housing and industrial development. The development of new urban areas means - in most cases- also the conversion of green space into sealed surfaces with respective impacts on the urban heat island effect. In addition, it is expected that the share of elderly will increase in the future. Figure 2 outlines the context conditions in blue and shows drivers that shape human vulnerability and exposure to heat stress in the city at present and particularly in the future in yellow, such as the accessibility to green space or the economic capacity of different households that might influence the level of social integration, but also the individual capacity of the household to afford better insulation of the house or flat or air-conditioning in order to be better protected against heat stress. However, not all people can afford such measures (air-conditioning, improved insulation) and therefore present and future heat stress will be experienced differently in different households and city districts. Moreover, the trend of an ever increasing share of elderly is likely to have an impact on the strength of social networks and the active involvement of these people in civil society organization.

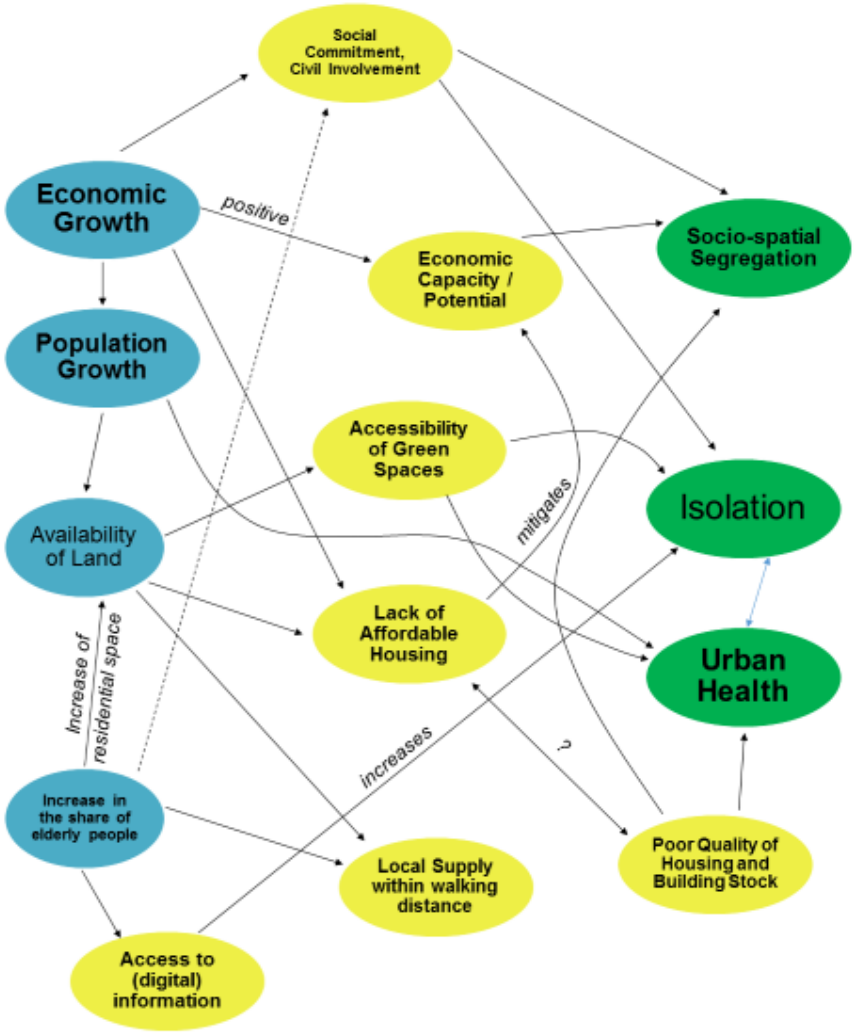

Figure 2: Linkages between key trends, factors that influence human vulnerability to heat stress (own figure)

Social isolation was a major problem that increased the likelihood to be adversely affected during the heatwave in 2003 in Europe. In addition, the lack of affordable housing and the respective high prices for renting or buying might also mean that positive economic effects do not really translate to additional purchasing power for people, especially for people with a lower income or pension. Unmanaged economic growth and significant increases in housing and rental prices might contribute to the fact that a supply of local goods cannot be guaranteed within walking distance of the city district. These processes, however, can be very different for the various districts of Ludwigsburg.

6 Participatory scenario development – story line development

Following the participatory scenario approach developed in the TRUC project (see Garschagen et al. 2016) a scenario workshop was carried out in the city of Ludwigsburg on 3rd of July 2017 where overall 11 employees of the Ludwigsburg municipality discussed parameters of socio-economic vulnerability and the main drivers of urban change (see table 1 and Fig. 2). To guarantee a holistic perspective, representatives of different departments participated in the workshop, covering the topics of sustainable urban development, urban planning, green spaces, civil engineering, business development, education, health, sports, children and family services, surveying, geo-information, and statistics. After a short introduction on the workshop goals as well as the topic and relevance of urban heat stress, in a first step parameters of socio-economic vulnerability related to urban heat stress were collected, followed by a ranking according to priority and data availability (see Table 2). The parameter can be split into different groups, such as urban development and open space, buildings and physical conditions of housing, economic aspects, health, age and societal structures, e.g. social networks. In the second part of the workshop main drivers of urban change to be used for the two intersecting axes of the participatory scenario approach were discussed. The discussants' inputs were clustered and workshop participants proposed putting spatial development related to (economic) growth on one axis and development/quality of open green areas on the other. The parameter selection was based on the importance of the aspect for ongoing processes in urban developments and their relevance for urban heat stress and heat related vulnerabilities and risks. The participants were also asked to name factors that might enhance the capacity of the city to deal with heat stress and, vice versa, factors that might deteriorate and hamper respective approaches of the city and individual households. In a follow-up discussion after the workshop the axes were refined as "climate-sensitive vs. non-climate-sensitive urban development" and "strongly prioritizing vs. not prioritizing urban growth" (see Figure 3), since the city is confronted with climate change and the necessity to provide new space for housing and economic activities due to the booming economy in the region (see Garschagen et al. 2018).

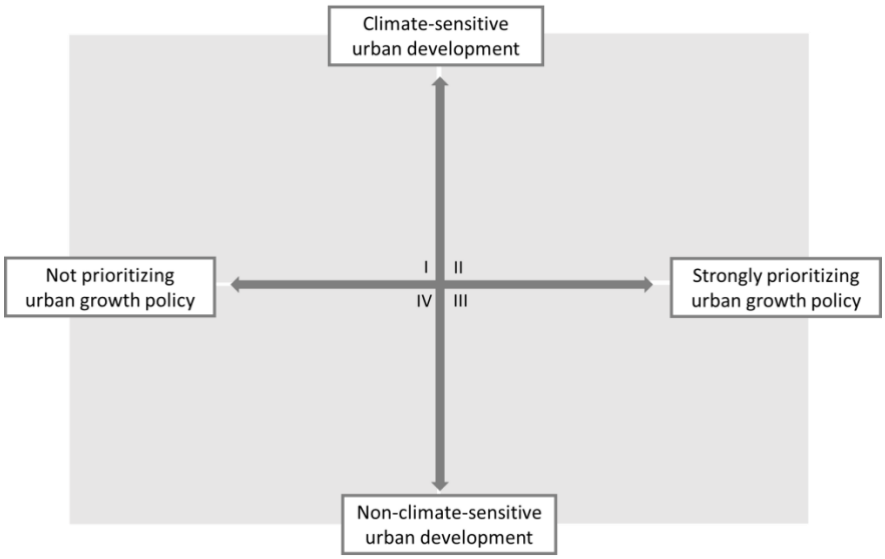

Figure 3: Two axis on drivers of urban change as result of the participatory scenario mapping (source: Sandholz et al. 2018)

Subsequently, four different future visions for Ludwigsburg were developed in the participatory scenario approach, as defined by the two axes and making use of the socio-economic parameter as very important aspects of urban development. The four quadrants were filled with socio-economic parameters collected during the workshop under the respective scenario (c.f. Figure 3). Important is also the fact that participants had to juxtapose positive development trends of a parameter in one scenario with a more negative or unwanted development in the opposite scenario. Among others, future developments of urban green spaces and population development under the four scenarios were integrated into the four future visions. Based on this input a storyline was written by the researchers involved for each of the scenarios to elaborate more in-depth on the potential urban future under the respective influences in each of the quadrants. Figure and storylines were matched with the workshop participants from Ludwigsburg, to assure the greatest possible reality and closeness to urban actors. An example of how the storylines look for the different scenarios is presented in table 3.

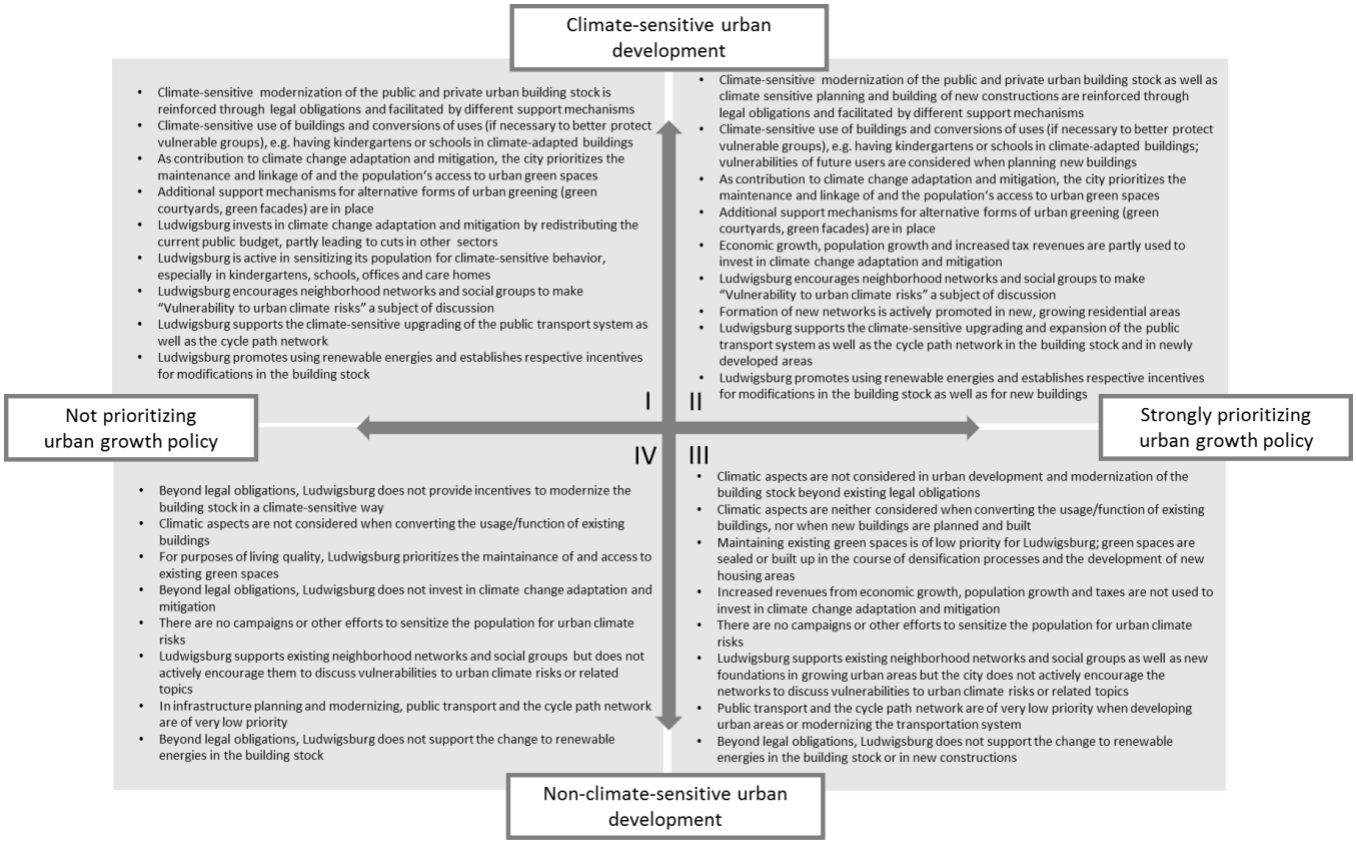

Figure 4: Results of the participatory scenario mapping in Ludwigsburg (source: Sandholz et al. 2018)

Scenario I: Ludwigsburg does not prioritize urban growth policies but focusses on climate-sensitive urban development	Scenario II: Ludwigsburg prioritizes urban growth policies and focusses on climate-sensitive urban development
The municipality of Ludwigsburg supports the climate-sensitive modernization of the existing building stock as well as maintaining, expanding and upgrading existing green and open spaces by means of tailored urban planning instruments. Pressure on green areas is comparably low, only few spaces are lost for building or infrastructure purposes. This makes not only a significant contribution to climate protection but also	The municipality of Ludwigsburg addresses the complex challenges the growing urban population poses for a climate-sensitive urban development by means of different measures such as regulations, incentives and awareness campaigns. Among others, infill developments in selected particularly heat prone built-up areas are to be prohibited, financial incentives for climate-sensitive modernization of the existing building stock and for new constructions are put in place.

substantially improves urban climate and the amenity value of the urban area. New municipal financial incentives for modernizing or greening own houses however are not in place, as the non-increasing urban budget due of e.g. absent tax incomes from commerce is spent on other sectors. The municipality sets up awareness campaigns to inform on heat stress and to convince private house owners to modernize and green their houses.	In addition, the city seeks to preserve as many green and open spaces as possible, despite the considerable settlement pressure. Climate aspects such as wind corridors to cool down inner-city areas are predominant aspects for decision-making on land use and conversion of green spaces. To counteract negative climatic impacts from densification and losses of green and open spaces, the municipality supports alternative forms of small-scale greenery and green infrastructure.
Scenario III: Ludwigsburg prioritizes urban growth policies but does not focus on climate-sensitive urban development	Scenario IV: Ludwigsburg does not prioritize urban growth policies and does not focus on climate-sensitive urban development
The comparably low priority of climate-sensitive urban development in parallel with high demands on housing and commercial space results in considerable infill development. Due to absent municipal regulations and incentives on climate-sensitive urban development, inner-city areas are densified and surfaces are sealed, new residential areas emerge in the outskirts. Climatic aspects are hardly considered in the construction of new or the modernization of existing buildings and quarters, fresh air corridors are hardly considered, their benefits diminish significantly. Maintaining and upgrading existing green and open spaces or alternative forms of small-scale greenery such as roof or façade greening are not actively	As urban growth is not a priority of the municipality, settlement pressure is comparably low. Building activities are, however, still ongoing to a limited extent, but do not have to follow standards to protect the urban climate. Consequently new constructions emerge particularly in attractive inner-city areas, areas that are generally prone to heat stress get additionally densified, and fresh air corridors get impaired. Ludwigsburg tries to preserve parks and green areas from getting built-up to preserve the area's attractiveness. However, qualitative and climate-sensitive upgrading is scarce, like small-scale greenery which is mostly carried out as individual initiatives. Modernization of the building stock is not actively pushed beyond the limits of legal requirements; additional financial incentives for

promoted by the municipality. As a result, urban climate and quality of life in some areas of Ludwigsburg are getting worse. Particularly densely built-up areas suffer increasingly from heat stress during summer.	climate-sensitive action are not provided. As a result, particularly densely built-up inner-city areas are increasingly prone to heat stress.

Table 2: Ludwigsburg storylines: exemplary extract on the development of building stock, citing of uses and green urban areas under the four scenarios (source: Garschagen et al. 2018)

These storyline narratives and the mapping of the participatory scenarios (see Fig. 4 and Tab. 2) can illustrate potential urban futures, depending on decisions taken by the municipality and the wider regional context for example in terms of migration and economic development. The results of the participatory scenario approaches and the storyline narratives were also used as one input for the more quantitative scenario development that is still ongoing. However, the following chapter provides some preliminary results and findings for selected indicators.

7 Quantitative forecasting scenarios: future exposure and vulnerability to heat stress – case study city of Ludwigsburg

The development of quantitative forecasting scenarios is still ongoing in the ZURES-project. Therefore, results for some selected indicators, particularly the population growth and the changes in population density as indicators of exposure as well as the growth of the elderly population as a proxy for a population group very vulnerable to heat stress are illustrated using specific scenarios. In the scientific literature and in the stakeholder workshops conducted in the city of Ludwigsburg, the elderly were identified as an important parameter to assess human vulnerability to heat stress. The first challenge when applying quantitative scenario methods at local scale for a specific city context – such as in Ludwigsburg - is that data is often rare and indicators selected have to be modelled or existing scenario data has to be gathered that allows analyzing future development trends. Linkages between the qualitative scenarios and the forecasting quantitative approach are outlined in Figure 5.

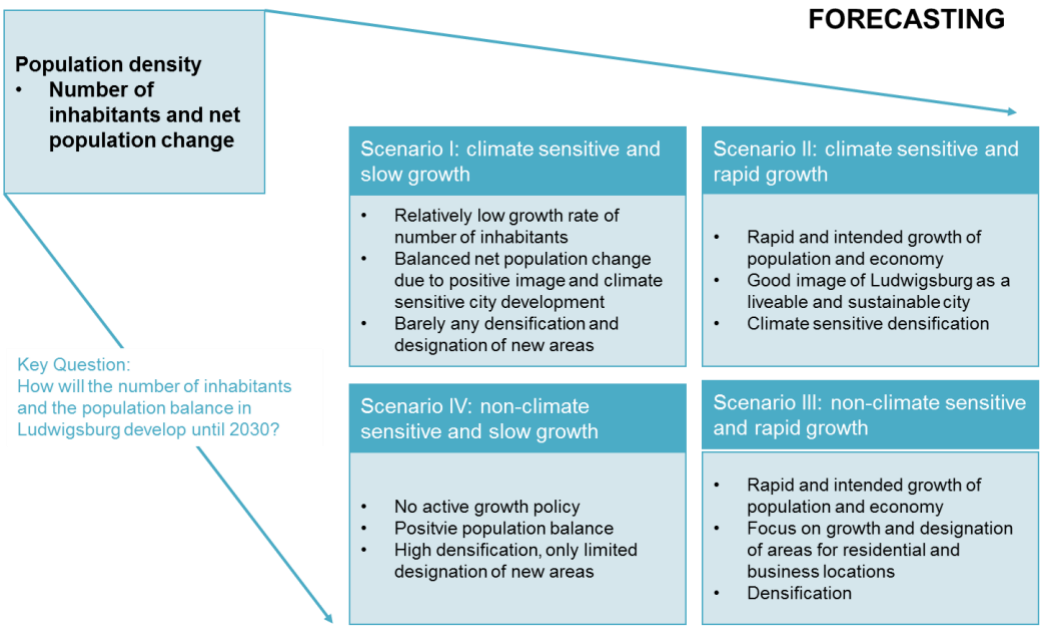

Figure 5: Linkages between Forecasting scenarios and participatory scenario results

While downscaled data from global SSP-scenarios exist for population development at GRID-cell level for urban areas worldwide (see Jones et al. 2018), these scenarios are based on global modelling approaches that do not account for the local specific context conditions and trends, like those outlined in Figure 3 for Ludwigsburg as a representative of a booming medium-sized city in Germany. Consequently, we had to use a different approach to develop and illustrate future developments and scenarios of exposure and the development of the elderly within the city. Since urban planning has to base its calculation for the development of new urban areas on the population data provided by the official Statistical Office of the State of Baden-Württemberg (StaLaBW), we also used this data as an entry point. Based on the experience of the major in-migration in 2015 (refugees from Syria and North Africa) the StaLaBW (2016) today does not provide a single forecast, but rather different population scenarios for the city in the State of Baden-Württemberg in order to illustrate the potential development corridors (see e.g. Waldherr 2016). In this regard, three population scenarios exist from StaLaBW for the city of Ludwigsburg. While the “low growth” scenario assumes a rather minor population increase in the city of about 3% between 2015 and 2030, the “high growth” scenario assumes an increase by more than 21% in the population over the same period (see Fig. 6). This means that in terms of the planning of new housing space, these scenarios imply very different necessities for urban extension and/or densification. The differences between the scenarios are, for example, linked to different assumptions about sub-national and international migration and the changes in live expectancy of male and female, however, restrictions in terms of the non-availability of land for new housing areas in specific cities is not considered (see Hochstetter and Brachat-Schwarz 2016; Brachat-Schwarz 2016). These scenarios make a difference for risk-informed decision making in

local risk management and urban planning. Particularly in the high growth scenario major conflicts between the necessity to extend or densify urban areas versus the protection of green space and the preservation of open space for cold air stream corridors emerge and would require different risk reduction and adaptation measures in the context of urban heat stress compared to the low growth scenario.

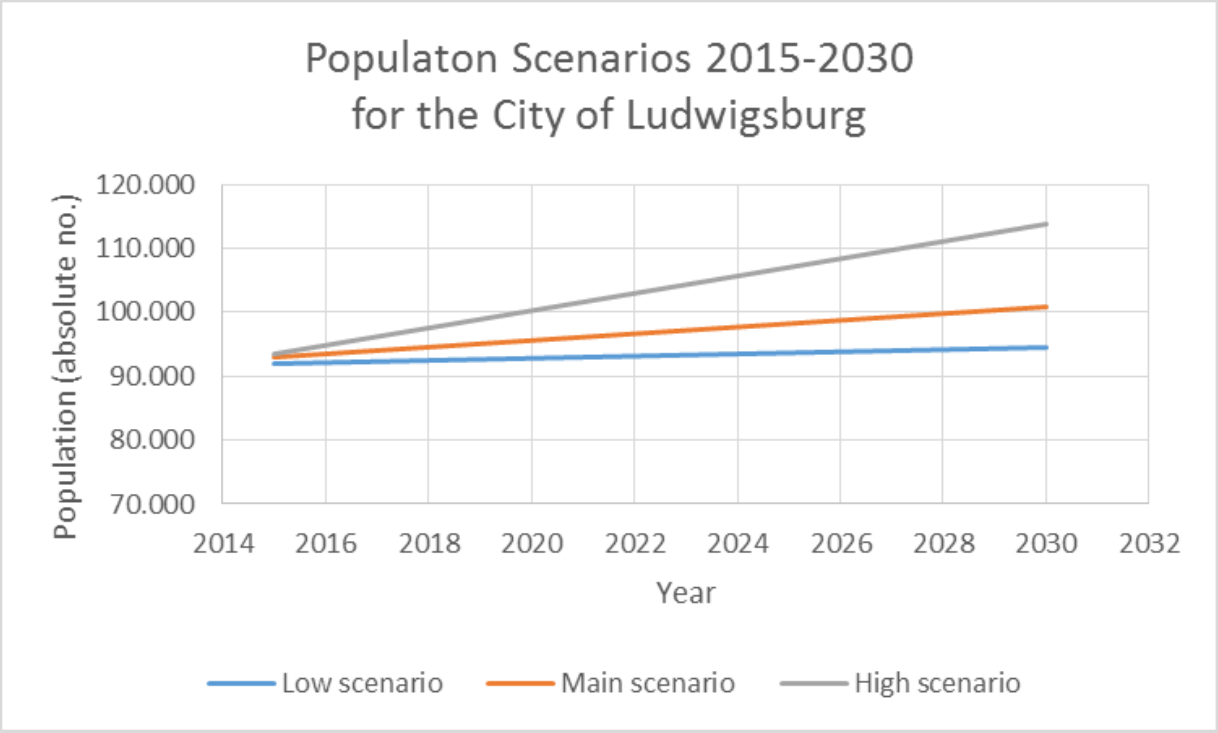

Figure 6: Population Scenarios for Ludwigsburg 2015-2030 (own figure based on data of StatLaBW 2016)

It is noteworthy that the StaLaBW scenarios can be linked to the scenarios developed in the participatory workshop in Ludwigsburg. While for example the low growth scenario of StaLaBW refers primarily to the qualitative scenario I (climate sensitive and slow growth), the high growth population scenario of StaLaBW can be associated with scenario II and III of the participatory method outlined before. Because StaLaBW does not officer inner-city distribution scenarios additional data had to be gathered to illustrate potential future developments at city district scale. In this regard, the approach developed by Biregio and the city of Ludwigsburg was found that is also used and calculated specifically for the City of Ludwigsburg and its city districts. The scenario approach of Biregio and the City of Ludwigsburg (2017) estimates for the City of Ludwigsburg an overall population growth of about 11% between 2016 and 2031 (which can differ significantly between city districts) and thus stays in the medium development range (main scenario) calculated by StaLaBW. Biregio and the City of Ludwigsburg (2017) provides data regarding the development of the urban population for specific city districts and for different age groups until the year 2031. Also the number and share of elderly people (population 65 years and older) is calculated and therefore, can inform the exposure and

vulnerability scenarios to heat stress. Figure 7 outlines changes in population exposure, while figure 8 presents the share of the elderly 2016 and 2013 based on the Biregio scenario at city districts scale (see Fig. 7 and 8). The exposure scenario 2031 shows an increase in density of people particularly in the city districts South and Ossweil in Ludwigsburg (see Fig. 7), while the city center and the city district East continue to have a high population density. While in terms of the exposure to heat stress the central and East districts can be seen as hotspots today (see also combined Fig. 9), it is evident that also the South district will further densify. The heat hazard map does not account for climate change yet, even though this will be analysed in the ZURES project. However, the main intention to explore opportunities and constraints of vulnerability and exposure scenarios at local level can be realized, when focusing on future changes in population and particularly focusing on the share of and increase in the elderly population as one of the most significant indicators to assess population groups vulnerable to heat stress. The analysis of the increase and share of elderly in different city districts according to the Biregio scenario for 2031 reveals that the city center (a hotspot of exposure to heat stress) solely shows a 5% increase in the elderly population and a relatively low share of elderly in the entire population. That means, the share of and growth in the elderly population in the city center is relatively low compared to other city districts in Ludwigsburg. The most significant increases in the elderly population according to the scenario 2031 emerge in the districts South and Ossweil with 30 and 36% growth of elderly. The city districts North and East as well as West also show an increase in the share of elderly, however, the growth rate of elderly in these districts ranges from 16% to 23% in the next 15 years. The highest share of elderly in the overall population can be found in the district Hoheneck with about 26% in 2031, however, this district does not rank among the districts that are highly heat- exposed and therefore this district is not seen as a future hotspot. Overall, the Biregio-scenario of the share and growth of elderly as proxies for vulnerable population (see Fig. 9) shows a quite different pattern compared to the often-used population density.

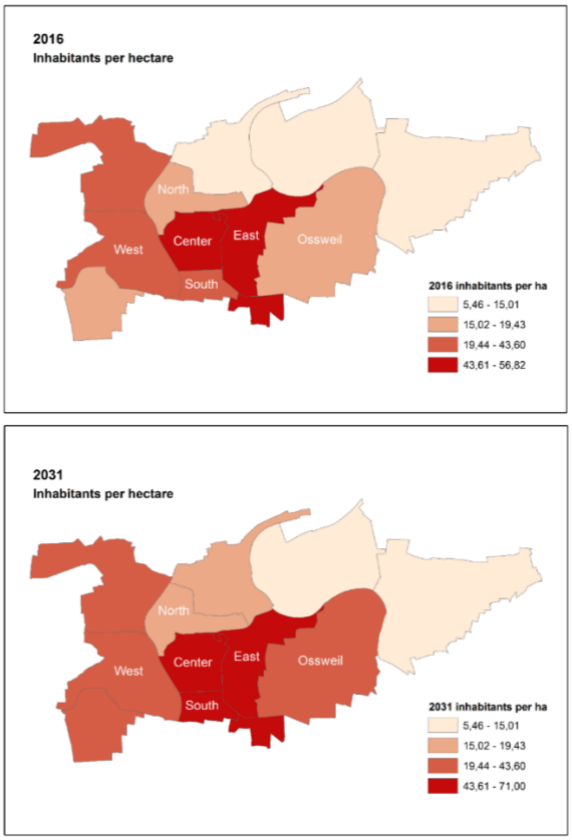

Figure 7: Present and future population distribution in different city districts of Ludwigsburg in 2016 and 2031; quantile method (source: own figure based on population scenarios of Biregio and City of Ludwigsburg 2017)

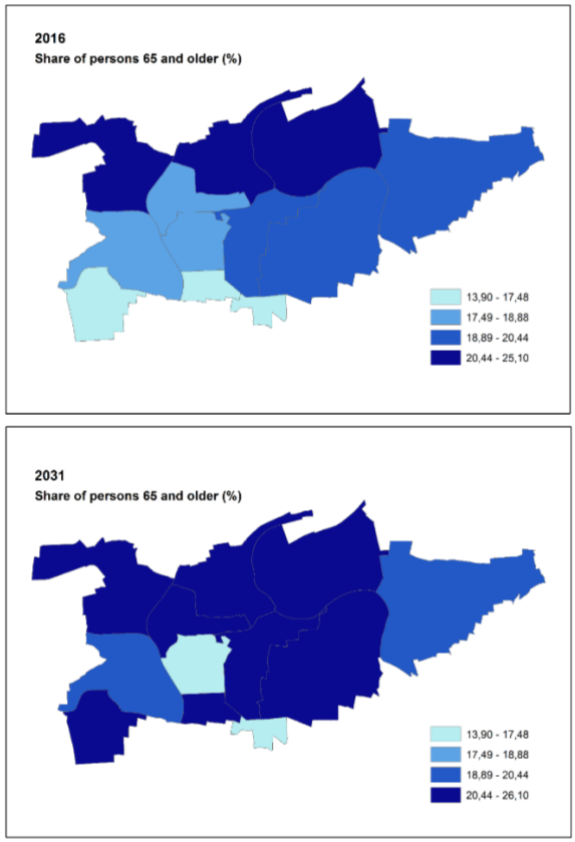

Figure 8: Present and future share of elderly in different city districts of Ludwigsburg 2016 and 2031 according to scenarios of Biregio and City of Ludwigsburg (2017)

The city center of Ludwigsburg is characterized by a high density of people and this area is also highly exposed to heat stress at present (during day and night times) and in the future (see Fig. 9). However, it is the districts on the periphery and the first ring around the city center that emerge as those with the highest increase in elderly and a large share of elderly in the total population in 2031. Pflugfelden district at the south-west periphery of the city and the district South close to the city center are characterized by a significant increase in elderly in the future and a relatively high share of elderly on the district population in 2031 according to the Biregio-scenario (see Fig. 9).

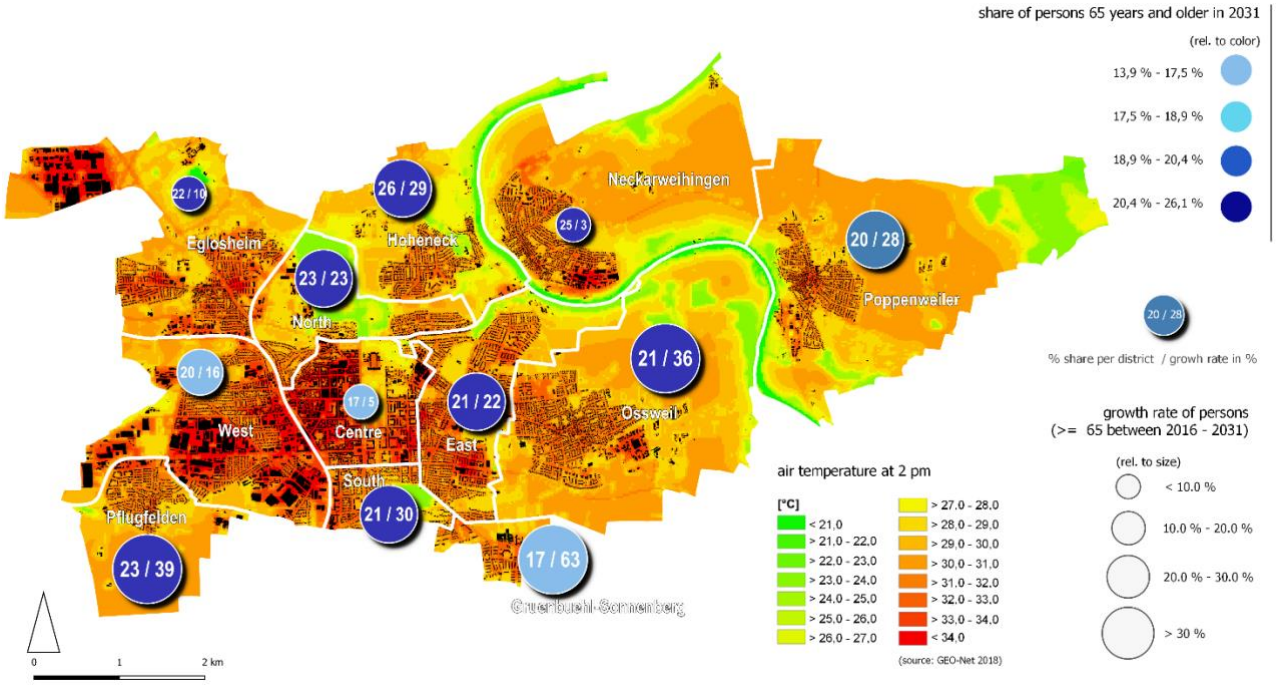

Figure 9: Scenario: Human Vulnerability 2031 in Ludwigsburg at city district scale – proxy elderly (overlay of the scenario of the elderly 2031 at city district scale and the heat stress (2pm) daytime in Ludwigsburg [own map based on data of Biregio and City of Ludwigsburg 2017 and heat stress data GEO-Net 2018])

That means for example, that the district South is likely to increase in terms of population density, the share of elderly in the district population and the growth of elderly ranks among the highest in Ludwigsburg with about 30% in the next 15 years (see Fig. 9). Consequently densification and urban expansion strategies in these districts need to account for heat stress related vulnerabilities and risks with a clear priority. That means for example securing urban green and areas with shade and good air ventilation as well as trying to initiate an urban development that enhances the number of young people and families in these districts. Moreover, it is also evident that more indicators are needed to better represent the multi-faceted nature of human vulnerability to heat stress. In this regard, the project has also developed first scenarios of socio-economic development, particularly focusing on the urban poor in Ludwigsburg. However, the approach is still being discussed with officials, particularly urban and environmental planners as well as statistic experts of the city involved in the project, since we are basing our assumption about socio-economic changes of the household structure in different city districts especially on different scenarios regarding the type of housing (e.g. social housing versus high price apartments). That means in one scenario we assume that the priority of the new

housing developments lies on the provision of social housing, while in another scenario we assume that the new housing space primarily encompass expensive apartments or houses for wealthy people.

8 Opportunities and challenges in terms of the applicability and usefulness of the results and remaining mismatches

Making progress in terms of risk-informed decision making is particularly relevant when major decision are taken that influence risk patterns for a longer time, such as the further urban growth and its impact on heat stress related risks in cities. While climate change data and downscaling approaches for assessing temperature changes and heat stress at the local level are quite advanced, the development and application of exposure and vulnerability scenario remains an area where further efforts are needed. The paper however shows that implementing and enhancing risk-informed decision making at the local level can already make use of scenario data provided, for example, by the official statistical offices of states or of cities in Germany. That means various big and medium-sized cities use own scenario approaches and data for assessing future states of population growth or decline or demographic changes, for example linked to the share and growth of elderly as one of the groups most vulnerable to heat stress. Even though methodological challenges remain, the paper demonstrates that scenario information for assessing future vulnerability can be developed and can complement existing exposure maps. This information can particularly be helpful in strengthening and enhancing urban resilience, for example in terms of the definition of priority areas for urban renewal. Through the amendment of the federal building code, priority areas for urban renewal that receive funding from national level can also address climate change related risks and risks to sustainable urban development. The scenario information (data and maps) can be applied in such funding proposals for urban renewal for specific districts and their prioritization. Next to the mitigation of further heat stress, it is also relevant to communicate these scenarios into different city departments for example in terms of the need to provide housing for younger families in potentially aging districts or to avoid a strong densification in districts that are already quite exposed and vulnerable to heat stress. The scenarios also underscore that future decisions about land-use and the specific housing types that are planned have impacts on the social and demographic composition of the citizens with the different districts. Thus, vulnerability and exposure can be influenced through the decisions taken today. This approach is also relevant to other cities that prepare adaptation and risk reduction strategies to heat stress, for

example cities in India that were exposed to severe heat waves in 2015 and 2018 (see e.g. Amdavad Municipal Corporation 2018)

Finally, the paper also underscored that various mismatches still exist and most likely will remain. For example, various societal trends and scenarios are modelled for a shorter or medium-term time span, such as in the case of Ludwigsburg for the next 15 years to 2030 or 2031. However, climate models particularly predict very significant changes of the climate for longer periods, such as for 2050 and 2100. These temporal scale challenges need further attention. However, decisions for expending or densifying urban areas - due to the need to provide housing in booming medium-sized cities in Germany (e.g. Ludwigsburg) - require risk-informed decisions now. Hence, the examples show that such information can be gathered and made available for decisions that influence urban heat related risks for the next decades. However, more indicators for scenarios of vulnerability have still to be calculated.

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