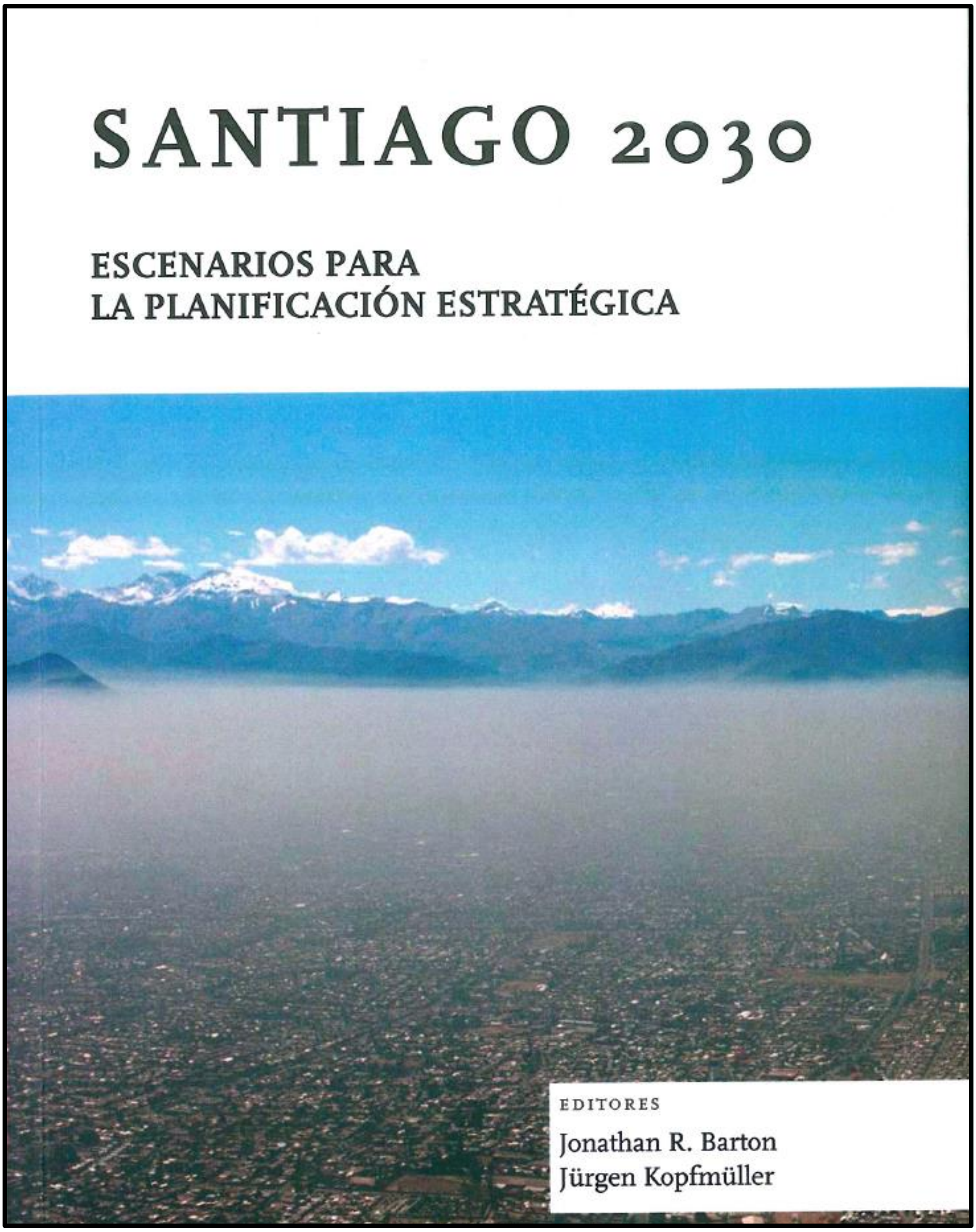
English version following the book chapter

Urban monitoring and explorative scenario development

– an integrative approach for land-use and flood risk management in Santiago de Chile

See Kindler, A., Banzhaf, E., Reyes-Paecke, S., Weiland, U., Müller, A. 2016. Escenarios para ordenamiento territorial y gestión del riesgo por inundación. In this book, pp. 131-160.



English version following the book chapter

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English version following the book chapter

Urban monitoring and explorative scenario development – an integrative approach for land-use and flood risk management in Santiago de Chile

by *Kindler, A., Banzhaf, E., Reyes-Paecke, S., Weiland, U., Müller, A. 2016. Santiago 2030.*

Abstract

In many agglomerations of newly industrializing countries population growth is the major driver for urban land-use dynamics going along with increasing natural hazards such as flood risk. Providing tools for urban planners and decision makers to manage these processes sustainably, an integrative approach of urban monitoring and explorative scenario development is applied. Regarding urban development and sustainability aspects, the proposed set of indicators for major driving factors helps to analyse the respective changes in space and time. These monitoring results are the prerequisites to develop conceivable explorative scenarios. With respect to land-use and flood-risk management such indicator-based monitoring and explorative scenarios are adequate information and decision support instruments.

Exemplified on the Metropolitan Area of Santiago de Chile (MAS) we first performed a status-quo analysis of land-use and population dynamics focussing on settlements exposed to flooding and on specific environmental quality targets over time. On this baseline we then elaborated the three indicator-based explorative scenarios *Business as Usual*, *Market Individualism*, and *Collective Responsibility* for the year 2030 to outline and analyse various development options for land-use and flood-risk management. Scientists and relevant stakeholders have critically dealt with these explorative scenarios on transdisciplinary workshops, presented in this study.

Keywords:

urban growth; status quo analysis; sustainability indicators; urban environmental quality; target values; Metropolitan area of Santiago de Chile (MAS)

1. Introduction

In many agglomerations of newly industrializing countries, urban growth leads to the expansion of built-up areas and these dynamics especially appear as urban sprawl. The major driver for urban land-use dynamics is population development. With respect to global changes worldwide, the population influx has been distinctly high in cities for many years. As the world has become more urban than rural, it is a tremendous task to manage land use in urban regions (UN 2012). As foreseen in the Sustainable Development Goal 11 (SDG 11) by the *2030 Agenda for Sustainable Development* it is demanded to “make cities … resilient and sustainable” (UN 2015) for which urban monitoring and scenarios are appropriate instruments.

To face the challenge of SDG 11, population statistics are vital: they provide information about size, spatial distribution and composition of urban dwellers. Such spatial database depends on a stable methodological acquisition procedure and comparable indicators (UN 2008).

Case studies from Latin American cities show successful and less successful experiences with strategic planning aiming at building and managing urban futures (Steinberg 2005). Census data in Latin America comprise general demographic information and are essential for the design and realization of political strategies, investments, and decision making. In Chile, the National Statistics Institute (INE) produces, analyses and publishes Chilean official and public statistics every ten years. Nonetheless do uncertainties lead to discontinuity of information flow. In our case, the most recent census from 2012 was withdrawn from publication in 2013 (Bianchini et al. 2013), because methodological deficiencies made the comparability with previous censuses impossible. Therefore the last published censuses are from 1992 and 2002 (INE 1992; INE 2002). Such a lack of most recent statistical information demands for alternatives to facilitate spatial information management.

Scenarios provide a valuable option to fill the gap of knowledge between data from the past and future: on the basis of adequate indicators explorative scenarios are elaborated to predict different future developments, e.g. linear and non-linear population growth, land-use changes and urban risks. They are aligned (1) to make common reflections on possible future tracks as a tool for public discussions of the current state and various possible directions of urban development over a longer period of time; (2) to improve steering potentials for decision makers by informing on future land-use and risk management contexts as well as potential consequences of planning decisions (Hall 2000; Swart et al. 2004; Kindler et al. 2010).

In this section, empirical research and results are depicted based on the theoretical and conceptual design of the study. The urban monitoring and related explorative scenarios are grounded on a set of indicators for major driving factors of urban development and sustainability aspects. First, the status quo analysis gives evidence on land-use, population and environment-related trends in the Metropolitan Area of Santiago de Chile (MAS) over two decades. Second, the three explorative scenarios Business As Usual (BAU), Market Individualism (MI), and Collective Responsibility (CR) support the concept for alternative development paths describing possible futures exemplified by the study area. After comparing the results of the scenarios, final conclusions are drawn, especially for land-use and flood-risk management.

2. Theoretical and conceptual background

The integrative sustainability concept of the Helmholtz Association (Kopfmüller et al. 2001, 2009) has been adopted for the present research. It is based on three general sustainability goals: ’Securing human existence‘, ’Maintaining society’s productive potential‘, and ’Preserving society’s options for development and action‘ and consists of a set of rules that describe minimum conditions for sustainable development to be guaranteed for all human beings of present and future generations (Kopfmüller et al. 2001, 2012).

2.1 Explorative Scenarios

A scenario in general is defined as the “description of a possible future situation”, i.e. a “conceptual future” (Kosow and Gaßner 2008, p.11; Amer et al. 2013). The basic idea behind scenarios is not to predict *one* future development, but to describe and analyse credible alternatives for future development options which allow for if-then statements: '*if* certain factors develop in a certain way, *then* certain effects may happen' (Alcamo et al. 2008). Scenarios "are efficient tools for synthesising and communicating complex and extensive information to decision makers and the public." (EEA 2001, p.3)

Explorative scenarios are mainly created on the basis of quantitative indicators depicting accurate past and present developments and trends, and reflecting societal factors by their conjoint interpretations. When working out different explorative scenarios it is crucial not to limit to negative and positive polarities, but rather to enhance a wider spectrum of potential future options. The goal of explorative scenarios might comprise awareness rising, the stimulation of creative thinking, and gaining insight into interdependencies and socio-spatial implications (EEA 2000; Hammond 1998; Rotmans et al. 2000; van Notten and Rotmans 2001); they have been generated manifold (Börjeson et al. 2006; Kok et al. 2011; Riahi et al. 2007; Svenfelt et al. 2010; Wangel 2011).

As an innovative aspect we first combine a monitoring of physical and socio-demographic indicators to be our starting point for *status quo* analyses and for specific environmental quality targets. Based on these primary analyses we then derive three scenarios for environmental quality and quality of life assessment (WBGU 2016, p. 275). We could establish target values due to the benefits from our previous transdisciplinary workshops on which we critically deliberated these values with local and regional stakeholders from different fields.

We elaborated three scenarios for our research referring to existing global scenarios (cf. Raskin et al. 2008; UNEP 2007; UNEP 2010): The basic 'philosophy' of the BAU scenario is characterized by the perseverance of liberalization and privatization trends. It is assumed that whereas market forces persist, public regulation activities remain weak. Social protection measures are still in place, including subsidies for specific target groups. The leading ideas behind the MI scenario are greater individual freedom and freedom of action. The role of the markets advances to become the principal driver for all social transactions subject to the principles of supply and demand. The CR scenario is defined by more social and environmental justice, the main goal of which is tighter regulation of market activity and large public investments, the embedding of technologies into society and the decoupling of socio-economic development from resource use (Krellenberg et al. 2010; Hölzl et al. 2011).

2.2 Scenario indicators and target values for land-use and flood-risk management

An indicator-based urban management system is a tool to identify the extent of the real urban development processes complied with the envisaged sustainability. It needs to comprehend the actual status of environmental, ecological and social construction and should also integrate its dynamics (Repetti and Desthieux 2006). Holden (2006) for instance focuses on specific aspects to investigate whereas Huang et al. (1998), and later scientists such as Nader et al. (2008), Li et al. (2009) develop a synthetic set of indicators to assess diverse factors such as demography, standard of living, and land and their respective interactions.

The main purposes of sustainability indicators are described in detail a.o. in OECD (1997), Weiland (1999), Weiland et al. (2011) Fraser et al. (2006), and Reed et al. (2006) for land management.

Li et al. (2009) use status values for the present situation and target values for future time steps. The target values of indicators are planned values coming from institutional directives and do not exist for all indicators (UNEP 2002). They may be established for a global understanding of a profound issue such as measuring quality of life, or a national quality rating. In order to encompass the complex interrelations between processes of urban growth, their relation to environmental impacts and the objective of this research two groups of indicators have been selected according to OECD (1997): the indicators of urban patterns refer to population, land use and its management, and the indicators for urban environmental quality provide information relevant e.g. for flood-risk management.

3. Methodology

In our integrative approach we first monitored major urban drivers by selected indicators over two decades. With this knowledge and the applied indicators, we developed three explorative scenarios for urban land-use and flood-risk management. Our objective is to monitor, analyse and assess land-use and population dynamics and interrelations of environmental aspects in the MAS. One specific of the study area being discussed here is settlements exposed to flood risk. They picture how land use determines the level of flood risk through direct exposure. The observed changes on land use and population allow for elaborating scenarios that can be used as decision support tools in land-use and flood-risk management.

3.1 Study area

The study area comprises 33 out of 34 independent municipalities with own mayors that represent the MAS (see Fig. 1). It covers an area of 2,118km² with about 5.9 million inhabitants corresponding to the year 2009 (Encuesta CASEN 2009). According to Hölzl et al. (2011) the spatial differentiation of the MAS into clusters is applied. These clusters comprise one or more municipalities of the MAS which are characterized by their geographical location, similar socio-economic and demographic features. The clusters represent aggregated spatial units which are meaningful for the status analysis and the development of scenarios comparing different parts of the MAS. They serve as an intermediate scale between the entire MAS for which the analysis would suffer from inner urban differentiation, and the single municipality for which the scenario development would be too detailed and not appropriate for the aim of the investigation.

Therefore the MAS is subdivided into four clusters which are referred to as *Centre, Peri-Centre, Eastern Peri-Centre* and *Periphery* (see Fig. 1). The *Centre* consists of the municipality Santiago only, 17 municipalities belong to the *Peri-Centre,* the *Eastern Peri-Centre* is composed of six municipalities, and the *Periphery* has nine municipalities.

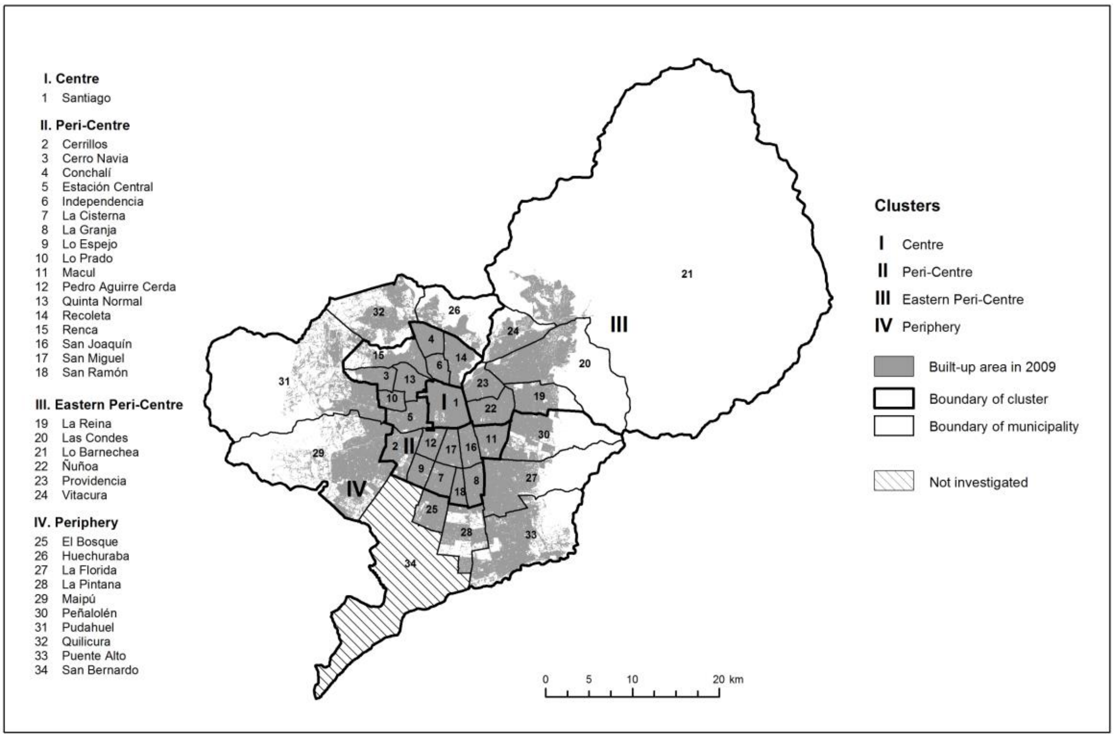

Fig. 1: Spatial division of the MAS into four clusters and the built-up area in 2009 (own sources)

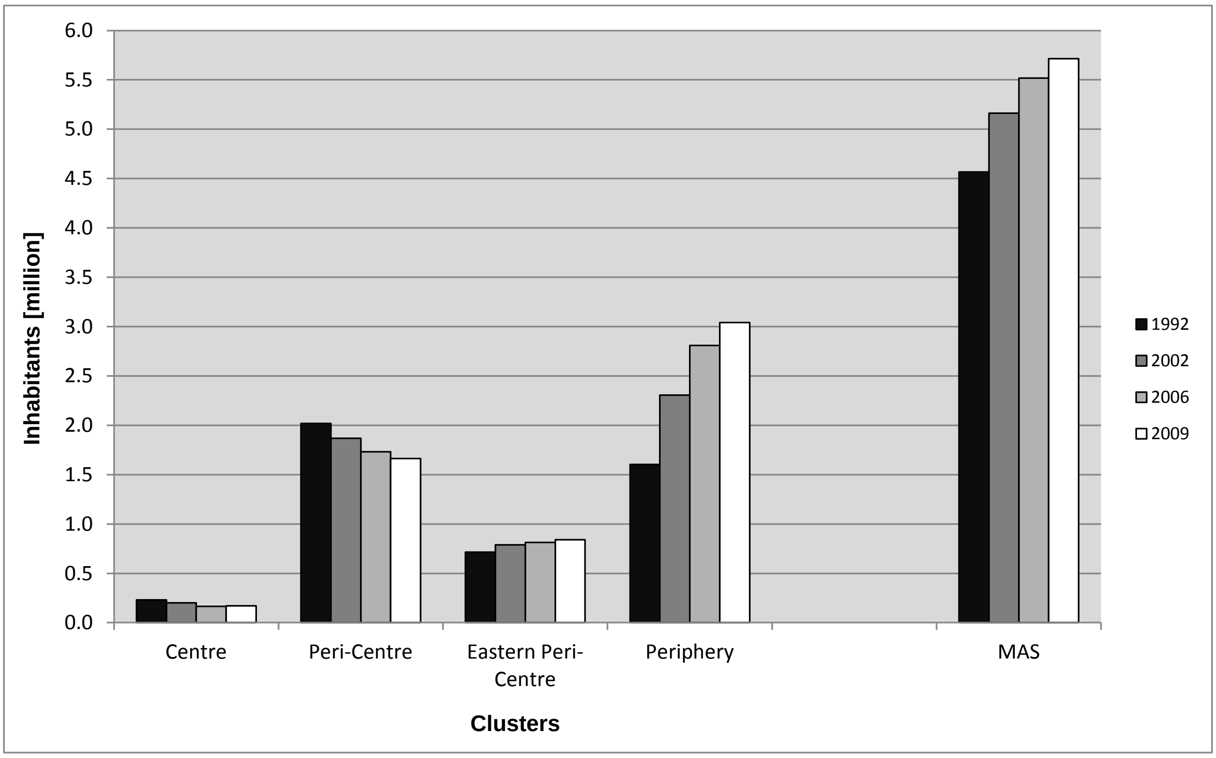

Fig. 2: Population development in the clusters of the MAS between 1992, 2002, 2006 and 2009 (data sources: census data 1992 and 2002; Encuesta CASEN 2006 and 2009)

During the past decades the MAS has experienced a rapid urban expansion and a fast increasing population development (see Fig. 2). High environmental pressure is envisaged through the transformation of formerly agricultural land into built-up area, and diminishing green spaces. Like many other cities the MAS tries to implement sustainable urban development (UNEP 1992; Barton et al. 2007; cf. extensive database in IISD 2010). Increasingly impervious land cover results in long-term environmental impacts, especially the loss of green spaces and reduced retention areas for rain water during precipitation events in winter. These complex processes demand for an appropriate land-use management to overcome constraints for quality of life and mitigate risk production for people and goods (Romero and Vásquez 2005; Banzhaf et al. 2012).

3.2 Characterization of applied indicators

In order to analyse and present urban development processes in the MAS, (1) indicators depicting major driving factors, and (2) indicators referring to sustainability in terms of optimizing the relation between housing and flood-risk management were selected (see Tab. 1).

Table 1: Aspects and associated indicators for land-use and flood-risk analyses and management

Aspect of the Integrative Sustainability Concept	**Indicator**	**Spatial scale**	**Temporal scale for monitoring and initial analyses**	**Data source**
Major driving factors				
Population	1. Population density [inhabitants / ha]	MAS, clusters	1992, 2002 2006, 2009	Census data 1992, 2002; Encuesta CASEN 2006 and 2009
Building density	2. Built-up area [ha]	MAS, clusters	1993, 2002, 2006, 2009	Remote sensing data
Imperviousness	3. Degree of imperviousness[ha]	MAS, clusters	1993, 2002, 2006, 2009	Remote sensing data
Sustainability indicators				
Green spaces	4. Amount of green spaces [ha]	MAS, clusters	2001; 2006	Remote sensing data
	5. Amount of green spaces per inhabitant [m^2/inh.]	MAS, clusters	2001; 2006;	Remote sensing data; census data 2002, Encuesta CASEN 2006

Elements at risk	6. Proportion of new settlements and infrastructure in areas facing a high flood hazard level (i.e. one or more events every two years)	MAS, clusters	1993, 2002, 2009	Remote sensing data and GIS data
	7. Proportion of population living in areas facing a high flood hazard level	MAS, clusters	2002	Census data and GIS data

With respect to their applicability in research and practice, only indicators with sufficient data base could be chosen (cf. Weiland et al. 2011). As a consequence, major driving factors are represented by the indicators population density, built-up area, and degree of imperviousness (indicators 1-3).

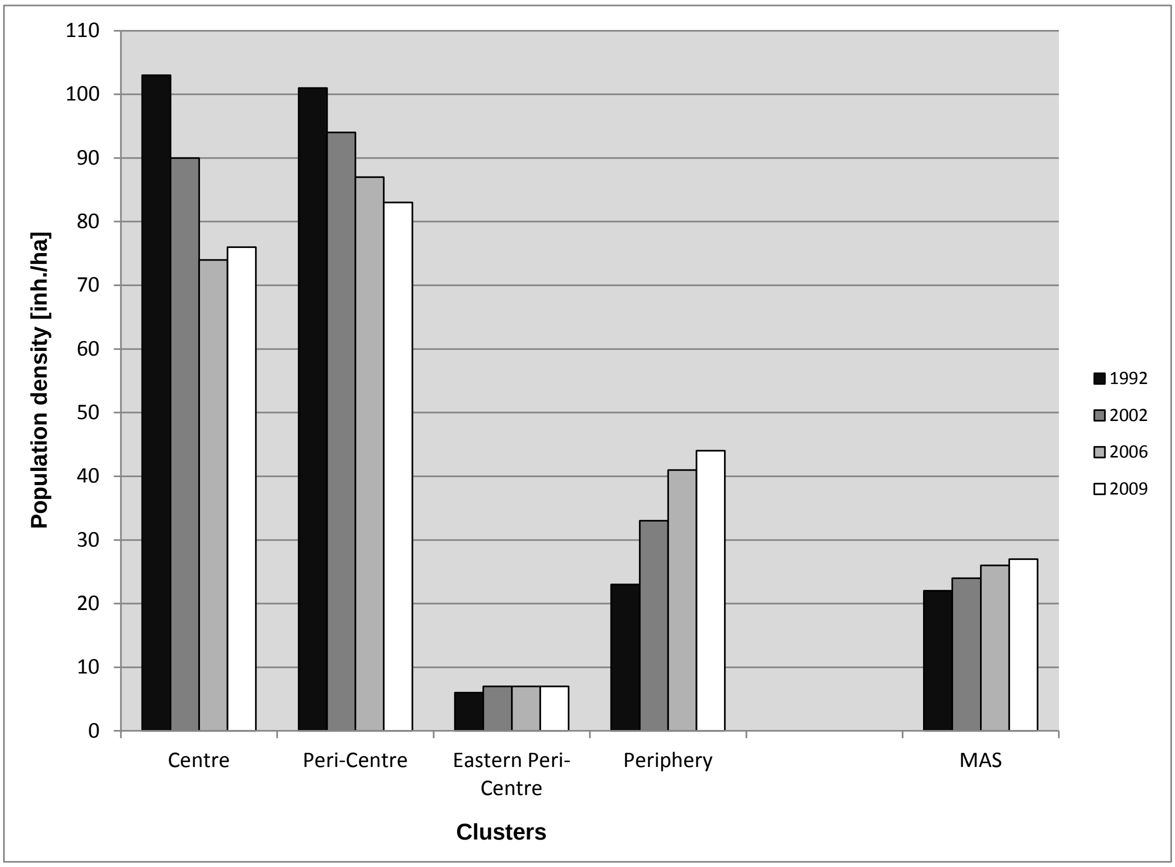

Fig. 3: Population density in the clusters of the MAS in 1992, 2002, 2006, and 2009 (data sources: own calculations based on census data and Encuesta CASEN)

Sustainability indicators refer to human activities in land use as part of the built and natural environment and its management. They provide information on the amount of green spaces, as well as the proportion of new settlements, infrastructure and population in areas facing high flood hazard level (indicators 4-7). Indicators describing the current status in the MAS and its clusters in various time spans are depicted in detail as follows:

1. The number of inhabitants per hectare characterizes the population density at a given point in time. By analysing this indicator over time, its dynamics show the

spatial distribution of population as a potential driver for urbanization processes including urban sprawl (see Fig. 3).

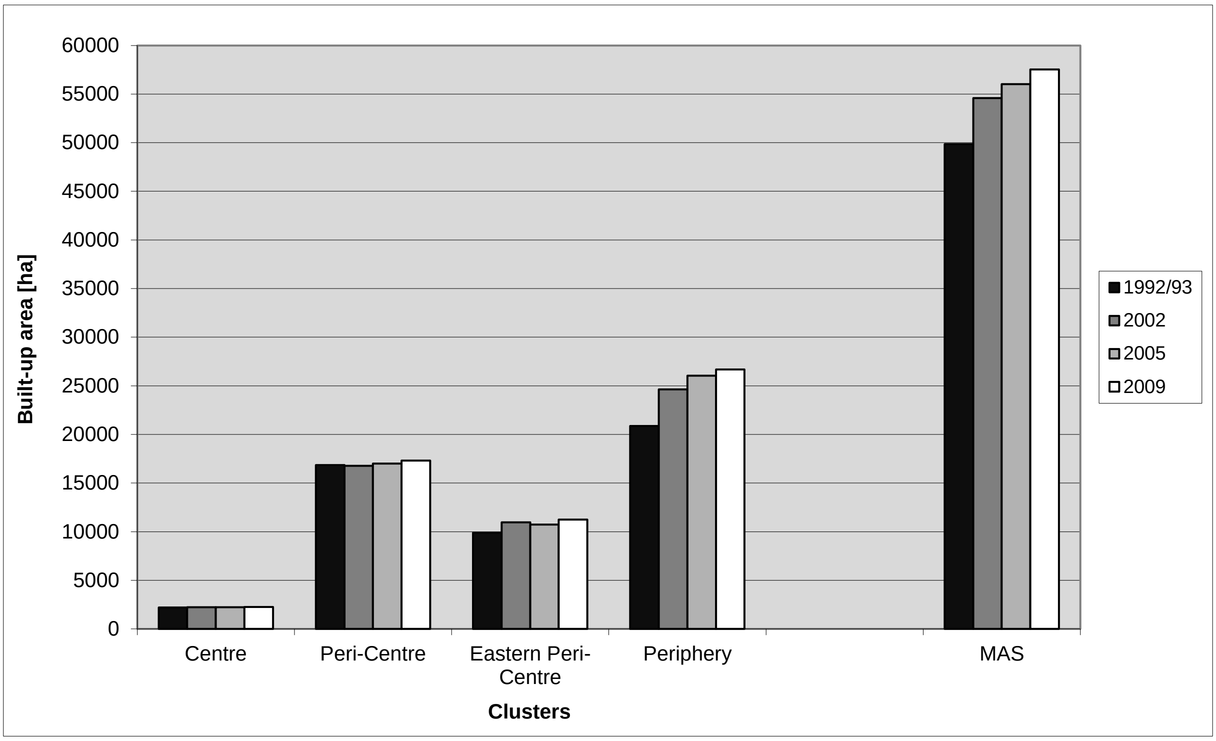

Fig. 4: Built-up area in the clusters of the MAS in 1992/93, 2002, 2005, 2009 (data sources: own calculations based on remote sensing data)

2. The built-up area in hectare [ha] refers to the total amount of buildings, road network and the remaining urban built infrastructure at a point in time. This indicator depicts the rapid urban expansion over time and is a driver for high environmental pressure and long-term environmental impacts due to land transformation processes (see Fig. 4). Thus it is closely linked to the indicators 6 and 7.
3. The degree of imperviousness groups impervious surfaces into degrees and provides information on surface infiltration capacities – respectively its reduction due to the increase of the degree of imperviousness. Built-up areas are subdivided into the categories “total-to-high degree of imperviousness” (100% to 70%) (see Fig. 5a), “intermediate degree of imperviousness” (<70% to 40%) (see Fig. 5b), and “low degree to no imperviousness” (< 40%) (see Fig. 5c).
4. Public and private green spaces contribute to secure urban ecosystem services. In this respect, green spaces have high infiltration capacity of storm waters, and the amount of green spaces per cluster is selected as indicator for the potential flood risk prevention (see Fig. 6).

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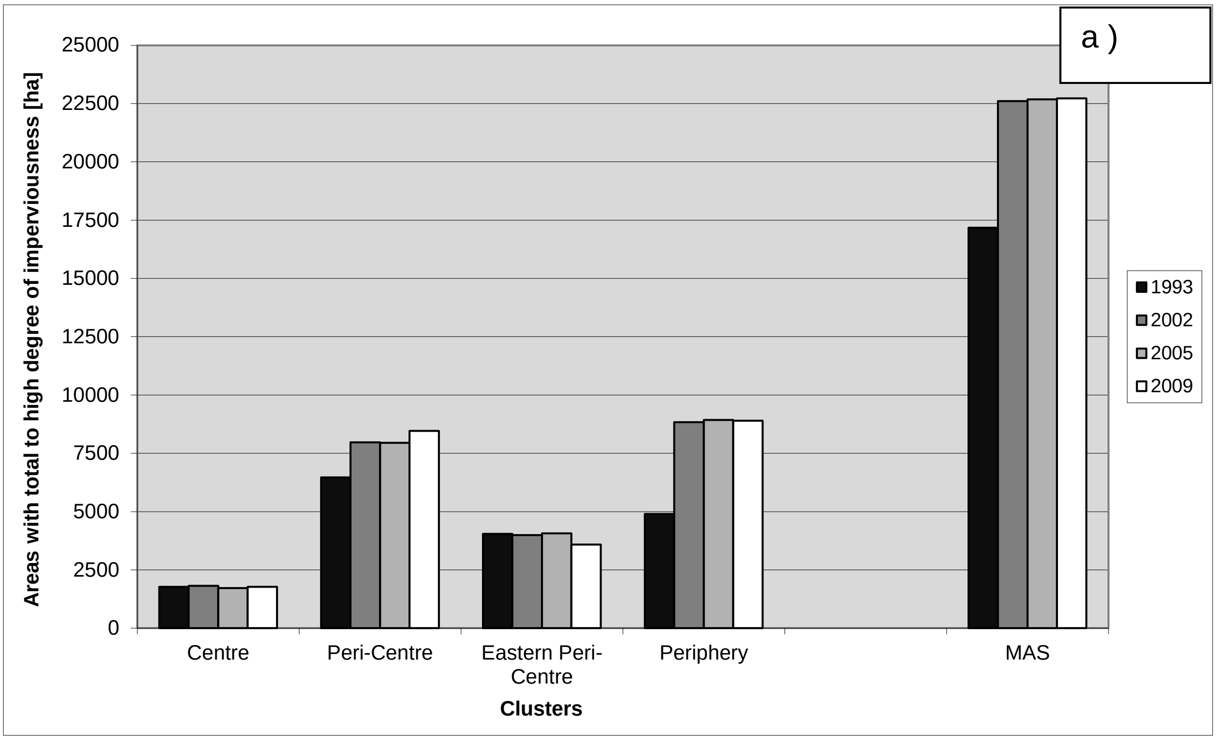

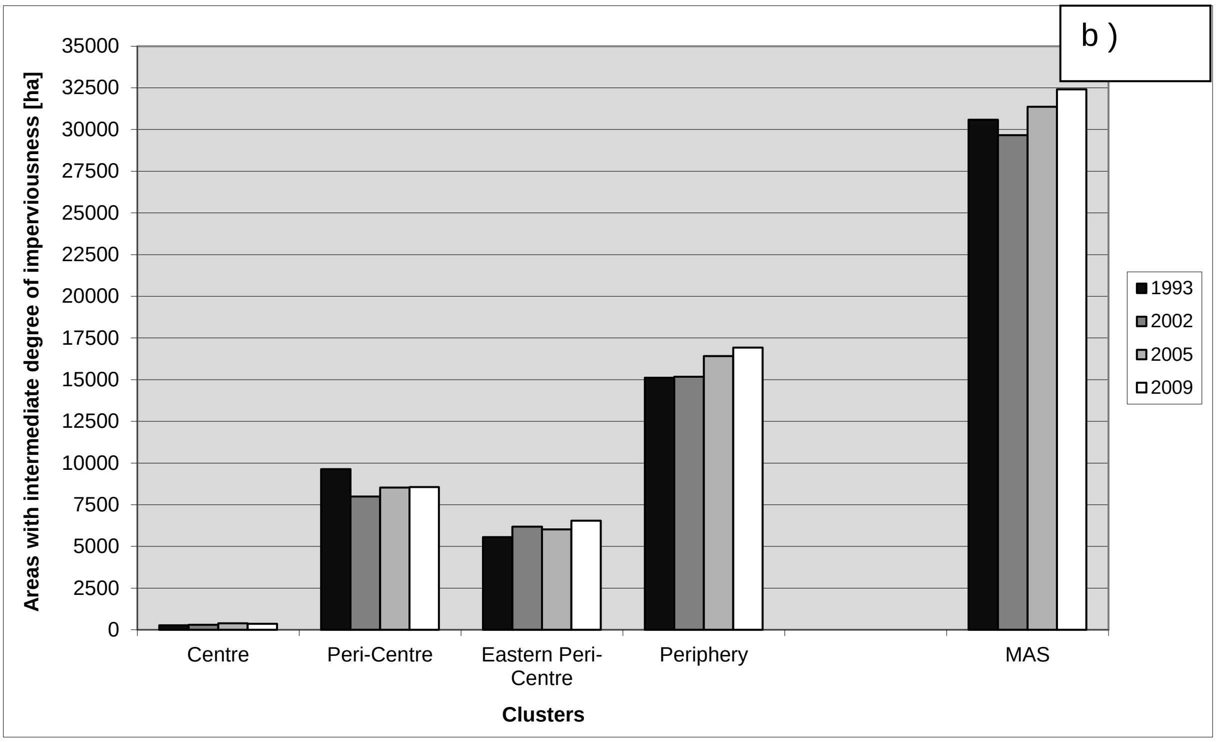

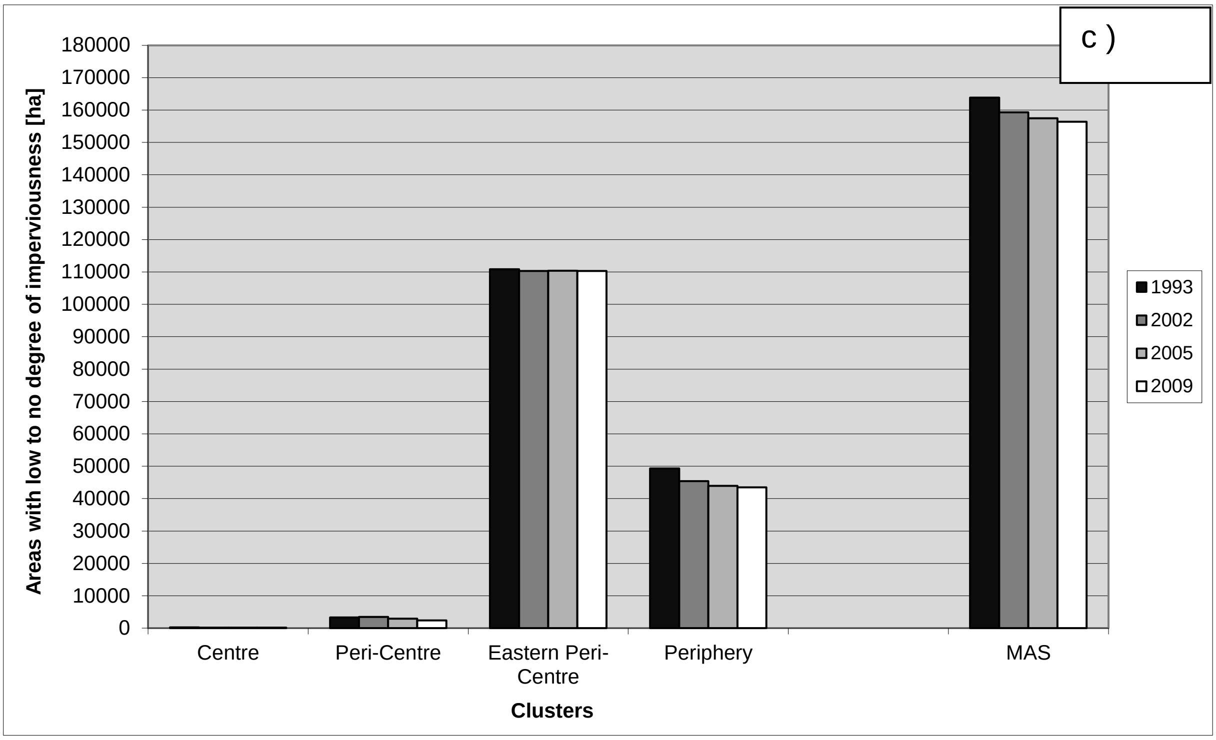

Fig. 5 a)-c): Areas with different degrees of imperviousness in the clusters of the MAS in 1992, 2002, 2005, and 2009 (data sources: own calculations based on remote sensing data)

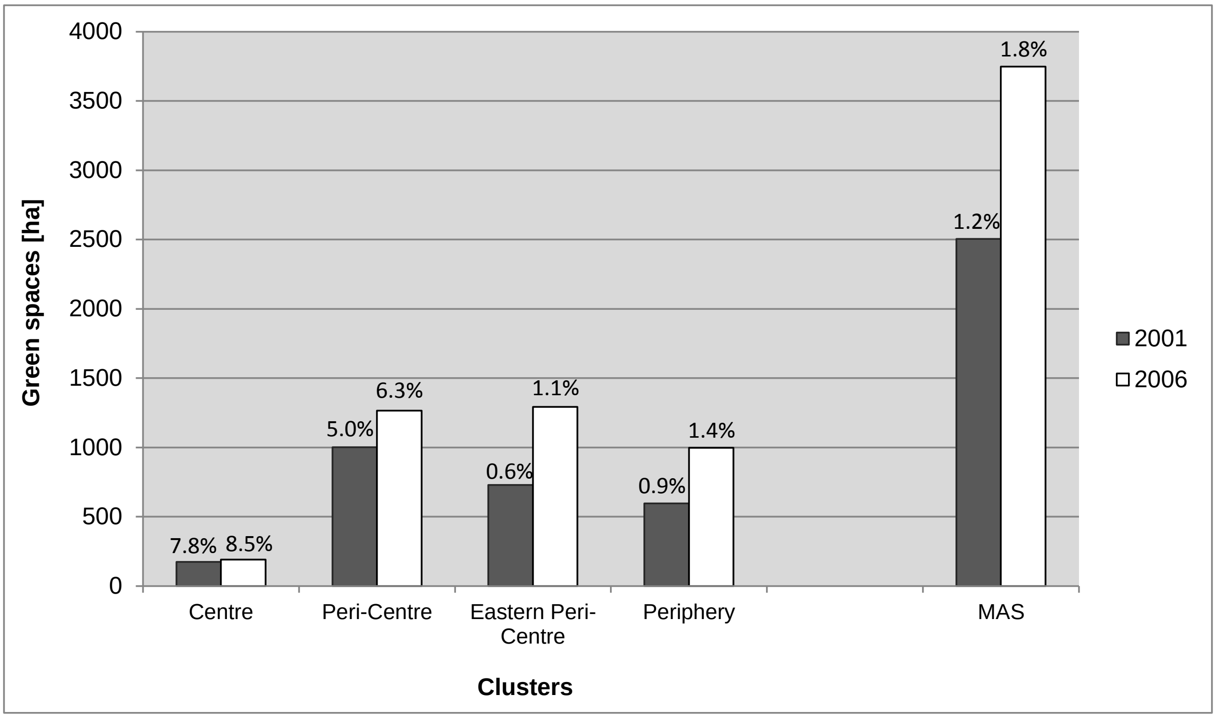

Fig. 6: Amount of green spaces in the clusters of the MAS in 2001 and 2006 (data sources: own calculations based on remote sensing data)

5. For the social dimension the amount of green spaces per inhabitant reveals the urban environmental quality and also serves as an indicator for the quality of life in a city (see Fig. 7).

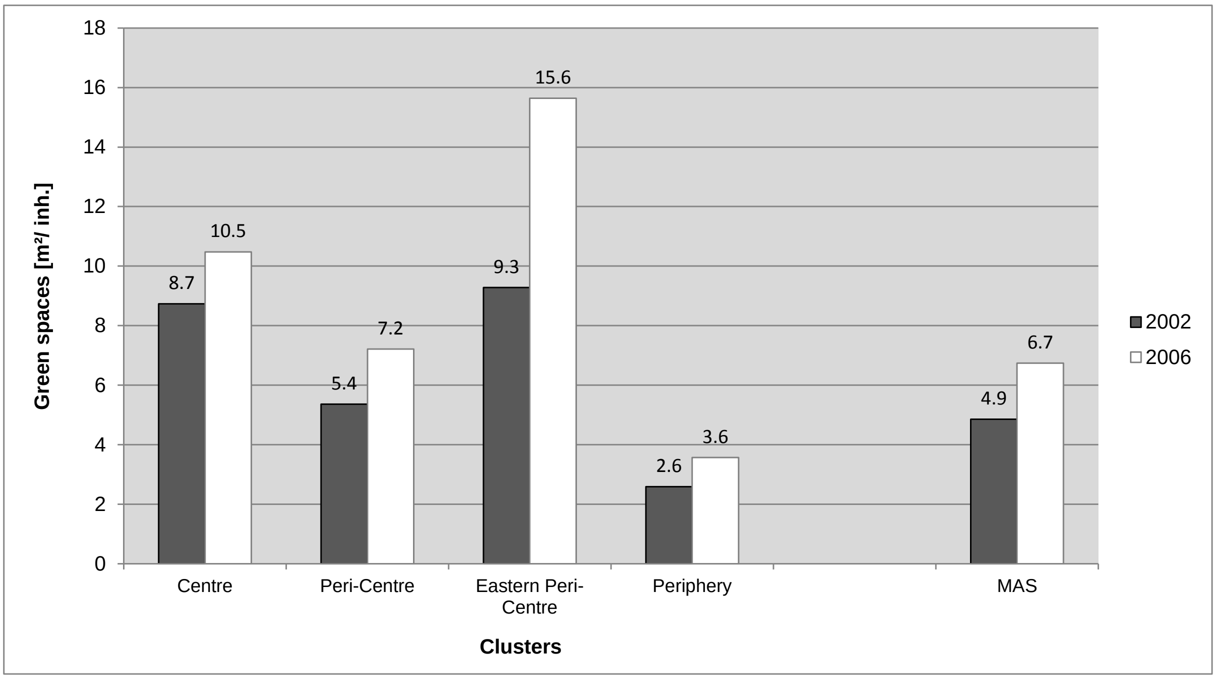

Fig. 7: Green spaces per inhabitant in the clusters of the MAS in 2002 and 2006 (data sources: own calculations based on census data in 2002 and Encuesta CASEN in 2006; amount of green spaces based on Secretaria Ministerial Metropolitana de Vivienda y Urbanismo (2003) and on Reyes Päcke and Figueroa Aldunce (2010))

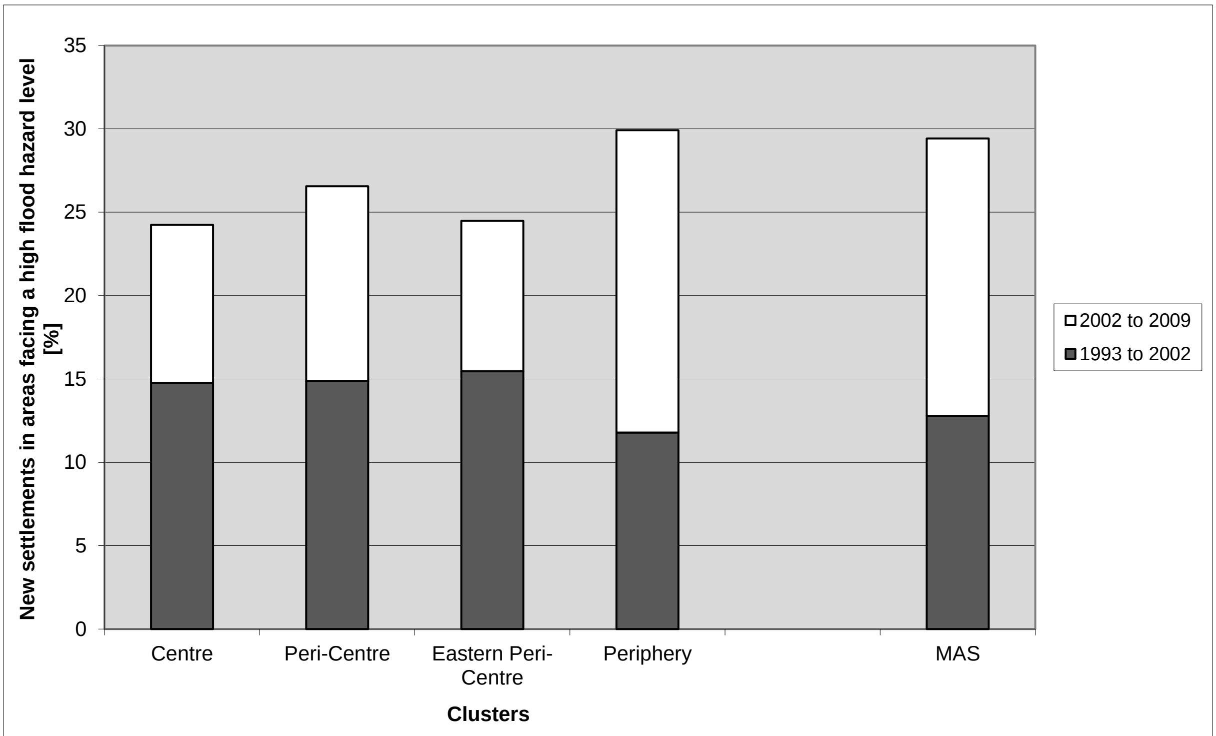

Fig. 8: New settlements in areas facing a high flood hazard level in the clusters of the MAS; time spans: 1993-2002 and 2002-2009 (data sources: own calculations)

6. To measure the urban environmental quality against flooding, the indicator proportion of new settlements and infrastructure facing a high flood hazard level with one or more events every two years is quantified (see Fig. 8).

7. The last indicator corresponds to the number of population living in areas facing a high flood hazard level and was selected in order to show the spatial distribution of population endangered by flooding (see Fig. 9).

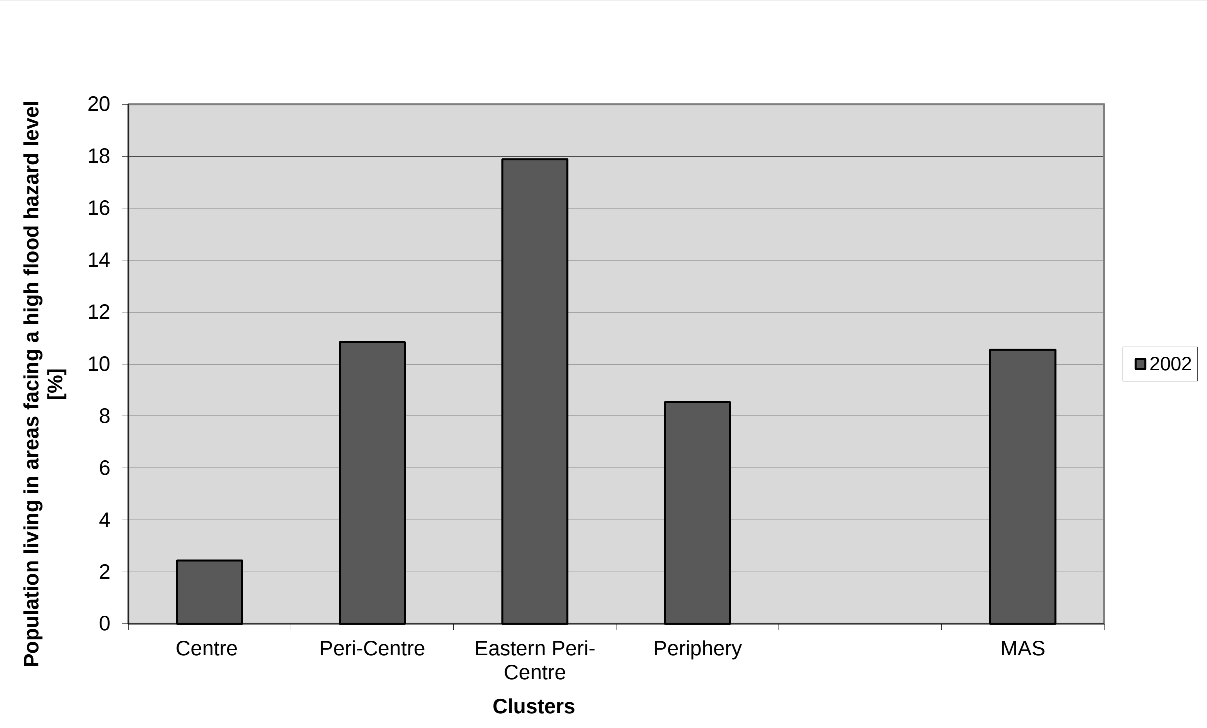

Fig. 9: Population living in areas facing a high flood hazard level in the clusters of the MAS in 2002 (data sources: own calculations)

With the exception of indicator 7, all indicators are investigated for time series to calculate rates for spatial and temporal developments and to design a database of past and recent processes as well as projections for the year 2030. These indicators are used to give recommendations for urban and regional planning at the local scale.

3.3 Explorative scenarios of land-use and flood-risk management

Our prerequisites for scenario development contained the monitoring of drivers with the above-mentioned indicators and the analysis of past development processes (Weiland et al. 2011). Hence, we could design the scenarios by elaborating storylines, analysing and assessing the three different scenarios, and taking into account the response by stakeholders to appraise their policy relevance.

3.3.1 *Parade of the storylines for the three scenarios*

Storytelling is an important tool for strategic planning and the development of scenarios, as telling - and understanding - stories is indicative for planning and maintaining sustainable cities (Eckstein and Throgmorton 2003). Therefore the scenarios are analysed on the basis of storylines offering a differentiated view on underlying dimensions and indicators. To work out a well-understood comparison between the storylines and the analysis of the scenarios, Table 2 is elaborated. Furthermore, Table 2 gives a deeper comprehensibility of the evaluated scenario trends generated in Table 3.

English version following the book chapter

Table 2: Storylines for major driving factors and sustainability indicators on land-use and flood-risk management in the three scenarios BAU, MI, CR

Indicator	Business As Usual (BAU)	Market Individualism (MI)	Collective Responsibility (CR)
Major driving factors			
1. Population density [inh./ha]	Number of urban population is increasing moderately; decrease in rural populations; inner urban migration processes; number of households increase with fewer persons per household.	A strong increase in the number of urban population (approx. 2% until 2030); in-migration as main driving force; a strong decrease in rural population, partly becau-se former rural areas incorporated into the MAS and partly because of migration of the younger generations towards the *Centre* and *Peri-Centre*; unbiased distribution of population; lower birth rates resulting in downtrend to start families, small households or single person households as dominant household types; almost no multi-generation households.	Decreasing birth rate, stagnating growth rate of the urban population of the MAS; very little in-migration from outside; inner-urban migration within the MAS; dominant living form is households with families and multi-generation house-holds, but only few single households.
2. Built-up area [%]	City is expanding further towards the rural areas; spatial leap-frog development; in *Eastern Peri-Centre* and *Periphery* a tentative urban redevelopment proceeds; predominantly single-family houses; some huge shopping malls in *Periphery*; plenty of intermediate sized commercial sites in *Centre* and *Peri-Centre.*	A strong push of urban growth into rural and sensitive or even protected areas; highly ex-panding urban area; increase in predominantly commercially used buildings in the *Centre* and *Eastern Peri-Centre* resulting from economic development; large lot sizes in surburban regions well connected to city centre; strong dominance of single family houses with medium to large lot sizes in the eastern part of the *Peri-Centre* and *Ea-stern Peri-Centre* and in the leap-frog developments towards the northern and the southern parts of the *Peri-phery*; re-emerging informal settlements, predominantly in the *Periphery*; significant urban expansion; increasing number of newly constructed residentially used high -rise buildings in the *Eastern Peri-Centre*.	"The compact city": successfully achieved process of urban densification characterized by a slow-down of urban growth into the rural areas and the re-urbanisation of the *Centre*, *Peri-Centre* and *Eastern Peri-Centre*; redevelopment and revitalisation of derelict land as well as closing of existing gaps within the city; additional satellite cities associated with a slow extension of the existing road network; multi-storey buildings as dominant building type in central areas of the city; result no informal settlements; industrial and commercial areas on smaller sites closely connected to public transport and housing areas; evenly distributed shopping facilities within the compact city.
3. Impervious areas [%]	Strong increase in impervious surfaces	Vigorously increasing amount of impervious urban surfaces. A strong spatial leap-frog development leading to significant extension of the transportation network.	Moderate speed of increasing impervious surfaces
Sustainability indicators			
4. Green spaces [%]	A slow increase in private green spaces, especially in the *Eastern Periphery*. Public green spaces in *Centre* and *Peri-Centre* are maintained, but neither the number nor the quality is increasing. New	Still existing public green spaces with less quality and quantity; increasing amount of private green spaces, especially in the rich parts of the city and the suburban environment;	Maintenance of public green spaces and creation of green corridors gaining importance; Green spaces become a central component for new urbanizations, as an

	public green areas are built up in the *Periphery*, but they are small and with scarce vegetation cover due to rising shortage of irrigation water. Therefore, these green areas do not contribute to rainwater infiltration and winter floods are frequent.	Construction of new urban parks by granting and privatization of public spaces is strongly promoted by local authorities. This policy increases the surface of green areas in high-income municipalities, exacerbating the difference between different zones of the city; amount and type of vegetation secured in upper class areas through augmenting irrigation to maintain a private green environment.	adaptation strategy for climate change by means of: areas for storm water infiltration and riverside buffer zones for winter overflows. Native vegetation adapted to water scarcity and higher temperatures are included by design in green urban spaces. The promotion of technologies for recycling grey urban waters allows a sustainable management of irrigation water. Environmental functions of green spaces are achieved.
5. Green spaces per inhabitant [m²/inh.]	The densification process in the *Centre* and *Peri-Centre* contributes to a sustained increase of population density, with no new public green areas. Brownfields and derelict land are destined for housing and infrastructure. There are no policies aimed at increasing public green spaces. This indicator shows strong differences between municipalities and is positively correlated with income level of inhabitants.	Subsidies for housing in *Centre* and *Peri-Centre* are maintained, increasing population density but without new parks, which increases the deficit of green area per capita in these areas of the city. Established private green spaces in the outskirts, not accessible to everyone. Vegetation of public spaces diminishes due to water scarcity, the lack of water optimization strategies, and the exclusion of better adapted species.	Rising amount of green spaces per capita. Newly created urban parks on derelict grounds (e.g. unused railways, former landfills) improving urban quality in densely populated municipalities. Public priority is given to the construction and maintenance of green areas in municipalities with higher population density and greater green areas deficit, to achieve the goals of improving quality of life. Social functions of green spaces are achieved.
6. Proportion of new settlements and infrastructure in areas facing a high flood hazard level [%]	Construction and urban development prohibited in regions that have at some point been identified as areas at risk with possible exceptions.	Constructions often of poor quality, building codes usually neither fulfilled nor updated and no existing structural controls	Long-term perspective thinking leading to constructions associated with higher financial expenses, and consequently to more safety; responsible methods of construction; creation of risk control works using green technologies and minimal damages over natural landscapes.
7. Proportion of population living in areas facing a high flood hazard level [%]	Constant rate in the central areas, increasing towards the periphery where new construction sites evolve.	Proportion rising in the periphery as real estate is economically worthwhile in outlying areas facing a high flood hazard level	Stable rate in all parts of the MAS, reduction of risk as a main target of urban planning.

3.3.2 *Workshops as science-practice interface*

On our transdisciplinary workshops and meetings such as on the international conference "*Desarrollo urbano sustenible en Megaciudades de América Latina: Santiago 2030*" in Santiago de Chile in October 2010 we discussed and refined these scenarios as an interdisciplinary research group with local and regional decision makers. Workshops increase the mutual understanding, support the sensitivity towards the options different futures offer and facilitate to transfer results gained from the analysed scenarios into practice (Lira 2006; Reed et al. 2006). In these transdisciplinary workshops, we gained appreciative response for the results of the scenario analyses regarding their policy relevance for a sustainable urban land-use and flood-risk management which we incorporated into our results. Our validated assessment thus fosters the significance for management and planning decisions.

4. Results of the scenario analysis and assessment

4.1 Scenario analysis and assessment

The analysis and assessment of the three scenarios BAU, MI, and CR is grounded on Tables 1 and 2extended by various futures (see Table 3). Based on the storylines, the investigated time span ranges from 2006/2009 until 2030.

Major driving factors and sustainability indicators listed in Table 3 give directions towards increasing, stagnating or declining tendencies, their symbols represent the different trends. The clusters I - IV (see Fig. 1) serve as spatial units in Table 3.

Only for the sustainability indicators (4-7), target values exist that are necessary to carry out scenario assessments (see Table 3). The target value of the Regional Government of the MAS for green spaces is to provide each inhabitant with a minimum of 10 m^2 of green spaces (Gobierno Regional Metropolitano de Santiago 2014, p. 77). This target value indicates which clusters currently have a lower surface of green spaces per inhabitant (II and IV), and which have exceeded this target by now (I and III). The target value of settlement areas and population facing a high flood hazard level (6 and 7) is ‘0’, because in the future, no person and no new settlement should face a high flood hazard level. For these indicators, scenario assessments are carried out referring to these target values and elaborated on hue gradation (see legend of Table 3).

4.1.1 *Business As Usual*

Supposedly, in this scenario the past and recent mode of development will continue in the future. Population density will further decrease in the inner clusters of the MAS (*Centre* and *Peri-Centre;* see Table 3), while it will increase strongly in the *Periphery* – but starting from low figures. Built-up areas will increase moderately in the inner clusters and strongly only in the *Periphery*. Accordingly, impervious areas with low to no degree of imperviousness will decrease in most clusters, while areas with intermediate degree of imperviousness will increase in all clusters.

Urban sustainability, assessed by the selected targets, will only be achieved to some extent. Until 2030 the target value of the amount of green spaces will be approached but not attained in the MAS. Within the four clusters the scenario analysis provides different results. In the *Centre* and the *Eastern Peri-Centre* the target values of green spaces and for the amount of green spaces per inhabitant will be attained due to large historical parks and little population increase. In the other two clusters *Peri-Centre* and in the *Periphery* the target values will be approached because some small green spaces and private gardens will be created but it won’t be attained. Based on the assumption of a stable or increasing future development, the indicators proportion of new settlements and infrastructure developments in areas facing a high flood hazard level and the proportion of population living in such areas will not attain the target value of “0” in any cluster of the MAS. There is no chance to approach both indicators towards ‘0’ until 2030.

Table 3: Scenario analysis and assessment

Indicators	**Clusters**	**Status quo & target values**		**Alternative future trends**			**Scenario assessment**		
Major driving factors									
1. Population density [inh./ha]		**2009**	**Target**	**BAU**	**MI**	**CR**	**BAU**	**MI**	**CR**
	MAS	27	no	+	+	+			
	I	76	no	-	+	0			
	II	83	no	--	+	0			
	III	7	no	+	0	++			
	IV	44	no	++	+	+			
2. Built-up area [%]	MAS	27.2	**no**	+	++	+			
	I	96.9	no	0	+	0			
	II	86.9	no	+	+	+			
	III	9.3	no	+	++	+			
	IV	38.7	no	++	++	+			
3. Impervious areas [%]	MAS	43.7	no	++	++	+			
	I	97.7	no	0	+	0			
	II	94.8	no	+	+	+			
	III	24.5	no	+	+	+			
	IV	62.1	no	+	++	+			
3a. Areas with total to high degree of imperviousness [%]	MAS	10.3	no	+	++	0			
	I	76.3	no	0	+	0			
	II	43.6	no	+	++	+			
	III	3.0	no	0	0	0			
	IV	12.8	no	0	+	+			
3b. Areas with intermediate degree of imperviousness [%]	MAS	15.3	no	+	+	0			
	I	15.9	no	+	+	0			
	II	44.1	no	+	+	0			
	III	5.4	no	+	++	+			
	IV	24.4	no	+	++	+			
3c. Areas with low to no degree of imperviousness	MAS	74.4	no	-	-	0			
	I	7.8	no	-	-	0			

[%]	II	12.3	no	-	-	0			
	III	91.6	no	0	-	0			
	IV	62.8	no	-	--	0			
Sustainability indicators									
4. Green spaces [%]		**2006**	**Target**						
	MAS	1.8	2.3	+	0	+			
	I	8.5	8.5	0	0	0			
	II	6.3	7.8	+	0	+			
	III	1.1	1.1	+	+	+			
	IV	1.4	3.7	+	+	++			
5. Green spaces [m²/inh.]	MAS	6.8	10.0	0	0	++			
	I	11.5	11.5	0	0	0			
	II	7.3	10.0	+	-	+			
	III	15.9	15.9	0	0	+			
	IV	3.6	10.0	+	+	++			
6. Proportion of new settlements and infrastructure in areas facing a high flood hazard level [%]	MAS	29.4	**0**	+	++	-			
	I	24.2	0	0	0	-			
	II	26.6	0	0	0	-			
	III	24.5	0	+	+	-			
	IV	29.9	0	+	++	-			
7. Proportion of population living in areas facing a high flood hazard level [%]	MAS	10.6	**0**	+	+	-			
	I	2.4	0	0	0	-			
	II	10.8	0	0	0	-			
	III	17.9	0	+	+	-			
	IV	8.5	0	+	+	-			

Legend of symbols in Table 3:

Symbol	**Meaning**	**Symbol**	**Meaning**
++	Strong increase	-	Decrease
+	Increase	--	Strong decrease
0	Stable		

Legend of hue gradation for scenario assessment in Table 3:

Hue gradation	Meaning
(dark)	Target won't be attained
(medium grey)	Target will be approached but not attained
(light grey)	Target will be attained

4.1.2 *Market Individualism*

In this scenario, population density will increase in almost all clusters due to the neoliberal economy connected with growing socio-spatial differentiation and rural poverty thus leading to migration into the cities (see Table 3). Only in the *Eastern Peri-Centre* population figures remain stable. Built-up and impervious areas increase everywhere, but most in the *Eastern Peri-Centre* and *Periphery*, the latter most in the *Periphery,* because the urban sprawl occurs in these two clusters. The discrimination of various degrees of imperviousness shows a more differentiated picture. The highest degrees of imperviousness will be attained in the *Centre and Peri-Centre*, while intermediate degrees of imperviousness will occur in the *Eastern Peri-Centre* and the *Periphery*. As a further witness of urban growth patterns, areas with low to now degree of imperviousness will decrease and partly nearly disappear.

Target values of the sustainability indicators 4 to 7 won't be attained in the MAS. The amount of green spaces will be stable in the MAS, but according to the assumed future development the target value will be only attained in the *Centre* and *Eastern Peri-Centre* mainly due to further urban sprawl. It has the chance to approach the target value in the *Peri-Centre* and the *Periphery*.

The target value for green spaces per inhabitant will not be attained in the clusters *Centre* and *Peri-Centre*. There will be good conditions to approach the target value in the *Periphery*, and it will be attained in the *Eastern Peri-Centre* through the construction of new urban parks by granting and privatization of public spaces because this cluster will be consolidated as the more affluent part of the MAS.

For the indicators 6 and 7 in the *Centre* and *Peri-Centre* a stable situation is supposed, that means no modification of the existing flood hazard level. But especially in the *Eastern Peri-Centre* and the *Periphery* an increase or even strong increase is assumed so that target values will not be attained.

4.1.3 *Collective Responsibility*

In this scenario, population density will be stable in the inner clusters of the MAS, but even in this scenario it will increase in the *Eastern Peri-Centre* and the *Periphery*. This phenomenon is due to the fact that these areas are most appreciated by the residents. A retributive social and economic policy will lead to social welfare on the one hand and the advancement of medium-sized towns outside the MAS on the other. Correspondingly, built-up areas and impervious areas will increase slightly or remain stable. Areas with total to high degree of imperviousness will increase only in the *Peri-Centre* and the *Periphery*, areas with medium degree of imperviousness in the *Eastern Peri-Centre* and the *Periphery*.

In comparison to the above explained scenarios, this scenario will attain the target value for the amount of green spaces in both, the MAS and the *Centre*, *Eastern Peri-Centre* and the *Periphery* due to an assumed increase or a stable development of green spaces. In the *Peri-Centre* an approach to the target value will be expected.

Based on an increase or a stable development of the green spaces per inhabitant the target value will also be attained in the MAS because of implementing steady public policies for construction and maintenance of green spaces in municipalities with higher population density and greater green spaces deficit.

Due to the decrease of new settlements and infrastructure developments as well as population living in areas facing a high flood hazard level, the target values for indicators 6 and 7 will be approached in both, the MAS and the clusters. This contrasts the other two scenarios where the target value of ‘no new settlement and infrastructure’ respectively ‘no population living in areas facing a high flood hazard level’ will definitely not be attained.

4.2 Comparison of the scenario assessments

When comparing the results of the three scenarios we could deduce the following statements: Due to their different hypotheses and causal contexts, all scenarios show different trends not only for the major driving factors, but also for the sustainability indicators. Only for the latter, special benchmarks can be found in literature and are recommended as target values. The Regional Policy for Green Spaces (Gobierno Regional Metropolitano de Santiago 2014, p.77) establishes a target value of 10 m^2 per inhabitant and 100 ha of new green spaces per year. Hence, the following comparison of the scenarios comprises only the assessment part (see Table 3).

Clearly more targets (nine) for the four sustainability indicators will be obtained in the scenario CR compared to the other scenarios, and considerably more targets will be approached (eleven). The scenario MI produces the worst results in terms of the selected sustainability indicators (thirteen targets won’t be attained, and only four targets will be attained, and three targets will be approached but not attained) which witness the opposing trend of neoliberal economy. The scenario BAU proceeds in a linear development and shows medium results compared to the others (four targets will be attained, five will be approached and ten will not be attained). The results reveal a larger distance between MI and CR than between BAU and MI.

Additionally, in both, the MAS in total and in each of the four clusters, the development of the indicators shows differences. For green spaces, the scenarios predict some positive trends especially in the *Centre*, the *Eastern Peri-Centre*, and the *Periphery* towards a more sustainable development and negative trends in the *Peri-Centre*. Flood risk related indicators depict a negative and unsustainable trend.

The scenario analyses clarify the different power of the selected sustainability indicators. The scenario BAU tentatively is biased towards economic gain and less in favour of environmental protection. It can contribute to a more sustainable development in some cases but in the field of flood-risk management a substantial input is missing. In the scenario MI the situation is more severe concerning sustainability than in the last named. Land market rules over environmental awareness and determines the intensity and direction of urban expansion. In most of the cases the target values will not be attained so that this scenario contrasts most to a sustainable development. The scenario CR raises more the environmental awareness and has the potential to increase the sustainability in the MAS by approaching or attaining target values and by integrating land-use and flood-risk aspects.

In a cross-scenario-analysis the following priorities become obvious regarding the contribution to sustainable urban development: numbers and rates of green spaces per capita should be increased especially in the *Peri-Centre*, and with less priority in the *Periphery*. The following issues should receive priority in future urban development decisions concerning areas facing a high flood hazard level: (1) the prohibition of new settlements and infrastructure developments; (2) the decrease of exposed population.

4.3 A point of discussion: using explorative scenarios in urban policies for land-use management

Being rooted in an interdisciplinary and transdisciplinary environment we made two essential work steps feasible: exploiting the available quantitative data for the purpose of a status quo analysis (Banzhaf et al. 2013), and discussing the three explorative scenarios with relevant stakeholders. As a transdisciplinary community, we deemed to develop different scenarios being set against short-sighted policies and preferential treatment of single or isolated planning processes (comparable to van Notten et al. 2003). Our workshops revealed to be vitally important platforms to bring decision makers from different sectors and levels together who do neither exchange their work experience nor their priorities related to their specific fields in daily work process. In this context we have found gains and challenges. Interchanging ideas with individuals brought forward a helpful input to adjust or approve our scenarios and to get the statements more pointed. Nonetheless, these meetings were not understood as a correction of the scenarios to satisfy presently valid regulatory requirements. The workshops also made barriers in the different approaches between scientists and practitioners visible: long-term interdisciplinary thinking stood against short-term sectoral methods. As a synopsis of our experience with the workshops we can state appraisals of explorative scenarios. Restrictively, the decision makers did not experience them as a whole but rather their single or sectoral issues and the illumination of different angles. Comparing our study to the research done by Höjer et al. (2011), the different prerequisites become obvious. Their futures studies were led by the researchers but not independent from the authorities which made it obligatory for the research group to adjust their research process to the ambitions of the steering group for policy strategies. In our case, no adjustments to the authorities’ work and their ambitions were considered to be necessary. Both studies have in common that despite some difficulties in the transdisciplinary work, experts within the authorities began to recognise the opportunities provided by futures studies.

5. Conclusions

As described by Börjeson et al. (2006) explorative scenarios are a useful instrument in times of rapid and irregular changes. A further criterion for the use of such scenarios is to convey the consequences of alternative developments for practitioners who have a disciplinary understanding about how the present system runs. Therefore the benefit of explorative scenarios is in elaborating strategic issues for an anticipatory planning (see also Barbanente et al. 2002). Furthermore, the value of scenarios as an instrument for land-use management becomes most evident when census data are missing. In the case of Chile, the sequence of census surveys is interrupted by methodological constraints and the data recording delayed by many years. Indicator-based scenario analyses portray the various options of urban development in the MAS related to land-use and flood-risk management. The study has shown that scenario analysis is a useful tool for urban planning. In particular, it allows us to understand the interactions between different urban policies that are applied by several institutions with no coordination between them: land-use planning and housing policies, green spaces policies, and flood-risk management.

Focusing on strategic planning for a sustainable urban development in the MAS the existing land-use management must be interlinked with the environmental planning (e.g. green spaces, flood risks). Only then urban life is ensured with focus on its amenities including good and secure environmental conditions for an increasing population.

Land consumption in the periphery should be decreased by making the inner urban areas more attractive for housing to various social groups and for commercial uses. Supporting re-urbanisation coincides with general demographic trends as for example the decrease of household sizes and the ageing of population, an occurrence that also takes place in the MAS.

Beyond our presented findings, conclusions regarding the applied methodology can be drawn. The scenarios are based on a detailed monitoring and analysis of past and present driving factors as well as on land-use and quality of life related developments and trends (c.f. Weiland et al. 2011; Banzhaf et al. 2014; De la Barrera et al. 2016). Therefore development options close to reality depicted in the storylines set the frame for the future, and the scenarios can illustrate differentiated and quite realistic options (Kok et al. 2011). Taking advantage of workshops as an instrument to develop scenarios by experts and scientists shows that such explorative scenarios are appreciated as informative and helpful tools for decision making in urban areas.

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