Addressing Future Uncertainties in Coastal Areas

An innovative process to support decision-making for climate change adaptation based on participatory foresight, artificial intelligence and prospective spatial risk assessment

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DISCLAIMER

The work hereby presented has been developed with the direct collaboration of government bodies, agencies, organizations and local communities. Nonetheless, the results presented in this thesis do not represent the official view of any of them and must be considered within the scope, aims and limitations of the present research.

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ABSTRACT

To date 44% of the world's population lives within 150 kilometers of the coast. Given the socio-economic growth and urban development trends, it is a widespread assumption that climate change will have severe impacts on coastal areas, being sea-level rise a threat of special concern due to the expected magnitude of its impacts.

Despite the urgency of moving towards climate change adaptation has been widely recognized in the recent years, significant barriers exist. One major handicap is the necessity to handle the many uncertainties surrounding future conditions and include them into the planning process. Another major obstacle is that it can be challenging for society to care about events that may take place decades from now.

Taking into account these challenges, this thesis aims to contribute to the field of climate change adaptation on coastal areas by providing transferable, participatory and foresight-based tools, to address future uncertainties on coastal areas as well as help to communicate the potential impacts of climate change and generate awareness among communities. A threefold process is proposed to : i) develop a replicable methodology to create explorative, participative, locally-based future scenarios; ii) translate a selected scenario into geospatial data through the use of Artificial Intelligence models; and iii) spatially assess the potential impacts of future sea-level rise combined with an extreme event on a future scenario.

The methods have been tested on a pilot site, involving over 60 stakeholders, including local communities, governments, private and public institutions and informal organizations. Results show the threefold process proposed in this thesis could be a valuable tool to assist decision-making on the context of climate change adaptation on coastal areas at the local scale. In particular, it could help to: enhance stakeholders’ engagement and increase awareness on present and future challenges; assess and visualize future impacts of climate change integrating physical and socio-economic systems; acting as a triggering point for climate change adaptation initiatives; and contributing to co-generate knowledge, promoting a multi-directional dialogue between the research community and society.

Further research is encouraged to explore the transferability of the process to other sites as well as to develop further theoretical and practical applications of the methodological approaches hereby presented.

RESUMEN

Hoy en día se estima que el 44% de la población mundial vive en la costa. Dadas las tendencias de crecimiento socio-económico y demográfico, se asume que el cambio climático tendrá efectos severos en las zonas costeras, siendo la subida del nivel del mar un riesgo de especial relevancia debido a la esperada magnitud de sus impactos.

A pesar de que la urgencia de avanzar hacia la adaptación al cambio climático ha sido ampliamente reconocida en los últimos años, aún existen importantes barreras para su puesta en práctica. Un obstáculo es la necesidad de incluir todas las incertidumbres que rodean las condiciones futuras e integrarlas en los procesos de planificación. Otro obstáculo es que a la sociedad le puede suponer un desafío preocuparse de eventos que pueden ocurrir dentro de varias décadas.

Teniendo en cuenta estos retos, esta tesis pretende contribuir al campo de la adaptación al cambio climático en zonas costeras, proponiendo herramientas transferibles, basadas en técnicas prospectivas y procesos participativos, para analizar las incertidumbres asociadas al futuro así como comunicar los impactos potenciales del cambio climático y generar toma de conciencia entre las comunidades afectadas. Se propone un proceso de tres fases para: i) desarrollar una metodología replicable para crear escenarios exploratorios, participativos y basados a escala local; ii) traducir un escenario seleccionado en datos geoespaciales a través del uso de modelos de inteligencia artificial; y iii) analizar espacialmente los potenciales impactos de una futura subida del nivel del mar combinada con un evento extremo en un escenario futuro.

Todos los métodos presentados en esta tesis han sido probados en un sitio de estudio, involucrando a más de 60 agentes sociales, incluyendo comunidades locales, gobiernos, instituciones público privadas y organizaciones informales. Los resultados demuestran que el triple proceso aquí propuesto puede ser una herramienta valiosa para asistir a la toma de decisiones en el contexto de adaptación al cambio climático en zonas costeras a escala local. En concreto, esta herramienta podría ayudar a: incrementar la involucración de los agentes sociales y su toma de conciencia sobre desafíos presentes y futuros; analizar y visualizar los impactos potenciales del cambio climático integrando sistemas físicos y socio-económicos; actuando como un punto de resorte para activar iniciativas de adaptación al cambio climático; y contribuyendo a la co-generación de conocimiento, promoviendo un diálogo bidireccional entre la comunidad científica y la sociedad.

Se necesitarán futuras investigaciones para explorar la transferibilidad del proceso a otras zonas así como para desarrollar aplicaciones, teóricas y prácticas, de las propuestas metodológicas aquí presentadas.

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CHAPTER 1: *Introduction*

1.1 Context and motivation

Coastal areas are among the most productive ecosystems in the world and constitute a prime space for human development. To date 44% of the world's population live within 150 kilometers of the coast (UN, 2010) and this percentage is expected to increase as population growth and urbanization are taking place on coastal areas at unprecedented scales (Blackburn and Marques, 2013). Moreover, 6 out of the world’s 10 mega-cities are located in coastal zones (von Glasgow et al, 2013) and their population is forecasted to grow to over 300 million people by 2025 (UN, 2010) concentrating a vast portion of the world’s economic activities, GDP and assets.

Given economic growth and urban development trends, climate change is expected to severely affect coastal communities (IPCC, 2007; IPCC, 2013), with sea-level rise being a major threat due to the expected magnitude of its impact to both human and natural systems (Nicholls and Cazenave, 2010; Cazenave and Le Cozannet, 2013). Climate change, and in particular, sea-level rise, will pose specific challenges to low-lying coastal areas (McGranahan et al., 2007; CIESIN, 2013).

In this context, it is critical to advance towards climate change adaptation, that is, “the adjustment in natural and human systems in response to actual or expected climate conditions and their effects in order to moderate harm or exploit beneficial opportunities” (IPCC, 2007). This need has been widely recognised in recent years by the scientific community (e.g. Easterling et al., 2004; Adger et al., 2009; Wilson and Piper, 2010; Aerts et al., 2011), international organizations (e.g. FAO, 2008; UNISDR and UNDP, 2012; UNEP, 2014), as well as governmental bodies all over the globe (e.g. EC, 2013; UKG, 2013; EPA, 2014).

In response to this demand, abundant research has been published on climate change adaptation in coastal areas, and in particular to the potential impacts of sea-level rise at global (e.g. Nicholls et al., 2011), regional (e.g. Tebaldi et al., 2012) and local scales (e.g. Lichter and Felsenstein, 2012).

Despite scientific and political efforts, significant barriers to climate change adaptation exist in financial, cultural and policy realms (Adger et al., 2009). One major disadvantage in climate change adaptation is the necessity to handle the many uncertainties surrounding future conditions and include them into the planning process (Aerts et al., 2011). Another major obstacle for gaining support from citizens, politicians and organizations for climate change adaptation is that it can be challenging for society to care about events that may take place decades from now, let alone fully understand their potential impact (Orlove, 2010). Therefore, in order to move towards climate change adaptation, it is necessary to support decision-making in coastal areas with tools and processes that deal effectively with these uncertainties and that help to communicate the potential impact of climate change to generate awareness among coastal communities.

Given the aforementioned challenges, Integrated Coastal Zone Management (Clark, 1992; Cicin-Sain 1998), offers an ideal approach to tackle climate change adaptation challenges in coastal areas (IPCC, 1994). Integrated Coastal Zone Management (ICZM) has been largely recognized internationally during the last few decades (IPCC, 1994; UNEP, 1995; FAO, 1998; UNEP, 2008). It takes into account both the interdependence and the disparity of natural systems and human activities; it provides a long-term perspective which takes into account the precautionary principle and the needs of present and future generations; and involves all parties concerned in the coastal management process (EC, 1999). ICZM also includes the enforcement of coastal governance, allowing adequate and timely participation in a transparent decision-making process by the local population and stakeholders in civil society concerned with coastal zones (UNEP, 1999). Moreover, working with an ICZM approach, a thorough knowledge of the natural and biophysical coastal environment must be combined with the knowledge of socio-economic, normative and cultural contexts. This is multi-disciplinary approach is fundamental when dealing with climate change adaptation.

While ICZM offers a solid conceptual basis, in order to effectively assist decision-making, it is necessary to look for specific tools and methods to support communities. As a result, foresight methods and, in particular, scenarios, are tools that have thrived in recent years to support decision making in contexts of high uncertainty, such as those related to climate change. Scenarios are often able to take into account the complexity of change, express different versions of the future, create options where the future is unclear, and facilitate the development of plans which improve the ability to respond to new challenges (Mietzner and Reger, 2005). Moreover, when based on integrative methods, scenarios can combine socio-economic trends with physical factors such as climatic forces (Moss et al., 2010), presenting a high potential for coastal planning in the context of climate change adaptation, facilitating the integration of future coastal risks, such as sea-level rise, with future socio-economic patterns.

Despite this, few studies have attempted to create integrative scenarios combining projections of changes in climate hazards and socio-economic trends (Moss et al., 2010). When scenarios of this nature have been made, some important limitations have arisen, such as the difficulty in combining qualitative and quantitative data in order to obtain a tangible final product, which constitutes a major obstacle for the use of scenarios in the decision-making process.

Geospatial data and visual information represent an opportunity for enhancing scenarios transferability. In this sense, Artificial Intelligence approaches open new and exciting possibilities to perform spatial simulations. Cellular Automata, Agent-Based Modelling, Artificial Neural Networks or Genetic Algorithms are powerful modelling approaches to understand, analyze and simulate urban and land dynamics (Silva and Wu, 2010). In constant development, some of these models show a strong potential to simulate future conditions on highly complex and rapidly evolving environments, as is the case in coastal zones.

With regard to future or prospective modelling, another relevant aspect for climate change adaptation is the inclusion of *potential impacts* -i.e. sea-level rise- on *future conditions*. Although much debate is still ongoing among the scientific ground on the extent of sea-level rise effects on coastal systems (Nicholls and Cazenave, 2010), potential impacts include loss and damage to human life, properties, infrastructure, tourism, transport, agriculture, aquaculture and natural and cultural resources among others (Mc Lean et al., 2001). Furthermore, sea-level rise might not only pose hazards to coastal areas directly, e.g. wetlands inundation and coastal erosion, but it also might magnify the harm potential of other coastal hazards, such extreme High Water Level (HWL) events.

The potential effects of sea-level rise, along with other coastal hazards, are being included in new and ambitious legislative and planning schemes all over the world. Relevant examples include the EU Directive for Flood Risk Management (EC, 2007), the New South Wales Coastal Planning Guideline for sea-level rise (SNSW-DP, 2010), the UK national flood and coastal erosion strategy (DEFRA and EA, 2011), the Community Risk and Resiliency Act to include future impacts of sea-level rise, storm surges and floods into New York State planning (NYS, 2014) or the Dutch Delta Programme 2015 to prepare the Netherlands to adapt to rising sea-levels (NG, 2014).

Together with assessing the physical impacts of future sea-level rise and extreme events, the assessment of future human systems' conditions, is recognised to be critical for climate change adaptation (IPCC, 2012). Although concepts such as 'future risk', 'future exposure' or 'future vulnerability', are starting to receive much attention and be thoughtfully discussed by the scientific community (Preston et al., 2011), the translation of such approaches into practice is scarce. Recent works (Neunmann et al, 2015) point out the potential to include dynamic spatial models of land use change to forecast future exposure to sea-level rise and explicitly assess relevant processes for coastal areas, such as urban growth. Nevertheless, new research is necessary to test the applicability of such approaches to support decision-making in the context of climate change adaptation, particularly at the local level.

Taking into account all the aforementioned challenges in climate change adaptation, this thesis is motivated by the hypothesis that, ICZM principles, foresight approaches, artificial intelligence models and spatial risk assessment methodologies could be combined in a coherent and reproducible approach; creating a process that could support decision-making and generate awareness for climate change adaptation at the local scale in coastal areas.

1.2 Objectives, research questions and scope

The ultimate *goal* of this thesis is to develop a process to support decision-making for climate change adaptation in coastal areas at the local scale, grounded on ICZM principles and based on participatory foresight methods, artificial intelligence models and prospective spatial risk assessment.

With this goal in mind, this thesis has been designed to address three major *objectives*:

i) To develop a replicable methodology to create explorative, participative, locally-based future scenarios.

ii) To translate a selected scenario into geospatial data, so that it could be potentially used in decision-making and planning processes.

iii) To assess the *potential* impact of future sea-level rise combined with an extreme event on the selected future scenario.

The *research questions* addressed in this thesis include:

- *How to incorporate ICZM principles into scenarios-making;*
- *How to spatially simulate the future conditions of a specific scenario ;*
- *How to visualize and assess future risk to human populations under a specific scenario;*

To answer these questions this thesis tests a variety of methods in a municipality in the South-Western Spain, being the spatial scale of the analysis local, an appropriate scale according to ICZM principles (EC, 2002). The analysis has been tested on a temporal scale of 100 years. The lower limit of the temporal scale is 1950 to gather sufficient historical data. Future horizon for all the scenarios is 2050, as this mid-term scale was considered more transferable for local planning purposes than longer-term scenarios (Wilson and Pipper, 2010). In conceptual and methodological terms, this thesis is an interdisciplinary work that integrate methods from social and natural sciences, such as social network analysis, causal analysis, spatial analysis, statistical and probabilistic analysis or cellular automata modelling, spatial fuzzy analysis, among others. The coastal hazard taken into account in this thesis has been coastal inundation due to sea-level rise and a High Water Level produced by a 1/500 years tide. The selection of this composite hazard responds to the current demands on the new planning schemes, such as the above mentioned EC Floods Directive (EC, 2007) on combining sea-level rise with other extreme events such as extreme tides.

1.3 Research design and thesis structure

The thesis has been developed in 3 phases according to the objectives as previously outlined. The first phase, *Participatory Foresight*, consisted in the elaboration of future scenarios for the study site robustly based on participatory approaches; the second phase, *AI-based LUCC Modelling*, was based on the translation of a selected participatory future scenario into geospatial data through the use of spatial Land Use and Cover Change (LUCC) models based on Artificial Intelligence (AI) techniques; the third phase, *Prospective Spatial Risk Assessment*, assessed the risk for human population to coastal inundation caused by sea-level rise and a High Water Level given by a 1/500 tide in the year 2050 under a selected scenario, using a combined probabilistic and deterministic approach for the hazard analyzed.

The sequential procedure selected allowed each phase of the research to be built on the outputs on the previous one; thus the three phases of the present work are interrelated and can be considered co-dependent, as presented in Figure 1.

A literature review of the state of the art in each area was performed, analyzing concepts, theories, methodological approaches and controversial issues or gaps, of interest for the topic and objectives of this thesis. Based on the literature review a conceptual or methodological approach was chosen for each phase taking into account the principles adopted by this research. Finally, the selected methods were applied to the study site and the results were gathered, and used as a basis for the following phase.

The work developed in the three phases was distributed across the seven chapters of this thesis, which is structured as follows. *Chapter 1* presents an introduction to the motivation, context, research objectives and design. *Chapter 2* presents a literature review of the state of the art on scenarios-making, LUCC models and artificial intelligence, and risk assessment, exploring the main concepts, trends and gaps in each field. *Chapter 3* describes the study site selected for this thesis, including the physical and socio-economic settings as more importantly, the characteristics that makes the site an ideal laboratory to test the methods developed in this thesis. *Chapter 4* presents the methodology designed for each of the phases of this thesis, including some innovative methods expressly developed for this work, such as the Participatory Future Scenarios, the modification of an Cellular Automata model to adapt it to the scope of this work, or the assembling of different methods to assess the selected hazards and spatialize risk in future conditions. *Chapter 5* show the results of the participatory future scenarios developed for the study site, a particular scenario, as selected by stakeholders, translated in geospatial information and finally, the risk to human populations in the selected future scenario. *Chapter 6* contains the discussion regarding the results obtained in this thesis, differentiating a global discussion to assess the outputs of this work as a whole, and also three separate discussions to assess the methods developed as well as the results obtained in each phase. Finally, *Chapter 7,* devoted to the conclusions, revisits the thesis goal, objectives and research questions and presents the implications of the results of this thesis as well as a final conclusion. It also introduces future lines of research, presenting some preliminary work already initiated in the context of this thesis. Finally, an Appendix is also included with additional information and complementary data to the work presented in the main body of the thesis.

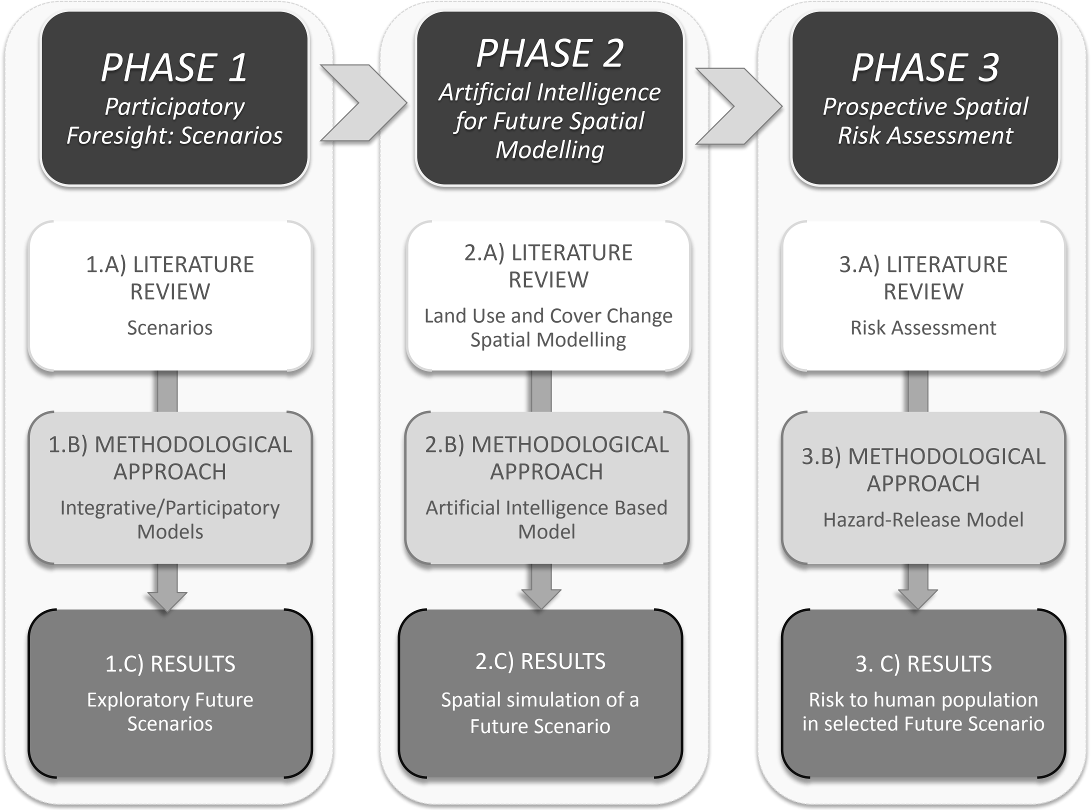

Figure 1. **The three phases of this thesis**. Each phase included a literature review, a methodological development and the results of applying selected methods on the study site. The three phases are interconnected and were developed in a consecutive order in which Phase 2 uses results of Phase 1, and Phase 3 is fed by Phase 2 (Self-elaboration).

CHAPTER 2: *State of the Art*

Introduction to the State of the Art

This chapter focuses on performing a critical and selective review of the state-of-the-art in three fields of research: i) Scenarios; ii) Land Use and Cover Change Models and iii) Risk Assessment. For each field of research, first an introduction to the main concepts, terms, current theories and controversies are examined to extract the most valuable information for this thesis. In addition, the main conceptual and methodological approaches are reviewed and compared in order to choose the most compelling methods to be use in this thesis (Chapter 4) ; taking into account their coherence and adequacy with the scope and goals of the research, already presented in the Introduction. At the end of this chapter, a conceptual approach linking the three fields examined is presented. The approach provides the conceptual basis to construct the methodology.

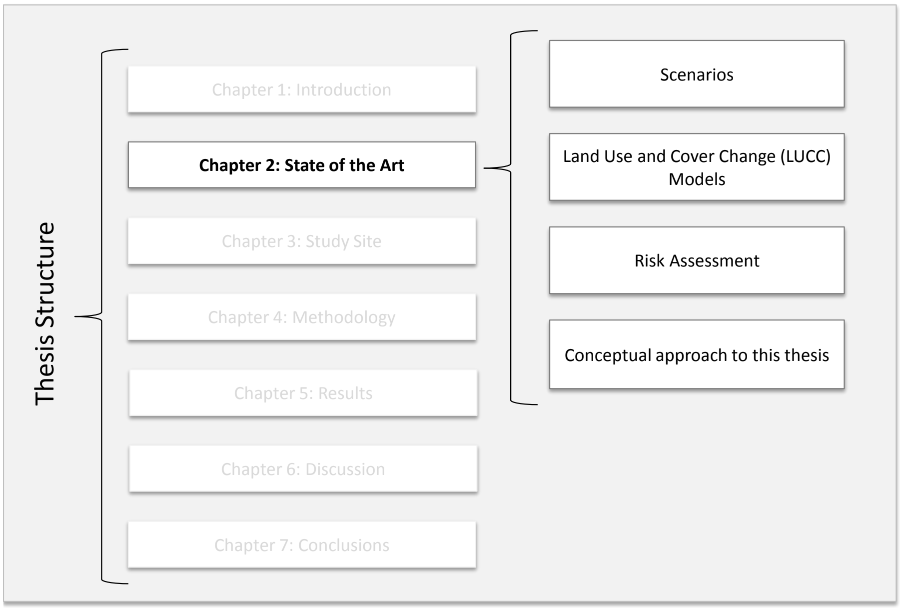

Figure 2. **Chapter 2 'State of the Art' presentation**. The State of the Art chapter is composed by the following four sections: scenarios, land use models, risk assessment and the conceptual approach to this thesis (Self-elaboration).

2.1 Scenarios

The use of scenarios as a formal foresight method for planning and analysis, dates back to the late 1950s and early 1960s, when some pioneering research centers such as Stanford Research Institute, the Hudson Institute and the RAND Corporation promoted a systemic foresight thinking approach for military, social and public policy forecasting in the U.S.A. during the Cold War (Thomas,1994; Chemark, 2001). Almost simultaneously, an European school of foresight thinking was developed in France by G. Berger, under the name of "La Prospective", using scenarios to guide the formulation of public policies. Scenarios were subsequently adopted by the private sector, with major corporations as the Royal Dutch Shell Company adopting scenario planning as a permanent strategy in the 1970s (Jefferson and Voudons, 2011). During that decade, scenarios were used for the first the time in the environmental and sustainability fields, with the ground-breaking report from the Club of Rome's “The Limits to Growth”, which analyzed population and economic growth consequences for the Earth ecological capacity (Meadows, 1972). Although a decline in interest in the use of scenarios during the 1980s, the attention towards this tool revived from 1990’s onwards, which according to Godet (2001) can be attributed to an increasing perception of decision-makers of the uncertainties related to the environment and the new developments in the field of strategic management. Since the 2000's scenarios have become a widespread tool in the environmental field and have been used to analize all kind of phenomena at different scales, from sustainability studies at the global scale to specific environmental problems at the regional and local levels. The best-known examples of scenario studies are the Special Report on Emissions Scenarios (Nakicenovic et al., 2000), the Global Environment Outlooks (UNEP, 2002), and the Millenium Ecosystem Assessment Scenarios (WRI, 2005), best known as 'SRES', 'GEO' and 'MEA' respectively. These initiatives have had a major impact in the international community and, given their credibility, are frequently used as baseline scenarios for further foresight assessments.

Despite the widespread use of scenarios, the definition of what is a scenario remains to be a challenge among practitioners[1]. Though a general consensus exist in stating that scenarios are not forecasts, projections or predictions (Porter, 1985; Alcamo et al., 1995; Schwartz, 1996; van der Heijden, 1996; Jarke et al., 1998; Schneider et al., 2007). In contrast to these concepts, scenarios are considered as a "tool for envisioning future pathways" (WRI, 2005) and to illustrate possible developments based on logic and coherence of what could happen in a specific field of study (Tress and Tress, 2003). Therefore it is clear the difference between the holistic "scenarios" concept as understood in the field of foresight, and the term "scenario" as used in the field of modelling, where it does refer to a fixed, variable dependant projection.

In this thesis, scenarios are defined as "plausible description of how the future might develop, based on a coherent and internally consistent set of assumptions about the key relationships and driving forces" (Nakicenovic et al., 2000). According to this definition and as pointed out by Heugens and Oosterhout (2001), there are five major characteristics that should be fulfilled by any scenario: i) *No probabilities are assigned.* Scenarios depart from the premise that complex future phenomena cannot be anticipated probabilistically because there is a point beyond which the accuracy of predictions cannot be guaranteed (van der Heijden, 1994; 1996). ii) *Multiplicity of storylines*. Scenarios do not rely on a single storyline; instead, by exploring certain crucial assumptions a number of different narratives are developed to investigate the same questions about future conditions (Heugens and Oosterhout, 2001). iii) *Plausibility*. Scenarios can contemplate normal as well as alternative situations, but they never should go beyond the realm of possibility (Beck, 1982); they must be plausible "connecting past, present, and future in a rational

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[1] Mietzner and Reger (2005) provided an extensive review and discussion about different scenarios definitions.

manner" (van der Heijden, 1996). iv) *Narrativity.* Scenarios should depict how different variables may affect one another in an aggregate and understandable way (Schwartz, 1996), in this sense, a set of forecasts of individual variables independently assessed is not a scenario (Linneman and Klein, 1983). v) *Internal consistency.* Different events within scenarios must be related by causal and coherent arguments; otherwise, as van der Heijden (1996) declared scenarios tend to become internally inconsistent and ambiguous.

Under this common umbrella of scenarios, a wide variety of approaches and applications have emerged over the last decades, which can be differentiated according to their nature and features. Table 1 shows a scenarios classification based on the approach, techniques, temporal and spatial scales and the nature of the outcome. There are two approaches to develop scenarios: the explorative and the normative approach. If the goal of the study is to survey multiple futures -under the assumption that the future is inherently uncertain- the proper approach would be the exploratory. This approach aims to explore the wealth of

Classification criteria	**Types**	**Description**
Approach	Exploratory scenarios	Take the present as their starting point and envision alternative paths into the future
	Normative scenarios	Begin with the identification of a particular future situation and then trace its origins and lines of development back to the present
Techniques	Qualitative scenarios	They are not quantifiable, they normally are based on stories or narratives
	Quantitative scenarios	They use numerical, measurable data, they usually rely on models
	Integrative Scenarios	They combine qualitative and quantitative techniques
Temporal Scale	Short-term scenarios	Short-term scale is usually between 3 to 10 years
	Mid-term scenarios	10-50 years
	Long-term scenarios	Over 50 years
Spatial Scale	Local scenarios	Municipality to supra-municipality areas
	Regional scenarios	National to sub-national or regional areas
	Global scenarios	Worldwide area

Table 1. Scenarios classification. Different existing approaches, techniques and scales in scenarios-making are presented. Based on, and modified from, O'Riordan *et al.* (1993), EEA and ICIS (2000) (Self-elaboration)

thinkable options for the future, including radical outlooks, by performing a 'what-if' analysis (van't Klooster et al., 2012). The SRES (Nakicenovic et al., 2000) or the GEO scenarios (UNEP, 2002) are recognized examples of exploratory scenarios. In contrast, when the scenario exercise is made to explore the ways to achieve or avoid specific situations or planning goals, then the normative approach would be the most adequate. This approach is usually based on *back-casting*, meaning that after defining desirable-or undesirables- futures, the next step is to 'move backward to the present situation' (van't Klooster et al., 2012). The final goal of this approach is to develop strategies, measures and policies to achieve -or avoid- the predefined futures.

Regarding the techniques, scenarios can be developed i) using qualitative techniques, ii) quantitative techniques or iii) a combination of both methods (EEA, 2007), being the integrative approach the most rare and yet the most promising for scenarios applications (Moss et al., 2010). Scenarios can be developed for short (e.g. 3 to 10 years), mid (e.g. 10 to 50 years) and long term horizons (e.g. over 50 years), as well as for local, regional or global scales. Finally, according to the nature of the scenarios outcomes, scenarios can be considered Business as Usual (BAU) or alternative, depending if they assume a continuation of present trends or explore different trajectories.

Taking into account the scope and goals of this thesis, explorative scenarios based on integrative techniques and applied to the local scale for a mid-term temporal scale would present the highest affinity for the present research.

In terms of applications, scenarios are currently used in numerous fields of research (e.g. environment, transportation, energy, water, agriculture and economics) and at all geographical scales (i.e. from global to local studies). As an indicator of this bloom in scenario literature, the European Environmental Agency made an extensive scenarios' review and listed 263 scenarios studies available for the pan-European scale between the years 2006 and 2008 (EEA, 2011).

The massive increase in scenarios studies over the last years, many of them lead by international organisations, can be explained by the recognised uncertainty of the economic and geopolitical context together with the climate change and environmental uncertainties. Table A1 (Appendix) provides some examples of the application of scenarios in the European Union during recent years. In this selection exploratory scenarios stand over normative scenarios because the aim of most studies was to explore the *what-if* alternatives rather than considering closed and predefined future options.

Contrasting with the widespread use of scenarios, to date there has been little agreement regarding the methodological aspects of this tool. Although there have been some attempts to establish a general scenario-making method (De Jouvenel and Hugues, 2000; van der Heijden, 2005; Abildtrup et al., 2006; Mahmoud et al., 2009) the issue remains on debate. The lack of a general framework creates a myriad of methodological approaches -some of them compared in Bishop et al. (2007) and EEA (2007), which vary according to the aims, needs and limitations of each research.

Albeit their differences, most scenarios studies have three important elements in common: a) driving forces identification, b) scenarios logics definition and c) scenarios depiction. i*) Driving forces*, also known as keystone processes (Marcucci, 2000), drivers (Wood and Handley, 2001) or causative factors (Geist et al., 2006), are ‘any natural or human-induced factor that directly or indirectly causes a change in an ecosystem’ (WRI, 2005).

In scenario analysis the identification of driving forces is made in the initial phase of the study because in order to estimate future changes it is first necessary to understand the causes of past changes. ii) The *scenarios logics definition*, refers to the conceptual framework to structure the alternative scenarios. It provides order to a range of potentially divergent issues and in doing so allows comparison across different narratives (Metzger et al., 2010). It also seeks to establish internal consistency between the various assumptions that underpin the different scenarios. The standard tool to develop scenarios is the two-dimensional scenario matrix (Schwartz, 1991). In this method the two most important and uncertain factors generate the two axis of a four-quadrant matrix that reflects four alternative scenarios. *Scenarios depiction.* The final scenarios are commonly described using narrative storylines often depicted as narratives complemented with a varied range of techniques such as: illustrations (Enfors *et al.*, 2008), causal loop diagrams (Loibl and Walz, 2010), pictures and drawings (Kok *et al.*, 2006) or collages (Kok *et al.*, 2007) among others. These techniques aim to facilitate the comprehension of the storylines.

The review of scenarios-making literature revealed there are three major methodological challenges that need to be addressed to increase scenarios reliability:

i) Scenarios studies tend to be focused either on participatory processes or on quantitative analysis and modelling, although they can integrate both as shown in Table 1. When the scenarios studies integrate qualitative and quantitative techniques, it is usually through the involvement of experts rather than real and open participatory processes. For example the EU PRELUDE Project (EEA, 2007) combines modelling processes with experts consultation as a participatory way for generating scenarios. At the global scale it must be difficult involve stakeholders but at the regional and particularly, at the local scale, efforts could be made to achieve a real integration of participation and modelling.

ii) *Lack of clarity in the methodological process.* The wide diversity of methods applied to scenarios-making makes quite difficult to compare and assess the different studies in a systematic way. Furthermore, the methodologies used to develop scenarios are often not-explicitly explained. This situation was named as the ‘methodological chaos’ of scenarios by Bradfield et al. (2005). Mahmoud *et al.* (2009) pointed out that scientists have been discouraged from using scenarios for collaborative decision making due to a lack of guidance on how to formally use them. The obscurity surrounding the methodology of some scenarios exercises decreases their reliability and credibility among both the general public and the experts. As Alcamo (2008) underlined 'all types of scenarios can reach a higher level of scientific acceptance if they fulfil two important conditions of the scientific method: transparency and reproducibility'.

iii) *Repetitiveness*. Many scenarios generated by scenarios studies are quite similar to others and their storylines and key uncertainties are quite alike, which undermine their credibility. As argued by van't Klooster *et al.* (2012) this is possibly explained by the common practice of *recycling of scenarios*, that is, the use previous scenarios a starting point for new scenarios studies, generally global scenarios downscaled to regional scales. A review of projects based on scenarios applied within the European Union confirmed many of the studies were based on pre-existent scenarios (Table A-1, Appendix). If the aim of the exploratory scenarios is to investigate all the possible futures within a geographical area and/or field, so the use of predefined scenarios is itself a contradiction and a limitation to the power of the scenario exercise.

Summing up, to date, there is not a clear, step-by-step methodology to develop exploratory scenarios that integrate environmental and socio-economic processes, qualitative and quantitative data, and that are originally developed for the local scale.

2.2 Land Use and Cover Change Models

Land Use and Cover Change (LUCC) models are used for future spatial modelling. These models emerged to assist the analysis of the causes and consequences of land use changes, in order to better understand the functioning of the land use system and to support land use planning and policy (Verburg et al., 2004). In this thesis, the term *LUCC model* is defined as "a representation of the interactions between different non-linear systems -both biophysical and anthropic- that influence the dynamics of land use and land cover change, which depend on the natural systems, but also on social, economic, political and technological changes that occur at different scales, and constrain the evolution of a specific territory' (Lavalle et al., 2011).

Originated during the 1950's in the field of urban and transport modelling in the United States of America, LUCC models have evolved from traditional models such as linear and mathematical models, to complex dynamic models. Abbott (1989) and Cunge (1989) introduced the notion of "generations" to explain the progression of LUCC models, and Silva and Silva and Wu (2012) applied this notion to explain the evolution of LUCC models over the last decades. According to Chau and Chen (2001) and Silva and Wu (2012), each generation model presents some innovations and addresses specific problems at a given moment: the *first generation* developed large-scale urban models based on static and deterministic principles; the *second generation* continued to be based on deterministic principles and was characterised for using a sector-by-sector approach; the *third generation* of models were oriented towards seeking solutions for specific problems and required highly specialise users; the *fourth generation* become much more useful to a wider range of end users and relied on GIS environments; and finally, the current generation of land use models , the *fifth generation*, is acknowledged to integrate computer dynamics with 'artificial intelligence'(AI) technology, such as artificial life, intelligent stochastic simulation models, evolutionary computing, spatial DNA, and knowledge-based intelligent systems (Wu and Silva, 2010). The analysis of the five generations shows a progressive evolution from static, deterministic approaches (e.g. linear mathematical modelling) to more dynamic and non-linear approaches (e.g. supported on GIS and artificial intelligence) that emulate more accurately the real and complex behaviour of land use and cover changes.

There has also been a switch in the field of application of LUCC models, from being mainly applied to the urban and transport planning fields, to be expanded to the environmental field from the 1990's onwards, due to the recognition that LUCC are behind many environmental problems at the global scale (Lambin et al., 2001). Although during the 1990s, most environmental LUCC models were focused on deforestation (Kaimowitz and Angelsen, 1998; Lambin, 1997) more recent efforts also address other land use conversions such as urbanization or agricultural intensification (Verburg et al., 2002).

The classification of LUCC models is an on-going debate among the scientific community and many efforts have been made to establish model categories. Mitasova and Mitas (1998) differentiated between deterministic, stochastic and agent modelling. Briassoulis (2000) distinguished models according to their use: decision support, explanation, prediction, impact assessment and prescription models. Parker et al. (2003) recognized seven broad, overlapping categories of models: mathematical equation-based, system dynamics, statistical, expert system, evolutionary, cellular, and hybrid. Verburg et al. (2004) proposed a classification land use change models based on their perspectives -micro, macro, and cross level- and the level of integration. Koomen and Stillwell (2007) propose to distinguish models by its temporal resolution (dynamic vs. static models), spatial resolution (zones vs. grids), central objective (land use vs. land user), simulation approach (deterministic vs. probabilistic), simulation process (transformation vs. allocation) and level of integration (sector specific vs. integrated). And Silva and Wu (2012) propose a more holistic classification system based on 6 criteria: different modelling approaches, levels of analysis, spatial scales, temporal scales, spatial and non-spatial dimensions, and different planning tasks.

Comparing the existing LUCC models based on their modelling approaches, both Empirical-Statistical Models coupled with GIS, and Artificial Intelligence Based Models are of particular interest for this thesis. They both present a high potential to emulate complex LUCC processes that should be analyzed.

Empirical Statistical approaches have been widely applied during the last decades for LUCC modelling. Being the best example the CLUE-family models: CLUE, CLUE-S and Dyna-CLUE (Veldkamp and Fresco, 1996; Verburg et al., 2002; Verburg and Overmars, 2009), which have been tested from transnational to sub-regional scales all over the globe. On the other hand, approaches based on Artificial Intelligence models, such as Agent-based modelling (e.g., Cellular Automata, Genetic Algorithm, or Artificial neural networks are increasingly gaining ground in the field of land use modelling due to their capacity to manage large amount of data, emulate complex spatial patterns and incorporate dynamic behaviour. Cellular Automata are models of particular interest to simulate land use dynamics given their natural affinity to represent highly complex spatial forms through relatively simple rules (White and Engelen, 1997).

2.3 Risk Assessment

‘Risk assessment’ can be understand as a methodological framework to measure the risk poses by a specific hazard including quantitative and qualitative understanding of risk, i.e. its physical, social, economic and environmental factors and consequences, as stated by the United Nations (UNISDR, 2009). Similarly to scenarios, formal risk assessment procedures were also originated in military research during World War II, to avoid chemical and nuclear plant failure (WB, 1997). For many years risk assessment was mainly used in fields such as aerospace, oil, military industry and engineering industries; being afterwards extended to the public health sector, natural disaster preparedness and mitigation, and, as fast-growing trend, in the field of climate change adaptation.

When risk assessments are performed in the field of climate change, they normally are based on future projections for the hazard considered (e.g. future sea-level rise), while using present conditions for the exposure and the vulnerability factors (e.g. current population distribution). This gap is starting to be acknowledged by different researchers and the need of new frameworks to assess future exposure and vulnerability recognised (Cardona et al., 2012). Scenarios show a strong potential to address this issue, since, if they are developed spatially (e.g. land use), scenarios have the ability to show future exposure and vulnerability conditions. Hansen (2008), Kebede et al. (2010) and Lavalle et al. (2011) are examples of authors who have proposed the use of spatially explicit scenarios to assess potential future impacts in the context of climate change, at the regional and local scales. This thesis aims to contribute to this line of work, by presenting an alternative approach from the aforementioned authors, to spatialize scenarios, as well as to assess future risk, based on the principles and objectives stated in Chapter 1, Introduction.

In this thesis, risk will be assessed based on the definition provided by Alexander (2000) in which risk is determined by (1) the nature of the *hazard*, (2) the *exposure* to potential hazard impacts, and (3) the *vulnerability* of the assets exposed to the hazard. The three components are individually presented and examined in the next paragraphs.

Although *hazards* have been defined by numerous authors (i.e. Burton, 1993; Blaikie et al., 1994; Alexander, 2000; Brooks, 2003; Cardona, 2003), one of the most comprehensive definition is given by the United Nations (UNISDR, 2009) who describes a hazard as “a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation”. This definition recognises that hazards can be led either by natural or human processes. An important consideration to take into account is that a hazard is a threat, not a real event; if a supposed hazard can be measured in terms of real damage or harm it is no longer a hazard but has become an event, disaster or catastrophe (Birkmann, 2006).

Thus, hazards are described in purely physical terms (Brooks, 2003) considering the extent and nature of the danger (e.g. height of an extreme tide). Hazards can be expressed mathematically as the probability of occurrence of an event of certain intensity, in a specific site and during a determined period of exposure time (Cardona, 2003). The outcomes of hazard analizes are often expressed in terms of frequency of occurrence, return period, or probability of exceedance. An important aspect when quantifying hazards is the relation between magnitude and return period; each magnitude is tied to a specific return period or its inverse, frequency. This relationship in a particular hazard is always an inherent characteristic of a specific locality or region (Bryant, 2005). As the magnitude increases, so does the return period, meaning that more powerful events are less frequent. Risk assessment often focus on these less frequent but highly dangerous events, which are known as *extreme events* due to their devastating capacity to human systems. Nevertheless the link between hazards, risk and disasters is not only determined by the scale of the hazard but also by the other two components of risk: exposure and vulnerability.

Exposure focuses at the elements at risk; hence, exposure can be formed by the people, property, or other elements present in hazard zones that are thereby subject to potential losses (UNIDRS, 2009). An exposure analysis usually involves the inventory of all items that are subject to the physical demand imposed by the hazard (e.g. the quantity and distribution of people and physical objects) (Chapman, 1999). Exposure is a clear determinant of the level of risk. As Lavell (2003) underlined, population dynamics, demand for location, and the gradual decrease in the availability of natural safer lands, leads human population to be located in potentially dangerous places, increasing their exposure to natural hazards. The spatial distribution of land uses is also deeply linked to exposure, being land planning a key factor in risk reduction (Wilson and Pipper, 2010). Agreeing with Cardona et al. (2012) while exposure to events is unavoidable, land use planning and location decisions can be used along with other structural or non-structural methods, for preventing risk on a given geographical area.

The third element of the risk equation is vulnerability, which determines the severity of the elements at risk (Wisner et al., 2003). The concept of vulnerability was initially used in the engineering field, considering the physical resistance of the construction designs and materials to physical forces (e.g. ground motion, wind and water). Nevertheless, over the past 30 years the concept of vulnerability has evolved significantly, as important developments have been made in the understanding of people’s and ecosystems susceptibility to hazards (UNIDRS, 2009). Vulnerability assessment is nowadays as frequent as risk assessment, as it is widely used by the Climate change researchers’ community. The raise of vulnerability assessment has been accompanied with considerable efforts within the practitioners to define the term (Blaikie et al., 1994; Villagrán de León, 2006). Yet, to date, vulnerability continues to lack a common definition and can thus be considered to be the most controversial elements of the risk assessment exercise. In this regard, Birkmann (2006) claimed the paradox of aiming to measure vulnerability despite we cannot define it precisely. In this thesis, vulnerability is considered in the terms proposed by the United Nations (UNIDRS, 2009) defined as: “vulnerability is the intrinsic and dynamic feature of an element at risk (community, region, state, infrastructure, environment) that determines the expected damage resulting from a given hazardous event and is often affected by the harmful event itself". From this definition, vulnerability is considered to be driven by physical, social, economic and environmental factors.

Different conceptual and methodological approaches exist towards risk assessment. Depending to the approximation to hazards, two approaches can be distinguished in risk assessment: the probabilistic and the deterministic. The use of one or another will depend upon data availability, the uncertainty involved with the hazard(s) under study and the purpose of the research. A probability-based risk assessment requires large amount of data on past events; the historic record has to be long enough to establish a reliable pattern of occurrence for many natural hazards (Noson, 2002). Both approaches have their weaknesses, while probabilistic approach can deal with problems regarding the (deficient) statistical significance of data, the deterministic approach can give the false sensation than results are “certain” and scenarios are “true” (Kirchsteiger, 1999). The reality is that both approaches are full of uncertainties and they can be complementary and benefit from each other. Deterministic events can be backed with a probabilistic analysis to ensure that the event is realistic (and reasonably probable), and probabilistic analysis can be checked with deterministic events to see that rational, realistic hypotheses of concern have been included in the analysis (McGuire, 2011). This integrative approach is particularly interesting to deal with highly uncertain hazards, such as climate change related hazards, in which assigning probabilities to a specific phenomenon (e.g. sea-level rise) is challenging. For this reason, in this thesis, an integrative approach will be taken.

2.4 Conceptual approach of this thesis

Taking into account the literature hereby reviewed, this thesis proposes to integrate the three fields of research explored: scenarios, land use modelling and risk assessment, by the conceptual approach presented in Figure 3. As the figure depicted, if risk is understood as a function of hazard, exposure and vulnerability (a 'pressure-release' model according to Blaikie et al., 1994), we can assume that for a given level of hazard the risk will vary accordingly to the exposure and vulnerability degree, which will indeed vary depending on the spatial distribution of assets and their characteristics (Merz et al., 2010). Assuming this premise, in order to asses risk in future conditions, both future hazards and future exposure and vulnerability must be addressed. Simulating future exposure conditions (e.g. future land uses) is possible through the translation of what-if socio-economic scenarios into spatial maps by the use of a Stochastic Cellular Automata model. The CA simulates land uses changes according to human-decision-making, pre-existing Land use Land cover Change (LUCC) patterns and a wide variety of physical and socio-economic factors. Future stakeholders' visions and planning decisions can be incorporated into the model through participatory techniques. The resulting future land uses maps can be considered exposure maps (Lavalle et al., 2011; Beckers et al., 2013), which can be combined with vulnerability maps (obtained from future projections of a proxy of vulnerability- e.g. population density, GDP/capita- and hazards maps to perform a spatial risk assessment in different, alternative future scenarios. The resulting future risk maps will allow to measure and visualize how the risk to a specific CC hazard varies as future exposure/vulnerability conditions do and how some planned/unplanned decisions affect the risk level in their territory in the mid-term future.

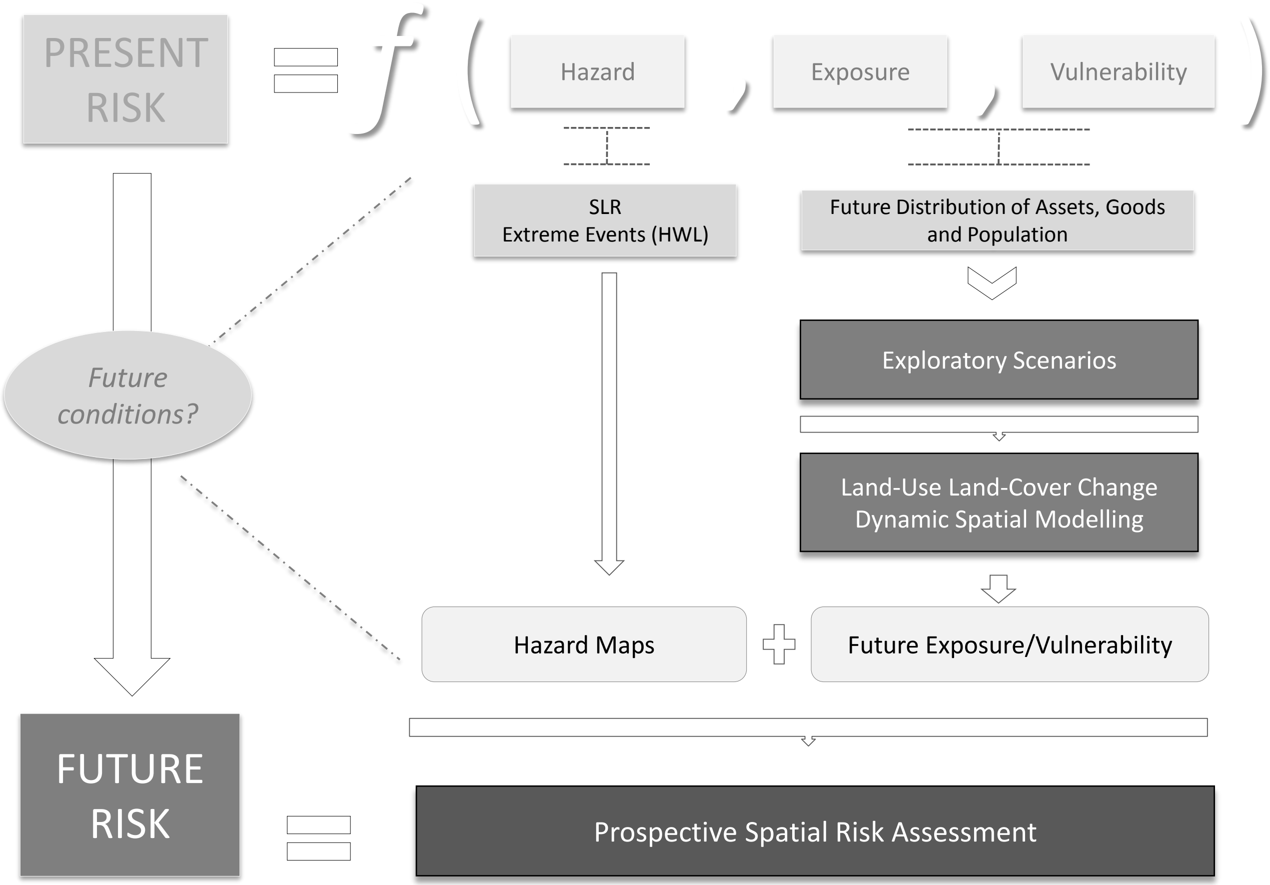

Figure 3. **Conceptual approach of this thesis.** The relationships between exploratory scenarios, land use spatial modelling and spatial risk assessment are shown, as well as the contribution of this thesis to assess risk in future conditions in contrast to the predominant risk assessment in present conditions (Self-elaboration).

CHAPTER 3: *Study Site*

Introduction to the study site

This chapter presents the study site selected for this thesis: the coastal municipality of Ayamonte (Spain). The chapter is structured on three sections: i) *natural setting*, which shows the unique location of the municipality, its peculiarities in physical terms and its high dynamism; ii) *socio-economic setting*, which describes the history of the site, from its foundation to the last decades' coastal planning initiatives; and iii) *suitability of the site for this thesis*, which analyses the reasons underpinning the selection of the municipality of Ayamonte to test the process proposed in this thesis.

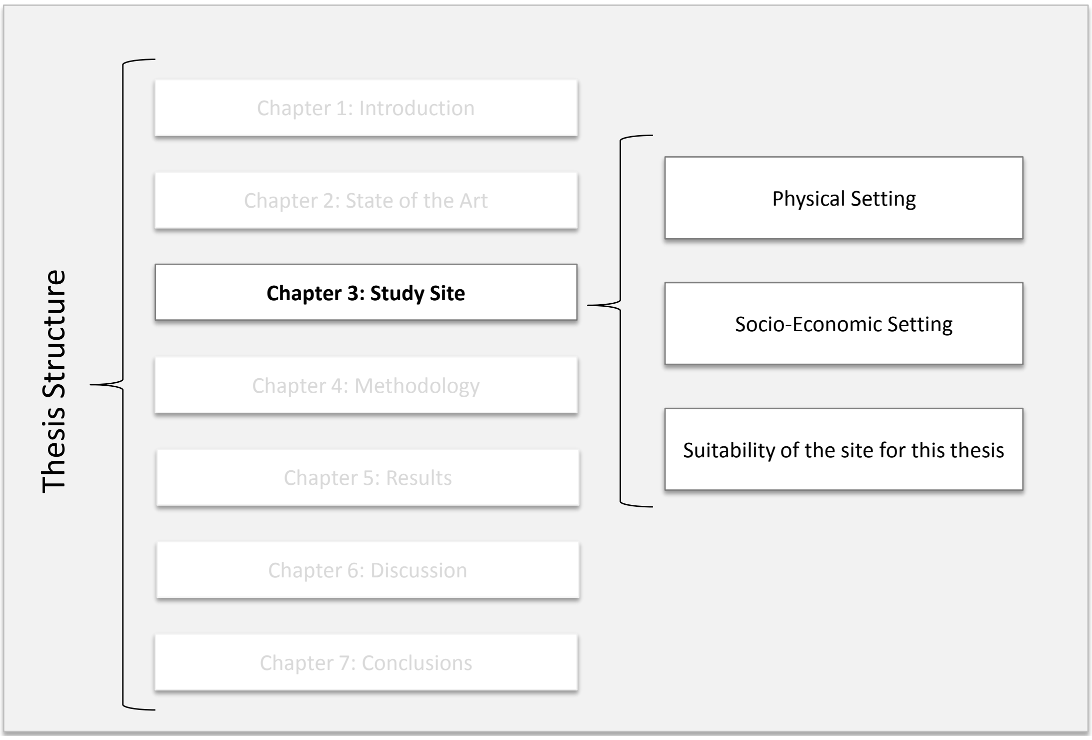

Figure 4. **Chapter 3 'Study Site' presentation.** Three sections are included in the Study Site chapter: physical setting, socio-economic setting and suitability of the site for this thesis (Self-elaboration)

3.1 Natural Setting

The area of study is the coastal municipality of Ayamonte, located in the South-western area of the Region of Andalusia, Spain (Figure 5). It lies in front of the Atlantic Ocean, on the margin of the Guadiana river estuary, one of the most important mesotidal fluvial systems of the SW Iberian Peninsula, and border between Spain and Portugal. The municipality covers a surface of 142.78 km^2, an average size for the region of Andalusia. The coastline has 7.5 km length and is confined by the Guadiana river on the East and Carreras river on the West.

The continental shelf is flat and wide extending over 20 kilometres to the coast (Lobo et al., 2003). The sedimentary deposits of the shelf are dominated by sandy deposits in the inner part, an extensive mud belt of very fine-grained clayey material in the middle part, and sandy and silty clay deposits in the outer shelf below 100m (Gonzalez et al., 2004). The wave climate is characterized by low-medium energy waves, dominated by waves from W and SW with approximately 50% of occurrences, although SE waves also have a significant influence with over 25% of occurrences (PE, 2013). Average offshore significant wave height is about 0.9 m (with 52.31% of wave heights not exceeding 1 m) with an average period of 4.6 s and peak average periods of 8 s (PE, 2013). There is an important seasonal variability and winter storm conditions can allow wave heights of 6 m. The SW and W dominant wave approach generate a strong longshore littoral drift from west to east that according with Gonzalez et al., (2001) generates a substantial sediment transport rate of 18x10^3 m^3 yr^1 . Tidal range is semidiurnal and mesotidal, with average tidal amplitudes of around 2 m, reaching 3.4 m at spring tides. Tidal currents at the Guadiana river mouth are about 0.6 m/s during peak flood tide and 1.2 m/s during peak ebb tide (Gonzalez et al., 2001).

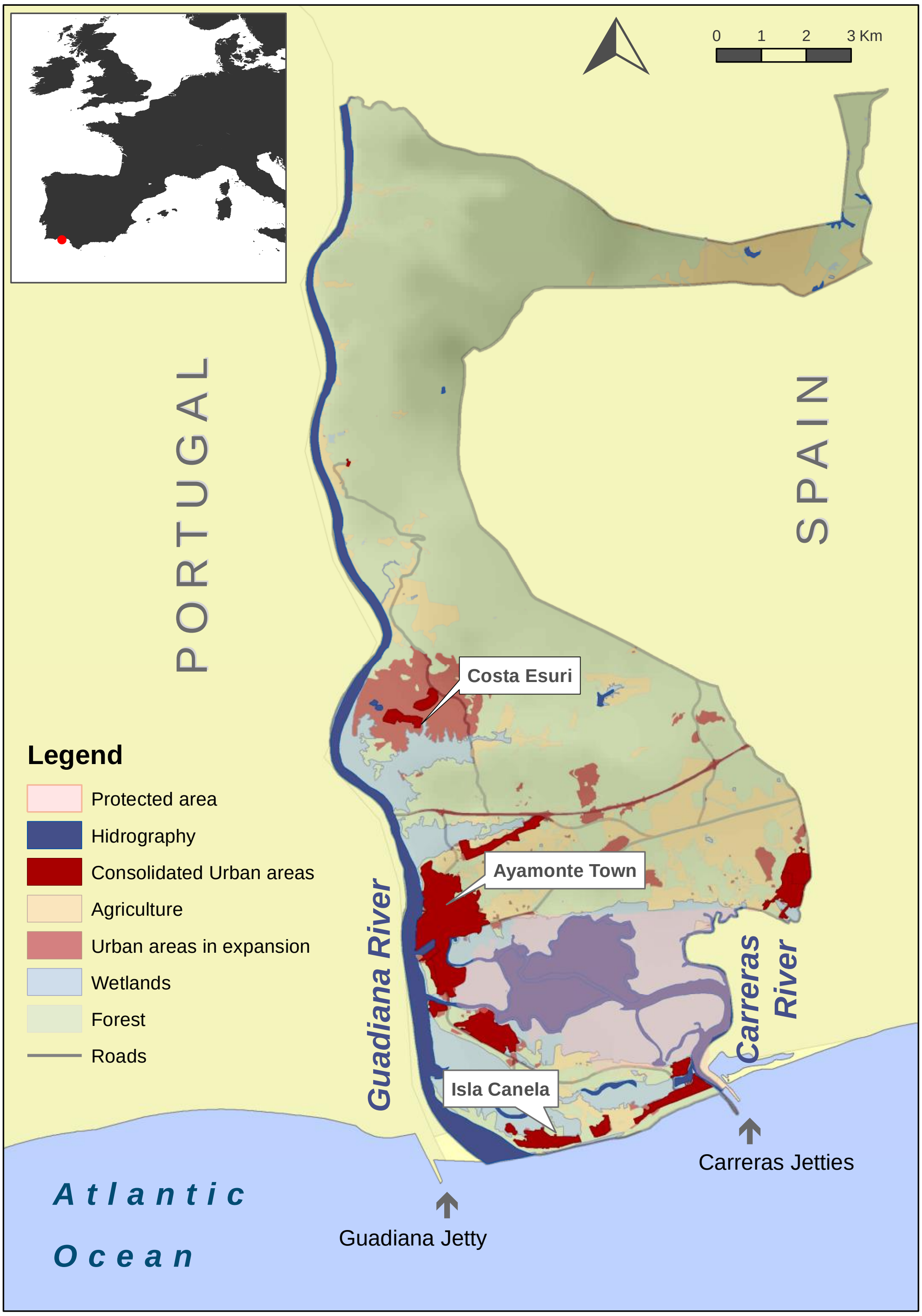

Figure 5. Study site map. Site location at the SW Spain: frontier with Portugal and facing the Atlantic Ocean. Main features of the study site, including: urban areas location (Ayamonte Town, Costa Esuri and Isla Canela), the two rivers, a protected area, and the surface covered by forest and crops (Self-elaboration).

The coastal morphology of the study site is strongly influenced by the presence of Guadiana estuary. Lying over the river mouth, the municipality has a smooth topography (as Figure 6 shows) that reaches a maximum high of 160 m above sea-level. The river mouth was formed as a narrow channel excavated by fluvial incision during the Pleistocene lowstand and flooded 6.500 years ago, during the Holocene. The river bed consists of Carboniferous schists and graywackes, the resistance offered by these hard materials defines the pattern of the bedrock river valley which is narrow and deep with 600 m wide and about 70 m deep (Boski et al.,2002). Only the final 5 km of the river valley is composed by Cretaceous and Jurassic limestones which permit a broader opening of the estuary, accommodating the extensive salt marshes on both sides of the inlet (Delgado et al., 2012). The Guadiana river is considered one of the most important sediment supplier of the adjacent Gulf of Cadiz shelf (Lobo et al., 2003) with a sediment supply estimated in of 57.9 x 10^4 m^3/yr for suspended load and 43.96 x 10^4 m^3/yr for bed load (Morales, 1993). Due to the river narrow morphology- which prevents sediments passing to offshore coast- and the high sediment supply, the estuary is in an advanced state of sediment infilling and therefore delta progradation is taking place (Morales, 1995).

Coastal morphology is controlled by wave activity, fluvial sediment supply and tidal activity, and is strongly influenced by the presence of the Guadiana estuary. Sedimentation is controlled by the interaction of sediment load delivered by the Guadiana River and the active longshore current which also supplies sand eroded from barrier islands and friable cliffs in the Portuguese Algarve to the West.

Figure 6. Study site photos (I). Top: Isla Canela. Bottom A) View of Guadiana river mouth from Ayamonte old town; B) Wetlands; C) Touristic apartments on very low lying area Eastern side of Isla Canela; D) View from the wetlands during a high tide (Source: Carrero, 2013)

In terms of anthropogenic action over the physical environment it is necessary to mention the coastal engineering works that have strongly influenced the sediment dynamics of the last decades. Over 40 dams have been built upstream since the 1960's to regulate the Guadiana drainage basin.

The dams regulate about 75% of the drainage area and have produced a drastic decrease in the volume of water and sediment supplied from the river to the estuary, and a strong estuarine dynamic modification (Rodríguez-Ramírez et al., 2008). Moreover, four jetties were built on the 1970s, two at the mouth of the Guadiana main channel –one is submerged- and two more at the mouth of the Carreras river, as indicated in Figure 5. The goal of all these engineering works was to safeguard the navigation and the entrance to the rivers, as they are of great importance for the fishing industry. The jetties' construction heavily affected the sediment dynamics of the area as described by several authors (Gonzalez et al., 2001; Ojeda and Malvárez, 2005; Rodríguez-Ramírez et al., 2008), creating an accretion area in the Western side of the Guadiana mouth, new beach of 2.07 km^2 (Boski et al., 2002) and an erosional trend on the Eastern side. Erosion episodes , concentrated on the central area of Ayamonte beach, caused losses up to 120 m of beach width in the 1980s (HITDMA, 2011). At present, the sediments have filled the Portuguese jetty allowing their bypass to the Spanish side again and the feeding of the coastal system.

As an effort to relief part of the physical distress caused by anthropogenic activities and to protect the ecological values of the municipality, a natural protected area was created in 1989, showed in Figure 5. About 1400 ha of the wetlands were recognised as an area of great ecological value, declared by the Regional Government as “Paraje Natural” and its land is classified as non-urbanizable and subjected to special protection (Ménanteau et al., 2007). In 2003 the protected area was as well inscribed in the Natura 2000 network. The green belt has been a safeguard for the wetlands ecosystem in the municipality preventing both urban and aquaculture developments.

3.2 Socio-Economic Setting

The town of Ayamonte was funded as a trading colony by the Phoenicians, who were attracted by its strategic location and marine resources. For the same reasons the town was later inhabited by Romans, Arabics and finally by Cristians in the XIII century (Feu, 2005). However it was on the first half of XVI century when Ayamonte truly became an important fishing, shipyard and trading centre for the region (Carriazo, 2001). The flourishing fishing sector grew to become the main economic activity in the 18th century, when the industrial production of canned and salted fish was successfully introduced in the area. By the second half of the 19th century the local economy was boosted by the canning industry, introduced by Italian and French businessmen who took advantage of the fishing and fish salting tradition of the area (Cáceres, 2007).

The 20th century marked the transition from a traditional and artisanal fishing sector to a modern and industrialized one. Ayamonte's fish production -mostly tuna, mackerel and sardine- was welcomed at national and international scales, especially France and Italy. The favourable international market situation together with new technological advances on food preservation and transportation, helped to expand Ayamonte's fishing sector (Rodríguez, 2001). The success of the canning industry had major effects in Ayamonte. The fishermen became dependant to the canning sector demands and most of the traditional fishing arts disappeared and were substituted by large, specialized ships for tuna, sardines and mackerel fishing (Cáceres, 2002). In urban terms, the town aspect as well as the population changed radically between 1900 and 1930: Ayamonte's harbour was expanded and deeply modified, numerous factories and constructions associated to the canning and fish salting industry were built around the beach and Guadiana river, the city centre expanded, the population doubled in size, and immigrants from the neighbouring Portugal and other parts of Spain came as workforce (Cáceres, 2007).

The economic crisis of the 1930s and the Spanish Civil War (1936-1939) had a clear harmful effect on Ayamonte, losing its fishing leading position (Rodríguez, 2001). From the 1950s the fishing-canning sector started a serious decline: the lack of profitability of these sectors caused the departure from Ayamonte of most of the businessmen and investors. As result, another economic crisis hit Ayamonte during 1970s, leading to the canning industry dismantling and a massive closure of factories. The number of factories drastically dropped from 41 , including 12 canning, 27 salting and 2 fish-flour factories, to only 2 (Feu, 2005). The canning crisis was a hard hit for the local economy, as it dragged the dependant fishing sector with it and the whole economy for that matter.

The decline of the fishing sector had two main consequences:

In parallel to the fishing sector's crisis, and as alternative to it, aquaculture was introduced during the 1970s as an alternative to the above mentioned crisis. Aquaculture development was promoted by regional and national initiatives (Decree 2595 of 1974 and National Law on Marine Farming of 1984). As a result, in 1986, four large aquaculture companies landed in Ayamonte and the major part of the western natural marshes of the municipality were transformed into fish-farms, which within five years transformed nearly 700 ha of marshes (Ménanteau et al., 2007). In environmental terms, aquaculture fast development fragmented the wetlands' habitats as well as affected the water collection capacity of the marshes tidal prism. In socio-economic terms, the initiative was a fiasco, as after a few years of production few companies managed to be profitable, and most of the farms were abandoned. Nevertheless, the sector did not disappear and there are still some aquaculture exploitations. Moreover, some areas of Ayamonte's marshes are still considered as "suitable areas" for the re-development of aquaculture, as recognised by the regional government (CAP, 2010).

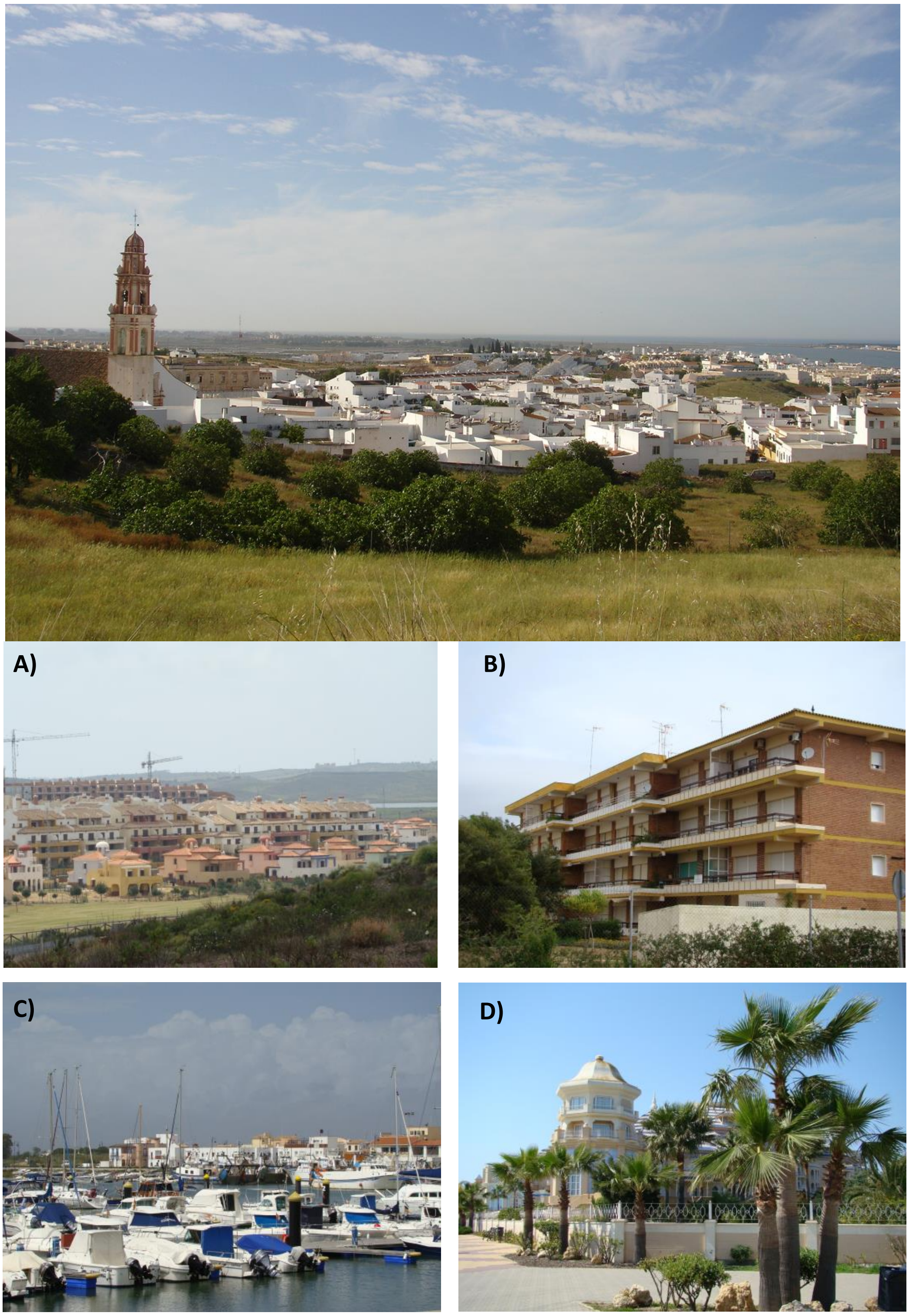

Figure 7. **Study site photos (II)**. Top: Ayamonte town. A) Costa Esuri under construction. B) Touristic apartments from the 1960s. C) Marina on Punta del Moral. D) Hotel from the 1990s (Source: Carrero, R. 2013).

Another consequence of the decline of the fishing sector in Ayamonte was the emergence of a new economic engine: the tourism. Tourism development started in Ayamonte in the 1960s when the "Act of Areas of Touristic Interest for the Nation" (1963)- promoted as one of the Franco's Regime "Development Policies"- created different centers for tourism all over the country , including one in the South of the municipality: *Isla Canela* (Figure 5). An ambitious promotional plan for the area was approved in 1964, covering a surface of 1,100 ha and considering 46,500 projected beds (Galiana and Barrado, 2006). However, according to Torres and García (2011) unlike other cases in Andalusia (e.g. the 'Costa del Sol') the project lacked of structured planning, had infrastructures deficiencies and the existence of wetlands (mosquitoes' infested of mosquitoes at the time), among others. As a result, Isla Canela did not reach the expected magnitude of impact and ended as a low-profile vacational-residential model for nationals. In addition, the oil crisis of 1973, the economic slowdown and the end of Franco's regime, with his death in 1975, meant the paralysation of the plans for the Areas of Touristic Interest and a subsequent set back of the touristic activity in the municipality of Ayamonte for almost two decades.

In the 1990's the tourism sector was re-launched by an alliance of the private sector with the local authorities who envisioned a new, ambitious plan for the municipality of Ayamonte. The idea was to transform the municipality in a luxury, high-end tourism destination based on two geographic nodes: the Southern coastal stretch corresponding to Isla Canela and the Northeastern river side of that was to be named *Costa Esuri* (see Figure 5).

In Isla Canela, the 1960's apartment blocks were substituted for modern, individual bungalows, two-story apartments and luxury hotel resorts. In addition, special attention was paid to green areas, sports and leisure facilities. A golf course, a shopping mall, a marina and different sports facilities were also planned to complete the tourism offer.

However, the 2008 economic recession froze the construction works leaving some hotels and apartments under construction. Costa Esuri has been the biggest touristic project of the history of Ayamonte and one of the greatest initiatives in the region of Andalusia. Despite its name, the area is not located on the coast, but on the Eastern side of Guadiana river, to the North of Ayamonte town (Figure 5). The plan was to build a brand new, outsized, self-contained urbanization with 6,000 houses and apartments for 20.000 people, 3 luxury hotels, 2 golf courses, a large shopping malls and a marina. The building works started in 2003 and they were never completed, as the developer company was the first important construction corporation to go to bankrupt in Spain in 2008. This situation left the construction plans paralysed and the project with no services (e.g. garbage disposal, water, sewage, public transportation, etc.) due to the cost of maintenance and the company bankrupt.

There are different plans that affect the municipality of Ayamonte. At the regional level, the “Andalusian Regional Land Plan” (POTA). At the subregional level the “Land Plan for the Western Coast of Huelva” and the “Special Plan for the Protection of the Physical Environment of Huelva Province". At the local level, the situation in Ayamonte has always been complex and many urban plans have been developed, modified and superimposed over the last years[2]. There are a multitude of subsidiary and complementary norms that organised the urban planning of the municipality by sectors. A holistic urban municipal land plan was elaborated on 2006, containing detailed information about the touristic developments of Isla Canela and Costa Esuri. However, and although the plan seems to be followed by the City Council, it has not been officially approved yet.

In terms of population, at present the municipality’s population is 21.000 inhabitants, mostly concentrated in Ayamonte town, with a 9% living in the urban areas closer to the beach. Coastal

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[2] Table A-2 on Annex provides a summary for all the land planning provincial and local norms and plans for the study site between 1985 and 2011.

urbanisation reaches a 15-29% of the land cover on the first 250 - 400 m to the coastline (Tejada, 2005). The current population density is over 140 inhabitants per km^2 and the population growth trend is positive, with over a 21% of increase in the last decade (2002-2012).

3. 3 Suitability of the site for this thesis

Ayamonte has suffered deep socio-economic transformations during the last century. It has been the target of different development initiatives from the national, regional and local level, which in many cases have failed. Only in the last 50 years the economic engine of the area has been swinging from the traditional fishing, fish-salting and canning industry, to the modern aquaculture, and to the sun-and-beach tourism and the residential sector.

The high socio-economic dynamism of the area makes it an ideal place to develop future scenarios, as stakeholders are particularly open-minded to different future options, especially considering that some of the most unexpected possibilities have already taken place. In addition, the diversity of land use and land cover changes occurred over the last years, associated to socio-economic changes, offers an ideal place to test spatialization of scenarios through Land Use and Cover models in highly dynamic areas. On the other hand, the management and planning of the coastal environment seems to be reactive to the actions taken. In a context of climate change adaptation, and agreeing with Cooper and Lemckert (2012), it would be very positive to move toward a “proactive” approach to coastal planning, analyzing how different development paths in the area could lead to different risk levels.

In terms of risks, and being a low-lying coastal area, Ayamonte is highly exposed to coastal hazards, such as coastal inundation. As indicated by Rodriguez-Ramírez *et al.* (2008), sea-level rise can affect the already human-induced-modified tidal regime and wave refraction-diffraction patterns along the Huelva coast and can induce as well higher efficacy of erosional events, leading to a future retreat of about 10-15 m of the coastline. Ayamonte coastal line, wetlands and submerged sandbars are expected to considerably change over the next years, yet uncertainty remains regarding coastal erosion and accretion, as well as sandbars and wetlands migrations rates (MF, 2013). The Spanish Ministry of Environment commissioned a special report (HITDMA, 2011) which recognised Isla Canela erosive process to be of extraordinary relevance given its magnitude (i.e. losses of 180 m of beach width in the 1980s) and its convergence with an intensive urban development, which will be severely affected in the coming years by the coastal retreat. The report also indicated that the building model followed in the coastal zone was irrational, and unreasonably exposed to natural hazards. In addition, the lowest-lying area of the municipality -i.e. beaches and riverside- concentrate increasing population densities as well as economic activities related to tourism, from which local communities are highly dependent. The most valuable coastal ecosystems in the study site, such as dunes and wetlands, are located under 10 meters high above mean sea-level.

For all these reasons, Ayamonte was selected to test the threefold process proposed in this thesis. This site has provided the ideal setting to: develop exploratory future scenarios, spatializing one of them (the one considered the ‘most plausible’ by the stakeholders involved) and performing a coastal inundation risk assessment taking into account sea-level rise and an extreme High Water Level.

CHAPTER 4: *Methodology*

Introduction to the methodology

The methodological construction of this thesis was divided in three phases according to the goals of this research presented in Chapter 1, Introduction. This trifold process aimed to first, develop a replicable methodology to create explorative, participative, locally-based future scenarios; second, translate a selected scenario into geospatial data, so that it could be potentially used in decision-making and planning processes; and third, assess the *potential* impact of future sea-level rise combined with an extreme event on the selected future scenario. The methods followed, created, modified for the three phases are summarized in the present chapter.

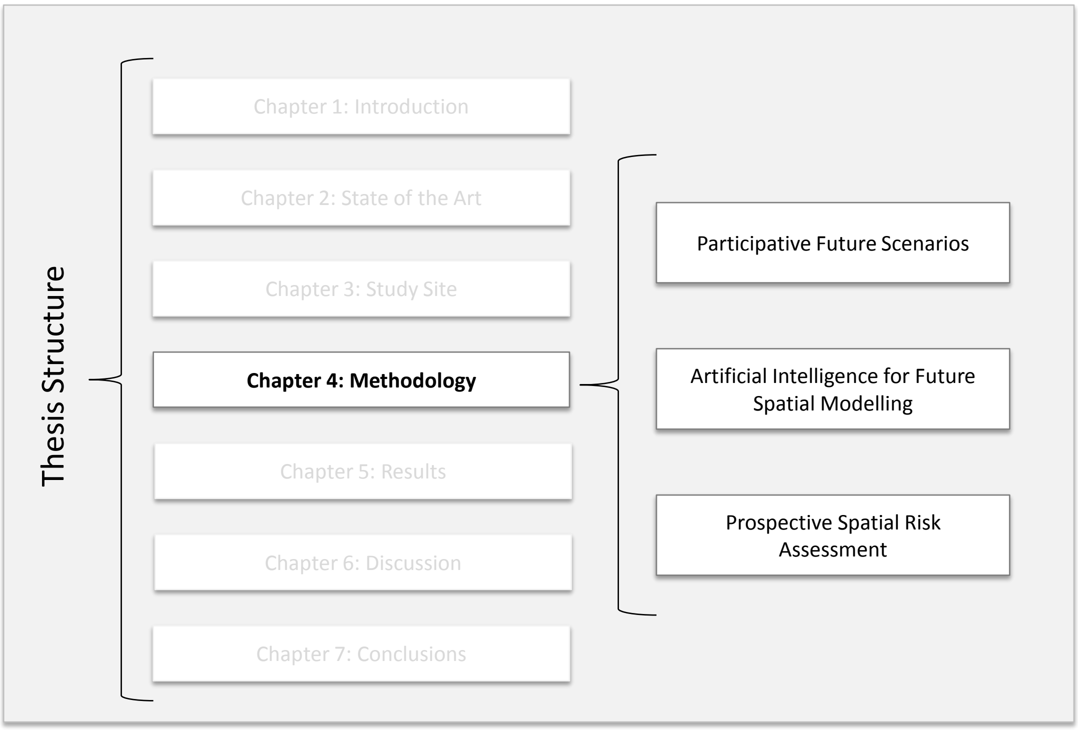

Figure 8. Chapter 4 ‘Methodology’ presentation. Three sections on the Methodology Chapter: Participative Future Scenarios, Artificial Intelligence for Future Spatial Modelling and Prospective Spatial Risk Assessment (Self-elaboration).

4.1 Participatory Future Scenarios (PFS)

A new, custom-made scenarios methodology was expressly developed for this thesis, denominated "Participative Future Scenarios" or "PFS". This methodology was designed taking into account the thesis goals and in particular, the ICZM and governance principles. In this sense two important premises were considered: the use of a *participatory approach,* so that stakeholders were to be involved from the beginning to the end of the process in an organised and structured manner; and the *integration of different types of information* during the analysis, including terrestrial and marine data, quantitative and qualitative, physical and socio-economic data, and environmental policies and normative. In addition, it was decided to follow an *explorative approach* (see Chapter 2), as it fits better with the thesis aim on exploring future possibilities in an open, non-predefined manner.

The approach proposed by Schwartz (1996) was taken as a conceptual basis to construct the PFS methodology. The six steps composing the PFS methodology were: Step 1) Setting the scenarios boundaries; Step 2) Analizing stakeholders; Step 3) Analizing Driving Forces; Step 4) Establishing the scenarios framework; Step 5) Describing scenarios; and Step 6) Validating results. This methodological framework included several new themes: a) the inclusion of a first stage to identify and engage stakeholders as well as a final validation by the stakeholders themselves and a group of experts; b) for each step a specific method was developed promoting the inclusion of participatory techniques. The whole process is summarised step-by-step in the next sections and complemented with additional info presented in the Appendix.

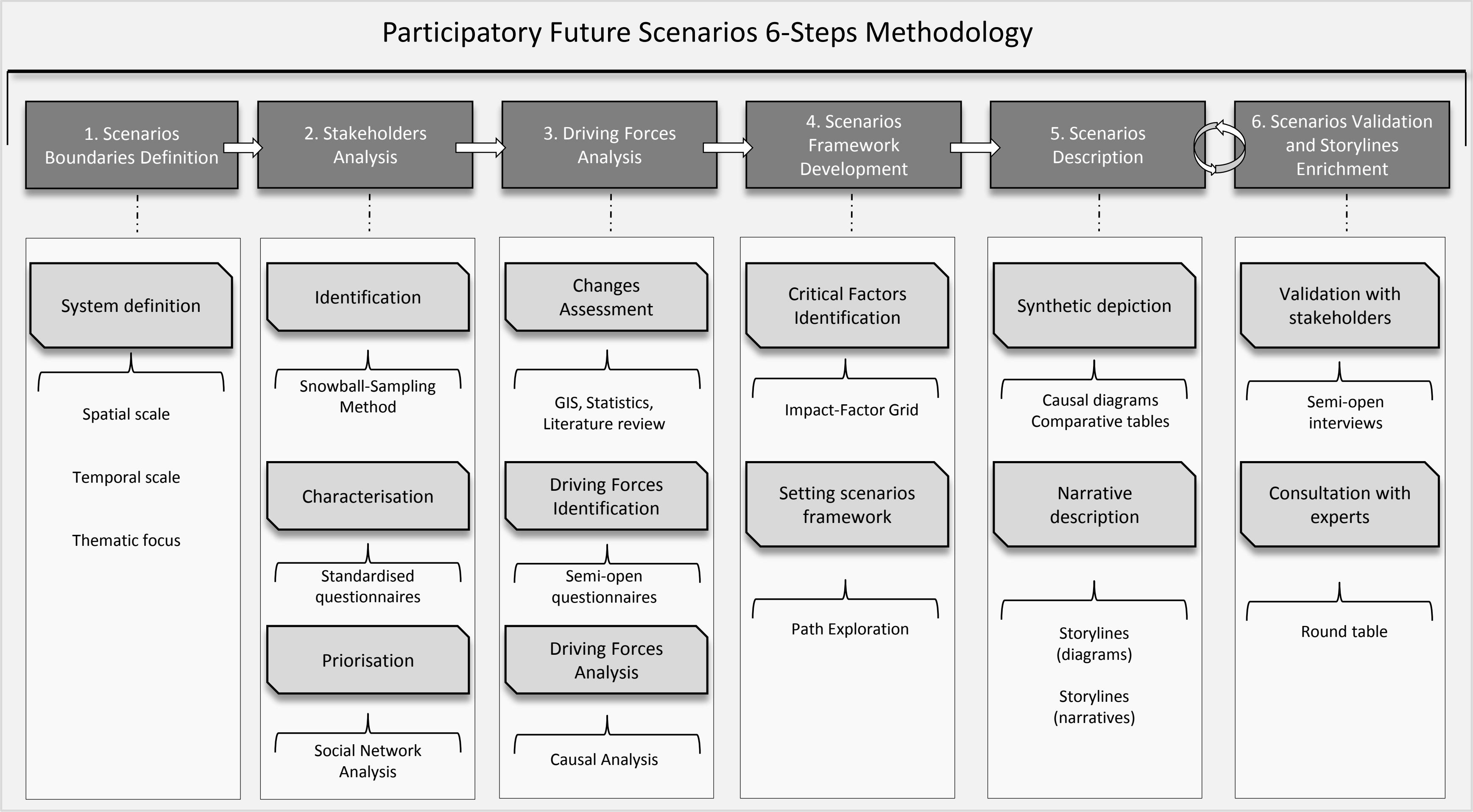

Figure 9. Participative Future Scenarios methodology. The Participatory Future Scenarios (PFS) methodology as it has been originally developed for this thesis, including 6 well differentiated steps with their corresponding sub-steps as presented in the figure (Self-elaboration).

4.1.1 *PFS Step 1*: Scenarios boundaries definition

The first step of the PFS methodology was to define the system boundaries. A classification diagram, based on a literature review of previous scenarios studies, was used to define three key scenarios boundaries: the temporal, spatial and thematic dimensions. See Appendix, Figure A-1.

4.1.2 *PFS Step 2*: Stakeholders analysis

In this thesis stakeholders are defined as those individuals, organisations and institutions 'who are affected by or can affect a decision’ (Freeman, 1984). For this thesis, and according to Reed et al. (2009) three stages were distinguished to analize stakeholders: (i) identification; (ii) characterization; and (iii) priorisation.

i) *Identification.* Stakeholders were identified on the field using the Snowball Sampling Method (Goodman, 1961). This kind of method is a non-random sampling technique that guarantee the inclusion of all participants originally developed to study populations of unknown sizes that are difficult to access and for which there are not previous studies or formal records (e.g. Eland-Goossensen et al., 1997; Luyet et al., 2012). In this thesis the Snowball Sampling Method was applied following Goodman (1961) with a slight modification to ensure a good network of initial contacts on the site, as explained in the Appendix (Figure A-2).

ii) *Characterization*. Information about stakeholders was gathered by interviews based on standardized questionnaires (Patton, 1990; García, 2002). The information collected included: the name of the stakeholder, the scale of action of each individual/organisation, the nature and institutional character, the uses and activities developed on the coast as well as the self perception of dependence on the coast. The questionnaire designed to characterize stakeholders is shown in the Appendix, Questionnaire Q1 (questions 1-6).

iii) *Prioritization*. This phase was based on a Social Network Analysis, which consist in “analyzing characteristics of the pattern of distribution of relational ties and drawing inferences about the network as a whole or about those belonging to it considered individually or in groups" (Bandyopadhyayet al., 2011). To perform the SNA in this thesis, Pajek was used. This software-based model was created for the analysis and visualisation of social networks based on graph theory and matrix algebra as described in Batagelj and Mrvar (2003). In this thesis, Pajek was fed with the data gathered through the interviews performed during the Snowball Sampling Technique, as shown on the Questionnaire Q1 on the Appendix (questions 7-8). Three analysis were performed within the model to assess the stakeholders' network size, stakeholders' centrality as well as stakeholders' connections strength and directionality.

4.1.3 *PFS Step 3*: Driving forces analysis

An identification of driving forces is a critical step of scenarios making. In this thesis, driving forces were identified combining quantitative and qualitative techniques considering based on the conceptual approach showed in Figure A-3 (Appendix). The identification was made in three stages as summarised below:

i) *Coastal system assessment.* Spatial and non-spatial changes of the 'coastal system' - which included both the socioeconomic and the biophysical subsystems -were assessed through a trifold analysis of i) spatial data; ii) statistical data; and iii) bibliographic review of previous studies. Statistical data included: population datasets, immigration and emigration, number of active fishing boats, fish catches, etc.; spatial data included: surface covered by urbanized areas, surface covered by salt marshes, protected areas, etc., previous studies included information about shoreline morphology changes, aquifer pollution, or exotic species introduction, among others. Data was gathered within the spatial and temporal boundaries of the system defined on Step 1.

ii) *Driving forces identification*. A preliminary identification of driving forces was made through a participatory exercise using individual semi-structured interviews. The process was designed according to García (2002). The final questionnaire (Questionnaire Q2, Appendix), took into account the recommendations for interviewers presented in Vliet et al. (2007). The semi-structure interviews were launched in the studied area during an extensive field campaign involving local stakeholders such as the City Council, Fishermen Unions, Chamber of Commerce, the Institute for Marine Workers Welfare, Hotels, beach bars, conservationist groups, transportation companies, beach maintenance workers, local shop owners and citizens, among others. All interviews were made on a voluntary basis.

iii) *Causal analysis and final driving forces identification*. The preliminary set of driving forces derived from the previous participatory exercise (qualitative data) was validated by crossing the results with the empirical information compiled in the coastal changes assessment (quantitative data). A causal analysis was performed to explain relationships between driving forces and changes. The cause effect analysis proposed in this thesis is based on the differentiation between proximate factors and underlying driving forces as theorised by Geist and Lambin, (2002), who stated "proximate causes are human activities or immediate actions at the local level (i.e. agricultural expansion) whereas underlying driving forces are fundamental social processes (i.e. human population dynamics or agricultural policies) that underpin the

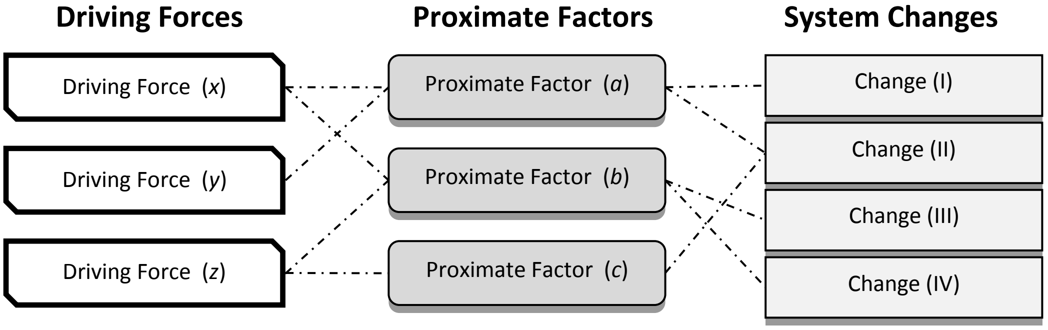

Figure 10. **Causal Analysis approach**. Conceptual diagram showing relationships between driving forces (left column), proximate factors (central column) and system changes (right column) (Self-elaboration).

proximate causes and either operate at the local level or have an indirect impact from the national or global level". A cause effect diagram was thus created using three parameters: underlying driving force, proximate cause and system changes. The underlying driving forces identified in the participatory process were translated to the study-scale through the proximate causes. Analogically proximate causes are related to the changes measured in the system. As shown by Figure 10, multiple interactions among the three parameters could be assessed by this approach (e.g. driving force (x) contribute to changes (I) to (IV) through proximate factors (a) an (b)) . To increase the reliability of the analysis the process was driven by an expert team.

4.1.4 *PFS Step 4*: Scenarios framework development

To explore several plausible future configurations of a given area of study a scenarios framework has to be developed, addressing the questions 'What could happen if?' or How could the driving forces evolve under certain assumptions?'. In this thesis the scenarios' framework was developed in two stages: the identification of critical factors and the development of the framework itself.

I) *Identifying the critical factors of the system*. In this thesis, Critical Factors were defined as the most important and uncertain driving forces in the system, thus the potential shapers of different futures. Critical Factors were first identified using an Impact Factor Grid as described in Linss and Fried (2010). The Impact Factor Grid classified the driving forces into four types: active, ambivalent, buffering and passive elements, depending on their capacity to influence or be influenced by other driving factors. Both Active and Ambivalent elements were considered the most important driving forces of our system, as they both have a strong influence over the others drivers. The uncertainties surrounding these driving forces were explored with the information extracted from the semi-structured interviews performed during Step 3, Driving Forces Analysis.

II) *Defining the scenarios logics*. For the development of the scenarios framework itself a method is proposed conceptually inspired on the "decision trees", commonly used in risk analysis, uncertainty analysis and strategic planning (Marsh, 1993; Goodwin and Wright, 1998). The method, named here as Scenarios Path Exploration, has been developed for this thesis and consists in investigating how the course of events could change over time taking into account the Critical Factors previously identified. As Figure 11 shows, the path exploration starts with a path representing the current (mainstream) path and starts to diverge every time a Critical Factor appears in the system. In this method there are not predefined nor maximum or minimum number of scenarios. In the conceptual example given in Figure 11, four Critical Factors generate five scenarios.

4.1.5 *PFS Step 5*: Scenarios description

It is well known among authors that to develop the storylines is necessary to set the scenario

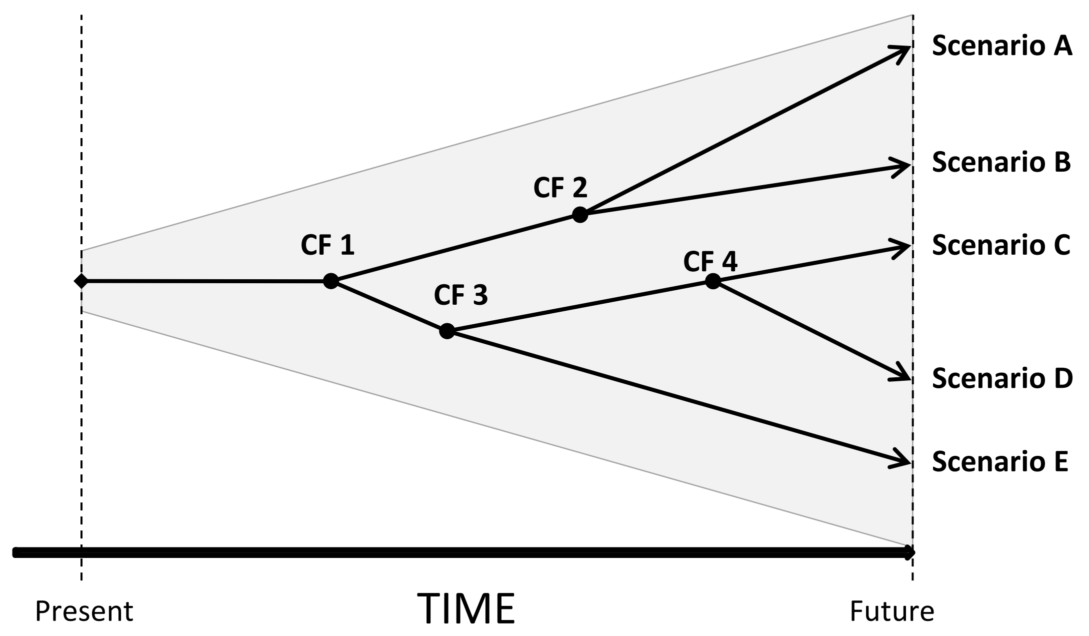

Figure 11. Scenarios Path Exploration approach. Diagram shows how four Critical Factors (CF1, CF2, CF3, and CF4) divert the paths of five hypothetical alternative scenarios A, B, C, D and E (Self-elaboration)

assumptions, which are a coherent and internally consistent set of principles about key drivers and relationships (Metzger et al., 2010). Taking into account the scenario logics, alternative scenarios were generated taking into account each scenario should tell a story -or storyline- that should be logical, convincing and plausible. Drawing storylines is a challenging exercise where a balance between plausibility and creativity should be reached. In this thesis, to increase the reliability and the strength of storylines, scenarios assumptions were based on a causal analysis. Following the conceptual approach proposed in Step 3 'Driving Forces Analysis', for each scenario the causal analysis distinguished between future driving forces, future proximate factors and future changes. The rationale of this approach is based on the fact that assessing causal relationships assist in predictive studies (Serneel and Lambin, 2001) and can be summarized as follows: if in the present baseline scenario certain drivers have led to certain proximate factors that caused certain changes, in an alternative future scenario, depending of the dominant driving forces some changes will continue to take place, while others will end or being less important due to the disappearance or the decrease of their respective driving forces.

Based on the causal analysis, a set of assumptions were established for each scenario and translated into comparative tables and diagrams that help to have an overview of the different scenarios to develop the storylines with stakeholders. The tables and diagrams constitute the skeleton or the basis of the proto-storylines that are not fully developed as narratives yet in this step. The development of storylines in two stages was made considering the participative approach followed in this methodology. Therefore, although storylines could be developed by a group of experts based on the casual analysis technique, they were contrasted and enriched by stakeholders to be coherent with the pro-participatory approach followed by this thesis.

4.1.6 *PFS Step 6*: Scenarios validation and storylines enrichment

A crucial final step of the scenarios methodology presented in this thesis is the validation of scenarios (scenarios assumptions and proto-storylines) with stakeholders. Different techniques can be used to discuss results –e.g. round-tables, focus groups or individual interviews- the selection ultimately depends on the characteristics and limitations of the study as well as the stakeholders’ commitment to collaborate as a group. Whereas discussing results in a group can be an enriching process, according with Tompkins et al. (2008) some individuals may not be able to articulate their preferences in a group setting, and therefore in some cases individual participatory processes can be preferred to collective ones. In this thesis, individual participation was chosen to validate scenarios results in order to guarantee the freedom of expression as well as the confidentiality of the views expressed by the stakeholders involved.

To apply the method in the study site, eleven different representative stakeholders (identified during the "stakeholders' prioritization", on Step 1, were involved. Individual semi-structure interviews were held based on a 2-stages approach, in which the PFS results were first presented to participants on different formats, and second, the results were discussed by semi-structured interviews[3]. Interviews were based on fourteen questions regarding the plausibility of each of the scenarios and their characteristics according to the themes presented in Questionnaire Q-3 (Appendix). Observations and comments were taken into account to complete and improve the storylines, which were fully developed as narratives. Final scenarios were as well discussed with a group of experts who provided valuable insight that was taken into consideration and included in the Discussion Chapter of this thesis.

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[3] For more information on the Interview phases for scenarios validation, see Table A-3 (Appendix).

4.2 Artificial Intelligence for Future Spatial Modelling

The spatialization of future scenarios was performed through the application of a Land Use Land Cover Change (LUCC) Model. To select the model two literature reviews were performed: the first, to identify the most suitable land use change *modelling approach*, and the second to select the most suitable *model* for spatializing scenarios according to the goals of this thesis. Once the model was selected, the second part of the methodology was dedicated to the application of the model in the study site, following previous works and including some new methodological additions specially developed for this thesis.

4.2.1 Selection of the LUCC Model

A literature review was performed to compare five different LUCC modelling approaches: four Artificial Intelligence (AI) based approaches, and one non-AI based. The approaches based on AI techniques included: i) Cellular Automata, ii) Agent-Based Models (ABM), both from the field of 'artificial life'; iii) Genetic Algorithm, belonging to the intelligent stochastic optimization processes; and iv) Artificial Neural Networks, from the field of evolutionary computing. The non-AI based modelling approach included in the comparative analysis was the Empirical-Statistical modelling approach, which was explored given its wide application and tradition in land use change modelling research. All modelling approaches were compared in terms of the models' strengths for LUCC analysis, their spatial nature and their capacity to work with geo-data.

After the review of the different LUCC modelling approaches and taking into consideration the conclusion of that review (i.e. the potential of Cellular Automata for LUCC modelling), a comparison between four different LUCC models was performed: three Cellular Automata-based models and one Empirical-Statistical based model. The four models were compared in terms of their goal, the developer organisation, the spatial allocation of change mechanism, the land use maps needed for the calibration, the spatial resolution, the factors included to explain land use change, the types of land use changes taken into account, the inclusion of a validation procedure in the model, the availability and the existence of official training material.

After the comparison, Dinamica EGO was finally the model selected for this thesis. The model simulate LUCC dynamics using both Markov Chain Matrices to determine the quantity of changes and a Stochastic CA approach to reproduce spatial patterns of changes based on transition probability maps (Soares-Filho et al.,2001; 2002). In terms of the model architecture, it consists in a software environment written in C++ and Java, with a graphical interface that allows the sequencing and integration of different algorithms to build models and sub-models as well as the management of different data in form of matrices, tables, equations, constants and spatial data. The model has been applied to a wide variety of research fields to simulate different LUCC processes at regional and local scales simulating processes such as urban growth (Almeida et al., 2003) or tropical deforestation (Soares-Filho et al., 2004). The model's customization for this thesis is presented in the Methodology (Chapter 4).

4.2.2 Application of the Cellular Automata model on the study site

Dinamica EGO model was applied in the study site on three stages (as shown in Figure 12). First, an acquisition, selection and transformation of the model's input data was undertaken, considering the objectives of this thesis and the study site spatial characteristics. The second phase consisted in the calibration of the model, based on a retroanalysis, that is, a simulation from the past to the present. The retroanalysis allowed to set the transition rules and the probabilities of change, which helped to explain the location, amount and spatial characteristics of the Land Uses and Cover Changes (LUCC) occurred in the study site. During the calibration, the relationships between a variety of explanatory factors (physical and socio-economic) that influence the land conversion processes, were also analyzed. Statistical-spatial tests based on fuzzy approaches were performed to assess the accuracy of the retroanalysis. Finally, the third and last phase, consisted in the simulation of future spatial scenarios according to the parameters established during the calibration phase. In addition, some parameters were modified according to an external procedure (scenarios parametrization) that helped to translate the selected Participatory Future Scenario, obtained during the first phase of this thesis, into readable parameters for Dinamica EGO model.

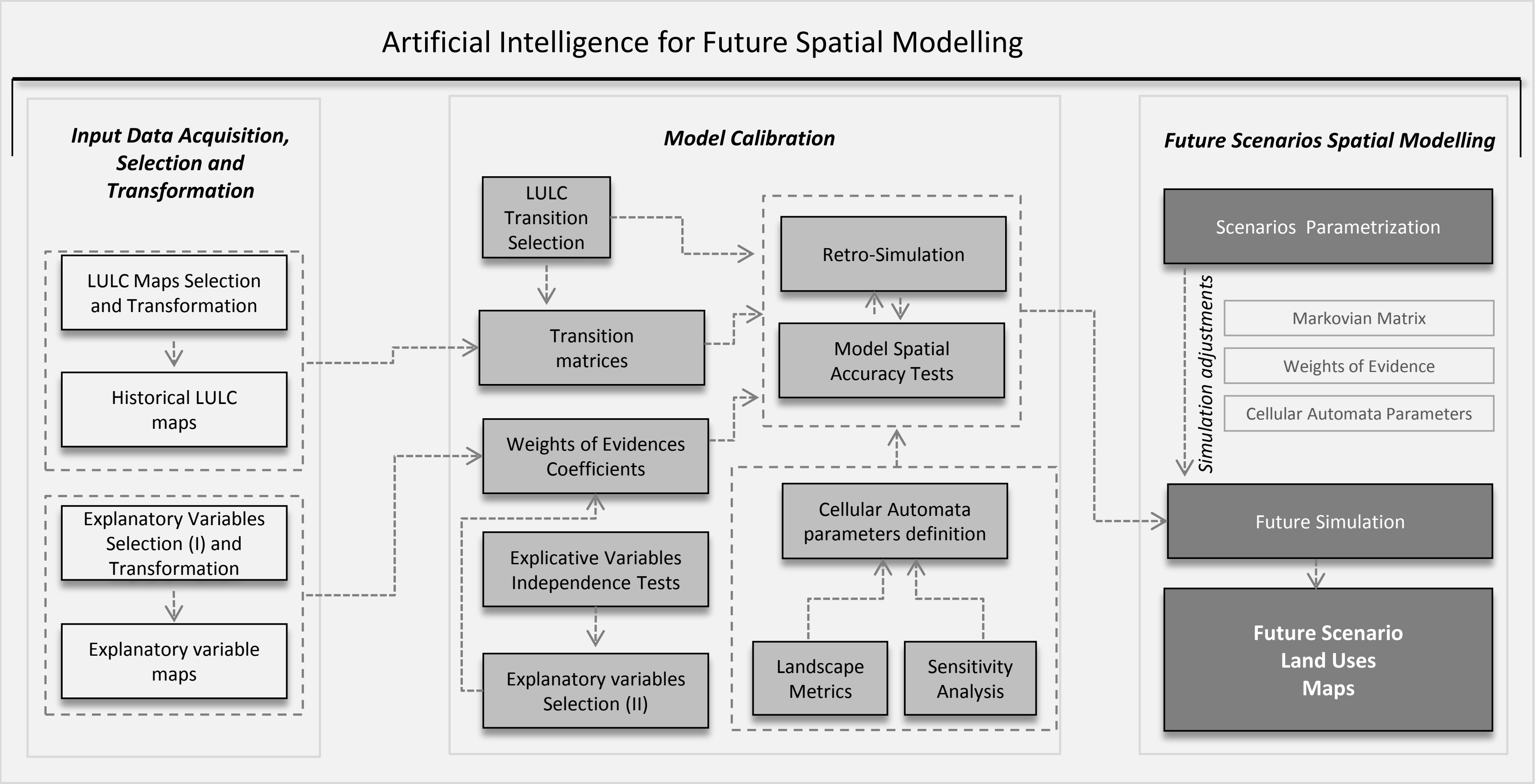

Figure 12. **Artificial Intelligence for Future Spatial Modelling methodology.** Methodology designed to apply the Cellular Automata model in the site, divided in three stages: input data preparation, model calibration and future scenarios modelling. The components of each stage as well as the relationships between them are depicted in the figure (Self-elaboration)

i) Input data acquisition, selection and transformation

Two different categories of input data were required to apply Dinamica EGO model: Land Use/Land Cover (LULC) maps and explanatory variables maps. For both categories of data, it was first necessary to acquire and select a variety of datasets and second, transform them into readable parameters for the model.

Land use/land cover maps were acquired from the Regional Environmental Network System of the Andalusian Ministry of Environment (REDIAM, 2013-2015). Two LULC maps were necessary for the model, one for the initial year (Ti) and another for the final year (Tf) of the calibration period. The selection of Ti and Tf maps was based on two criteria. First, a review of previous works showed that a time span of less than 10 years is more appropriate to model multiple land use changes in highly dynamic areas, particularly when urban processes are included (e.g. Fuglsang et al., 2013). Second, as explained in the Introduction Chapter, this thesis is focused on the analysis of multiple and simultaneous changes occurring in coastal areas during rapidly changing /highly transformative times.

Explanatory variables maps were created upon data acquired from the extensive geo-data bases “DEA 100” (ICA, 2010), as well as the Regional Environmental Network System of the Andalusian Ministry of Environment (REDIAM 2013-2015), including the special geo-data series from CMA (2009). To identify adequate explanatory variables, a selection procedure based on four conditions was applied as presented in Equation 1.

Explanatory variables had to be processed into a readable data architecture for Dinamica EGO. All the data was transformed to raster, with a cell resolution of 10 meters, and the same geographic coordinates and reference system. Some of the explanatory variables required as well further modifications, e.g. transformation into maps of distance.

(Equation 1)

$$W = \{vi, \dots\dots\dots, vn\}$$

$$Z \in W$$

$$vi : Z \rightarrow (C1 \vee C2) \vee (C3 \wedge C4)$$

$$W = \mathit{Finite\ group\ of\ possible\ explanatory\ variables}$$

$$vi = \mathit{Explanatory\ variable}$$

$$Z = \mathit{Group\ of\ explanatory\ variables\ of\ interest\ for\ the\ model\ calibration}$$

$$C1 = \mathit{condition\ 1\ 'spatial\ nature'}$$

$$C2 = \mathit{condition\ 2\ 'existence\ within\ the\ study\ site\ limits'}$$

$$C3 = \mathit{condition\ 3\ 'previous\ studies\ evidence'}$$

$$C4 = \mathit{condition\ 4\ 'identification\ by\ stakeholders'}$$

ii) Model Calibration

Model calibration included: i) a multi-temporal analysis to quantify the amount of LULC occurred in the study site during the calibration period; ii) a quantification of the influence of the explanatory factors on each LULC change through a conditional-probability based method; and iii) adjustment / definition of the Cellular Automata parameters by a sensitivity analysis. The three stages of the calibration are described on the following paragraphs.

- *LULC Multitemporal Analysis*

This step allowed to quantify the LULC changes by land class during the calibration period, without taking into account the location of those changes. Land Use/Land Cover changes (LUCC) were quantified by a transition matrix obtained from the cross-tabulation of the initial and final land use maps following Soares-Filho et al. (2002). The transition matrix was then transformed into a Markovian Chain Probability Matrix, which compute the average percentage of each land class that change to another class each year. Taking into account that each LULC transition had to be analyzed in depth during the calibration, this thesis proposes a technique to select the most relevant transitions. The technique, tested on site, was based on percentage of change in the two different matrices used by the model, according to the following criteria:

- If the percentage of change > 0.1 in the Multi-Step Matrix and > 1 in the Single-Step Matrix: the transition was considered very relevant.

- If the percentage of change > 0.01 in the Multi-Step Matrix and > 0.1 in the Single-Step Transition Matrix: the transition was considered relevant.
- If the percentage of change < 0.01 in the Multi-Step Matrix but > 0.1 in the Single-Step Transition Matrix: the transition was considered marginally relevant.
- If the percentage of change < 0.1 in the Single-Step Transition Matrix: the transition was considered not relevant.

- *Explanatory variables influence Quantification*

To identify and quantify the effects of the explanatory variables over land use changes, the Weights of Evidence Method (Goodacre et al., 1993; Bonham-Carter, 1994) was applied in Dinamica Ego model as described by Soares-Filho et al. (2002, 2004). The Weights of Evidence Method (WoE) is based on a Bayesian approach in which the weight of each variable for each transition is calculated by a conditional probability analysis. Non-statistically significant WoE were eliminated following Soares-Filho et al. (2002). In addition, to ensure the spatial independence assumption among the considered variables (i.e. avoiding double-counting effect of factors), two correlation analyses were performed in the model: Cramer´s Coefficient and the Joint Information Uncertainty (Bonham-Carter, 1994). These tests showed the degree of spatial dependence between the explanatory variables, based on the ratio of overlapping areas. For the correlation analyses, according to Ximenes *et al*. (2011), the threshold value used to exclude a variable was >0.50 for both indexes.

- *Cellular Automata Function Definition*

After performing the Multitemporal Analysis, that allowed to quantify the LUCC in the study site during the calibration period, and assessing the influence of explanatory variables over those LUCC, the third element to calibrate the model was the definition of the Cellular Automata functions, which allowed to define the location and shape of possible LUCC.

The two available Cellular Automata transition functions of the model, based on stochastic selection algorithms, were used in this thesis: one to simulate the expansion/contraction of previous land use/land cover patches, the other to simulate the generation of new patches through a seeding mechanism, as presented by Soares-Filho et al. (2002). In order to apply the two CA functions in the study site, three parameters had to be defined, regarding size, isometry and variance of the patches. *Patch size* indicated the surface covered by the new patches generated by the CA function, either by expansion or sudden formation. *Patch isometry* was used to define the spatial shape (e.g. more linear or more isometric) of the new patches *Patch variance* allowed controlling the diversity in patch sizes (e.g. homogeneity vs. heterogeinity).

These three parameters had to be defined for the two CA functions for all the modelled transitions analyzed in the calibration. To date, there is not an established method to set the CA functions parameters. Previous works suggested the use of landscape analysis metrics combined with visual analysis techniques (Mas et al., 2010). In this thesis, both techniques were combined and integrated with and spatial accuracy test in an iterative process that here is called “Model sensitivity analysis to CA functions” and described below.

The model sensitivity to CA functions was assessed by a systematic, structured approach consisting in three steps: first, an external landscape analysis software (Patch Analyst) was used to calculate different landscape metrics indicators that helped to understand the spatial nature and characteristics of land uses/land cover patches in the study site. The indicators analyzed included mean patch sizes and associated standard deviation. Second, the three parameters of the CA function (i.e. size, isometry and variance) were initially defined using average values derived from the landscape metrics analysis. Third, two spatial accuracy tests were performed, based on the K-fuzzy similarity method developed by Hagen (2003) and integrated into Dinamica EGO model as described by Soares-Filho et al. (2001). The two tests were run into Dinamica Ego model to assess the spatial coincidence of the simulated map –with the defined CA parameters-with the real map. The tests provided both spatial and numerical results, indicating the areas of the study where the model accurately predicted changes as well as the percentage of spatial affinity or cells coincidence.

The two components of the sensitivity analysis, that is, CA parameters definition and model spatial accuracy test, were repeated iteratively until reaching an acceptable spatial accuracy result (what is discussed in Chapter 6).

iii) *Future Scenarios Spatial Modelling*

There is not a methodology to model alternative future scenarios in Dinamica EGO model. In this thesis, a process called "scenarios parameterization" is proposed. The process consists in choosing the predominant land use/land cover changes on a selected explorative scenario and translate them into spatial processes that the CA model can emulate. To facilitate this task, a

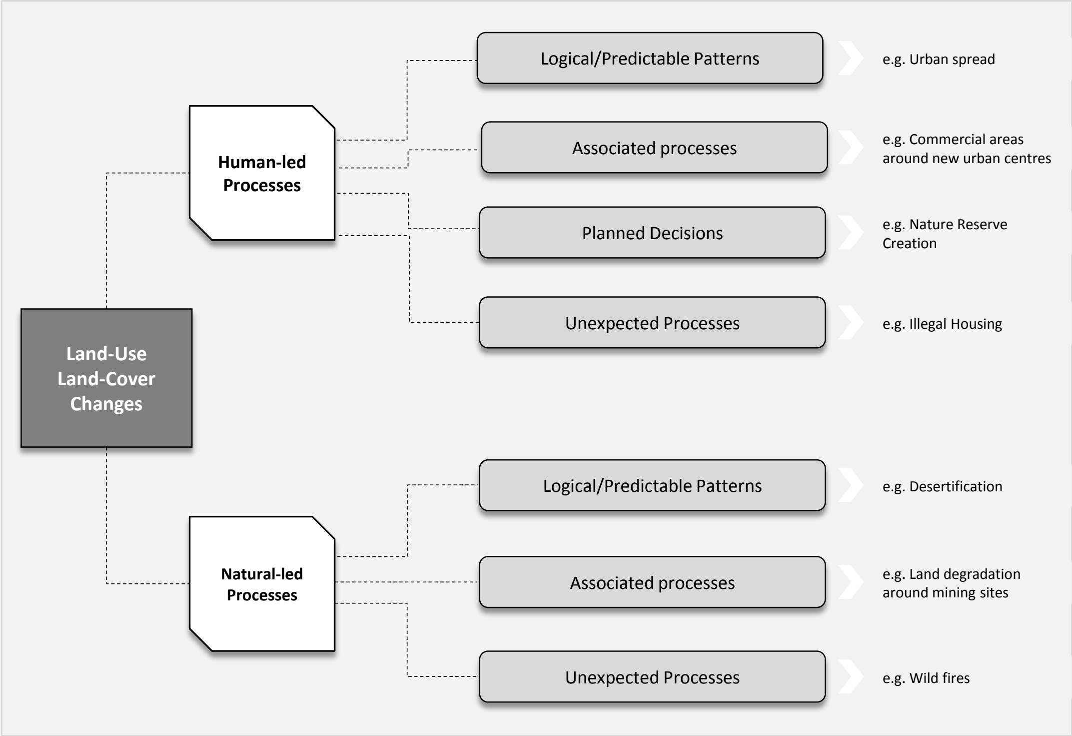

Figure 13. **Conceptual basis for scenarios parametrization.** This conceptual approach is intended to be of help to translate scenarios into readable parameters for CA- models (Self-elaboration).

conceptual basis is presented on Figure 13. Under this approach is assumed Land use Land/Cover Changes can be either human or natural-led processes. In both cases, changes can be explained by logical/predictable patters, associated processes to the logical patters, planned decisions (only for human-led processes) and unexpected processes.

These processes can be translated to the CA model by combining the different components of the model, that is, modifying the quantity of changes, location or shape of changes or patterns according to the process to be emulated. The following modelling structure is proposed for scenarios parametrization:

For logical/ predictable patterns (can continue a pre-establish trend or not):

- Markovian Matrix: conserving the original values for a Business as Usual behaviour of specific transitions or modifying the values to increase/decrease the rate of specific transitions.
- Weights of evidence: conserving WoE structure for a Business as Usual behaviour of specific transitions or modifying the structure to increase/decrease the rate of specific transitions.
- Cellular Automata functions: conserving the original isometry, variance and size values for a Business as Usual behaviour of specific transitions or modifying the parameters to increase/decrease the rate of specific transitions.

For associated process (associated to either logical patterns or planned decisions)

- Markovian Matrix: increasing/decreasing rates for specific transitions according to associated processes.
- Weights of evidence: increasing/decreasing the attraction/repulsion of WoE to specific transitions according to the associated process.
- Cellular Automata functions: modifying percentage of changes due to expansion or new patch formation according to spatial behaviour of the associated process emulated.

For planned decisions

- Weights of evidence: using WoE to define new favourable or restricted areas.

For unexpected processes

- Cellular Automata ‘patcher’: increasing patch formation (over expansion processes) to allow the generation of isolated new land uses.
- Cellular Automata stochasticity: increasing the variance and isometry of new patches.

4.3 Prospective Future Spatial Risk Assessment

Introduction

In this thesis, the methodology to assess the risk to human population on a selected future scenario for the study site was based on the risk approach presented on the State of the Art Chapter. The three components of the risk equation (hazard, exposure and vulnerability) were analyzed independently and later combined as shown in Figure 14.

First, coastal inundation hazard was assessed by integrating Regional Mean Sea-level rise projection with an extreme High Water Level produced by a 500 years return period tide. Future global Mean sea-level rise was derived from current global sea level models, while Regional Mean Sea Level for 2050 was calculated by an empirical approach. Extreme High Water Levels were calculated by an Extreme Value Analysis for a 1/100, 1/200 and 1/500 years tide. Both astronomical and meteorological components of the tide were taking into account. The final inundation level (sea-level rise for 2050 and 1/500 years tide) was spatialized following a bathtube approach. *Second,* future exposure was assessed on terms of land use/land cover exposure. The spatialized scenario obtained from the AI based modelling was used to emulate a possible future distribution of assets on 2050 on the study site. *Third,* vulnerability was assessed in terms of the human population affected. A projection of the population for the study site was performed based on historical data from official census from 1900. The population was projected to 2050 and population densities estimated for the future scenario, based on the urban expansion simulated by the Cellular Automata model.

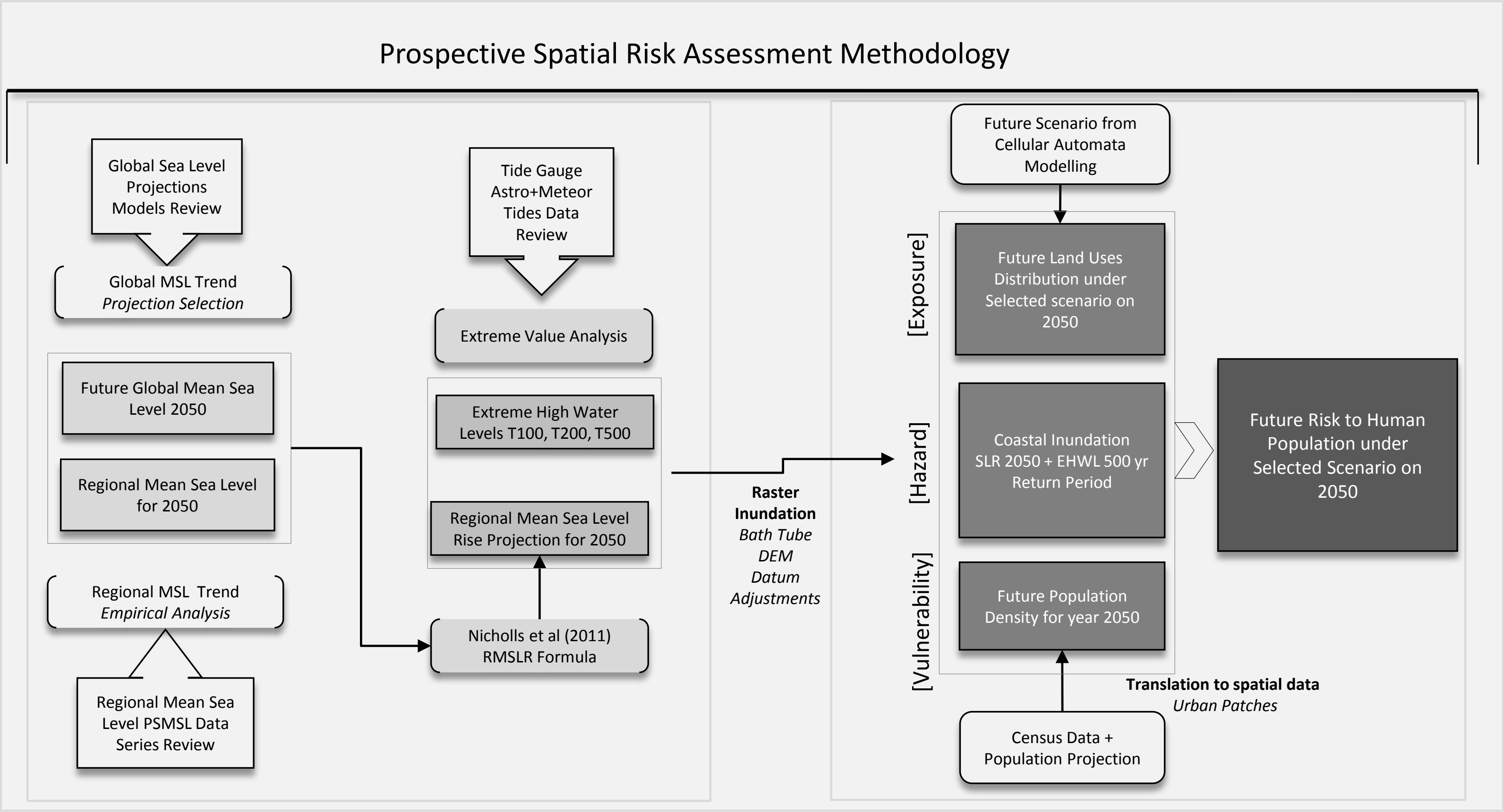

Figure 14. **Prospective Spatial Risk Assessment methodology**. The methodology is based on the analysis of the Hazard studied in this thesis (Future sea-level rise and Extreme High Water Levels), Exposure (distribution of future land uses, obtained by the modellization with the Cellular Automata), and Vulnerability (future population density), and their integration to spatially assess risk to human population in a selected scenario (Self-elaboration).

4.3.1 Hazard assessment: Coastal inundation

The hazard assessed in this thesis was a coastal inundation produced by a combination of sea-level rise (SLR) and Extreme High Water Levels. Coastal inundation was considered a critical hazard for the reasons given in Chapter 3, Study Site. Relative Mean Sea-level rise and Extreme Water Levels were assessed by different methods as described in the following paragraphs.

- *Relative Mean Sea-level rise (RMSLR)*

Relative Mean Sea-level rise (RMSR) was estimated following the formula proposed by Nicholls et al. (2011) as described in Equation 2.

(Equation 2) $$\Delta RSL = \Delta SL\, g + \Delta SL\, rm + \Delta SL\, rg + \Delta SL\, vlm$$

$$\Delta RSL = Change\ in\ relative\ sea\ level$$
$$\Delta SL\ g = Change\ in\ global\ mean\ sea\ level$$
$$\Delta SL\ rm = Regional\ variation\ in\ sea\ level\ due\ to\ meteo - oceanographic\ factors$$
$$\Delta SL\ rg = Regional\ variation\ in\ sea\ level\ due\ to\ changes\ in\ the\ earth's\ gravitational\ field$$
$$\Delta SL\ vlm = Regional\ variation\ in\ sea\ level\ due\ to\ vertical\ land\ movement$$

The formula was applied on the study site taking into account two considerations: a) the target year to assess the expected change in global sea -level was 2050, as this was as well the time horizon for the scenarios; and b) the components “regional variation in the gravitational field” and “regional variation due to vertical movements” were not assessed due to the low significance of these variables for the study site. Relative Mean Sea-level rise was therefore assessed as the combined effect of Global and Regional Sea-level Changes, which were analyzed as follows.

Global Sea-level Change for 2050 was first approached by a literature review of the most relevant SLR projections published during the last decade. The review, included process-based and semi-empirical models as well as synthetic and alternative methods to project Global SLR.

Sources included Rahmstorf (2007), IPCC-AR4 (2007), Pfeffer et al. (2008), Steffen (2009), Jevrejeva et al. (2012), Hunter (2012) and IPCC-AR5 (2013). Projections were compared in terms of expected Global SLR, inclusion of uncertainty range, model approach, consideration of Greenland and Antarctic Ice sheets and temporal scope of the model. A second comparison of the IPCC-AR5 SLR projections was performed, using the upper limits of the projections instead of the mean value, according to Nicholls et al. (2014).

Regional Sea-level Change for 2050 was assessed by an empirical approach following based on i) the analysis of historical records of Mean Sea-Level and Mean Sea-Level trend estimation; ii) the removal of the global sea-level change influence, and iii) the extrapolation of the regional sea-level trend to the target year, 2050.

The analysis of the historical Mean Sea-levels for the study site was performed using tide gauges data from the Permanent Service for Mean Sea-level (PSMSL, 2015), given their reliability in terms of data quality and control (Holgate et al., 2013). The Regional Trend of Mean Sea-level rise was then contrasted with the Global Trend, previously selected from the Global Projections Analysis, for the same period, that is, 1971-2010. The influence of the Global trend signal was removed as recommended by Nicholls (2011) and Fraile (2013).

- *Extreme High Water Levels (HWL)*

Extreme High Water Levels were estimated for the study site by a probabilistic approach. Recorded tide level data was used as a base for an analysis based on the Extreme Value Theory (EVT), a classical approach to deal with low probability events. To apply the method, first a review of tide gauge data availability was performed, considering quality and length of the series, gaps, as well as availability of data for both astronomical and meteorological components of the tides. Extreme Sea-level (ESL) can be assessed by the analysis of the total sea-level (astronomical + meteorological) or by the individual analysis of the meteorological and astronomical components of the tides. In this thesis the first approach, total sea level, was selected taking into consideration the recommendations given by Pugh (1987) and MAGRAMA (2011).

Once the data series was selected, the Extreme Value Analysis was perfomed on R environment and using in2extRemes model after Gilleland and Katz (2011). First the Block Maxima Method was applied to the data series to select the daily maxima sea-level. Resulting data was adjusted to a Generalised Extreme Value distribution (Gilleland and Katz, 2011). From the GEV function, the Returns Levels were obtained for a Return Period of 20, 50, 100, 200 and 500 years, with a confidence interval of 95%.

4.3.2 Future Exposure and Vulnerability

Coastal inundation, caused by the estimated mean sea-level rise for 2050 and an extreme High Water Level of a 1/500 years tide, was spatialized in a GIS environment (ArcGIS 10) using the bathtub approach following Poulter and Holping (2008). The bathtub approach was applied on the study site on a grid of 10 x 10 m cell size, using an 8-cells connectivity rule.

The Integrated Digital Elevation Model from the Regional Ministry of Environment (CMA, 2014) was selected to apply the bathtube approach. This DEM provides continues data and hydrological connectivity among the sea and the coast. Sea-level datum –data from tide gauges and the DEM) were adjusted to the same 0 (hydrological 0) according to the datum references (the datum adjustment diagram is shown on Figure A-17 in the Appendix).

The future exposure assessment was based on the exposed land uses (cells) of the future scenario. Future exposure for different land uses was quantified by spatial algebra operations in a GIS environment (ArcGIS 10).

Future vulnerability was assessed in terms of human population density. The study site population data was obtained from the National and Regional Census Systems and combined to reconstruct the population changes in the study site during the last century (1900-2010). Decadal data was used to perform a quadratic polynomial (which gave a best fitting value than linear and exponential models) projection of the population for the year 2050. Population density was calculated assuming population to be *uniformly distributed only* in urban areas (as the census data is for permanent population). Urban areas on 2050 were quantified as the sum of all urban patches simulate by the Cellular Automata model on the selected scenario.

CHAPTER 5: *Results*

Introduction to the results chapter

This chapter presents the results of the 3 phases of this thesis: Participative Future Scenarios, Scenarios Spatialization and Spatial Risk Assessment in Future Conditions. As explained in Chapter 1 ‘ Introduction’ each phase is complementary to the following one, and therefore all the results presented here are not just valuable as itself, but overall, in relation to the others. Some complementary information to the results is provided in the Appendix and indicated through the chapter..

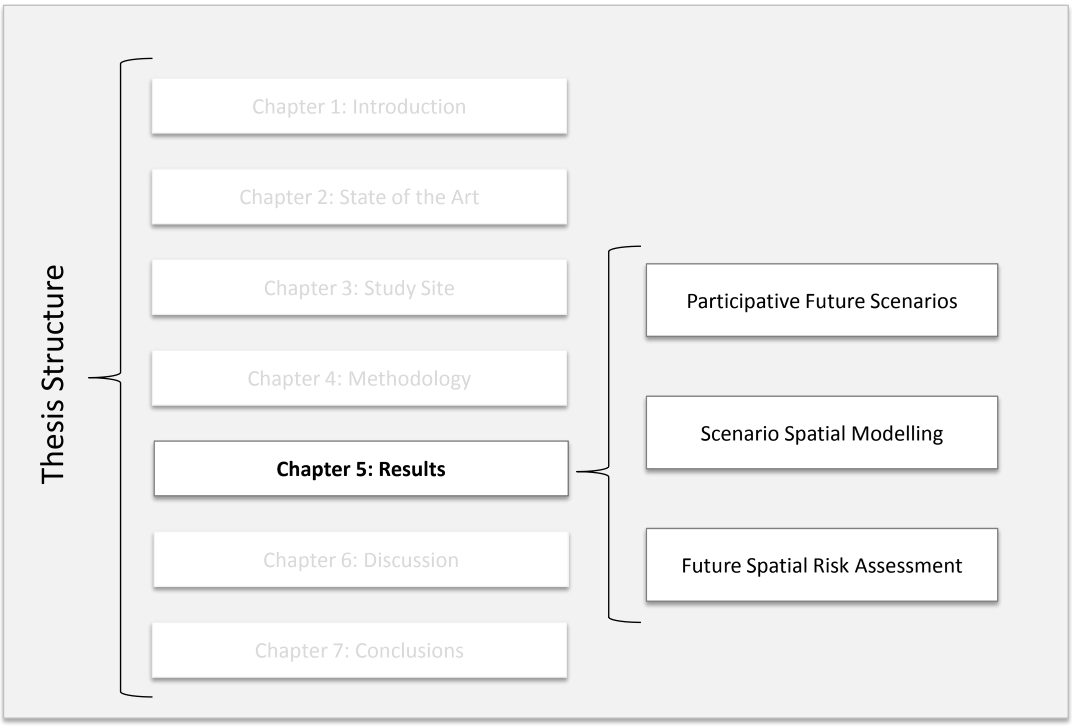

Figure 15. **Chapter 5 `Results’ presentation**. Three sections, corresponding to the three phases of the thesis, are presented on the Results Chapter: Participative Future Scenarios, Scenarios Spatialization and Future Spatial Risk Assessment (Self-elaboration).

5.1 Participative Future Scenarios

The PFS methodology sequence above described was tested in the study site in three different field campaigns over a two-year period, involving over 60 people and institutions that participate on a voluntary basis, as well as a group of experts that provided support[4] along the whole process also on a voluntary basis..

5.1.1 *PFS Step 1*: Scenarios Boundaries

Taking into account the goal and scope of this thesis, final boundaries were set as follows. The PFS temporal boundary covered 100 years, as driving forces were studied since 1950 and the scenarios were projected to 2050, which was considered an appropriate temporal horizon for stakeholders' visions.

5.1.2 *PFS Step 2*: Stakeholders Analysis

The stakeholders were identified through the Snowball Sampling Method and included: government bodies and agencies at the local, regional and national levels; public companies; large private companies (e.g. hotels, tour operators, real state agencies); small local businesses (e.g. bars, restaurants, shops); citizens groups; coastal users (e.g. tourists, sportsmen); workers unions and associations; neighbours and citizens groups; and NGO's among others, reaching a total of 64. The Social Network Analysis of the stakeholders allowed to estimate the weight, degree, direction and strength of the connections. Regarding "stakeholders weight" (Figure A-4, Appendix), the most relevant stakeholders, '*central stakeholders*', were: Local inhabitants,

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[4] Support included literature recommendations, advice for the field work design based on personal experience as well as discussions about the approaches used. The experts' team included representatives from universities, regional government and coastal planners.

Fishers, Chiringuitos [5], Hotels, Restaurants and Tourists. Other significant stakeholders were: the City Council of Ayamonte, the Chamber of Commerce, the Ship Workers Association, the National Directorate for Coastal Areas, Windsurf schools, State agencies, Nautical clubs, Small local business, Shellfish gatherers and the Construction Company *Iscasa*.

Regarding "stakeholders' connection degree" (see Figure A-5, Appendix), the best connected stakeholders were, by order of importance: the City Council, the Beach Bars, the Ayamonte Fishers Union, the Fishers, Restaurants, Hotels and the Ship Workers Association. Figure A-6 (Appendix) shows the predominant direction as well as the strength of the connections analyzed; the best-connected stakeholders, which presented bi-directional, strong connections among them, were the City Council of Ayamonte, Fishers, Chiringuitos, Hotels, Restaurants, the Ship Workers Association and the Fishers Union.

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[5] *Chiringuitos* are a special type of beach bars typical of Spanish coastal areas. They are located on the beach area, and usually operate only during summer season.

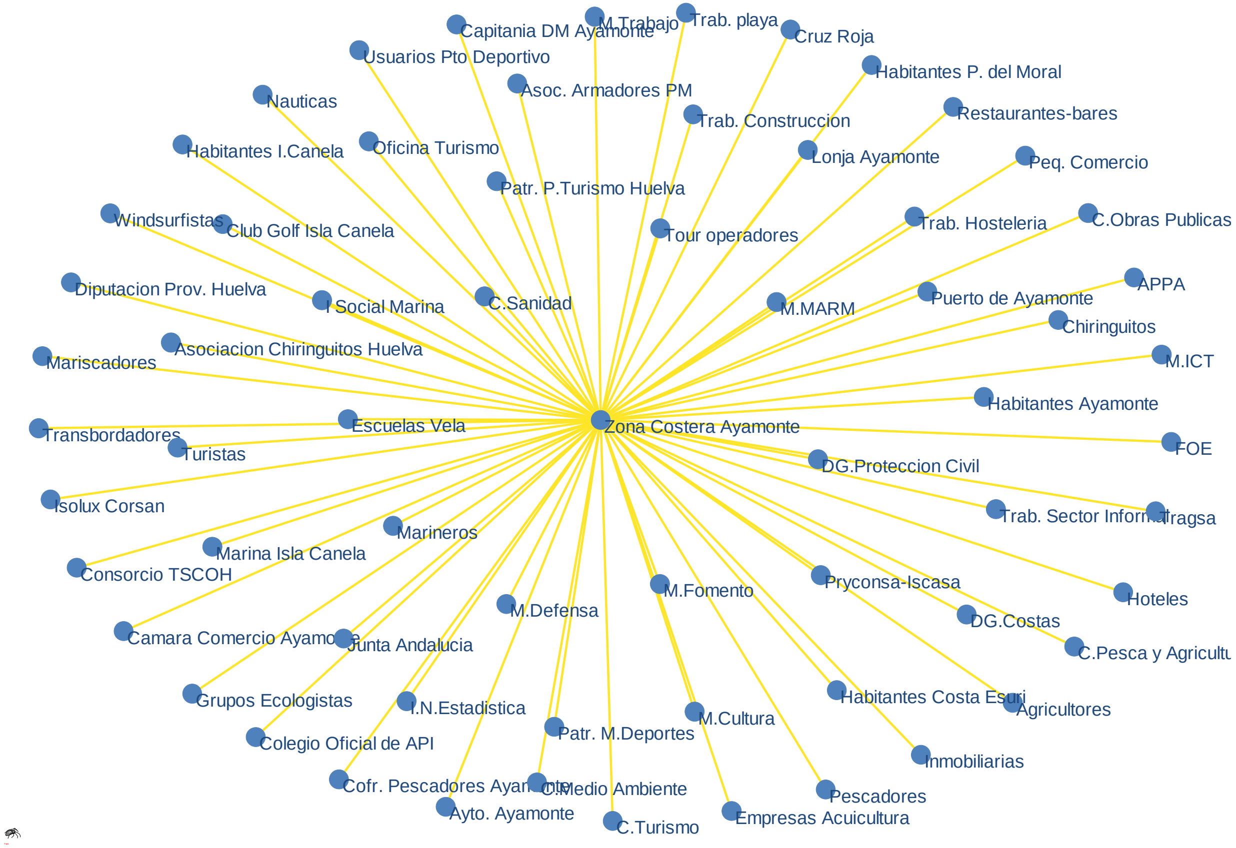

Figure 16. Stakeholders' Spectrum. The figure graphically present the 64 stakeholders identified in the study site through the Snowball Sampling Method, including government bodies at the national, regional and local levels, public agencies, private companies, small business and local communities, groups and associations among others (Self-elaboration).

5.1.3 *PFS Step 3*: Driving forces analysis

During the first phase of the analysis (see methodology chapter for details) the following changes were identified in the biophysical environment: shoreline morphology modification, sand bars position change, dunes destruction, loss of forest/shrubs surface, aquifer pollution, groundwater depletion and salinisation, fresh water pollution, river sediments decrease, and river discharge decrease. Changes detected in the socioeconomic environment included: population increase, urbanized area increase, salt marshes transformation into aquaculture farms or urban fabric, infrastructures expansion, surface dedicated to dry-land crops decrease, surface dedicated to intensive agriculture increase, appearance of areas dedicated to renewable energies, protected areas increase, protected heritage increase, increase of migration processes, fishing boats decrease and fishing catches increase.

As roots of these changes, a *preliminary set* of 17 driving forces were pointed out by stakeholders, including socio-economic forces (i.e. tourism), physical forces (i.e. erosion), political forces (i.e. renewable energies subsidies), and cultural forces (i.e. heritage conservation). All changes and driving forces are summarised in Table A-4 and Figure A-7 of the Appendix respectively. All the quantitative and qualitative data crossed through the application of a causal analysis, helped to differentiate a final set of 11 underlying driving forces, 24 proximate factors and 23 changes. Figure 17 depicts the causal analysis results and it shows how several driving forces produced each coastal change while simultaneously each driving force produced several direct changes on the system. The causal analysis clearly showed that ‘Tourism Expansion’ and ‘Public Policies Implementation’ were the most impacting driving forces attending to the number of changes produced in the coastal system.

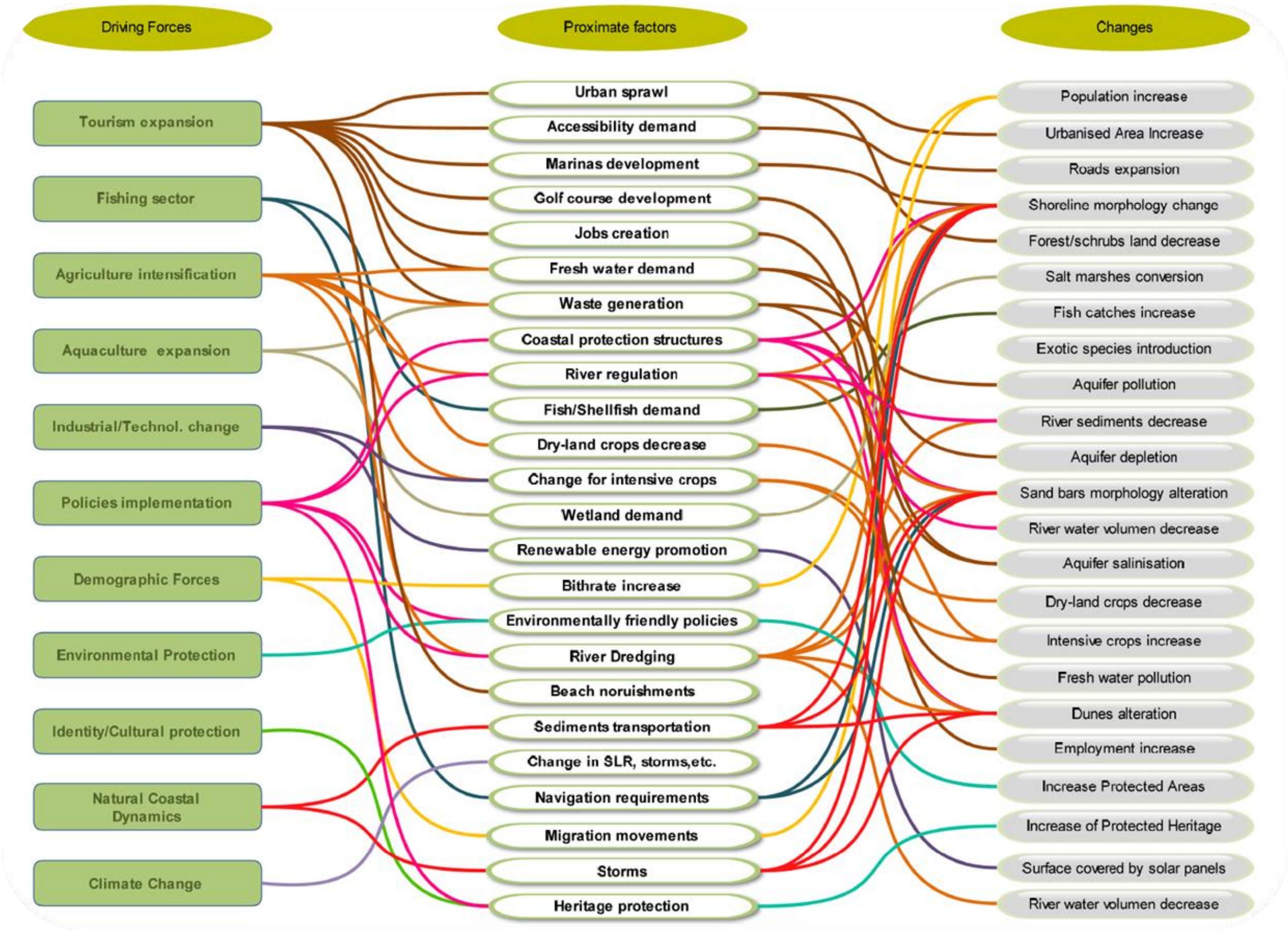

Figure 17. Causal Analysis for the study site. The diagram indicates the connections between the driving forces, proximate factors and changes identified in the study site according to the empirical-participative methodology explained on Chapter 4. The multicausality of changes is clearly appreciated in the figure (Self-elaboration)

5.1.4 *PFS Step 4*: Scenarios framework

During the first stage, the Impact Factor Grid[6], which helped to identify the critical elements on the system, indicated that 'Public Policies Implementation' and 'Climate change' were decisive driving forces because they strongly affect the system while are little affected by the system, at the local scale of the study. On the other hand, the economic forces 'Tourism Expansion' and 'Agriculture Intensification' have had a very strong influence in the system over the past 50 years. 'Demographic Forces' was identified as an ambivalent force, that is, it influences and is influenced by the other forces. Whereas 'Fishing', 'Aquaculture' and 'Environmental protection' were passive elements, greatly affected by other forces, and 'Identity Heritage Conservation' shown almost no influence over the system. The findings of the Impact Factor Grid were used also to support the exploration –performed with the stakeholders- of the major uncertainties of the system, which on the case study were: Which will be the future of tourism after the current economic crisis? Will the economic model continue to be the same or it will change? What will happen with the fishing sector? Will it finally disappear? There is any possibility of re-developing this sector? Is there a real possibility to exploit renewable energies in the area? If yes, which ones? What should be done regarding the management of the coastline and wetlands? Will there be some protective measures? And finally, how will climate change affect the socio and biophysical systems?

The second phase results –*scenario logics*- were obtained based on the critical driving forces previously identified and the uncertainties detected. The PFS logics obtained, shown in Figure 18, was characterised in the following terms: the current economic crisis context was considered as an inflection point. After that inflection point two options appeared: choosing a conservative approach, which means to continue the existing model of the exploitation of tourism, or taking

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[6] The Impact Factor Grid is shown in Figure A-8, Appendix.

an unusual approach, looking for other alternatives of economic and social development on the area. Is interesting to note public policies are fundamental shapers on the study site and can strongly affect other driving forces such as tourism or environmental protection degree if taking an unusual approach, another two options of development were identified: one based on the recuperation of old sectors (fishing and aquaculture) and another based on innovative approaches. Moreover, the innovative approaches could be more technological oriented (renewable energies development) or sustainability oriented (reconversion of all economic activities). This logic provided four alternative scenarios: Scenario 1 (Intensive Tourism Forever), Scenario 2 (Fishing Sector Rebirth), Scenario 3 (Green Energy Power) and Scenario 4 (Paradigm Switch).

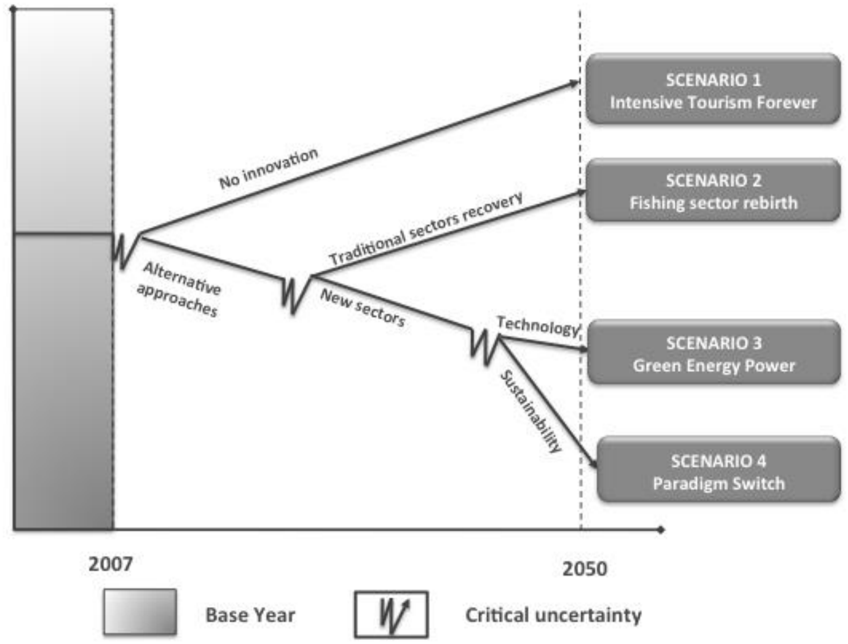

Figure 18. Scenarios logics for the study site. Four exploratory scenarios were obtained after applying the Path Exploration Method. The figure illustrates how the path evolves from the baseline year (2007) to the future horizon year (2050) and how critical uncertainties are used as triggering points to explore alternative futures (Self-elaboration)

5.1.5 *PFS Step 5*: Scenarios Description

Table 2 offers a summary of the main characteristics of each scenario in terms of main economic sector, landscape, public policies, demographics, and environmental protection, society and climate change potential effects. The table shows how on Scenario 1 the predominant economic sector would be tourism, and public policies and planning would be oriented to its promotion, moreover environmental protection would not be a priority on this scenario. In demographic terms an increase in population is expected, and in societal terms a gradual loss of traditional values and local culture and traditions are expected. Climate change is expected to pose important threats to this scenario, potentially causing economic damages to touristic sector as well as entailing a high risk for the population, that are heavily dependent on the coast in this scenario.

The characteristics of all scenarios were discussed with stakeholders and proto-storylines based on diagrams were developed accordingly to create a general picture of each scenario. As an example, Figure 19 shows the causal diagram for Scenario 1 [7](Intensive Tourism Forever), which synthetically shows the potential driving forces, proximate factors as well as potential changes under this scenario. As the figure shows, the proximate factors identified for Scenario 1 included: marinas development, accessibility demand, golf courses and accommodation demands among others. Some of the potential changes identified on this scenario included: wetlands decrease, urbanised areas increase, infrastructure expansion, new build-up areas near the sea and rivers, population increase, among others.

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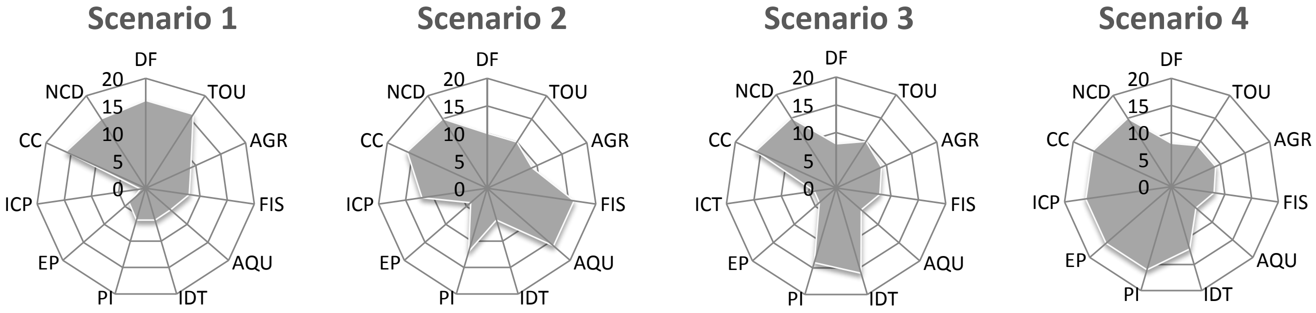
[7] See Appendix, Figures A-9, A-10 and A-11 for the diagrams developed for scenarios 2, 3 and 4 respectively.



Scenarios' diagrams. DF: demographics; TOU: Tourism; AGR: Agriculture; FIS: Fishing; AQU: aquaculture; IDT: Industry; PI: Policies Implementation; EP: Environmental Protection; ICP: Identity cultural protection; CC. Climate Change; NCD: Natural Coastal dynamics.

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Main economic sectors	Tourism	Aquaculture and fishing	Renewable Energies	Diversified economy
Landscape	Highly urbanized beach and river side. Infrastructure growth	Aquaculture farms growth over the wetlands	Offshore and Inland windpower farms and solar panels fields	More green spaces, more room for the river and the sea
Public Policies	Urbanisation promotion Low protection of environment	Policies promoting aquaculture/ industrialization	Green energies policies	Environmental and cultural protection. I&D promotion
Demographics	High population increase	Not large population increase	Not large population increase	Population decrease
Environmental protection	Low	Not especially relevant	Green technological approach	High . Sustainability
Society	Loss of traditional community values/traditions	Recovery/Transformation of the traditional fishing culture	Potential changes in community character influence by the technological sector	Identity and traditional values partially preserved; new values potentially emerge
Climate Change potential effects	Major impacts/losses on tourism sector (e.g. from, SLR, marine extreme events, heat weaves). High population exposure.	Major impacts/losses on aquaculture farms (e.g. storms, SLR) and fishing sector (e.g. SST)	Major impacts/losses on offshore wind farms (e.g. from storms & SLR)	Less dramatic effects. Economic sectors spatially distributed over the territory. Population less exposed.

Table 2. Description of the four exploratory scenarios developed. Main features explored for each of the four PFS developed for the study site (Self-elaboration)

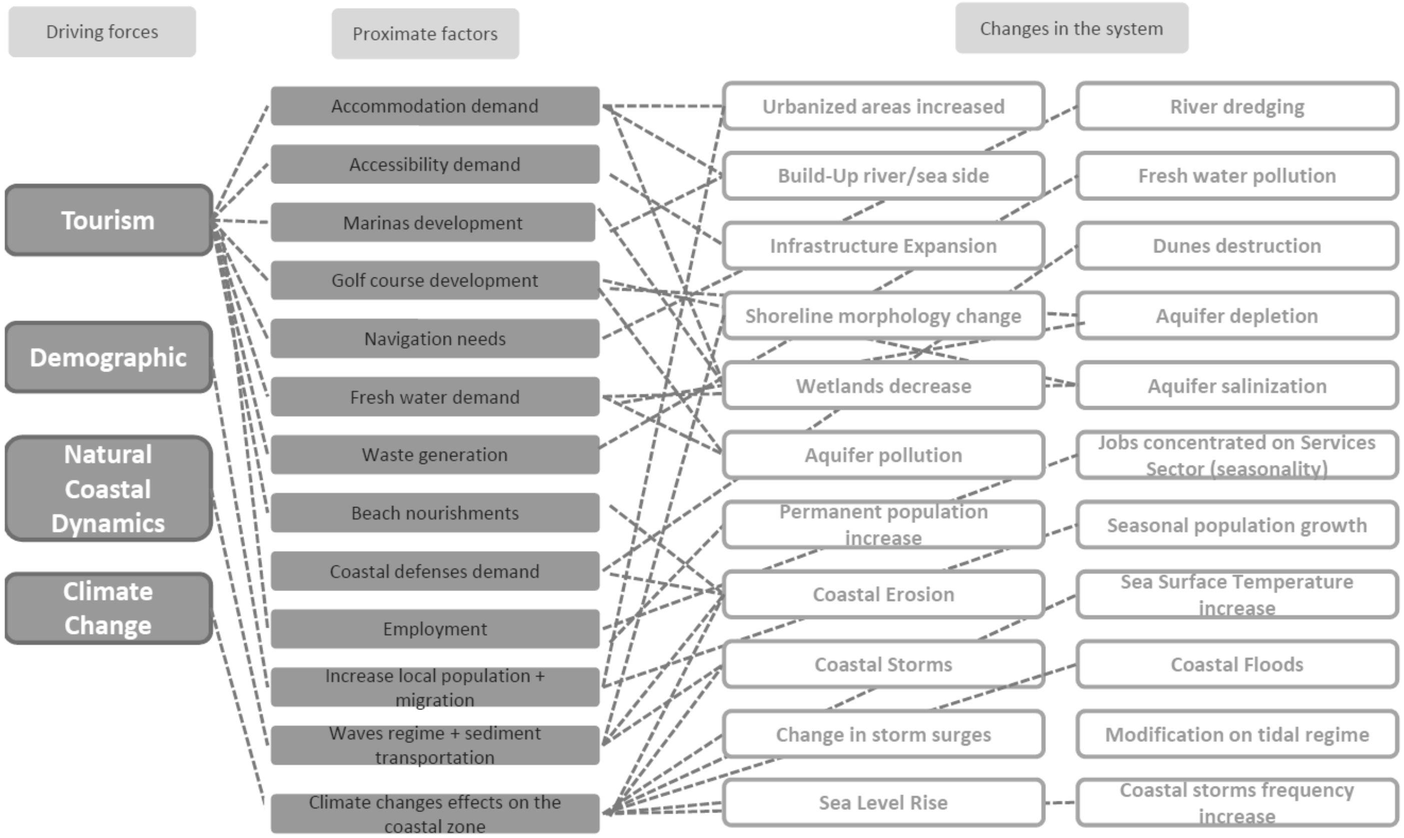


Figure 19. **Storyline diagram for Scenario 1**. The diagram shows the predominant driving forces under the explored scenario as well as the possible proximate factors derived and potential changes in the system based. Storyline diagrams like this were used to discuss scenarios results and develop storylines with the stakeholders (Self-elaboration).

5.1.6 *PFS Step 6*: Scenarios validation and storylines enrichment

The four scenarios were validated by the stakeholders through 11 extensive, individual interviews. Validation results are summarised in Table 3. During these interviews three major conclusions were obtained: i) All four scenarios were considered valid, that is, plausible in the study site according to interviewees views and experience; ii) Scenario 4 was selected as the preferred one by the majority of participants; and iii) Scenario 1 was considered the most plausible among the interviewees and selected as the one to be used for the spatialization phase. Additionally, the participants provided inputs to enrich the storylines.

After the validation with the stakeholders', a second validation was performed with a group of experts, which also provide insights to increase reliability, robustness of the scenarios, e.g. the inclusion of existing planning schemes. Both the stakeholders and experts views were taken into account to develop the resulting four storylines associated to the 4 scenarios (summarised in the Appendix, Tables A-5 to A-8).

Theme Explored	**General conclusions**
Scenarios plausibility	All interviewees considered the 4 PFS were plausible for the study site
Scenario considered most probable	Most interviewees (85%) considered Scenario 1 as the most plausible
Scenarios least probable	Most interviewees (80%) considered Scenario 4
Reasons why scenario 4 was considered less probable	Lack of capacity Lack of information Problems at the policy-making level Lack of entrepreneurship Lack of (political) direction
Scenario considered more profitable	Most interviewees (80%) considered scenario 1 would be the one that bring more economic revenues for the municipality (although tourism sector vulnerability and seasonality was recognised).
Favourite scenario	80 % Scenario 4; 20 % Scenario mix
Suggestion of alternative scenarios	None (only suggestions to enrich the obtained PFS)
Touristic sector considered as the solely alternative for the municipality	85% considered not the only, but the principal
Foresight exercises	100% considered they are useful for coastal planning
Participative processes	100% interviewees considered participative processes should be included in real coastal planning
Climate Change	100% interviewees considered climate change should be included into coastal planning for the mid and long term
Most vulnerable scenarios regarding climate change	Scenario 1 and 3 were considered the most vulnerable to climate change possible effects
Scenarios promoted	If the interviewees were decision-makers they would promote Scenario 4 (80%) or a mix of different scenarios (20%)

Table 3. Scenarios validation by stakeholders. Summary results obtained from the on-site application of the Questionnaire Q-3 (Appendix) through individual, extensive interviews (Self-elaboration)

5.2 Artificial Intelligence for Future Spatial Modelling

5.2.1 Model Selection Results

As Table 4 shows, *Genetic Algorithm* and *Artificial Neural Networks* present a great potential for specific stages of LUCC modelling -e.g. selecting the input variables (Pijanowskia et al., 2002) or optimising land uses spatial configurations (Seixas et al., 2007) - but these models cannot be used by themselves for a comprehensive spatial modelling analysis and need to be integrated with other modelling approaches. As noticed by Wu and Silva (2010) *Agents-Based Modelling* (ABM) and *Cellular Automata* (CA) do not have this limitation and therefore they are both rapidly gaining ground and being increasingly implemented in LUCC studies. Whereas ABM is focused on the human influence over LUCC and it is a recommendable approach to represent the 'non-spatial dynamics' of LUCC by incorporating the social processes on decision making (Matthews et al., 2007), Cellular Automata is a powerful approach to simulate the 'spatial dynamics' given their natural affinity to represent complex spatial forms through relatively simple rules (White and Engelen, 1997). In addition Cellular Automata models show a high capacity of performing dynamic spatial modelling, as they can easily incorporate geographic and remote sensing data and they can integrate a diversity of other models, including ABM. Although Empirical Statistical models show a strong potential to incorporate the influence of drivers of change and can operate with spatial data, an important drawback is the fact that the linear approaches of statistics do not accurately represent the complexity of land use changes and can constraint simulation (Koomen and Stiwell, 2007).

Modelling approach	**Strengths for LUCC analysis**	**Spatial nature**	**Capacity to work with geo-data**	**Examples**
Non-Artificial Intelligence Approaches				
Empirical-Statistical Models	• Can provide information on the behaviour of key drivers of change. • Data can be managed at multiple scales.	No	If coupled with other model	CLUE , CLUE-S Verburg et. Al., (2002) Verburg and Overmars (2009)
Artificial Intelligence-based Approaches				
Cellular Automata	• Show a strong potential to represent spatial processes at the local scale. • Can replicate real-world spatial patterns, particularly fractal structures.	Yes (cells/ grid)	Yes, natural affinity to work with spatial data	SLEUTH Janz et al. (2004)
Agent-Based models	• Can incorporate individual decision-making and the interactions with the environment. • It is possible to include cross-scale feedbacks.	No	If coupled with other model	FEARLUS Ponhill et al. (2001)
Genetic algorithm	• Can deal with nonlinear optimization problems (optimal spatial configuration of land uses). • Can help to define land allocation rules.	No	If coupled with other model	Seixas et al. (2007)
Artificial Neural Networks	• Useful for land cover classification/cluster and land pattern learning. • Can help to select suitable input parameters for LUCC models.	No	If coupled with other model	Pijanowski *et al.* (2005)

Table 4. Comparison of various LUCC modelling approaches (Self-elaboration)

As deduced from Table 5, the two models with a bigger potential for this research are the CLUE and Dinamica EGO models, given the flexibility of the model in terms of spatial resolution, the possibility to model multiple land use changes, the variety of factors that can be included in the model to explain LUCC, the availability of training material (e.g. developers' scientific papers, general guidelines, course offering, etc.) and the free availability of the model for research purposes. After a deep comparison of models, Dinamica EGO was considered to present a greater programming flexibility, allowing the construction of sub-models within the model, customising the model steps creating nested iterations, dynamic feedbacks, linking the model to external models, creating independent sub-regions inside a model and other customizable options. The high flexibility of Dinamica EGO was considered its major advantage, but there were other positive sides of this model over CLUE, such as the fact that it needs less external data processing and analysis (e.g. most operations can be performed within the model), it is compatible with more data formats (e.g. CLUE only works with ASCII files while Dinamica EGO works with GeoTiff, ERmapper and ASCII) and it presents regular and frequent updates and bugs fixing by the developers.

Model	Goal	Developer	Spatial allocation of changes mechanism	LUCC maps for calibration	Spatial resolution	Factors included to explain land use change	Land use changes	Validation procedure included in the model	Availability	Official training material
CLUE (Empirical-Statistical)	Allocating multiple land use change in a flexible way	VU University Amsterdam	Logistic gression alysis and cision-rules	At least 2	Changeable (Designed for <1x1 km)	Biophysical (e.g. precipitation) and Socio-economic (e.g. economic conditions)	Multiple	No	Free for research purposes	Yes
SLEUTH (CA)	Simulating urbanisation processes	California University	Self-modifying cellular automata	5 for urban uses	1 km to 30 m	Six: slope, land use, urban, exclusion, transportation, and hill shading	Urbanisation	No	Free	Some
Metronamica (CA)	Simulating different LUCC at the regional scale	Research Institute for Knowledge systems	CA transition rules	At least 2	Changeable (Max. 25 x 25 m)	Biophysical and Socioeconomic	Multiple	No	Free	No
Dinamica EGO (CA)	Modelling multiple ,complex LUCC in a flexible environment	University of Minas de Gerais	Marcov chains and CA	At least 2	Changeable	Biophysical and Socioeconomic. Unlimited number.	Multiple	Yes	Free for research purposes	Yes

Table 5. **Comparison of specific LUCC models.** Comparison based on the main characteristics and features of interest for this thesis (Self-elaboration).

5.2.1 Cellular Automata Modelling Results

Input Data Acquisition and Preparation

Applying the two criteria specified on 4.2.2, the period 1999-2007 was considered as the most representative time span to assess complex land use changes in the site. The selected LULC maps: 1999(T0) and 2007 (Tf), were based on CORINE land cover classification and were reclassified into 10 representative land use/land cover classes: urban, green/recreational, industrial 1, industrial 2, crops, shrubs, wetlands, beach, water and non-vegetated.

Input Data	Acquisition Original Data	Transformation	Additional operations
Land use/Land cover Maps			
LULC Map 1999	Andalusian Ministry of Environment	Vector to raster + AT*	Reclassification to 10 classes
LULC Map 2007	Andalusian Ministry of Environment	Vector to raster+ AT	Reclassification to 10 classes
Explanatory Variables Maps			
Slope	Cartographic Institute of Andalusia	New raster+ AT	Creation of slope map
Trails	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Roads	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Litology	Cartographic Institute of Andalusia	Vector to raster+ AT	–
Planned industrial areas	Ayamonte City Plan	Digitalisation + AT	Creation of binomial layer
Planned Touristic Areas	Ayamonte City Plan	Digitalisation + AT	Creation of binomial layer
Elevation	Cartographic Institute of Andalusia	New raster+ AT	–
Protected Area	Cartographic Institute of Andalusia	Vector to raster + AT	Creation of binomial layer
Wetlands	Cartographic Institute of Andalusia	Vector to raster + AT	Creation of binomial layer
Industrial areas	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Rivers	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Golf courses	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Ports	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Commerce	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of map of distance
Aquifer	Cartographic Institute of Andalusia	Vector to raster+ AT	Creation of binomial layer

Table 6. Input Data for the Cellular-Automata Model. AT = All transformations, including geographic reference coordinate system, layer extension and cell resolution (Self elaboration)

Fifteen explanatory variables were selected: slope, trails, roads, litology, planned industrial areas, planned touristic areas, elevation, protected area, wetlands, industrial areas, rivers, golf courses, ports, commerce and aquifer. The source, transformations and additional spatial operations to all input data are summarised on Table 6.

Model calibration

After applying Dinamica EGO in the study site the following results were obtained. Regarding the *quantification of changes*, 25 LUCC transitions were identified as *relevant transitions*, explaining 99.25% of changes occurred in the study site between 1999 and 2007. All the transitions are presented in the Appendix, Table A-9.

Table 7 shows the relative percentage of change by land category for each transition as well as the surface affected during the calibration period. Attending to the surface affected, the most significant land use changes (>100.000 m^2) during this period were: shrubs to urban (462.650 m^2), shrubs to non-vegetated (209.780 m^2), shrubs to crops (159.370 m^2) and non-vegetated areas to shrubs (149.190 m^2). Other important LUCC (>10.000 m^2) were: crops to non-vegetated (78.240 m^2), non-vegetated to crops (72.690 m^2), shrubs to green (56.990 m^2), crops to industrial 1 (27.830 m^2), crops to urban (23.990 m^2) and wetlands to green (20.430 m^2).

On the other hand, change rates on a year basis were also identified through the Markovian Chains. Results, as summarised in Table 7, indicated the higher yearly change rates for the transitions non-vegetated to shrubs (5.85% yr^{-1}) and non-vegetated to crops (2.75% yr^{-1}). Other relevant yearly change rates (>0.3% yr^{-1}) were crops to non-vegetated (0.78% yr^{-1}), shrubs to urban (0.73% yr^{-1}), beach to water (0.73% yr^{-1}), shrubs to non-vegetated (0.44% yr^{-1}) and green/recreational to urban (0.42% yr^{-1}).

Regarding the *location of changes*, the effects of the 15 explanatory variables over land use changes were explored for the 25 transitions, that is, 375 Weights of Evidences (WoE) were analyzed. According to the selection criteria explained in the methodology, 102 WoE were

LUCC transition	**Yearly Change Rate** [(1)]	**Transfromed Surface (m^2)**
Shrubs to Urban	5,54%	4.450
Shrubs to Non-vegetated	2,51%	300
Shrubs to Crops	1,91%	1.800
Non-vegetated to Shrubs	32,65%	50
Crops to Non-vegetated	4,42%	23.990
Non-vegetated to Crops	15,91%	27.830
Shrubs to Green	0,68%	78.240
Crops to Industrial 1	1,57%	462.650
Crops to Urban	1,35%	56.990
Wetlands to Green	1,11%	9.740
Shrubs to Industrial 1	0,12%	159.370
Non-vegetated to Urban	1,79%	209.780
Wetlands to Urban	0,27%	4.980
Non-vegetated to Industrial 1	1,05%	20.430
Urban to Industrial 1	1,95%	3.930
Wetlands to Industrial 1	0,21%	3.060
Beach to Water	5,27%	280
Water to Beach	0,26%	1.690
Water to Non-vegetated	0,23%	2.460
Green to Urban	3,30%	2.220
Water to Crops	0,18%	8.160
Non-vegetated to Water	0,19%	4.790
Urban to Non-Vegetated	0,13%	72.690
Beach to Non-vegetated	0,48%	149.190
Industrial 1 to Green	0,17%	870

Table 7. Relevant LUCC transitions. Relative change and transformed surface between 1999-2007. (1) Indicates the relative change by land category in % (e.g. 1.95% of all urban surface changed to industrial uses between 1999 and 2007) (Self Elaboration)

eliminated for presenting a not significant coefficient for any transition range[8]. The remaining 273 WoE were preserved in the model. As an example, Figure 20 shows the behaviour of the variable ‘distance to previous urbanised areas’ over the transition ‘shrubs to urban’. As the figure depicts, the Weight of Evidence (WoE) shows a strong positive correlation (>1) during the first 150 m., that is, the presence of existing urbanised areas favours the change from shrubs to urban on a 150 m. radius. The correlation gradually decreases, and it takes null or negative values from 840 m. onwards, thus not affecting or disfavouring the conversion respectively. The behaviour of the WoE is coherent with reality, as in the study site, urbanisation is often lead by expansion processes on the proximity of other urbanised areas.

A spatial correlation analysis was performed to eliminate the variables dependant variables.

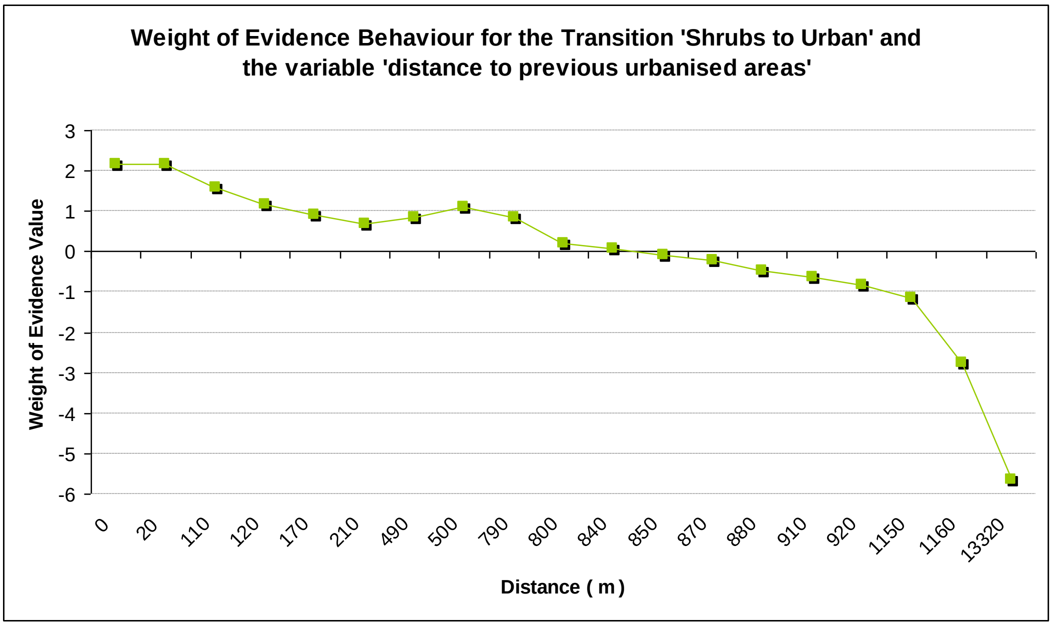


Figure 20. Example of Weight of Evidence behaviour on the study site. The figure shows how the distance to previous urbanized areas has a significant effect on the transformation of shrubs to urban, first favouring and then repelling the transformation (Self-elaboration).

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[8] For more information on WoE coefficients and first selection see Appendix Table A-10 and A-12.

Crammers and Joint Uncertainty indexes showed pairs of variables were dependent for land use transitions in 40 cases[9]. In all the cases where both indexes were above the threshold value, the weight of one of the explanatory variable was excluded, i.e. for the transition from urban to industrial land, the pair of variables 'protected areas' and 'wetlands surface' had a Crammers and Joint Uncertainty indexes above 0.55 and consequently, the weight of wetlands was eliminated for that particular transition.

Once the spatial independence of the variables was guaranteed, the WoE method was applied to the study site to obtain 25 probabilities maps (one for each land use transition) depicting the most favourable areas for a change according to the explanatory variables influence. Figure 21 shows four examples of probabilities maps. Red areas indicate a high probability of change for that specific transition, while blue indicates low probabilities for a specific transition.

For example Map A indicates a high probabilities for the transition 'shrubs to non-vegetated' in the middle, eastern side of the municipality, around industrial areas and roads; Map B indicates a very high probability of transition for 'shrubs to urban' around the planned touristic area of Costa Esuri; Map C shows a high probability for the transition 'shrubs to green/recreational' in very localised areas near roads and commercial areas; and Map D depicts high probabilities for the transition 'wetlands to urban' in wetlands located in the proximity of current urbanised areas, as well as areas close to golf courses and commercial surfaces.

Once the quantification and location of changes were calibrated, the spatial behaviour of the changes was calibrated by adjusting the two Cellular Automata functions of the model and the parameters size, isometry and variance as showed in the Appendix. An iterative process of five simulations and validations cycles were carried out.

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[9] For more information on WoE spatial dependence and second selection see Appendix Table A-11 and A-13.

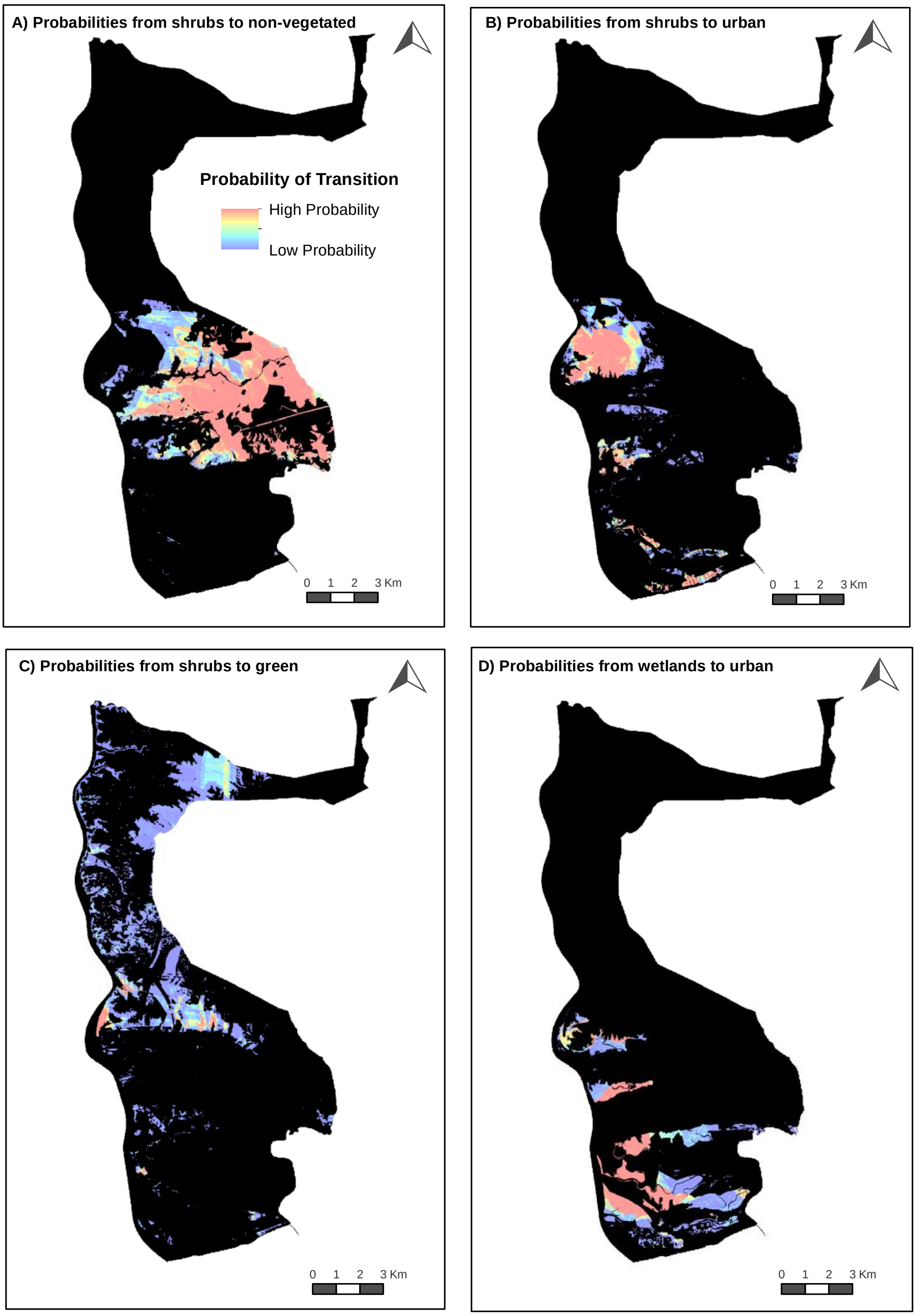

Figure 21. **Probabilities maps for four transitions**. A) Probabilities for the transition shrubs to non-vegetated. B) Probabilities for the transition shrubs to urban. C) Probabilities for the transition shrubs to green. D) Probabilities for the transition wetlands to urban (Self-elaboration).

The final simulated land use map for 2007 reproduced the most important land use changes over the study site. As illustrated in Figure 22 coherent patterns can be observed in phenomena such as urban expansion, new urban patches formation, conversion to crops, presence of green/recreational areas and the creation of new industrial areas among others.

As can be deduced from figure 22, the model was able to emulate the location, quantity and behaviour of changes for most of the analyzed land use transitions. Urban patterns were emulated accurately, together with agriculture intensification, wetlands decrease, green areas expansion and new industrial areas appearance. Not only these changes were simulated in quantity and location, but also their shape for most of the LUCC simulated

Regarding the spatial accuracy of the calibrated model, the spatial fitness test based on the K-Fuzzy analysis (Figure A-12, Appendix) indicated a 54.19% of prediction within a 1 window-cell, which means more than half of the changes were accurately predicted by the model within a 5 meters radius of that change. Moreover, as the graphs depicts, the rate of predicted changes by the model raise up to 67.56% within a 105 meters radius.

A visual spatial representation of the predictive capacity of the model is shown in Figure 23. Red, yellow and green colours indicating high, medium and low spatial accuracy of the model respectively. Note that the spatial accuracy test only applied to the cells that were in transition during the calibration period, thus the areas in black indicate absent of transitions during 1999-2007. The calibrated model accurately simulated the majority of land use changes occurred during 1999 and 2007, reproducing complex urbanisation processes occurred in the coastal fringe as well as nearby the river, the conversion to crops in the northern side of the municipality or the industrialisation processed on the centre. The figure shows as well how the model less accurately emulated the conversions to non-vegetated areas in the central, western areas of the municipality.

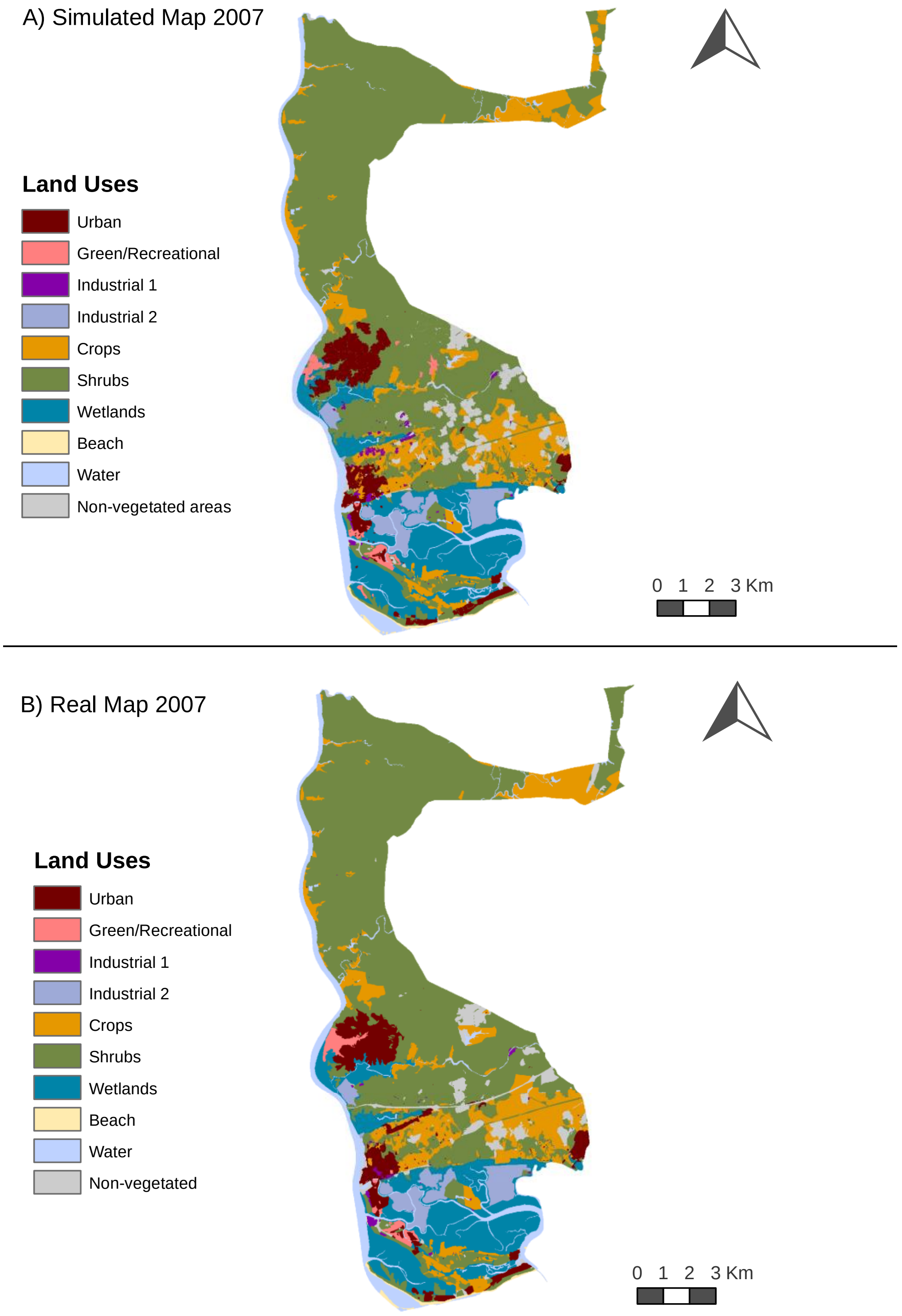

Figure 22. Simulated vs. Real map for 2007. Simulated land use map for the study site in 2007 (top) and Real land use map of the study site in 2007 (bottom) (Self-elaboration).

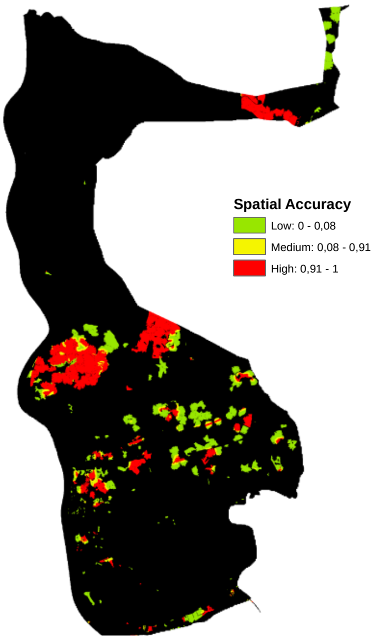

Figure 23. Visual spatial representation of the predictive capacity of the model. . Red, yellow and green colours indicate high, medium and low spatial accuracy of the model respectively (Self-elaboration).

Future Scenario Simulation

Based on the parameters of the model adjusted during the calibration, a future simulation for the Scenario 1 (Intensive Tourism) for the year 2050 was run. Nevertheless, as this scenario was not exactly a BAU scenario, that is, a linear continuation of the processes occurred between 1999 and 2007, some parameters were modified and other new parameters included as shown in the Appendix.

As table 8 shows, the following processes were taken into account to parametrize the scenario: i) logical trends: high rate of urbanisation, decrease of wetlands surface, increase of green, leisure and commercial areas, increase of industrial areas, increase of non-vegetated areas; ii) planned decisions: continuation of the protection of the wetlands, the promotion of industrial areas according to the municipality land use plan scheme and new communication lines contemplated in the sub-regional plan.

The resulting map for the Future Scenario 1 at year 2050 is shown in Figure 24. The map shows a clear urbanisation process occurring in different exes of the municipality. On the one hand urbanisation expands on the coastal fringe, accompanied by a considered increase of green/recreational areas in their proximity. Urbanisation also expands over Costa Esuri, where green and recreational areas expand notably as well.

Logical Trends	**Model Component Affected**
Continuation of high urbanisation rates	Markovian Matrix (only for selected LULC transitions) Cellular automata patch/expansion percentage (only for selected LULC transitions)
Decrease of wetlands	Markovian Matrix (only for selected LULC transitions)
Associated Processes	
Increase of green spaces/ leisure surfaces	Markovian Matrix (only for selected LULC transitions) Cellular automata isometry, variance and size (only for selected LULC transitions)
Increase of Industrial areas	Markovian Matrix (only for selected LULC transitions) Cellular automata isometry, variance and size
Planned Decisions	
Lesser protection of wetlands	Weights of Evidence (only for selected LULC transitions: decrease of restriction on protected area)
New industrial areas	Weights of evidence (only for selected LULC transitions: increase attraction to planned industrial areas)
Unexpected Processes	
Random new patches (stochastic)	Patcher Cellular Automata (isometry and variance parameters modification for specific transitions)

Table 8. Scenario 1 parametrization. Summary of the modelling process to translate the PFS 1 into a future scenario map through the use of the CA model (Self-elaboration)

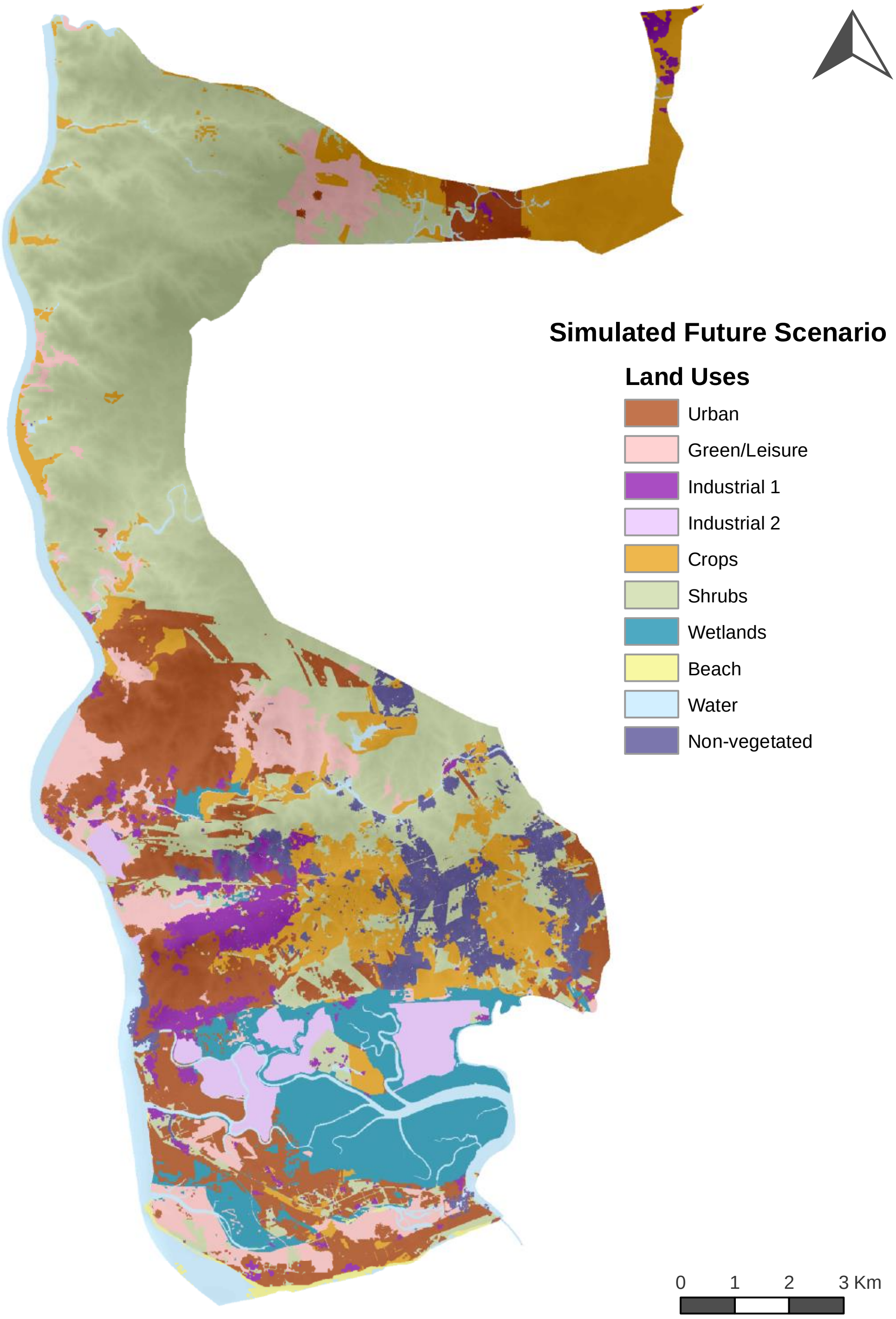

Figure 24. Simulated land uses maps for the study site under Scenario 1 on 2050 (Self-elaboration).

Urban growth occurs as well as on the limits of the old town of Ayamonte and a new urban development appears in the North-Western extreme of the municipality. On the other hand, there is a decrease on wetlands, which are partially transformed into urban areas, except for the wetlands included inside the Protected Area Limits. Industrial areas (type I) also increase notably, especially in the central part of the municipality. New crops in the centre and North-western side of Ayamonte are developed and new non-vegetated areas patches appear in the center-western side.

5.3 Prospective Spatial Risk Assessment

This review showed that the SLR projections included in the 5th Assessment Report from the IPCC (IPCC-AR5), presented a high confidence rate, include different Antarctic Ice Sheets melting contributions as well as other processes (e.g. land water storage, thermal expansion, etc.), and include the uncertainty range for each of these processes. In addition, although most projections of the IPCC-AR5 can be considered conservative, i.e. contrasting with high end projections presented by other authors, they can also be considered as more likely for mid-term projections, and therefore was the Global Projection selected for this thesis.

Figure A-13 (Appendix) shows the comparison of the projections: RCP60, RCP85, RCP26 and SRES A1B. They correspond to different greenhouse emissions rates considered by the IPCC (2013). As depicted by Figure A-14, the difference between the “optimistic” projection RCP26 (which assumes a low emission rate) and the “pessimistic” projection RCP85 – which assumes a high emission rate- increases as a function of time. In this sense, differences between “optimistic” and “pessimistic” projections are of 0.367 m for the year 2100, but only 0.041 m for the target year for this thesis, 2050. Considering Nicholls et al. (2014) RCP85 projection was finally selected to be applied in the study site. This projection estimated Global Mean Sea-level rise in 0.322 m for 2050 at 95% uncertainty limit.

From the three available tide gauges available stations for the study area, the station Cadiz III was selected for fulfilling the recommended time series, data reliability criteria described by (NOAA, 2010). Cadiz III station gathered Regional Sea-level data from 1961 to date (last records control identified corresponded to 2013). The data is provided by monthly means values after a data quality control procedure by the PSMSL. The complete Mean Sea-level series 1961-2013 is shown on Figure A-14 (Appendix). The 1961-2013 series only presented 3 gaps, which do not interfere with the series reliability for records over 30 years, as it was the case.

The regression analysis over the selected series (Figure A-15, Appendix) presented a Mean Sea-level trend of 4.87 ± 0.78 mm/yr. After the removal of the Global signal the final Regional Mean Sea-level rise was 2.87 mm/yr from the period 1971-2010.

The linear (no acceleration assumed) projection of the Regional Sea-level for the year 20150 gave a MRSL of 114.8 mm. Applying the formula for relative Mean Sea-level variation proposed by Nicholls et al. (2011) , the expected rise in Relative Mean Sea-level for the study site for 2050 was estimated on 436.8 mm.

Regarding Extreme High Water Levels, the tide gauge selected was H5 station, given the length and quality of the data series, its proximity to the study site and the recommendation by the National Ports Authority. Data from H5 tide gauge was provided by the National Ports Authority, including total sea-level (astronomical and meteorological), astronomical and meteorological components of the tide on an hourly basis from 1996 to 2008. The data had been subject to an exhaustive quality control process by the responsible organism (National Ports Authority) and therefore no further data treatment was necessary.

Extreme High Water Levels (EHWL), including the astronomical and meteorological components of the tides obtained for the 20, 50, 100, 200 and 500 years return period with a 95% confidence [10]. As table 9 shows, EHWL on the study site ranged from 417.64 ± 5.69 cm for a return period of 20 years to 428.92 ± 11.86 cm for a return period of 500 years.

Return Period	Central Value	Confident interval (95%)
20 years	417.64 cm	5.59 cm
50 years	421.82 cm	7.95 cm
100 years	424.39 cm	8.46 cm
200 years	426.56 cm	9.91 cm
500 years	428.92 cm	11.86 cm

Table 9. Results for the extremal analysis of High Water Levels . Extreme water levels at the study site for 20, 50, 100, 200 and 500 years return period. Water level produced by astronomical and meteorological tides. Huelva III tide gauge station. (Self-elaboration).

A Hazard Map was obtained through the spatialization of the Relative Mean Sea-level rise projection for 2050 (43.68 cm) combined with the Extreme Sea-level for the 1/500 years tide (428.92 cm), following a bathtub approach and adjusting the local datum as explained in the methodology. The resulting hazard map for inundation is shown in Figure 25, which distinguished between the flooded areas by projected Sea-level rise (green areas) and the added Extreme Sea-level produced by the 1/500 years tide (blue areas). The inundated area by the projected SLR would have an extent of 6.32 km^2, mainly in the very-low lying areas on the Southern side of the municipality. The flooded area would increase up to 14.98 km^2 if having an

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[10] The return level function obtained from the High Water Levels extremal analysis is shown in Figure A-16 on the Appendix

extreme Sea-level produced by a 500 years tide.

The hazard map was spatially integrated with the Future Land Uses Map for the Year 2050 under Scenario 1, to obtain a Future Exposure Map, shown in Figure 26. The exposed surface by each land use category under this scenario would be, by descending order: 9,854,450 m^2 for wetlands, 817,150 m^2 for urban areas, 543,470 m^2 for green/recreational, 452,060 m^2 for industrial areas

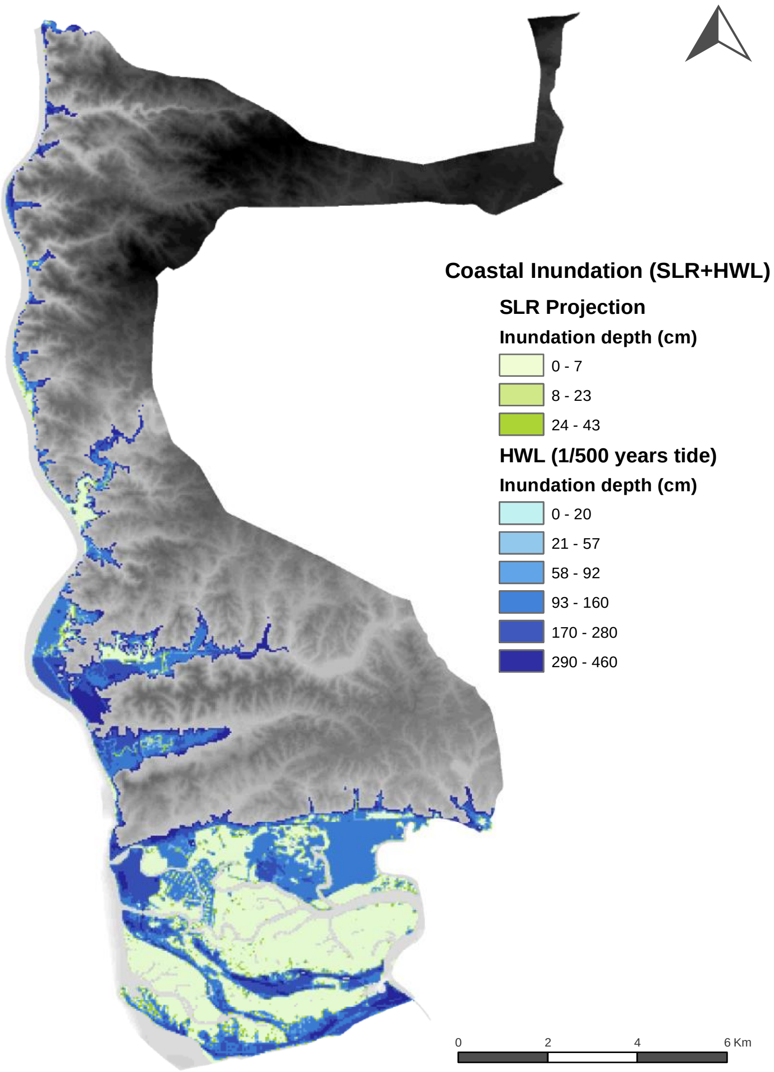

Figure 25. Hazard map 'coastal inundation'. Inundation produced by a sea-level rise assuming RCP 85 projection (IPCC, 2013) combined with a High Water Level given by a 1/500 years tide (Self-elaboration).

type II (e.g. aquaculture farms), 287,430 m^2 for crops, 283,730 m^2 for shrubs, 166,800 m^2 for industrial areas type I (e.g. manufacturing activities), 130, 600 m^2 for water bodies, 41,210 m^2 for beaches; and 37,500 m^2 for non-vegetated areas.

As deduced from the map, the high surface of wetlands exposed to inundation is a consequence their location on the most low-lying areas of the municipality. For the same reason, under the

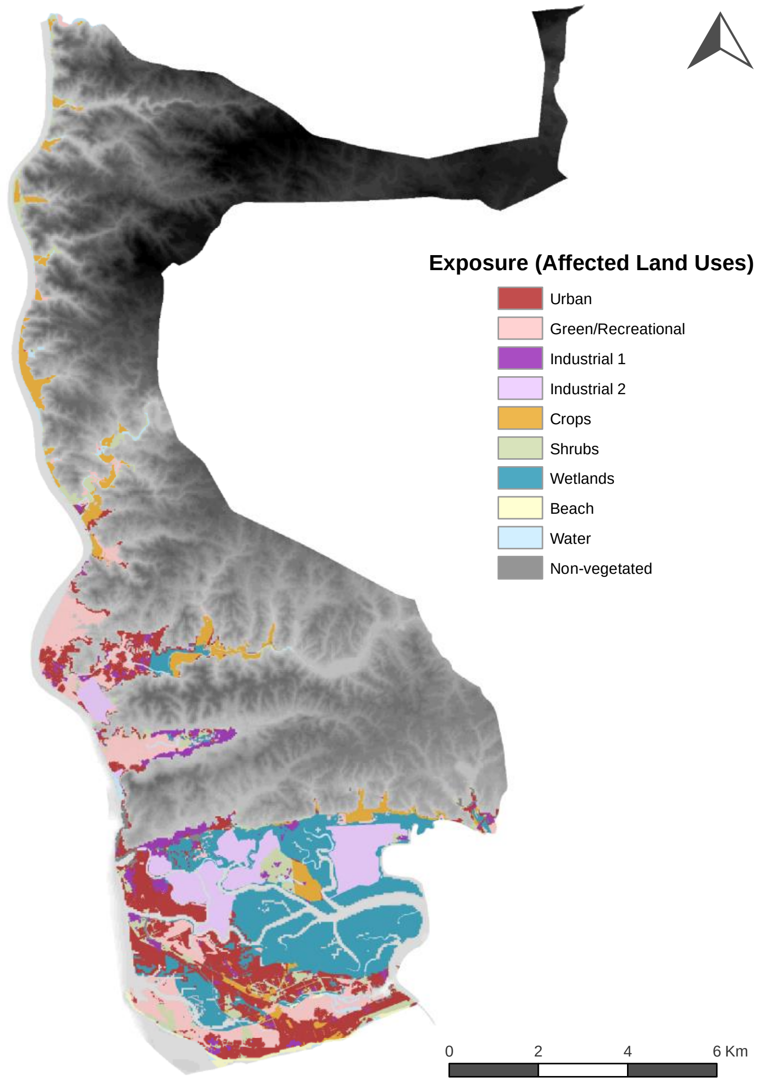

Figure 26. Exposure map for Scenario 1 on 2050. Exposure in terms of land uses under Scenario 1, for the year 2050, to the coastal inundation level assessed in this thesis (Self-elaboration).

Scenario 1, large portions of urban and recreational areas would be greatly exposed to extreme events as the one analyzed in this thesis.

According to the population projections' results, Ayamonte population at the year 2050 would be of 23,635 inhabitants under a non-linear polynomial projection, shown in Figure A-19 (Appendix). Under Scenario 1, the future urbanised surface of Ayamonte would be of 2,249,780 m^2, despicted on the map on Figure A-18 (Appendix). Considering the urban extension and population projected, the population density on that scenario would be of 0.0105 inhabitant/m^2.

Under the coastal inundation contemplated in this thesis, the human population at risk in Ayamonte in 2050 would be of 8.584 inhabitants, that is, over 36% of the total population, only taking into account the permanent (census) population. Figure 27 shows the urban areas affected by the inundation scenario, in purple. According to this projection the human population at greater risk would be the future residents of Isla Canela, Ayamonte town as well as part of Costa Esuri.

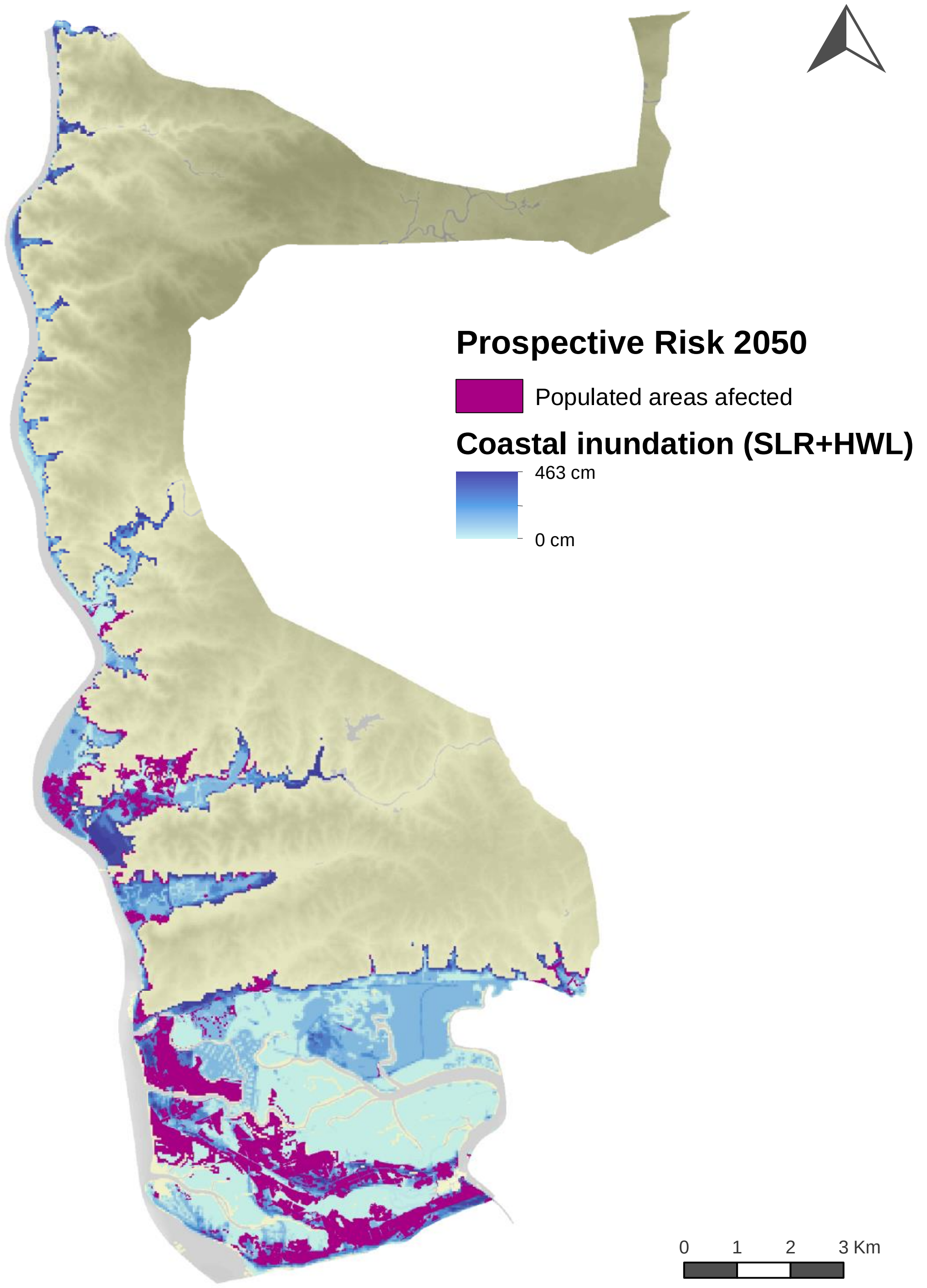

Figure 27. Prospective risk map for human population under Scenario 1 on 2050. Population affected by sea-level rise and Extreme High Water Level produced by a 500 year return period tide (Self-elaboration).

CHAPTER 6: *Discussion*

This chapter first presents a reflection about the contribution of this thesis findings' to current research trends and how the results obtained endorse, contrast or enrich recent works. Then a separate discussion on the results meaning, relevance and limitations are provided for each of the three phase of the thesis.

i) Thesis results' contribution to current research debate

Taking the *threefold process* as a result itself, findings contribute to the research demands presented by Serrao-Neumann and Choy (2014) who underlined the need to find new learning processes to engage stakeholders for climate change adaptation. The results also confirms Tschakert and Dietricht (2010) hypotheses- tested on different locations in Africa- on the helpfulness on forward-looking learning as a key element for adaptation in the context of climate change. Further, the process proposed in this thesis answers Ballinger and Rhisiart (2011) who, after recognising 'iczm should be in a prime position to facilitate the essential learning processes required for climate change adaptation and require application of exploratory scenarios', claimed for the application of such approaches at local levels and involving local stakeholders.

Results of 'Participatory Foresight: Scenarios', support findings published by Johson et al. (2012), who showed the power of participatory scenarios for social learning on socio-ecological systems in Minnesotta, USA; Malinga et al. (2013) who developed participatory scenarios to support decision-making for ecosystem management in South Africa; or Haatanen et al. (2014), who successfully engaged stakeholders on scenarios development for forest management planning in Finland. This thesis results' coincide with the aforementioned works in the engagement of stakeholders, the use of exploratory approaches and the focus on maintaining a degree of creativity on the process; although differ on the methods used, as the scenarios developed in this thesis followed a novel methodology. In addition, results on Participatory Future Scenarios confirms the current recognition of the potential of scenarios for coastal planning. In particular results corroborate the findings of Kaltenborn et al. (2012), Evans et al. (2013) and McNamee et al. (2014) on the use of participatory scenarios for discussing preferred futures in Norwegian islands, exploring possible climate change effects on the Great Barrier in Australia and scanning coastal resilience options in California respectively.

Results of 'Artificial Intelligence for Future Spatial Modelling', contribute to current debate on the application of Stochastic Cellular Automata (CA) models to simulate highly dynamic areas and in particular, to simulate future land dynamics at local scales, corroborating results given by Cabello et al. (2011) who simulated different future land use patterns in the Mediterranean or Fuglsang et al. (2013) who modelled future urban patterns in Denmark. Results of the application of the stochastic CA model Dinamica EGO clearly show the strength of this model for highly complex and dynamic areas, endorsing results given by Ferraz (2013), Vieilledent et al. (2013) and Malek and Boerboom (2015), who successfully simulate potential urban expansion and environmental risk in Sao Paulo, future deforestation in Madagascar and alternative land-use scenarios in Italy. In terms of modelling resolution, results of this thesis contrast with previous work on the application of CA-based models to assess future flood risk, such as Barredo and Engelen (2010) who proposed a 100 m resolution grid, in contrast with the 10 m resolution of this work.

Results of 'Prospective Spatial Risk Assessment', differ from other studies which assessed spatial-temporal changes, in the methodological approach selected. While this thesis combines participatory scenarios, Cellular Automata spatial modelling, an a risk-equation spatial model, Sahin and Mohammed (2013) spatially assessed coastal vulnerability to sea-level rise integrating a System Dynamics modelling, Geographical Information Systems and a Multi-Criteria Analyses of stakeholders' views on the Gold Coast, Australia. On the other hand, results on future population exposure to coastal inundation are highly aligned –in the conceptual basis- with recent works presented at the global scale, such as the presented by Neunmann et al. (2015) who spatially explicit estimates of the baseline population with demographic data in order to derive scenario-driven projections of coastal population development. On the regional scale Kebede et al. (2010) spatially assessed future exposure to sea-level rise in Kenia integrating future projections on urbanisation and GDP with Geographic Information Systems. This thesis results' contrast with Neunmann et al. (2015) as well as Kebede et al. (2010) by using a local scale for the future population exposure analysis and a dynamic spatial model to simulate future land uses.

ii) *"Participatory Foresight: Scenarios" results' discussion*

The first phase of this thesis has resulted in an innovative and original method to develop explorative scenarios at the local scale: Participative Future Scenarios or 'PFS'. The PFS method was designed to overcome the current challenges of scenarios-making presented in Chapter 2 'State of the Art'. In this regard, the PFS method addresses three major gaps identified in the literature, by: i) successfully integrating qualitative and quantitative data; ii) establishing a clear, reproducible and transparent method based on 6 well-differentiated steps that can be reproducible; iii) creating custom-made scenarios for a local area, without recycling or downscaling previous scenarios studies. In the following paragraphs each of the 6 PFS steps and their respective results are discussed.

Regarding PFS-Step 1, "*Scenarios boundaries definition"*, many participatory exercises have been reported to fail due to neglecting this phase (van Notten et al., 2003). In this thesis, the clear establishment from the beginning of the research of the temporal, spatial and thematic limits of scenarios, noticeably facilitated the implementation of the rest of the steps. I.e. clear spatial and temporal boundaries were key to define the data collection during the driving forces analysis, frame the stakeholders' identification process and set the scenarios framework boundaries.

Setting the temporal limit at a medium term horizon (2050) was found suitable to engage stakeholders in the development of visions about the future, as they could project themselves into the future. Yet useful for sea-level rise projections, longer, inter-generational, scales might had alienated participants from the debate, a challenge for climate change studies deeply discussed by the scientific community as noticed by Wunsch et al. (2013).

PFS- Step 2, "*Stakeholders analysis*", was a key step for the whole thesis. The threefold approach followed -stakeholders' identification, characterisation and analysis- answers Jepsen and Eskerod (2009) request by providing clarity on how to identify and determine stakeholders' importance. Results show the Snowball Sampling Method (SSM) to be a valid method to identify stakeholders in a coastal area at the local scale. First, the SSM has allowed identifying a large number of stakeholders in the study site, a total of 64, a considerable figure in comparison with other works that obtained much smaller networks (e.g. Suarez de Vivero et al., 2007). Agreeing with Eland-Gossenssen (1997) and Atkinson and Flint (2001) results show the SSM method is particularly useful to identify unofficial groups, which were not registered in any official record and would have been easily omitted by other identification methods. That is the case of chiringuitos, which presented a great power and influence in the study site but were not organized in an official association. Corroborating Luyet et al. (2012) findings, using different entry points when performing the SSM resulted in a heterogenic stakeholders' network. Moreover, the use of interviews based on semi-structured questionnaires simultaneously to the SSM permitted to obtain valuable data about stakeholders' characteristics and relationships as well as facilitated further collaboration during the following processes of the PFS development.

Endorsing Lim and Ncube (2013), the results of the "Social Network Analysis" showed the validity of this method to analyze and prioritize stakeholders. Stakeholders' centrality analysis helped to differentiate key groups as perceived by the rest of the groups, that is, internally powerful players. I.e. central stakeholders in the study site were fishers, beach-bars, beach restaurants/bars, hotels and locals; all of them strongly dependent on the coastal area on both economic and social terms and directly or indirectly linked to the coastal resources either all-year or seasonally. The perception of who were the most important stakeholders seemed to be closely linked to their dependence upon coastal resources. The degree and directionality of connection among stakeholders helped to identify the best interconnected players within the study site, such as City Council of Ayamonte, Fishers, Chiringuitos, Hotels, Restaurants, the Ship Workers Association and the Fishers Union. All these stakeholders presented a high number of connections not only with official administrations, but also with the more informal, smaller groups of the spectrum. Both central and best-connected stakeholders were encouraged to participate throughout all the PFS steps. Results confirm conclusions from Reed et al. (2009), who stated stakeholders' prioritization greatly facilitates and increases the success of a participatory exercise. Noteworthy is that the prioritized stakeholders not only provided relevant information for the scenario elaboration, but also empowered results and increased the process credibility among other groups, institutions and communities alike, which is a key matter in any participatory, pro-governance exercise.

Findings on PFS-Step 3, "driving forces analysis", confirmed that identifying driving forces by a participatory approach has offered several advantages. First, if driving forces had been identified only by experts, results would possibly have been accepted only by the scientific community, but they would have lacked credibility among the local communities. This finding agrees with Welp et al. (2006), who observed that a participatory approach increases the approval of the results by communities and also by policy-makers. Results also confirmed how establishing causal-relationships models through public participation gives an important creative input to the process and help to elaborate mental models that ultimately might be useful to support decision making or problem solving on a particular topic, as acknowledged by Mumford et al. (2012). Moreover, a participatory causal analysis, also increases the possibilities of taking into account emerging driving forces. In this thesis, for instance, climate change, environmental protection and identity/cultural protection were identified as emerging driving forces, which, despite not being particularly strong at present times, can be crucial in the future of the study site.

Results of the causal analysis show the possibility of crossing qualitative information with quantitative information, such as spatial and statistical data, that is, respecting ICZM principles. Results also show the distinction between underlying factors and proximate causes help to understand the multi-causality interactions of driving forces and changes in complex environments, supporting previous works findings such as Geist and Lambin (2002). Moreover, an important advantage of performing a causal analysis as it is proposed in this thesis, is that results could be used in further stages of scenario development, especially for narrative storylines setting and for its translation into models. I.e. in the study site the driving force ‘tourism expansion’ was related to urbanised area and population increase, infrastructure demand, leisure facilities demand, among other processes; these processes were included in later step of the PFS, as well as taken into account in the scenario spatialization. In this sense, results obtained agree with findings from Geist and Lambin (2001), who stated that the identification of causal relationships is required for predictive studies.

On the PFS-Step 4, “scenarios framework development”, results show that combining an *impact factor analysis* with the *path exploration method* can provide robustness and reproducibility, as well as flexibility to scenarios development. Differentiating among active, passive and ambivalent driving forces by an impact factor analysis, did help to understand driving forces influence within the internal system as well as how much each driver could be affected by external factors. I.e. results clearly indicated that public policies are fundamental shapers on the study site and can strongly affect other driving forces such as tourism or environmental protection. These conclusions were critical to develop the scenarios logics and narratives together with stakeholders.

Regarding the use of a path exploration approach to construct the scenarios logics, results show that this method increases the creativity and flexibility of the process. In this thesis, four critical uncertainties were successfully explored and discussed with stakeholders and finally used as critical factors for future plausible events. The number of uncertainties and scenarios were not pre-defined –but chosen and confirmed by stakeholders during a fieldwork campaign- which allowed a thoughtful explorative analysis. Moreover, in contrast to the majority of explorative scenarios studies -already debated on Chapter 2, State of the Art- the resulting scenarios were not categorically opposed or mutually exclusive, but allowed different variations of a trend; e.g. the green-technology scenario and the fishing-sector recovery scenario are different variations of an industrialization path. For all these reasons, the path exploration method proposed in this work is considered to help to overcome some of the limitations –rigidity, mutual exclusivity, repetitiveness, lack of creativity- associated with the widely extended 2 x 2 matrix approach.

Results of PFS-Step 5 “scenarios description”, showed that the use of diagrams and comparative tables were a strong support to establish the discussion with the stakeholders. Characterizing the scenarios by different themes (e.g. main economic sectors, landscape, public policies intervention, etc.) was found highly useful to allow the cross-comparison of four scenarios and to settle a structured way to discuss each scenario during the interviews. Also, holding individual -rather than group- and extensive interviews with stakeholders during this step was found to be appropriate in terms of the degree of openness of the participants, especially when discussing the plausibility of each scenario based on their knowledge and experience. The casual diagrams applied to scenarios –to define proto-storylines- provided better results with expert groups than with stakeholders; which confirms different representation of information might be used for different audiences when developing a participatory exercise. Both the discussion format with expert groups and individual interviews with stakeholders were found to be satisfactory methods to develop the scenarios storylines.

For PFS-Step 6, “scenarios validation and storylines development”, showed that all 4 scenarios were considered plausible by all the interviewed stakeholders, which show an effective understanding of the main driving forces on the study site as well as the effectiveness of the path exploration method. Moreover 100% of the interviewees considered foresight exercises useful for coastal planning and participative processes, and that these should be included into mid to long term coastal planning. This indicates a good perception of the participatory experiments performed during the field work of this thesis, as well as a strong will on behalf of the participants to promote this type of exercises into decision-making and planning, which corroborates Chirozva et al. (2013) on the ability of participatory scenarios to empower communities to explore their futures. Results indicated as well, a clear difference between the perceived *preferred* and *most probable* scenarios: Scenario 4 ‘Paradigm Switch’ and Scenario 1 ‘Intensive Tourism’ respectively. The reasons given to consider Scenario 4 not only the preferred but also the less probable included lack of institutional capacity, lack of information, lack of entrepreneurship, lack of (*political*) direction and problems at the policy making level. Interestingly Scenario 1 was considered to be the most profitable in economic terms, yet participants explicitly recognised the touristic sector vulnerability and seasonal character as a topic of special concern under this scenario. Results on stakeholders’ views on both Scenario 4 and Scenario 1 confirm Butler et al. (2013) observation on the capacity of scenario-making to contribute to problems recognition and identify power imbalances.

iii) “Artificial Intelligence for Future Spatial Modelling” results’ discussion

Based on the results obtained, the stochastic Cellular Automata (CA) model was successfully applied to simulate multiple land-use change processes on the study site (e.g. urban sprawl, industrialisation, agriculture intensification, etc.), modelling 10 representative land-use classes and 25 different land-use transitions and analysing the individual effect of 15 variables for each transition.

To discuss the representativeness of the results, there are three main aspects that any land-use change model should address: the quantity of the changes, the location of those changes, and the shape or patterns of land-use transformations. Looking at the calibrated results, and comparing the real map with the simulated one for 2007, it is very clear that: i) the model successfully reproduced the quantity of changes for all transitions and correctly predicted the change rate to urban areas, non-vegetated areas, crops and shrubs, which were the most relevant transformations in terms of quantity during 1999-2007. ii) The model effectively emulated the location of most of the transitions, as for example, most transformations to urban in the coastal fringe and Costa Esuri, the green/recreational areas that grow in the proximities of urban areas, the crops that appeared in the most suitable areas for agriculture on the centre and north of Ayamonte, or the non-vegetated and shrubs located all over the municipality. iii) The model was able to accurately predict the shape of numerous new as well as asymmetrical land-use formations, such as the shape of new urban developments, the new crops patches, the irregular green/recreational areas, and the borders of the extensive shrubs areas. As confirmed by the results of spatial accuracy tests, the model presented a high capacity to predict land use changes on the study site. The spatial fitness value obtained by the k-fuzzy test, a 54.19% prediction over a 5-m radius, is very high in comparison with other works in the field (e.g. Pereira et al., 2010).

In relation to how to increase the model predictive capacity, an interesting point of debate within the CA-modellers' community is the method used to calibrate the cellular automata parameters. In the case of the CA model applied on this thesis, two alternative methods could be used: the Genetic Algorithm (GA) and the Weights of Evidence (WoE). While GA show a strong potential for land use modelling in terms of simulating realistic landscapes, this is done at the expense of the location coincidence, as shown by Mas et al. (2010) results. By showing a high capacity of adjusting the effect of explanatory factors to reproduce past patterns, agreeing with Sourinho (2014), this method might be a better option for deterministic modelling, that is, Business as Usual projections. In contrast, the WoE are more flexible and suitable for exploratory scenarios, and therefore was the approach selected in this thesis. In addition, special attention was paid to not to excessively fit the WoE values –the so-called 'overfitting problem' underlined by Soarhes et al. (2013)- during the calibration stage, otherwise future changes -during the scenario simulations- would mimic the ones occurred during the calibration period. This thesis results' show WoE to be a valid method to calibrate a stochastic CA including the effect of external variables in a non-deterministic way, and, if not over-fitted, is a suitable method to reproduce future land use dynamics at local scale.

Some authors (e.g. Verburg et al. 2002) consider that CA models are not capable of explicitly address the competition (i.e. the same cell can be a candidate for various transitions) between different land-use types, the results of this thesis demonstrate the opposite. It has been possible to address the competition between 10 land-use types and to simulate 25 land-use transitions as well as to quantify the neighbourhood functions. That means that the model was able to reproduce simultaneously processes of urban sprawl, industrialisation, agriculture intensification, deforestation as well as the competition among them. While other scientific works demonstrate as well this possibility (e.g. Vielledent et al., 2013; Malek and Boerboom, 2015), it is interesting to point out the resolution of the thesis -local scale- as well as the amount of concurrent LUCC processes analysed. Moreover, results indicate that not only the model address competition and interaction among different land uses, but also that the spatial patters emerging from these interactions are consistent with empirical results, as tested during the calibration process.

The CA model has been able to successfully integrate physical explanatory variables (e.g. slope) with human-controlled variables (e.g. urbanisation). Moreover, results of this thesis corroborate Soares-Filho et al. (2010) findings, as the model has been effectively included various anthropogenic-related spatial determinants of changes such as: proximate causes (e.g. building a road), preferable sites (e.g. less steep land), or restrictive conditions (e.g. protected areas). Therefore, it has allowed to analyse the influence of certain spatial decisions over specific land-use changes. For instance, the creation of the nature reserve belt clearly limited urbanisation in the wetlands, whereas the creation of new industrial areas increase the non-vegetated areas. The model can help to elucidate or even measure the factors that lead to coastal artificialization. For instance in the pilot site, results show that the presence of golf courses or commercial surfaces facilitate the creation of coastal resorts in the surroundings.

This second phase of the thesis here presented has resulted in new methodological procedures to use the selected Stochastic CA model to spatialize scenarios. Three methodological results are discussed below.

The first methodological proposal to apply the CA model was to establish a quantitative criterion to select most significant transitions to take into account for the markovian chains. As shown in the results, from a total of 51 transitions, only 25 were selected after applying the selection criteria. The 25 transitions could explain 99.25% of the changes, which means the criteria did select the most relevant processes and only eliminated the residual ones. Crossing the information of the single step and multi-step transition matrices for this selection has been an useful criteria, as some transitions (e.g. shrubs to industrial) might have been residual over a year basis, but important when taking into consideration the whole simulation period. The thresholds to include/exclude a transition has to be however defined by the modeller for each case study, according to the dimension of changes and the detail of the study undertaken.

A second methodological proposal to apply the CA model, was a procedure to the select the explanatory variables based on four conditions. The method has given solid results on the study site. As the results show, the 15 variables selected showed correlation with all the land-use transitions modelled, being some of them more influencing than others, for example the variable 'distance to rails' affected to all the transitions during the calibration period, while the 'existence of protected areas' only affected two transitions during the that period. The advantage of using the proposed selection procedure is that it allows to incorporate some of the driving forces identified by stakeholders (e.g. existence of golf courses) while also including other variables proved to have a strong LUCC effect on previous studies (e.g. slope).

Third, a relevant and state-of-the-art methodological proposal of this thesis, was to establish a conceptual approach to translate socio-economic scenarios into spatial scenarios, what here has been named *scenarios parametrization*. For explorative scenarios, the CA model parameters must be necessarily modified in order to simulate 'alternative' spatial configurations, otherwise, the artificial intelligence behind the model would had only replicated historical trends, i.e. Business as Usual scenarios. To translate the explorative scenarios to the CA model, this thesis proposed to decode the main forces of the selected scenario into processes readable by the Cellular Automata. First, it is necessary to distinguish among natural and human-led processes, as well as logical trends, planned decisions and unexpected processes. I.e. in the study site, transitions from non-vegetated to urban were based on logical patters (e.g. expansion of previous urban areas) or planned decisions (e.g. new urban areas), while some transitions from shrubs to non-vegetated were considered unexpected processes (e.g. wild fires). Once the main processes of the scenario have been identified and categorised, they were translated to the model by adjusting the markovian matrices, the Weights of Evidences and the Cellular Automata parameters, as presented in the methodology chapter. I.e. in the Scenario 1 it was contemplated a high urbanization rate, but the protected area belt located on the wetlands, as well as other future green belt specified in the regional plan, were taken into account by creating new restrictive areas for the model and specifying a WoE accordingly.

The adjustment of the CA model parameters to replicate explorative scenarios, depends on the expert judgement, yet results on this thesis confirms three factors that help in this regard: having a practical knowledge of the study site dynamics, performing field work and cooperating with decision makers to emulate possible processes as realistically as possible. Ultimately is important to keep in mind, that the spatial explorative scenarios are still *explorative* scenarios, and a margin of uncertainty will always remain.

As results show, the scenario parametrization was a key methodological stage to obtain a coherent spatialization of the future scenario selected, simulating the most representative LUCC processes associated to the future scenario, while preserving the inherent dynamic spatial behaviour of the study site analysed during the calibration process. This was a relevant result given the prevalent lack of methodological guidance on how to translate explorative scenarios into spatial scenarios.

A final point of discussion on results of the application of the CA model to simulate future scenarios is the use of 'expert judgment' for specific modelling phases, e.g. scenarios parametrization. As Krueger et al. (2012) showed, expert opinion are of great importance in environmental models and it is used in all phases, from collecting input data, to weighting the importance of the model components or deriving computational rules, adding some extent of subjectivity to the model results. Recognising the need of expert judgment in a model might not jeopardise the validity of results, instead it is necessary to move towards a more open and transparent approach on modelling and a more systematic ways to use expert knowledge. This thesis findings aims to contribute to this debate and to inspire further research on how to include expert knowledge to simulate future scenarios with an stochastic CA model, finding a compromise between creativity –necessary for exploratory scenarios- and reproducibility.

iv) "Prospective Spatial Risk Assessment" results' discussion

Results on the third phase of this thesis show that it is possible to integrate a given spatial future scenario (Ayamonte in 2050 under Scenario 1), with a hazard analysis.

On hazard analysis results, the figure obtained for Regional Mean Sea-level rise for 2050 (43.68 cm) is strongly affected by the Global sea-level rise projections selected in this work: that is, the upper limit of the RPC 8.5 projection (IPCC, 2013). The RPC 8.5 projection is the most pessimistic IPCC Projection of the IPCC Fifth Assessment Report (IPCC, 2013), it assumes the highest greenhouse emissions rates considered on the IPCC Fourth Assessment Report (IPCC, 2007) and it includes the global processes currently accepted to affect global sea-level rise, such as the Antarctic ice sheets melting contribution, thermal expansion, land water storage among others. It is important to underline here that the RPC 8.5 projection is still quite moderate in comparison to high-end projections presented by other authors such as Rahmsorf (2007), Hunter (2012), or Jevrejeva et al. (2012). Therefore, although the upper limit of the RPC 8.5 projection was used in this work, the resulting 43.68 cm could be considered conservative. It can be stated that the moderate character of the projection chosen might help to gain acceptance in a decision-making context in comparison with a more catastrophic in terms of sea-level rise, which might seemed too unrealistic and generated lack of trust among stakeholders. This observation coincides with Moser and Dilling (2004) who suggested that fearful representations of climate change may be counterproductive.

The results obtained for the Regional Mean Sea-level trends matched previous works on the area (Fraile, 2013). Further, the acceleration in Regional Mean Sea-level rise observed in the series 1971-2010 (4.87 ± 0.78 mm/year), in comparison with the 1961-2010 series (3.99 ± 0.69 mm/year), correlated with the observed acceleration for the same period at the global scale (Church et al., 2013).

Results for High Water Level, as a combination of meteorological and astronomical tides, are similar to other works on the area of study. I. e. for a 1/100 years tide, estimated tide heights are: 421 cm using an Exponential function according with Fraile (2013), 437.26 cm using a Weibull distribution according to the National Ports Authority (PE, 2006), and 424.39 cm using a Generalised Extreme Value distribution according to this thesis. The differences among these figures can be attributed to the probabilistic function choice. The use of the 500 years return period tide to perform the inundation assessment in this thesis, agree with current trends on coastal inundation modelling (e.g. Kim et al, 2015) on assessing single low probability events – either a 500 or 1000 years return period flood- as a worst case scenario.

Given the scope and goals of the thesis, coastal inundation had been conducted based on a series of assumptions that must be considered to interpret results. First, as in the majority of the current sea-level rise assessments, no modifications on the tidal regime were assumed. This is an important source of uncertainty since some authors indicate that substantial alterations to tidal characteristics can be expected under high end sea-level rise scenario (Pickering et al, 2012).

Second, results of this thesis did not consider the coastal system response to sea-level rise, i.e. morphodynamic changes of the coastline. Yet to overcome this limitation, the Brunn Rule, has been traditionally applied, much debate is going on among the scientific community on the validity of this well-establish rule and some authors recommend its abandonment (Cooper and Pilkey, 2004). The National Flood Atlas proposes an alternative method for Spanish coasts, which, however, assumes a straight bathymetry (MAGRAMA, 2011). In a highly dynamic environment such as an estuary, there are many variables that can affect the future coastal line, such as changes in the sediment budget, changes in the currents, tidal regime, sea level rise, storms, and of course, direct human interventions, such a dredging or aperture of the sand barriers. Hence, to include future changes in the coastal line in the study site comprehensive morphodynamic models would be needed.

Another issue to consider is the application of projected sea-level rise to Digital Elevation Models (DEMs), which, as pointed out by Wesher (2007) present some uncertainties related to the algorithms used to derive topographic parameters , the grid cell resolution, or the surfaces modification among others. Moreover, static DEMs represent future shorelines, nor land subsidence, erosion, accretion and other natural adaptations. Some studies (e.g. Linhoss et al, 2015) are incorporating accretion models to simulate marsh migration as response to sea-level rise. As other possible source of uncertainties on DEMs use for coastal inundation Titus and Richman (2000) pointed at poor benchmarks and vertical resolution or the "concave up" profile of the coastal zone. Despite their limitations, the use of static DEMs, as the one selected in this thesis, continue to be a widespread practice within the scientific community and an accepted approach for initial sea-level rise assessments.

A final point of discussion to interpret inundation results is the use of the land-sea integrated DEM model (CMA, 2012), 40x40 meters-resolution, which represented the best data available at this time. This thesis recognises the need of high-quality digital elevation models for inundation assessments and agree with the general acceptance on the advantages of using Light Detection And Ranging (LiDAR) data for inundation analysis. Yet, continuous LiDAr data covering the whole study site was not available. The inundation results obtained in this thesis would inevitable differ using LiDAR data. In any case, it might be interesting to discuss if a digital model with a vertical accuracy of centimetres -i.e. based on LiDAR- that is highly useful in present-times studies, should be taken with caution when used for long term studies. That is, if LiDAR data had been used for future scenarios inundation, results would had provided a much accurate topographic representation of the wetlands today, yet not necessarily on the wetlands on 2050.

In terms of exposure, the results given in this thesis, under the assumption of Scenario 1, can be considered of concern for the study site. As the results show, an inundation event of almost 5 meters would affect a considerable surface the municipality, about 20%. The most affected land uses would be the wetlands, as they are extremely low-lying areas; which constitutes a good reason to prevent urban or industrial development to take place in such exposed areas. According to the model, urban and green/recreational areas would be the next most exposed land uses. These results are coherent with previous historical trends, as urban and associated leisure areas have been developed over the coastal stretch, wetlands and riverside, all low-lying areas. The high exposure of the urban and leisure areas located on Isla Canela as well as in the old town of Ayamonte would pose serious implications in terms of the human and economic assets at risk, as exemplified by the human risk analysis later discussed. Industrial areas -both manufacturing factories and aquaculture farms- would be highly exposed as well in this scenario. In this case, the potential economic losses are of major concern, especially due to the fact that most of the economic activities of the municipality would be directly affected (flooded) and disrupted. Crops would also be exposed, although in comparison with other economic relevant land uses, would be the less affected by the inundation. In total, almost one forth of the municipality would be inundated by a coastal inundation of 4.73 m. It is necessary to take into account that the hazard analysed in this thesis does not include storms/waves action, which would considerably increase the inundation level and thus the exposed areas. Further research would be necessary to integrate the hazards hereby explored, sea-level rise and tides, with extreme waves and storms. Previous work on the study site area on storms modelling (e.g. Guisado-Pintado, 2012) could be used as starting point for this line of research.

The risk to human population in the selected future scenario for the year 2050 was successfully quantified integrating the future projected urban areas simulated by the Cellular Automata model with a population projection derived from census data. Results indicate that over a third of the total population projected for the year 2050 would be affected by a coastal inundation caused by sea-level rise (assuming the projections of the IPCC RCP 8.5 and the continuation of current regional sea level trends) and a High Water Level of 1/500 years tide. Although two considerations must be taken into account to interpret this figure. First it could be considered a conservative result, as the projected population only took into account the inhabitants registered on the census, while un-censed population was omitted (e.g. seasonal residents). Second, population was projected based on a linear model, meaning it was assumed the population trend on the study site for the 2050 would be similar to the trends occurred over the last 100 years - the only available dataset. Yet non-linear demographic processes- e.g. migration- could increase or decrease the projected figure.

Population at risk might have been overestimated in this thesis as the possible reaction of the 'human system' to sea-level rise has not been taking into account. That is, being sea-level rise a slow-onset hazard, it is expected for communities to gradually adapt to this phenomena –i.e. housing retreat, house uplifting, etc.- a process out of the scope of this thesis. To this regard, it is worth to note that the CA model used in this thesis is able to predict how the territory change according to different human decisions, but it cannot predict human behaviour. An interesting possibility would be to set the CA model to simulate a scenario in two different stages, modelling a specific amount of years without adaptation and including spatial planning measures from a predefined moment. This could be possible by applying a 'sojourn time' function within the CA model. Further research would be necessary to analyse the viability of this approach for sea-level rise adaptation scenarios.

To end, results on the 'future risk to human populations' presented in this thesis, aims to contribute to the debate on how to assess risk to future hazards in *future conditions*, rather than in the present, and therefore findings presented must be taken with caution and within the scope of the work. Although spatializing future urban configurations and projecting local population trends add a great deal of uncertainty to the analysis results, and lack associated probabilities, it certainly provide insight for discussion and can be the starting point for further debate within the community. Communities and decision makers can "see" how much would be loss if nothing is done, as well as which elements of future plans (for instance, foreseen developments in the waterfront) would be at high risk. As it is increasingly recognized, climate change adaptation starts not by implementing measures but with internal changes in the perceptions and belief of individuals (CRED, 2009). Findings of the spatial prospective risk assessment might therefore be considered an initial point to foster debate within all stakeholders and advance towards climate change adaptation.

CHAPTER 7: *Conclusions*

The ultimate goal of this thesis was to develop a process to support decision-making for climate change adaptation in coastal areas at the local scale, grounded on ICZM principles and based on participatory foresight methods, artificial intelligence models and prospective spatial risk assessment. The results presented in this work show that the goal has been successfully addressed by proposing and applying a 3-phases-based process that, attending to the objectives stated in Chapter 1, allow to: i) create explorative, participative, locally-based future scenarios; ii) translate a selected scenario into geospatial data; and iii) assess the *potential* impacts of future SLR combined with an extreme event on the selected scenario.

In addition, the three research questions have been addressed. The relationships between the research questions, methods proposed and results obtained are summarized in Figure 30 and explained below:

- *How to incorporate ICZM principles into scenario-making?* Using an integrative, open, multidisciplinary methodology such as the Participative Future Scenarios (PFS). The PFS results are used as a basis for a spatial modelling exercise.
- *How to spatially simulate the future conditions of a specific scenario?* Translating the scenarios developed into spatial products based on geo-data (land uses) through the use of Stochastic Cellular Automata models. The resulting future scenario map is used as a basis for a prospective spatial risk assessment.
- *How to visualize and assess future risk to human populations under a specific scenario?* Spatializing the components of a classical Risk-Hazard Model, and using the simulated future scenario as a proxy of future exposure (land uses) and future human density as a proxy of human vulnerability.

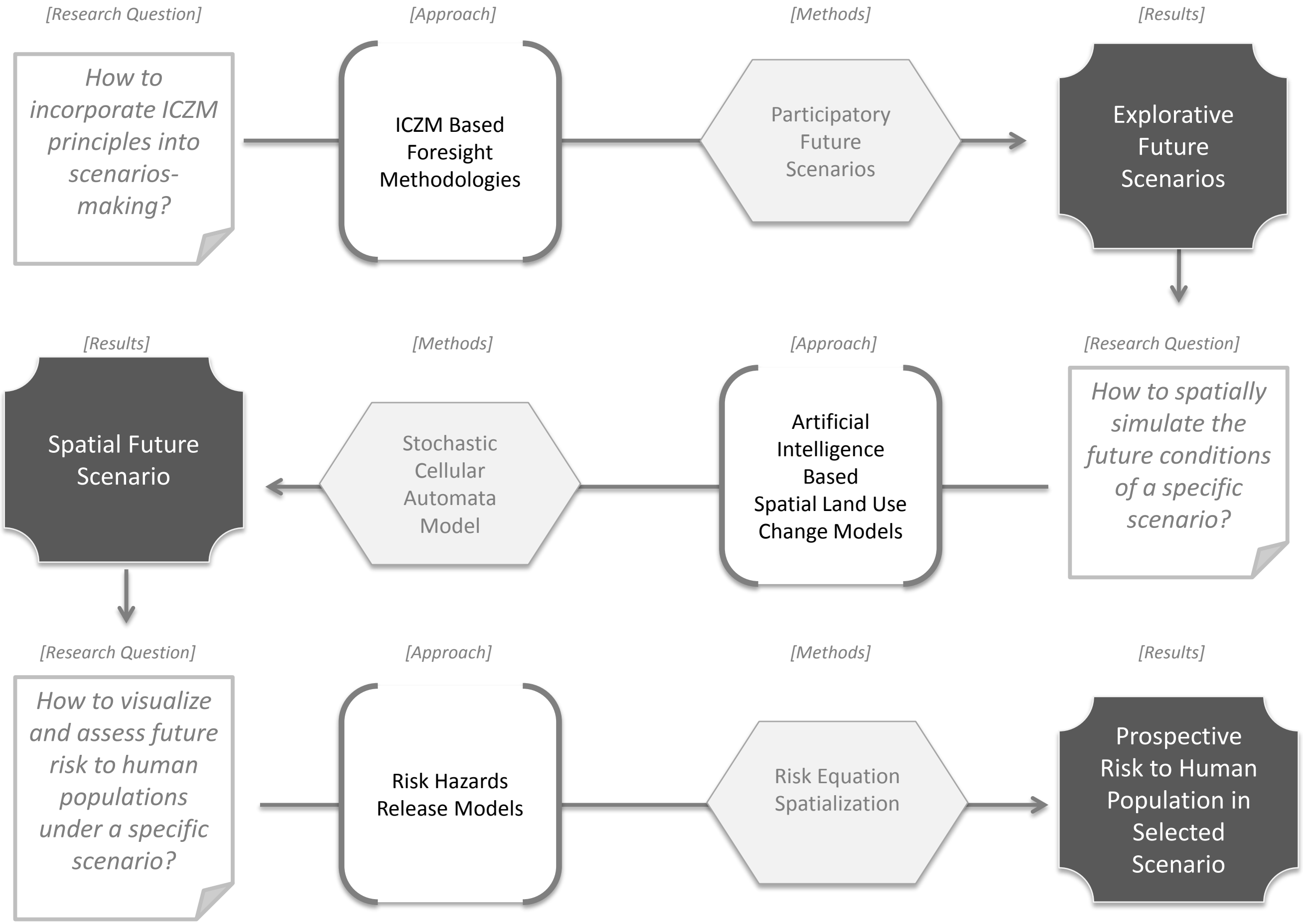

Figure 30. **Conclusions summary diagram**. Relationships between the research questions, the methods proposed in this thesis and the results obtained. (Self-elaboration)

The results obtained in each of the working phases of this thesis provided insights and contributions to different research fields, as well as entail different theoretical implications, as summarized below.

i) Conclusions from Phase 1: 'Participatory Foresight: Scenarios'

- To address the 'methodological chaos' (Bradfield et al., 2005) attributed to scenarios, this thesis provides a transparent and structured method: the Participative Future Scenarios (PFS).
- The six steps of the PFS have been designed to be transferrable and reproducible in different geographical or socio-cultural contexts.
- The PFS results show it is possible to integrate different type of data (quantitative and qualitative) through hybrid methods such as causal analysis.
- The path exploration method has been shown to provide a reliable alternative to the widespread used '2x2 matrix' method while overcoming the limitations of the method (discussed in Chapter 2 and 4).
- Presenting scenarios results in different formats (e.g. diagrams, tables or narratives) to different end-users (e.g. stakeholders –vs.- groups of experts) and adapting them to the audience is a useful strategy to debate scenarios results.
- Discussing scenarios results with the collaborating stakeholders has been identified as a critical step to increase scenario reliability and results trust within the community.
- The results obtained show it is possible to develop genuine scenarios at the local scale (in contrast to the "downscaled scenarios discussed in Chapter 2), incorporating regional and local policies.

ii) Conclusions from Phase 2: 'Artificial Intelligence for Future Spatial Modelling'

- Explorative, narrative-based scenarios such as the PFS can be successfully spatialized through Cellular Automata Models.
- The Cellular Automata model Dinamica EGO is able to simulate multiple land use processes (urban sprawl, industrialisation, agriculture intensification, etc.), address the competition between different land-use types and to reproduce multiple land-use changes at the same time in complex coastal environments.
- The model has allowed the successful integration on site of both physical variables (e.g. slope) with human-controlled variables (e.g. existence of protected areas), as well as quantifying the effects of these variables over land-use changes.
- Establishing a quantitative criterion to select most significant transitions to take into account into the model has been recognised as a helpful step in the application of the model.
- The explanatory variables taken into account in the model can be selected based on four arguments (as explained in Chapter 4), providing solid results.
- 'Scenarios parametrization' is here proposed as a critical step to ensure the successful translation of narrative, qualitative scenarios into spatial scenarios.
- When calibrating a Cellular Automata model to spatialize future scenarios a balance must be seek between the spatial accuracy and the flexibility of the model in order to not to compromise the capacity of the model to simulate alternative future scenarios.

iii) Conclusions from Phase 3: 'Prospective Spatial Risk Assessment'

- Regional Mean Sea-level rise has been successfully assessed for the study site through the approach proposed by Nicholls et al. (2011), and global projections have been integrated.
- The application of the GEV and Block Maxima method to estimate extreme sea-levels produced by meteorological and astronomical tides have given good results in comparison with other studies.
- Deterministic approaches to coastal hazards can be advisable in contexts of high uncertainty such as the future extend of Sea-level rise impacts.
- A Pressure-Release model and classic Risk Equation approach provide a solid base to start analysis in future conditions and it can be straightforwardly translated into spatial terms.
- Land uses represent a good indicator of 'future exposure'; a varied and representative number of land use classes must be selected to include the most relevant exposed assets within a study site (e.g. agriculture fields, urban areas, industrial areas).
- Future population density, based on population projections derived from census data, can be used as a proxy for future human vulnerability.
- It is possible to assess as well as visualise future risk to human populations integrating the future projected urban areas simulated by the Cellular Automata model with future population density.

Is this holistic combination of all phases in a process that started identifying stakeholders at the study site and ended assessing and mapping the potential risk to human populations in a selected future scenario , what could be consider as a valuable tool to assist decision-makers in coastal planning and climate change adaptation and here are scrutinized the reasons why.

First of all, the holistic process facilitates and promotes the implementation of ICZM, pro-governance principles on site. The scenarios-based process presented in this work has proof to enhance stakeholders' involvement from the beginning and to provide a unique opportunity to understand and contrast different opinions on relevant and critical problems affecting coastal areas. Agreeing with Biggs et al. (2007), scenarios have also turned out to be an effective way of engaging actors who might otherwise be unresponsive to scientific information, as well as been helpful in communicating scientific information to the wide public and helping to make more understandable what is commonly complex and challenging to communicate. In addition, the scenarios presented in this work can facilitate the integration of multi-level and multi-profile stakeholders -from official authorities to citizens- views and concerns regarding the future and can even provide a vehicle to mainstream these views into the planning process.

Second, the process presented in this thesis are in line with the *integrated assessment models of scenarios* (Moss et al., 2010) which represent "key features of human systems, such as demography, economy, agriculture, forestry and land use and can also incorporate simplified representations of the climate system, ecosystems, and in some cases, climate impacts". Results of this thesis corroborate that this kind of scenarios can provide valuable support to climate change adaptation research by coupling natural and human-induced processes as well as assessing the effect of planning policies or even lack of planning. In addition, the results presented in this thesis agree with other works that emphasize that assessing impacts, adaptation and vulnerability to climate change depends on a wide array of methods and tools and should include quantitative and qualitative approaches, models and frameworks. The different working phases of the thesis have been successfully coordinated, proving different data, models and approaches not only can be successfully combined but also, that the current technology, data availability and information access provide an unprecedented context to integrate different disciplines and work across research fields.

Third, the results of this thesis successfully address five principles identified by Prutsch et al. (2010), recognised as key points to achieve adaptation to climate change: i) *Ensure commitment*; as this thesis show, by working with stakeholders from the beginning, commitment and engagement can increase; ii) *Build awareness and knowledge*; awareness about present and future impacts of coastal risks, including sea-level rise and extreme High Water Levels, has been raised during the whole process; iii) *Identify and collaborate with relevant stakeholders*; this work show how to identify and how to collaborate with stakeholders effectively; iv) *Work with uncertainties*; scenarios are a suitable tool to work with uncertainties, to explore them and integrate them into further analysis such as risk assessment; v) *Explore potential climate change impacts and vulnerabilities and identify priority concerns*; the whole process shown in this thesis address both of these demands.

Fourth, a foresight participatory process as the one followed in this thesis could act as what Bussey et al. (2012) denominate a 'triggering point for adaptation plans'. According to this author, this point is often related to perceptions of risk, the value and quality of information about future conditions, and the availability of capital to invest in system transformation among others. The work presented in this thesis could affect both the perceptions of risk within the participating stakeholders as well as the quality of the information about future processes, and therefore could potentially initiate adaptation planning process or, at least, to induct discussions in this respect at the policy and decision-making level. In this sense, agreeing with Wilson and Pipper (2010) this thesis show that scenarios are highly useful to sensitize organizations about a range of possible futures, remove filters we impose on our thinking that exclude options outside current trends, build networks of common concerns and shared understandings and suggest alternative courses of actions.

And fifth, this thesis results' support new approaches to coastal planning, and state that it is necessary to re-think how we think about the future, going beyond traditional approaches. The threefold process presented in this thesis has been designed to be implemented together with a wide range of stakeholders, reaching local communities, government's bodies, public and private organisations, as well as experts and researchers, in order to exchange and produce new knowledge. This tool can therefore contribute to what has been denominated '*knowledge co-production'* or '*knowledge co-generation'*, an incipient paradigm in the context of climate change adaptation (Hegger and Dieperink, 2014). Aligning with these theories, the thesis results show that it is possible to promote a dialogue among scientists and researchers and society by a multidirectional process in which stakeholders' knowledge, needs, views and priorities are intertwined with scientific data and information. These approaches are being explored and promoted by both international organisations (e.g. UNESCO, 2009) as well as the academic and practitioners community (e.g. CRED, 2009, Hegger and Dieperink, 2014) and are being recognised as one of the best paths to advance to climate change adaptation. The results of this thesis aims to contribute to these development by proposing the process based on PFS and their spatialization as a "knowledge coproduction" exercise at the local level.

As a final remark, in terms of future lines of research, this thesis has explored and applied on-field innovative and integrative methods and approaches that have resulted in interesting outcomes and provide an excellent starting point for new and exciting possibilities. Two of these lines as well as preliminary work are presented below.

The results of this thesis open the possibility to explore *multiple dimensions of future risk*. In this work, attending to the goals and scope, risk to human populations was analyzed, by using future urbanization patters and future population density. Nevertheless, other dimensions of risk could as well be assessed, based for instance, on the analysis of economic and environmental vulnerabilities. To assess *future economic vulnerability*, the estimation of future economic losses could be performed by integrating flood-damage models with land use data. In this sense, the flood-damage model proposed by the Joint European Research Center (JRC, 2007) provide a suitable starting point. This model has been successfully applied to regional scales within the European Union and present potential for its application at the local scale. To apply the model in a future scenario in the study site it would be necessary to create synthetic flood-damage functions for each of the modelled land uses and integrate them with each of the land classes to create a vulnerability map. Following this idea preliminary synthetic damage functions were created for the study site, using the 10 land use classes modelled in the future scenario. The preliminary synthetic damage functions are show in the Appendix, Figure A-20, as well as a preliminary economic vulnerability map for maximum inundation values, Figure A-21. The economic vulnerability map shows how the most vulnerable areas in monetary terms correspond to urban and green/recreational land uses, which are located in the low lying areas of the municipality, and therefore highly exposed to inundation risks. Losses for the most vulnerable areas –for the sea-level rise and Extreme Water Level considered in this thesis- could range from 67 to 271 euros/m^2, considering the uncertainties of the model.

To assess *future environmental vulnerability*, a possible approach would be the use of ecosystem services. As a preliminary proposal, the work of Burkhard et al. (2009; 2012) was chosen to link ecosystem services to land uses. In this case, the method would consist in adapting the 'ecosystem services matrix' proposed by the authors (Burkhard et al., 2012) to the land uses modelled in this thesis and transfer results to a GIS environment, as shown in the Table A-14, on the Appendix. The preliminary results depicted in Figure A-22, on the Appendix, show how vulnerability based on different types of ecosystem services could be mapped on a future scenario. The four dimensions on ecosystem vulnerability show in Figure A-23 include: ecosystem integrity, provisioning services, regulating services and cultural services. In all cases, wetlands, shrubs and pastures present the highest levels of vulnerability, while built-up areas, such as urban, green-recreational and industrial present lower values as they are less rich in a ecological sense.

The two types of vulnerability above presented, based on flood-damage models or ecosystem services, are just two examples of the dimensions that could be explored based on the simulated scenario. Interestingly, depending of the target public of the scenarios exploring one dimension of vulnerability and or risk might be more useful than the others. Another line of research would therefore be to assess the visual communication capacity of different maps and how to adapt them, or which features must be represented to engage different audiences. I.e. policy-makers and decision-makers would probably be interested in an economic risk or vulnerability map whereas local communities might be interested in risk or vulnerability maps associated to human exposure or environmental values.

As this preliminary work shows, the results obtained in this thesis open different and exciting lines of research to be explored in the future.

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APPENDIX

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Tables

Questionnaires

Table A-1. Examples of scenarios-based projects developed in the European Union

Scale	Project Title	Duration	Goal
EU	ATEAM	2001-2004	To assess the vulnerability of human sectors relying on ecosystem services with respect to global change
EU	BIOSCENE	2002-2005	To generate scenarios for reconciling the conservation of biodiversity with declining agricultural use in the mountains of Europe.
EU	MOSUS	2003-2006	To develop and apply and integrated economic-ecological simulation model in order to quantify the interrelationships between socio-economic driving forces and the state of the environment.
EU	EURURALIS	2004-2008	To support policy makers in discussions about the future of rural areas in the EU-27 and to learn about the interacting of many forces that drive the future of rural Europe.
EU	SENSOR	2004-2009	To develop a broad view across policy arenas and land use sectors, which allow to simulate the impacts of fundamental changes of policy orientation (Common Agricultural Policy)
EU	FORESCENE	2005-2008	To develop an analytical framework for consistent environmental sustainability scenario building (forecasting, backcasting, simulation) in areas such as water, soil, biodiversity, waste and natural resources.
EU	SCENAR 2020	2006-2007	To identify future trends and driving forces that will be the framework for the European agricultural and rural economy on the horizon of 2020.
EU	TRANSUST. SCAN	2006-2009	To scan policy European scenarios for the transition to sustainable economic structures
EU	PRELUDE	2006-2009	To contrast future environmental scenarios for a Europe affected by changing patterns of land use, climate change, agriculture and demographics.
EU	SCENES	2007-2011	To develop and analyse a set of comprehensive scenarios of Europe's freshwater futures up to 2025

(Self-elaboration)

Table A-2. Municipal/Provincial Land Use plans and norms in the study site (1985-2011)

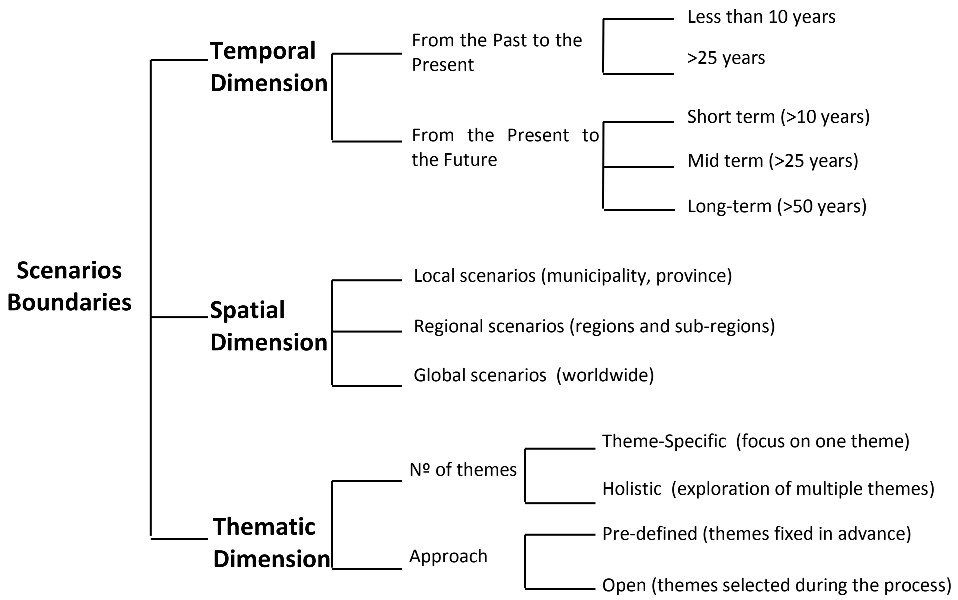
Scale of application	Planning Figure (*)	Action	Approval
Ayamonte municipality	PGOU	Modification	15/04/2011
Ayamonte municipality	PGOU	Modification	14/12/2010
Ayamonte municipality	PGOU	Modification	11/11/2010
Ayamonte municipality	ED	Formulation	26/10/2010
Ayamonte municipality	PGOU	Modification	05/08/2010
Ayamonte municipality	PGOU	Modification	05/08/2010
Ayamonte municipality	PGOU	Modification	29/04/2010
Ayamonte municipality	ED	Formulation	30/10/2009
Ayamonte municipality	PP	Modification	02/12/2008
Ayamonte municipality	ED	Formulation	02/12/2008
Ayamonte municipality	PEI	Formulation	28/05/2008
Ayamonte municipality	ED	Formulation	28/01/2008
Ayamonte municipality	ED	Formulation	28/01/2008
Ayamonte municipality	ED	Formulation	28/01/2008
Ayamonte municipality	ED	Formulation	28/01/2008
Ayamonte municipality	ED	Formulation	28/01/2008
Ayamonte municipality	ED	Formulation	17/11/2007
Ayamonte municipality	PP	Formulation	20/07/2007
Ayamonte municipality	ED	Formulation	25/01/2007
Ayamonte municipality	ED	Formulation	30/11/2006
Ayamonte municipality	ED	Formulation	30/11/2006
Ayamonte municipality	ED	Formulation	27/09/2006
Ayamonte municipality	PP	Formulation	27/07/2006
Ayamonte municipality	ED	Formulation	20/06/2006
Ayamonte municipality	ED	Formulation	20/06/2006
Ayamonte municipality	PP	Formulation	25/05/2006
Ayamonte municipality	ED	Formulation	25/05/2006
Ayamonte municipality	PERI	Modification	24/11/2005
Ayamonte municipality	ED	Formulation	29/09/2005
Ayamonte municipality	ED	Formulation	29/09/2005
Ayamonte municipality	PP	Formulation	28/07/2005
Ayamonte municipality	PP	Modification	28/07/2005
Ayamonte municipality	ED	Formulation	28/07/2005
Ayamonte municipality	NNSS	Modification	31/03/2005
Ayamonte municipality	ED	Formulation	31/03/2005
Ayamonte municipality	ED	Formulation	31/03/2005
Ayamonte municipality	ED	Formulation	27/01/2005
Ayamonte municipality	NNSS	Modification	25/11/2004
Ayamonte municipality	ED	Formulation	25/11/2004
Ayamonte municipality	ED	Formulation	25/11/2004
Ayamonte municipality	ED	Formulation	25/11/2004
Ayamonte municipality	PP	Formulation	27/05/2004
Ayamonte municipality	ED	Formulation	27/05/2004

Ayamonte municipality	NNSS	Modification	02/04/2004
Ayamonte municipality	ED	Formulation	18/12/2003
Ayamonte municipality	ED	Formulation	18/12/2003
Ayamonte municipality	ED	Formulation	18/12/2003
Ayamonte municipality	NNSS	Modification	29/05/2003
Ayamonte municipality	NNSS	Modification	25/07/2002
Ayamonte municipality	NNSS	Modification	23/07/2002
Ayamonte municipality	PP	Formulation	30/05/2002
Ayamonte municipality	PP	Formulation	30/05/2002
Ayamonte municipality	NNSS	Modification	31/05/2001
Ayamonte municipality	ED	Formulation	31/05/2001
Ayamonte municipality	ED	Formulation	31/05/2001
Ayamonte municipality	ED	Formulation	31/05/2001
Ayamonte municipality	NNSS	Modification	14/05/2001
Ayamonte municipality	NNSS	Modification	16/03/2001
Ayamonte municipality	NNSS	Modification	16/03/2001
Ayamonte municipality	NNSS	Modification	16/03/2001
Ayamonte municipality	ED	Formulation	28/09/2000
Ayamonte municipality	ED	Formulation	28/09/2000
Ayamonte municipality	NNSS	Modification	04/10/1999
Ayamonte municipality	PP	Formulation	25/02/1999
Ayamonte municipality	PERI	Formulation	25/02/1999
Ayamonte municipality	PERI	Formulation	25/02/1999
Ayamonte municipality	CAT	Formulation	27/08/1998
Ayamonte municipality	NNSS	Modification	03/07/1998
Ayamonte municipality	PP	Formulation	03/07/1998
Ayamonte municipality	NNSS	Modification	21/05/1998
Ayamonte municipality	NNSS	Modification	21/05/1998
Ayamonte municipality	NNSS	Modification	05/02/1998
Ayamonte municipality	NNSS	Modification	05/02/1998
Ayamonte municipality	NNSS	Modification	05/02/1998
Ayamonte municipality	PP	Formulation	30/10/1997
Ayamonte municipality	ED	Formulation	30/10/1997
Ayamonte municipality	ED	Formulation	28/08/1997
Ayamonte municipality	ED	Formulation	27/06/1996
Ayamonte municipality	ED	Modification	27/06/1996
Ayamonte municipality	NNSS	Modification	10/06/1996
Ayamonte municipality	ED	Formulation	30/05/1996
Ayamonte municipality	ED	Formulation	19/01/1995
Ayamonte municipality	NNSS	Formulation	09/01/1995
Huelva Province	PEPMF	Formulation	07/07/1986
Huelva Province	NSP	Formulation	25/06/1985

Source: Regional Ministry of Environment and Land Planning (2013). Urban Planning Consultation Service (Self-elaboration)

(1) PGOU = Municipal Land Plan; NNSS = Subsidiary land norms; PP: Partial Plan; ED = Study in Detail; PE = Special Plan; PERI = Special Plan for Internal Reformations; PEPMF = Special Plan for the protection of the Physical Environment; CAT = Urban Catalogue)

Figure A-1. Scenarios boundaries classification proposal

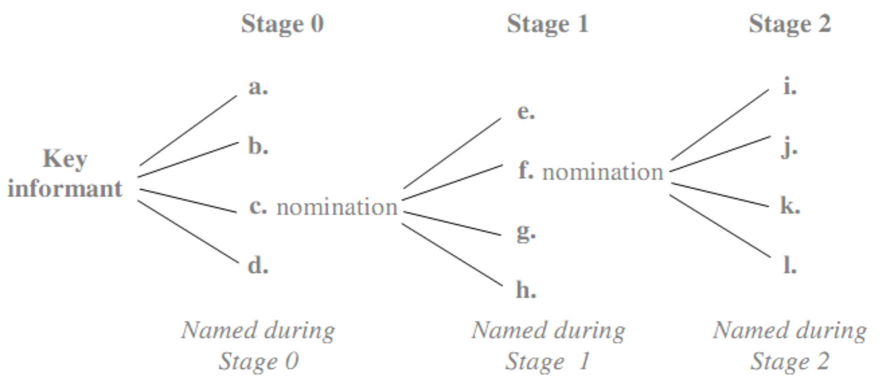


(Self-elaboration)

- *Temporal boundaries account for both the temporal threshold to the past -in order to study coastal changes and driving forces- and the temporal horizon to the future to create the scenarios.*
- *Spatial boundaries can range from the local to the global level.*
- *Thematic boundaries should answer the question of what will be the focus of the scenarios -i.e. holistic vs. specific theme scenarios- and may either be decided before hand or remain open to further discussion with stakeholders.*

Scenario boundaries should be decided taking into account the goal of the exercise, time and resources availability, and the ultimate purpose and end-users of the scenarios, i.e. scenarios used as input for further modelling exercises vs. scenarios used for public debate and decision-making. Regarding temporal boundaries, it is important to take into account the nature of the issues under study as the analysis of certain parameters needs a longer scale than others (i.e. climate change requires long term data analysis). Finally, when defining spatial and temporal scales, data availability and quality has to be considered, having in mind that prospective studies are often limited by the characteristics of historical sources (Bürgi *et al.*, 2004). This classification helped to define scenarios boundaries in the first step of the Participative Future Scenarios Methodology.

Figure A-2. Stakeholders' identification using the Snowball Sampling Method



Based on Goodman (1961) and Azorin (1962) (Self-elaboration)

Snowball Sampling Method Stages as originally proposed by Goodman (1961) and Azorin (1962) ([11])

- *Stage 0:* A core sample of individuals is selected from a finite population. Each individual in the sample is asked to name a certain number of individuals in the population, without naming him/herself, who meet a specific criterion.
- *Stage 1*: The individuals who were not part of the initial sample but which were named under the previous procedure become part of stage 1. Each individual in stage 1 is asked to name other individuals of the population under the same criteria as in step 0.
- *Stage 2*: The individuals named during stage 1, formed the sample for stage 2 and are again asked to name the individuals in the population who meet the criteria for stage 0.
- *Stage n*: the procedure is continued until the last stage, which is the one in which not any new individual of the population is named.

---

[11] Modifications to the method explained on the next page

Modifications to the original SSM applied in this thesis

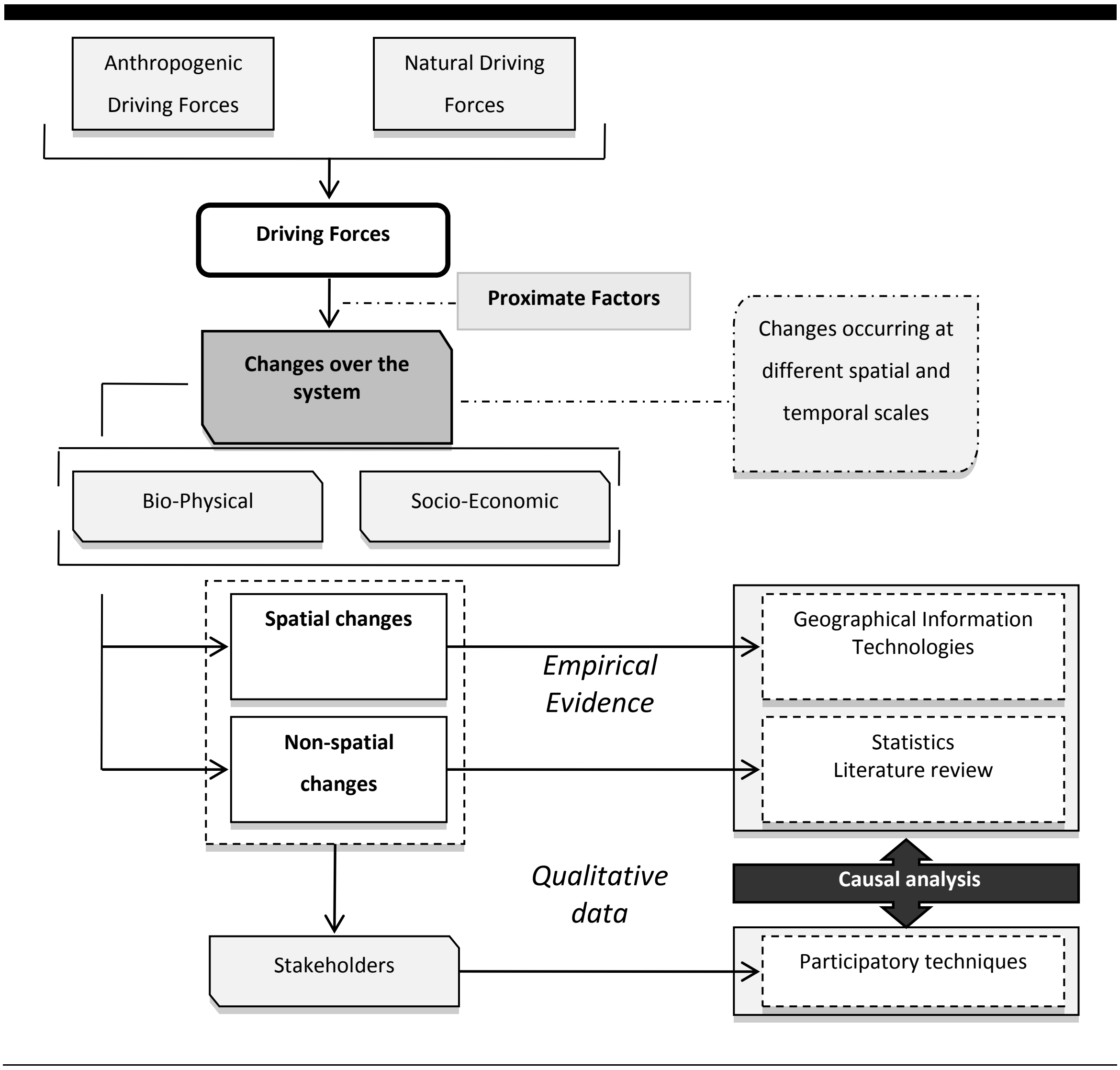
In this thesis, the SSM was applied as proposed by Goodman (1961) and Azorin (1962) with a slight modification: at Stage 0 the process began by contacting an individual who had a good knowledge of the network, which is called the *key informant*, instead of randomly selecting an actor. The key informant was asked to name others individuals who meet the inclusion criteria, without specifying the number of individuals who can name in order not to limit the data collected. Over the group of individuals named (stage 0) one actor was randomly chosen to continue the SSM as described above.

Furthermore, to apply the SSM in the study site the following aspects were taken also into account:

- *Target group/Inclusion criteria*: target population was defined as "all stakeholders (individuals, groups of individuals, associations, institutions) that use in any way (living place, resources exploitation, political influence, etc.) the coastal zone of Ayamonte", understanding "coastal zone" as the whole municipality as well as the territorial waters.
- *System entry points multiplicity*: two key informants were selected -two anthropologists with a wide knowledge of the study area- to initialise the SSM to guarantee two different entry points in the network system.
- *Number of nominees by stage*: There was no limitation in the number of nominees each participant could name.

As deduced from Figure A-2, the SSM assumes that the groups within a specific field are interconnected, that is, members know each other, so if they are asked who are key actors they will directly or indirectly know them (Scott, 1991). Due to these characteristics, it is a very suitable technique not only to identify, but to determine level of influence of different stakeholders. This is very interesting feature from a policy and management point of view since the perception of power can be detected (Faquharson, 2003). The connections between stakeholders were analyzed in this thesis through Social Network Analysis as described in the Methodology Chapter (Chapter 4).

Figure A-3. Conceptual approach to driving forces, proximate factors and changes assessment



(Self-elaboration)

Table A-3. Interview phases for scenarios validation with stakeholders

INTERVIEW PHASES	GOAL	FORMAT
Presentation of the scenarios results		
Study site	Introducing the system under study and presenting an overview of the changes occurred during the last 50 years.	Aerial photographs
Scenarios framework	Present and explain the scenarios framework based on critical factors.	Scenarios framework diagram
Driving Forces	Present and explain the driving forces evolution in each scenario with comparative tables and diagrams.	Driving forces comparative table and conceptual diagram
PFS Scenarios	Present and describe the proto-storylines and the scenarios assumptions.	Storylines synthetic tables
Validation of results		
Semi-structured Interview	Obtain stakeholders feedback regarding all the results presented and discuss the validity of the final scenarios. Gather information to complete storylines according to stakeholders' views.	Questionnaire

(Self-elaboration)

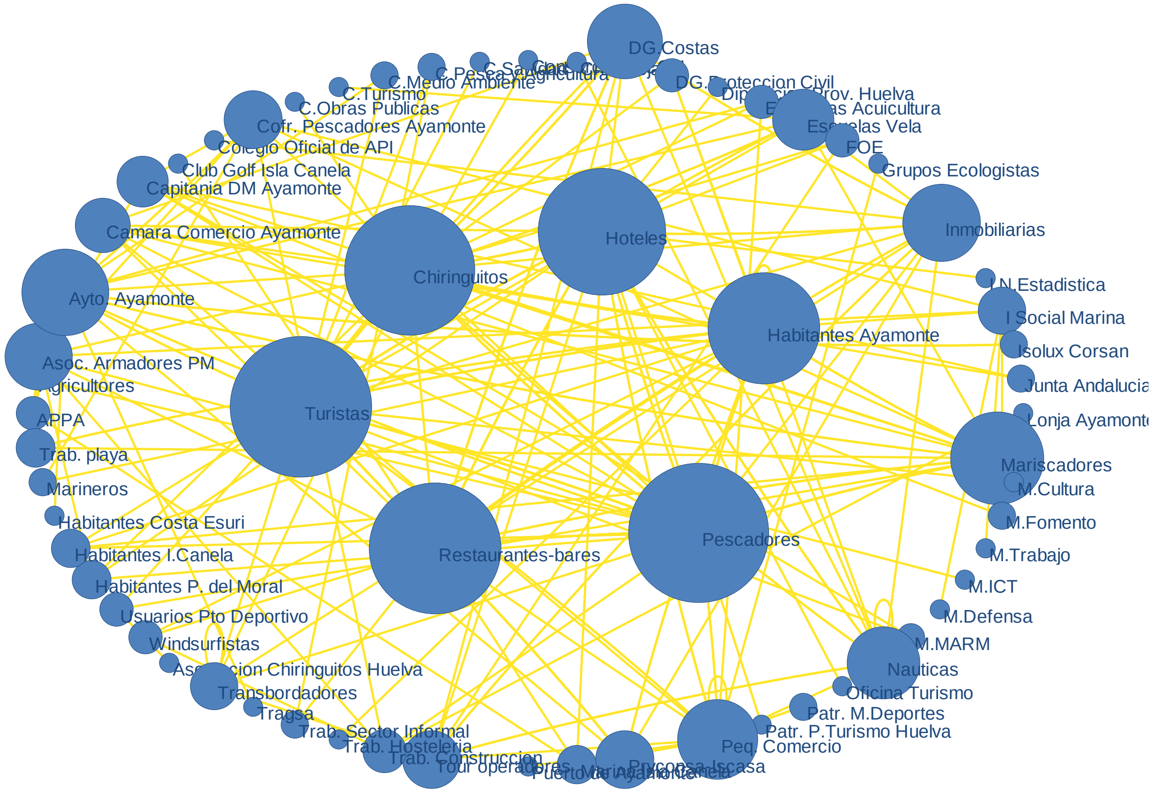


Figure A-4. Social Network Analysis (I): Stakeholders’ weight. (Self-elaboration)

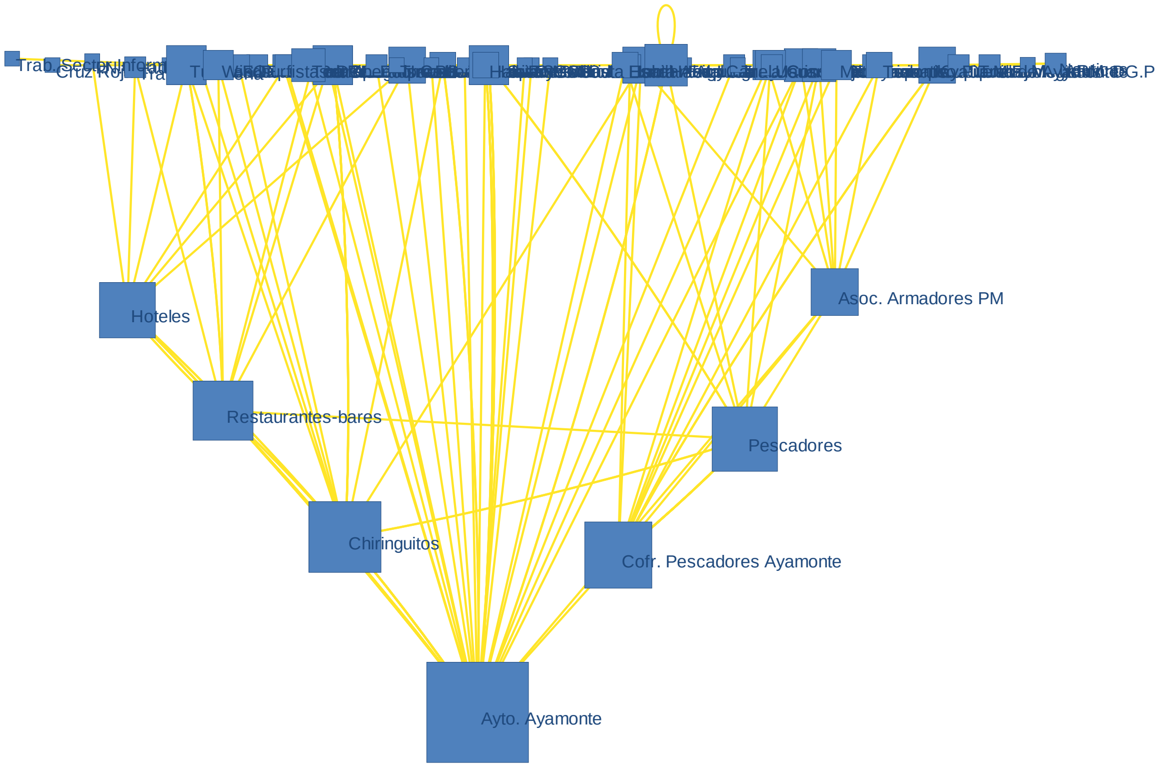


Figure A-5. Social Network Analysis (II): Stakeholders' connection degree (Self-elaboration)

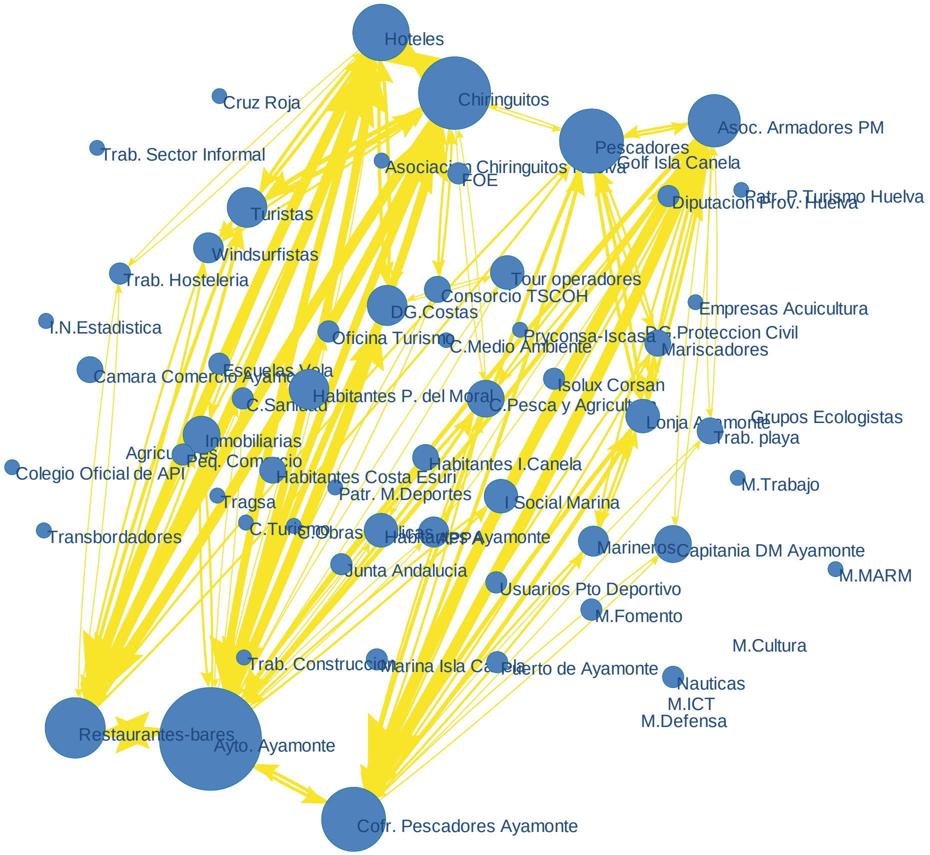
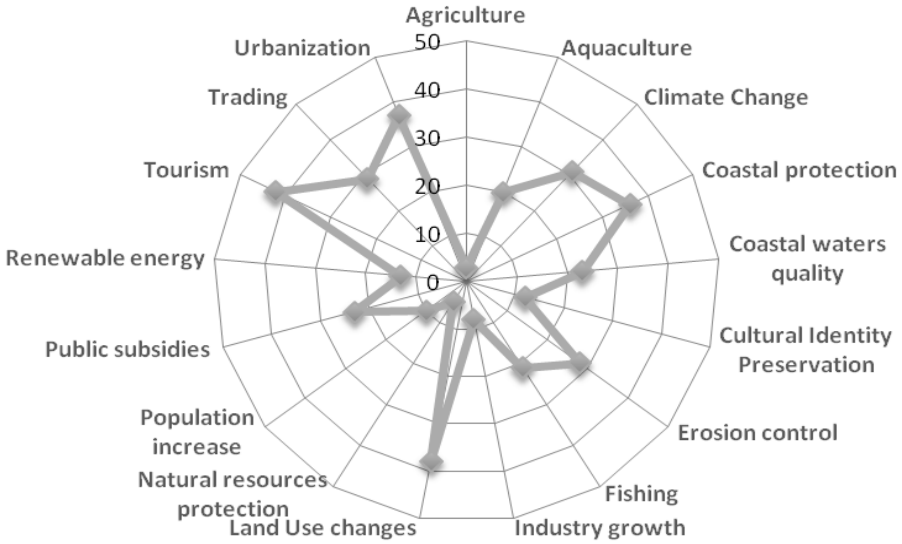


Figure A-6. Social Network Analysis (II): Stakeholders' connections directionality. (Self-elaboration)

Figure A-7. Preliminary Driving forces identified by stakeholders



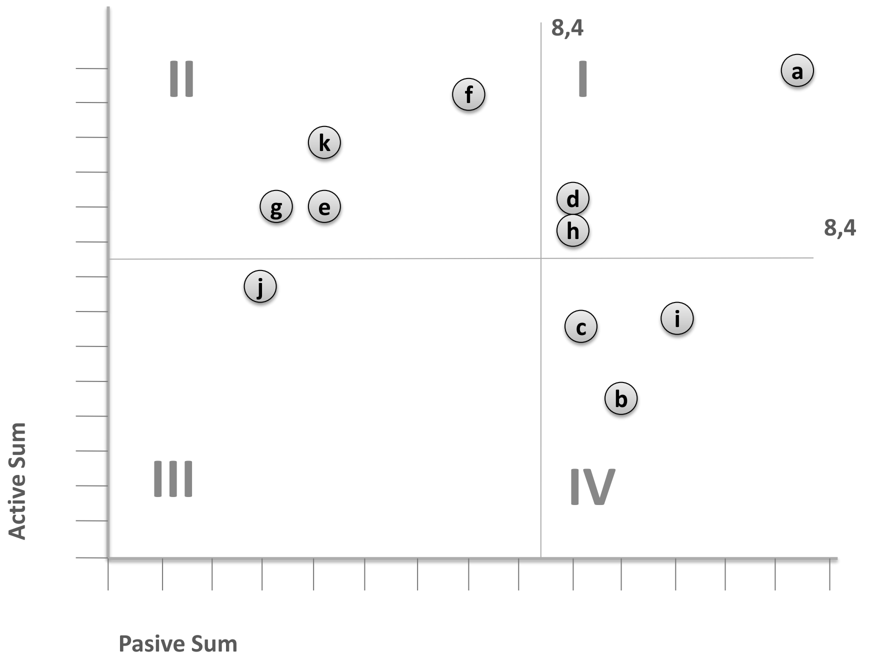
(Self-elaboration)

Table A-4. Coastal system changes

System	Parameter	Change	Data	Data source
Socio-Economic	Population	Increase	Statistical data	INE, 2010; IEA, 2010
	Urbanized area	Increase	Spatial data	CMA, 2009.
	Traditional dry-land crops	Decrease	Spatial data	CMA, 2009.
	Intensive agriculture	Increase	Spatial data	CMA, 2009.
	Aquaculture farms	Increase	Spatial data	MMA, 2007.
	Nº of fishing boats	Decrease	Statistical data	CAP, 2010.
	Fishing production	Increase	Statistical data	CAP, 2010.
	Infrastructure (roads)	Increase	Statistical data	MMA,2007
	Surface cover by solar panels	Increase	Quantitative data	ACC, 2010
	Immigration	Increase	Statistical data	IEA, 2010
	Emigration	Increase	Statistical data	IEA, 2010
	Natural protected areas	Increase	Spatial data	CMA, 2009.
	Protected heritage	Increase	Quantitative data	ACC, 2009.
Biophysical	Shoreline morphology	Modification	Previous Study	Ojeda and Malvárez, 2005.
	Surface covered by dunes	Decrease	Spatial data	MMA,2007
	Surface covered by salt marshes	Decrease	Spatial data	MMA, 2007
	Sand bars position	Modification	Spatial data	Ojeda and Malvárez, 2005
	Surface covered by forest/shrubs	Decrease	Spatial data	CMA, 2009
	Aquifer pollution	Decrease	Quantitative data	CHG, 2009
	Aquifer depletion	Decrease	Quantitative data	CHG, 2009
	Aquifer salinisation	Increase	Quantitative data	CHG, 2009
	Fresh water pollution	Decrease	Quantitative data	CMA, 2000
	Exotic species introduction	Increase	Quantitative data	Chícharo et al, 2009.
	River sediments *	Decreased	Quantitative data	MMA,2007
	River water flow * (*Guadiana River)	Decrease	Quantitative data	MMA,2007

(Self-elaboration)

Figure A-9. Impact Factor Grid



(Self-elaboration)

Code:
a) Tourism expansion;
b) Fishing maintenance;
c) Aquaculture growth;
d) Agriculture intensification;
e) Industrial-Technological change;
f) policies implementation;
g) demographic forces;
h) Natural coastal dynamics;
i) Environmental protection;
j)Identity and cultural protection;
k) Climate change

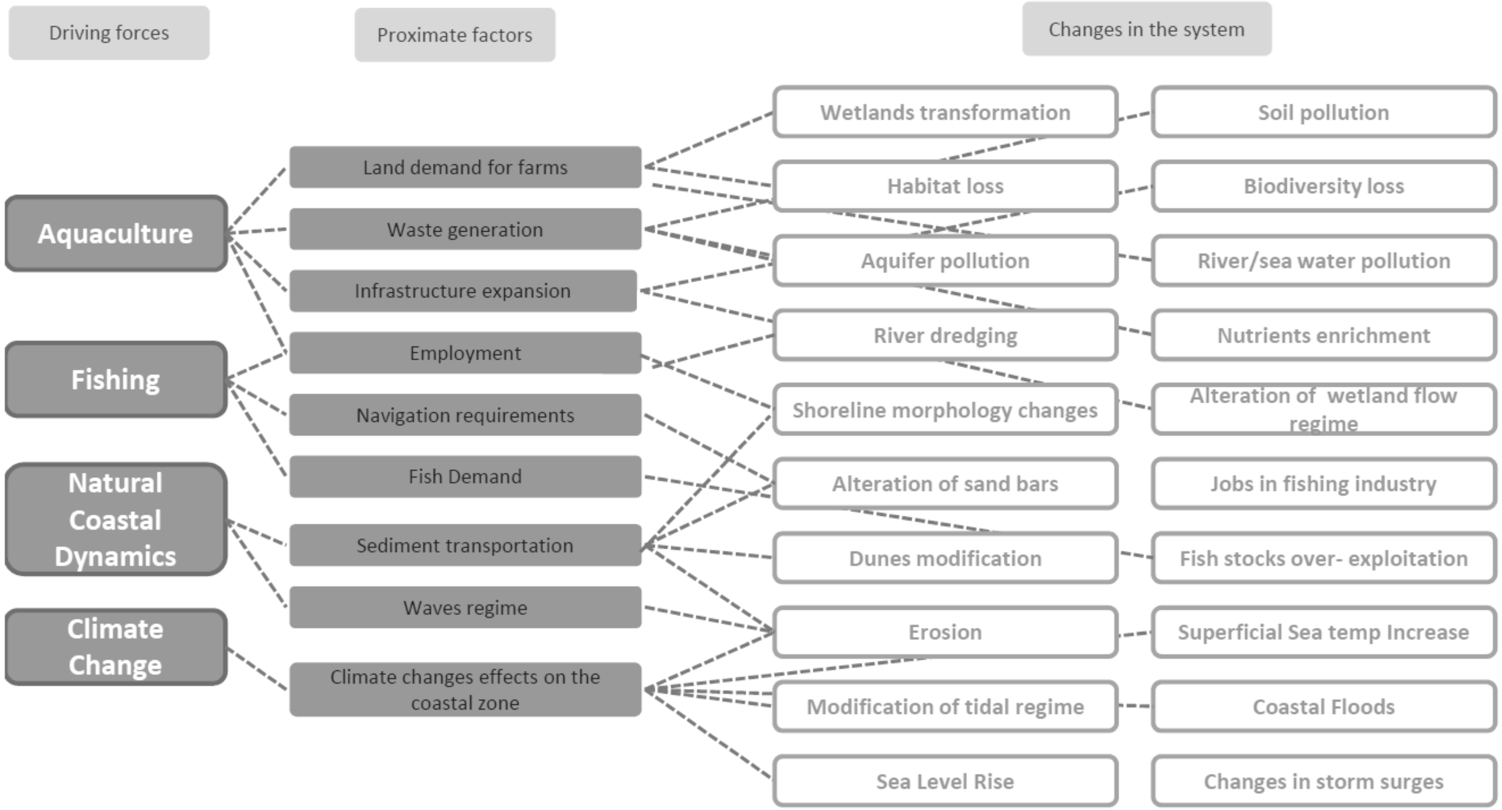


Figure A-9. Storyline diagram for Scenario 2 (Self elaboration)

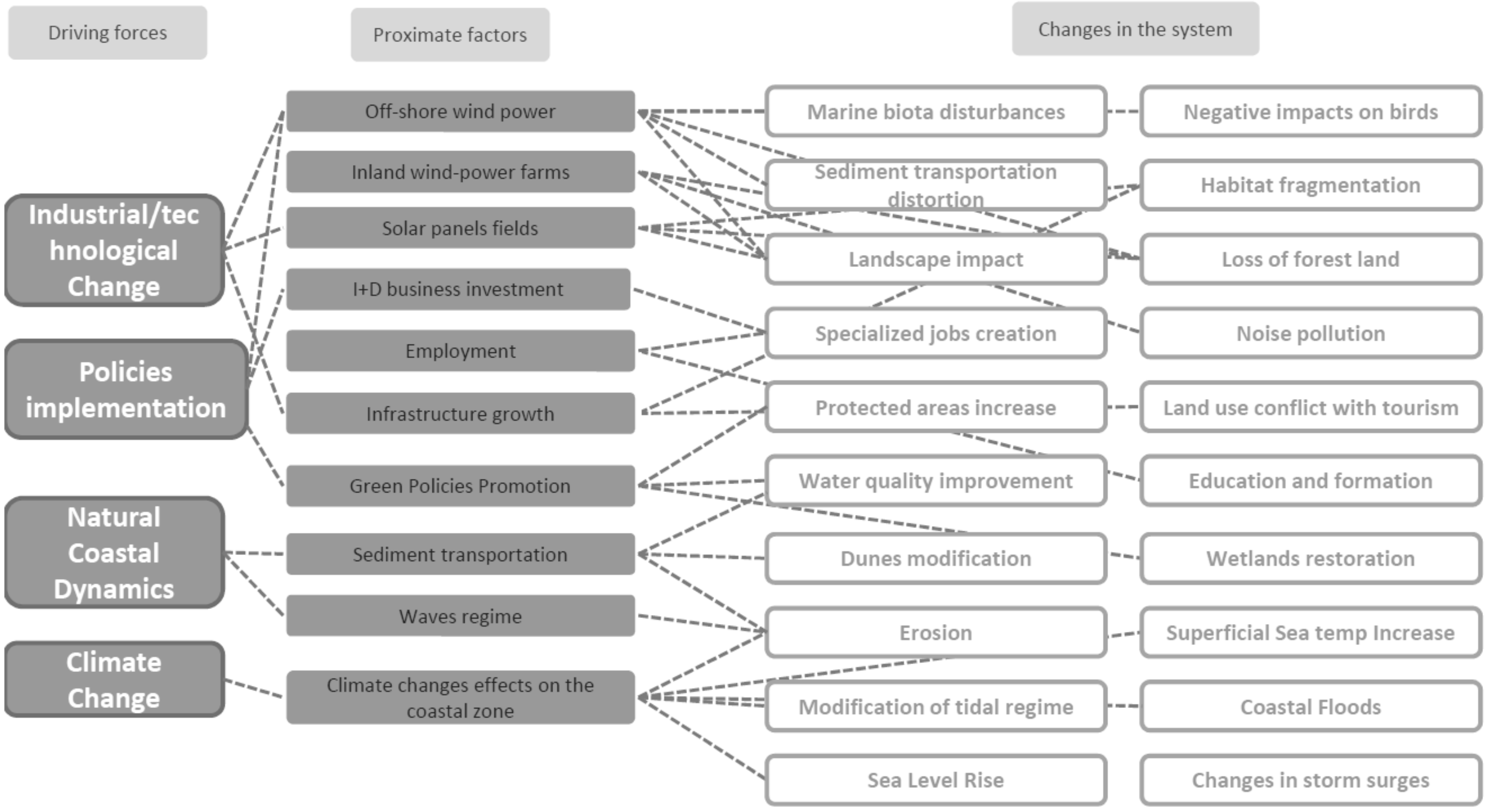


Figure A-10 . Storyline diagram for Scenario 3 (Self elaboration)

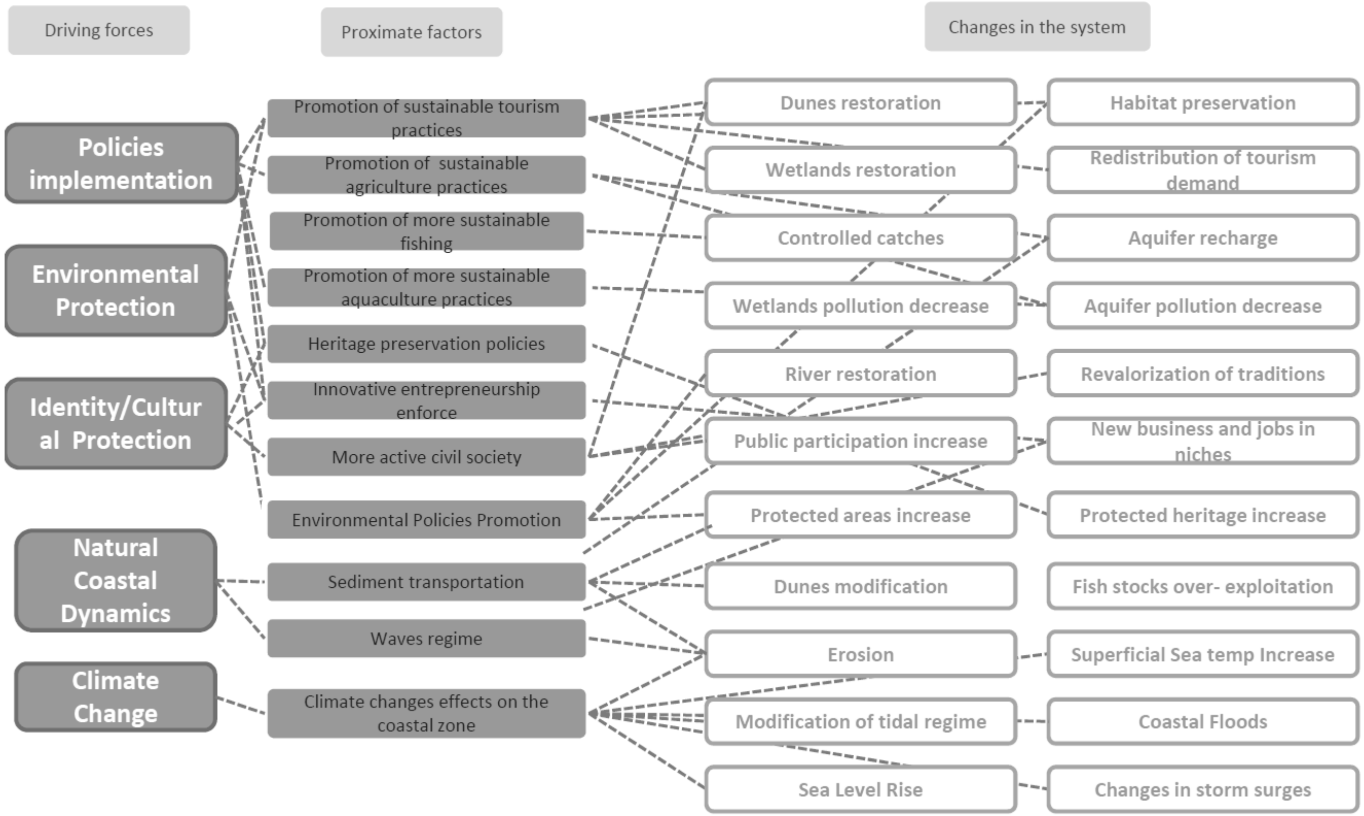


Figure A-11. Storyline diagram for Scenario 4 (Self elaboration)

Table A-5. Storyline summary for Scenario 1

Scenario 1: 'Intensive Tourism Forever'
This scenario is characterized by the continuation of the traditional tourism model that prevailed in the study area. This is a model based on the intensive exploitation of the "beach and sun". After the economic crisis of the late 2000's, there is a second bet for the intensive tourism model that was working before. In this context, the construction sector will continue to be a key piece in the local economy, concentrating many jobs in the area. Urbanization processes will continue occurring both at the beach and in the river side, where the new interests of developers are concentrated.
Population will grow both in terms of permanent population (population (locals plus immigrants seeking for jobs in tourism, as well as residential tourists) and temporal population made by the tourists. Therefore there will be a strong unbalance between the winter population and the summer population, which has to be taken into account for services provision (water supply, electricity, transport, etc.). This seasonality will affect also employment within the area, as most of the business activities will be concentrated during the summer season; hence people have to look for another alternative income source during the rest of the year.
In terms of policies, this scenario is fast-development prone, so policies will promote employment creation and investment in the area by private companies, that is to say market liberalization. On the other hand, environmentally friendly policies will not be a priority and no measures will be taken to enhance the current protected areas or to create new ones. Analogously, there will not be policies to protect cultural /identity issues, so traditions and heritage will be slowly lost.
Coastal dynamics will be more affected by the intensive tourism and the absence of environmental protection policies, these circumstances will lead to negative impacts that go from beach erosion to wetlands destruction among other effects.
Climate change will threat the tourism-dependent economy and also the human safety (population concentrated on the coast).

(Self-elaboration)

Table A-6. Storyline summary for Scenario 2

Scenario 2: Fishing sector rebirth
This scenario is characterized by the recuperation and re-enforcement of the fishing sector that has been historically very important in the area. One of the main reasons for this change is the increasing scarcity of fish on the oceans that has leaded the administrations to promote aquaculture.
Through a new set of regulations and a new approach to businesses, a modernization of the sector is promoted. Fishermen unions play a crucial role in leading the transformational process and a business strategy is drafted in order to make more competitive the old fishing industry.
One of the main changes in the sector is the recuperation of aquaculture farms that were abandoned during the ‘80s. These farms are run by local companies that promote the employment of local population.
Aquaculture expansion leads to wetlands loss, alteration of the flow regime, pollution of soil and waters, and biodiversity loss. Besides, pressures over fish stocks in the area increase and the river dredging (need for navigation) continue the alteration of the shoreline.
Environmental protection is hardly enforced, and ecological degradation has increased rapidly. Nevertheless, cultural and identity protection are better preserved as the traditional marine character of the village is recovered. Despite the new approach to the fishing industry, the maritime culture remains in the area and customs have not been lost.
Climate change effects will potentially impact the aquaculture sector as wetlands can be seriously affected by sea level rise and coastal storms.

(Self-elaboration)

Table A-7. Storyline summary for Scenario 3

Scenario 3 : 'Green Energy Power'
This scenario is characterised by the expansion of renewable energies. The municipality has decided to exploit its potential as green energy leader and has developed a program for solar and wind energy. The city council has taken advantage of the I+D European and regional policies that provide incentives to the public administrations to promote green technologies. Winds farms have been installed in the area, some of them located inland and others in a off-shore park. Besides a vast solar panel field has been installed in a plain area. The new industry has provided a new niche of specialised jobs and it is attracting the attention of investors that see the area a new experimental site for renewable energies business.
However, there is opposition of certain groups to the new industry because it has heavily impacted the landscape, causing a tourism decrease within the last years. Despite the old hotels and apartments in the beach continue existing; the plans to increase the urban areas or to build a new marina were abandoned.
Also population has gradually left the beach and has moved to the inside land, as the wind farms generate intensive acoustic pollution.
The coastal environment has been strongly modified starting with the off-shore wind power park, which is modifying the coastal dynamics (altering the sediments transportation) and causing the marine biota alteration.
On the other hand there have been some positive environmental effects, because together with the green energies promotion, the city council has decided to promote a greener and cleaner environment (also to compensate ecological disturbances cause by the wind mills and solar panels). In this sense wetlands restoration and water quality programs have been run. Climate change will potentially affect the new industry, as it is located in the coastal area, generating important economic losses.

(Self-elaboration)

Table A-8. Storyline summary for Scenario 4

Scenario 4: 'Paradigm Switch'
This scenario is characterised by a shift to sustainability in both environmental and society terms. The financial crisis of the late 2000's underlined the fragility of the economic system and the local government and the population realized that it was necessary to diversify the economy and build a more resilient society.
In this scenario the dominant approach is the application of sustainability principles in all sectors, under an innovative approach and ICZM principles. In tourism for instance, new activities are promoted as wetlands tours, bird watching, fishing practices observation, etc.
In the fishing sector, the old canning industry (famous in the beginning of the XX century) has been reinstituted due to the increasing demand of artisanal products, generating employment in the area. In the agricultural sector, environmentally friendly practices have been promoted, reducing drastically the use of pesticides and the exploitation of underground water.
Also environmental conservation activities have been developed as: dunes restoration, key habitat preservation, wetlands and riverside restoration, reforestation, etc. Cultural and identity preservation has also been strongly pursued, by different heritage conservation activities and revalorization of local traditions initiatives. This has been possible because due to the change in the paradigm of development, the civil society has become more active generating a higher degree of participation and involvement in decision-making.
Coastal environment has greatly benefited from all the measures taken and the whole coastal system has recovered its functionality in ecological terms. Climate change impacts are potentially slighter in this scenario due to the reduction of vulnerability in socio-economic terms (diversification of the economy) and physical terms (due to the restoration of the dunes barrier and wetlands.

(Self-elaboration

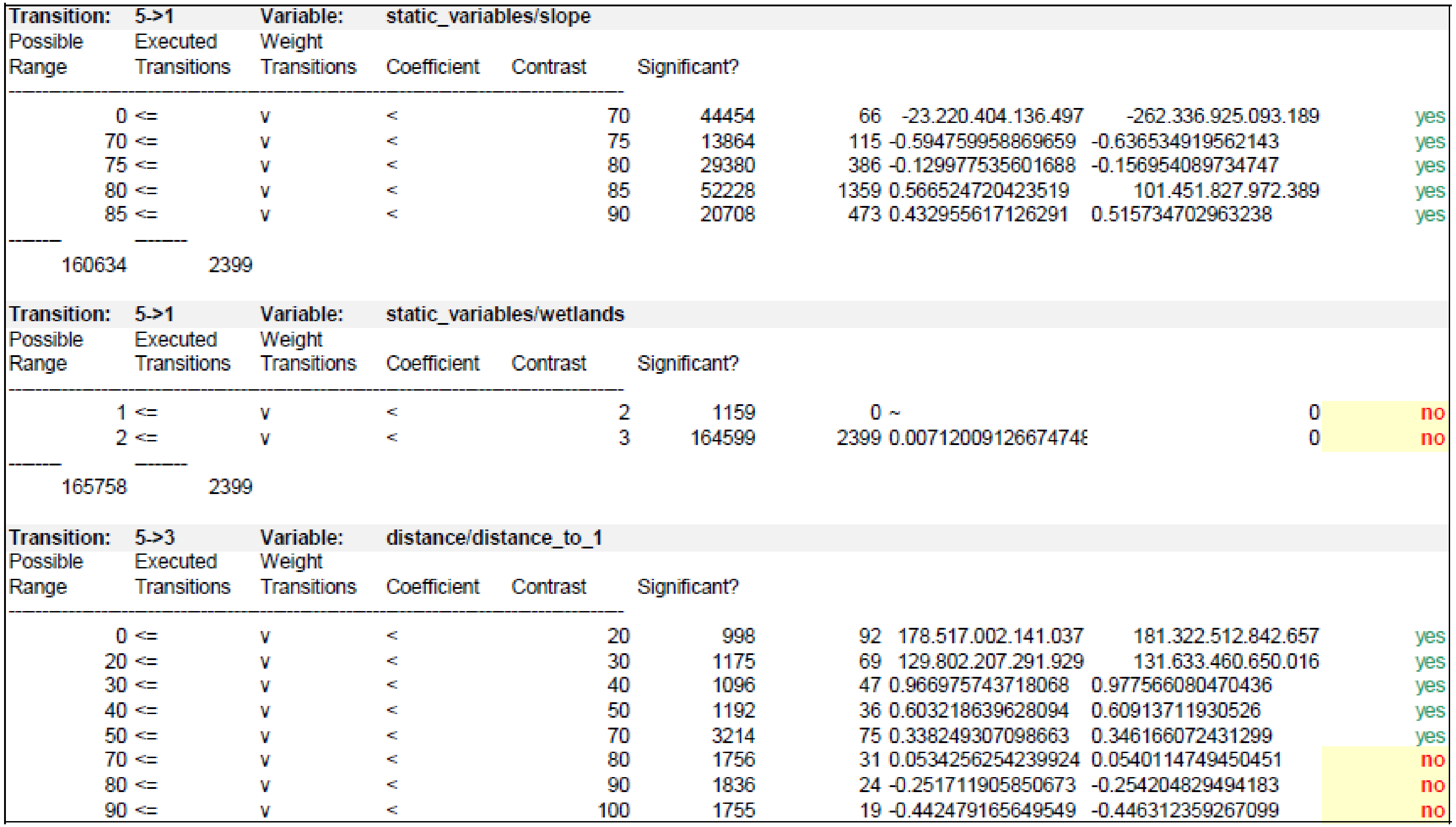
Single Transition Matrix (total changes rate)

		1	2	3	4	5	6	7	8	9	10
		Urban	Green/recreat	Industrial 1	Industrial 2	Crops	Shrubs	Wetlands	Beach	Water	Non-vegetated
Urban	1		--	1,9452%	--	0,0044%	--	--	0,0044%	--	0,1311%
Green/recreat	2	3,2985%		--	--	--	--	0,0183%	--	--	0,0183%
Industrial 1	3	0,0677%	0,1692%		--	--	--	--	--	--	--
Industrial 2	4	--	--	--		--	0,0022%	0,0284%	--	--	--
Crops	5	1,3546%	--	1,5714%	--		0,4037%	0,0079%	--	0,0034%	4,4178%
Shrubs	6	5,5448%	0,6830%	0,1167%	0,0001%	1,9100%		0,0029%	0,0004%	0,0046%	2,5142%
Wetlands	7	0,2717%	1,1145%	0,2144%	0,0022%	0,0038%	0,0016%		--	0,0044%	0,0469%
Beach	8	--	--	--	--	--	--	0,0172%		5,2659%	0,4818%
Water	9	0,0010%	0,0021%	0,0010%	0,0010%	0,1757%	0,0114%	0,0509%	0,2557%		0,2308%
Non-vegetate	10	1,7858%	--	1,0483%	--	15,9077%	32,6491%	--	--	0,1904%	

Multi-Step Transition Matrix (Yearly changes rate)

		1	2	3	4	5	6	7	8	9	10
		Urban	Green/recreat	Industrial 1	Industrial 2	Crops	Shrubs	Wetlands	Beach	Water	Non-vegetated
Urban	1		--	0,2456%	--	--	--	--	0,0006%	--	**0,0225%**
Green/recreat	2	0,4224%		--	--	--	--	0,0023%	--	--	0,0028%
Industrial 1	3	0,0082%	**0,0215%**		--	--	--	--	--	--	--
Industrial 2	4	--	--	--		--	0,0003%	0,0036%	--	--	--
Crops	5	0,1743%	--	0,1988%	--		--	0,0010%	--	--	0,7786%
Shrubs	6	0,7314%	**0,0914%**	0,0052%	0,0000%	0,2235%		0,0004%	0,0000%	0,0002%	0,4422%
Wetlands	7	**0,0324%**	0,1424%	**0,0267%**	0,0003%	--	--		--	0,0005%	0,0080%
Beach	8	--	--	--	--	--	--	0,0021%		0,6776%	**0,0831%**
Water	9	--	0,0003%	--	0,0001%	**0,0197%**	--	0,0064%	**0,0329%**		**0,0384%**
Non-vegetate	10	0,1201%	--	0,1522%	--	2,7475%	5,8512%	--	--	**0,0322%**	
		Urban	Green/recreat	Industrial 1	Industrial 2	Crops	Shrubs	Wetlands	Beach	Water	Non-vegetated

Table A-9. Transition matrices for the calibration period (1999-2007) (Self-elaboration)



```
Transition:   5->1          Variable:     static_variables/slope
Possible      Executed      Weight
Range         Transitions   Transitions   Coefficient   Contrast      Significant?
------------------------------------------------------------------------------
        0 <=        v         <              70         44454        66  -23.220.404.136.497      -262.336.925.093.189     yes
       70 <=        v         <              75         13864       115 -0.594759958869659  -0.636534919562143           yes
       75 <=        v         <              80         29380       386 -0.129977535601688  -0.156954089734747           yes
       80 <=        v         <              85         52228      1359 0.566524720423519        101.451.827.972.389     yes
       85 <=        v         <              90         20708       473 0.432955617126291   0.515734702963238            yes
-------       -------
   160634          2399

Transition:   5->1          Variable:     static_variables/wetlands
Possible      Executed      Weight
Range         Transitions   Transitions   Coefficient   Contrast      Significant?
------------------------------------------------------------------------------
        1 <=        v         <               2          1159         0 ~                                  0            no
        2 <=        v         <               3        164599      2399 0.00712009126674748                0            no
-------       -------
   165758          2399

Transition:   5->3          Variable:     distance/distance_to_1
Possible      Executed      Weight
Range         Transitions   Transitions   Coefficient   Contrast      Significant?
------------------------------------------------------------------------------
        0 <=        v         <              20           998        92  178.517.002.141.037      181.322.512.842.657     yes
       20 <=        v         <              30          1175        69  129.802.207.291.929      131.633.460.650.016     yes
       30 <=        v         <              40          1096        47 0.966975743718068   0.977566080470436            yes
       40 <=        v         <              50          1192        36 0.603218639628094   0.60913711930526             yes
       50 <=        v         <              70          3214        75 0.338249307098663   0.346166072431299            yes
       70 <=        v         <              80          1756        31 0.0534256254239924  0.0540114749450451           no
       80 <=        v         <              90          1836        24 -0.251711905850673  -0.254204829494183           no
       90 <=        v         <             100          1755        19 -0.442479165649549  -0.446312359267099           no
```

Table A-10. Example of Weights of Evidence Coefficients. Transitions 5>1 : crops to urban. Transition 5>3: crops to industrial 1 (Self elaboration)

Transition: **1->2**

First variable	Second variable	Chi^2	Crammer*	Contingency	Entropy	J.I.Uncertainty
distance/distance_to_1	static_variables/aquifer	202.944.425.095.352	0.119562717678582	0.118717183217647	0.770445405491985	0.0189949129734248
distance/distance_to_1	static_variables/d_commerce	428.902.628.104.723	0.122905138774169	0.171246567431955	112.889.686.525.237	0.0193656718642138
distance/distance_to_1	static_variables/d_golf	360.403.275.115.538	0.113025196754562	0.157838148994367	103.186.801.629.011	0.0177624786318308
distance/distance_to_1	static_variables/d_ports	205.099.175.482.632	0.268879188066004	0.355424062083805	0.857787408149805	0.0596168065495386
distance/distance_to_1	static_variables/d_rivers	278.490.091.953.221	0.0313180671007154	0.0442470580451753	164.319.655.052.001	0.00149797710744152
distance/distance_to_1	static_variables/d_roads	22.563.197.809.377	0.089258810289284	0.125237181885449	0.97884948823619	0.0111464410763648
distance/distance_to_1	static_variables/d_trails	934.083.066.284.535	0.181580798725877	0.248724114709457	147.088.481.959.618	0.027146509866462
distance/distance_to_1	static_variables/elevation	803.295.536.638.001	0.168201748524453	0.231416094370742	14.784.370.129.844	0.0205181203426434
distance/distance_to_1	static_variables/litology	633.484.961.350.229	0.149869448669834	0.207341498358012	139.384.108.167.567	0.0271257554284965
distance/distance_to_1	static_variables/p_industrial	774.708.833.857.947	0.00738715277989098	0.00738695122957955	0.116325452499661	0.00092714494100977
distance/distance_to_1	static_variables/p_touristic	257.181.163.242.002	0.134594528428772	0.133391710207417	0.333010005302876	0.0307909297639395
distance/distance_to_1	static_variables/prot_area	316.596.551.383.505	0.0472237652201592	0.0471711966464333	0.449272448009305	0.00797676907405256
distance/distance_to_1	static_variables/slope	172.779.943.873.055	0.0807841610820578	0.113507697320629	160.342.068.162.879	0.00742820796933137
distance/distance_to_1	static_variables/wetlands	359.317.069.134.972	0.0503090703832453	0.0502455247903427	0.444771257812322	0.010393692746388
static_variables/aquifer	static_variables/d_commerce	310.916.283.208.213	0.46798227870722	0.423863709316486	157.069.467.327.039	0.175743077765306
static_variables/aquifer	static_variables/d_golf	416.655.196.757.935	0.543483430192561	0.477516826664367	14.386.916.123.735	0.240433168647574
static_variables/aquifer	static_variables/d_ports	323.664.172.836.956	0.477682722319025	0.431030879205375	131.037.184.396.249	0.212527149106263
static_variables/aquifer	static_variables/d_rivers	115.550.908.865.219	0.285294727205855	0.274348096817402	218.527.008.397.865	0.0370389203707467
static_variables/aquifer	static_variables/d_roads	299.834.839.238.053	0.460159939225088	0.418025524065689	145.743.309.254.166	0.139729797727446
static_variables/aquifer	static_variables/d_trails	122.681.600.432.307	0.294295675068232	0.282323508314402	202.454.726.265.168	0.0484610467790735
static_variables/aquifer	static_variables/elevation	367.214.071.382.536	0.508589431671122	0.453328018844006	191.392.540.255.411	0.155996688184284
static_variables/aquifer	static_variables/litology	102.932.779.374.614	0.854351622732171	0.64956715007739	153.489.950.229.699	0.461673258264237
static_variables/aquifer	static_variables/p_industrial	493.109.669.615.078	0.0588772621112769	0.0587754767103189	0.696103005884643	0.00586659661662416
static_variables/aquifer	static_variables/p_touristic	285.363.338.706.301	0.0141636418276082	0.0141622213660824	0.919576577651139	0.000219449857567557
static_variables/aquifer	static_variables/prot_area	246.979.528.622.614	0.417097749792333	0.384954365323526	0.928413464164806	0.202748076228854
static_variables/aquifer	static_variables/slope	165.461.258.893.759	0.353543651464253	0.333325171394619	211.947.165.093.977	0.0571378646494603
static_variables/aquifer	static_variables/wetlands	203.015.520.261.362	0.378156731336158	0.353710736631601	0.949528881204018	0.154769937588833
static_variables/d_commerce	static_variables/d_golf	139.103.641.109.969	0.405405830837452	0.704632239598171	148.842.394.679.866	0.513492600747686
static_variables/d_commerce	static_variables/d_ports	152.074.378.789.637	0.366078075721334	0.719304548926944	129.304.976.795.647	0.584313336717714
static_variables/d_commerce	static_variables/d_rivers	11.864.481.241.387	0.109264954615488	0.277716101597544	254.558.273.227.938	0.0332398849986026
static_variables/d_commerce	static_variables/d_roads	231.791.013.031.786	0.165172939578051	0.37505536902884	184.937.271.114.711	0.0823133209216809
static_variables/d_commerce	static_variables/d_trails	766.401.420.632.299	0.260061334874147	0.59253183087414	217.798.611.175.838	0.21277632652172
static_variables/d_commerce	static_variables/elevation	753.837.493.101.388	0.275421686205898	0.588924463319996	219.990.402.370.721	0.195278005949664
static_variables/d_commerce	static_variables/litology	655.935.885.237.803	0.278429652345941	0.563445326128797	211.604.325.992.203	0.203248646411889
static_variables/d_commerce	static_variables/p_industrial	227.525.383.031.766	0.126596941340526	0.125594503749186	105.699.149.797.452	0.00673210013059404
static_variables/d_commerce	static_variables/p_touristic	48.744.265.105.731	0.185297708865542	0.182196230940777	126.023.890.553.818	0.0345580216260585
static_variables/d_commerce	static_variables/prot_area	716.647.109.607.374	0.224678055615478	0.219213206848993	135.525.595.997.584	0.0573332989730637
static_variables/d_commerce	static_variables/slope	993.123.061.196.908	0.0968392873660092	0.264172584225801	25.176.627.246.766	0.0355618400806081
static_variables/d_commerce	static_variables/wetlands	755.561.945.980.592	0.230697487807464	0.224793133982038	135.143.678.557.234	0.0572701181454436
static_variables/d_golf	static_variables/d_ports	145.672.365.778.126	0.415044876951124	0.712919913808843	120.731.550.121.566	0.61609853791561
static_variables/d_golf	static_variables/d_rivers	761.707.525.451.214	0.0948667994998414	0.226344490549535	24.798.399.871.773	0.0223621334410987
static_variables/d_golf	static_variables/d_roads	116.267.018.839.887	0.117357998473734	0.276278320060037	179.879.849.556.607	0.0533163302863672
static_variables/d_golf	static_variables/d_trails	85.150.659.129.857	0.3175342905882	0.613950061382531	205.800.294.564.521	0.240506491284878
static_variables/d_golf	static_variables/elevation	994.758.262.646.489	0.342832254335002	0.643086159743922	202.703.637.427.976	0.273204183139895
static_variables/d_golf	static_variables/litology	91.391.386.113.061	0.329713717506021	0.628307944810201	192.978.888.267.422	0.299046728252643

Table A-11. Example of independence analysis for explanatory variables: Chi, Crammer, Contingency, Entropy and Joint Uncertainty Indexes (Self-elaboration)

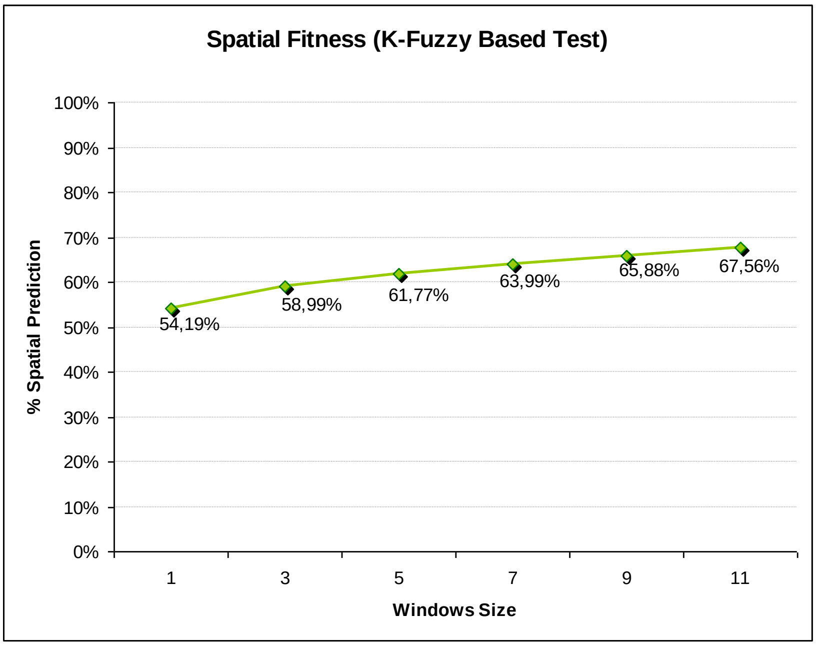
	Transitions																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Variables	1 to 3	1 to 10	2 to 1	3 to 2	5 to 1	5 to 3	5 to 10	6 to 1	6 to 2	6 to 3	6 to 5	6 to 10	7 to 1	7 to 2	7 to 3	8 to 9	8 to 10	9 to 5	9 to 8	9 to 10	10 to 1	10 to 3	10 to 5	10 to 6	10 to 9
distance to urban areas	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
aquifer	1	0	1	1	1	1	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	0	0	0	1
distance to commerce	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to golf	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to ports	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to rivers	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to roads	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to trails	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
elevation	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
litology	1	1	1	1	0	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
planned industrial	1	1	1	1	1	0	0	1	1	0	1	0	1	1	0	1	1	1	1	1	1	1	1	0	1
planned touristic	1	1	0	1	1	1	1	0	0	0	0	0	0	1	0	1	1	1	1	1	0	1	1	0	1
protected area	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1
slope	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wetlands	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	1	0	1	1	0	1	0

Table A-12. Weights of Evidence (WoE) Selection 1: Statistic Significance. 0= Statistically Significant WoE; 1=Statistically Not Significant WoE (Self-elaboration)

	Transitions																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Variables	1 to 3	1 to 10	2 to 1	3 to 2	5 to 1	5 to 3	5 to 10	6 to 1	6 to 2	6 to 3	6 to 5	6 to 10	7 to 1	7 to 2	7 to 3	8 to 9	8 to 10	9 to 5	9 to 8	9 to 10	10 to 1	10 to 3	10 to 5	10 to 6	10 to 9
distance to urban areas	x	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
aquifer	x	1	x	x	x	x	1	1	1	x	1	1	1	1	1	x	x	x	x	1	1	1	1	1	x
distance to commerce	0	1	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
distance to golf	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	1	1	1
distance to ports	1	0	0	x	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0
distance to rivers	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to roads	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
distance to trails	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
elevation	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
litology	x	x	x	x	0	0	0	0	x	0	0	0	0	0	0	x	x	0	x	0	0	0	0	0	0
planned industrial	x	x	x	x	x	0	0	x	x	0	x	0	x	x	0	x	x	x	x	x	x	x	x	0	x
planned touristic	x	x	0	x	x	x	x	0	0	0	0	0	0	x	0	x	x	x	x	x	0	x	x	0	x
protected area	x	x	1	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	1	x	x
slope	0	0	0	x	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wetlands	x	x	x	x	x	1	x	x	x	x	x	1	x	1	x	x	x	x	x	1	x	x	1	x	1

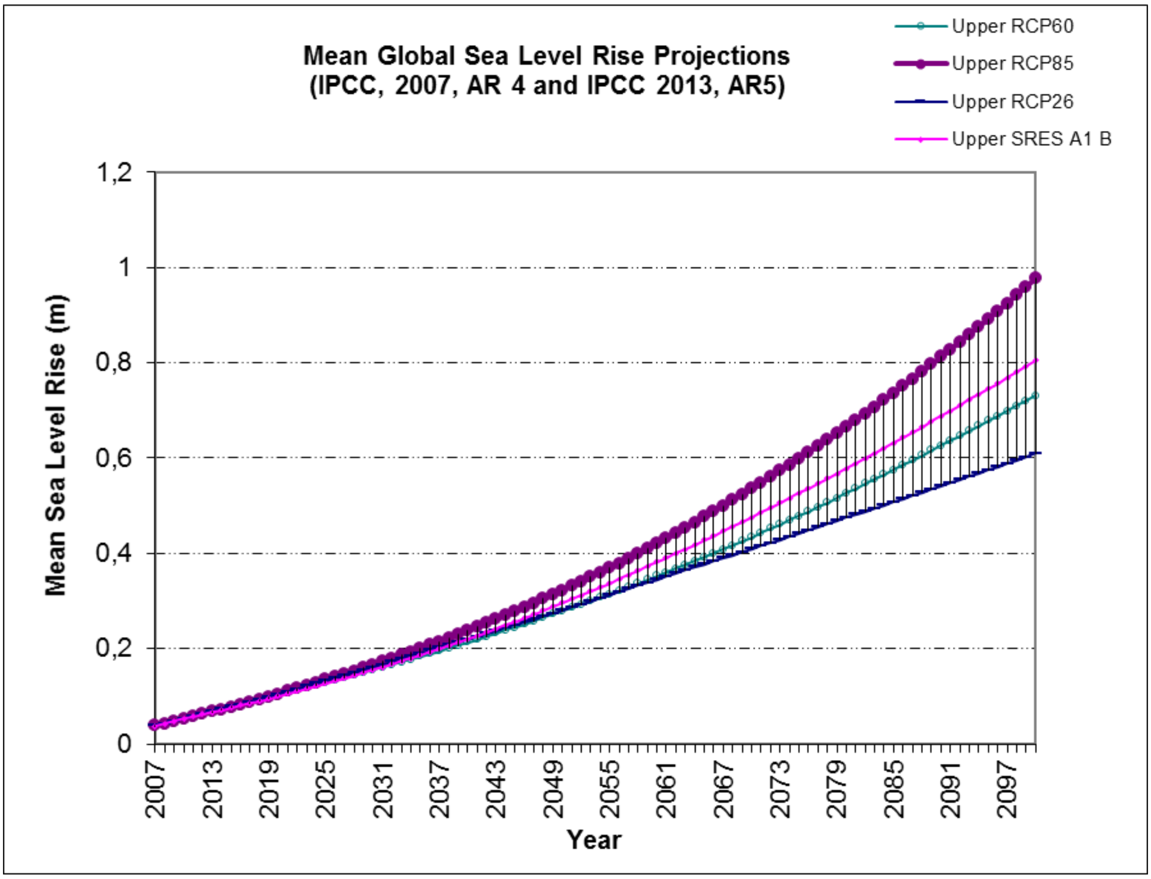
Table A-13. Weights of Evidence (WoE) Selection 2: Spatial Independence. 0= Spatially independent WoE; 1= Spatially dependent WoE; x= WoE eliminated on Selection 1. (Self-elaboration)

Figure A-12. Spatial Fitness K-Fuzzy Test results for the model calibration



(Self-elaboration)

Figure A-13. Comparison of selected Mean Global Sea Level Rise Projections of IPCC AR4 (IPCC, 2007) and IPCC AR5 (IPCC, 2013)



Data source: Church et al., 2013 (Self-elaboration)

Figure A-14. Mean Sea-level PSMSL Data for selected station (1963-2013)

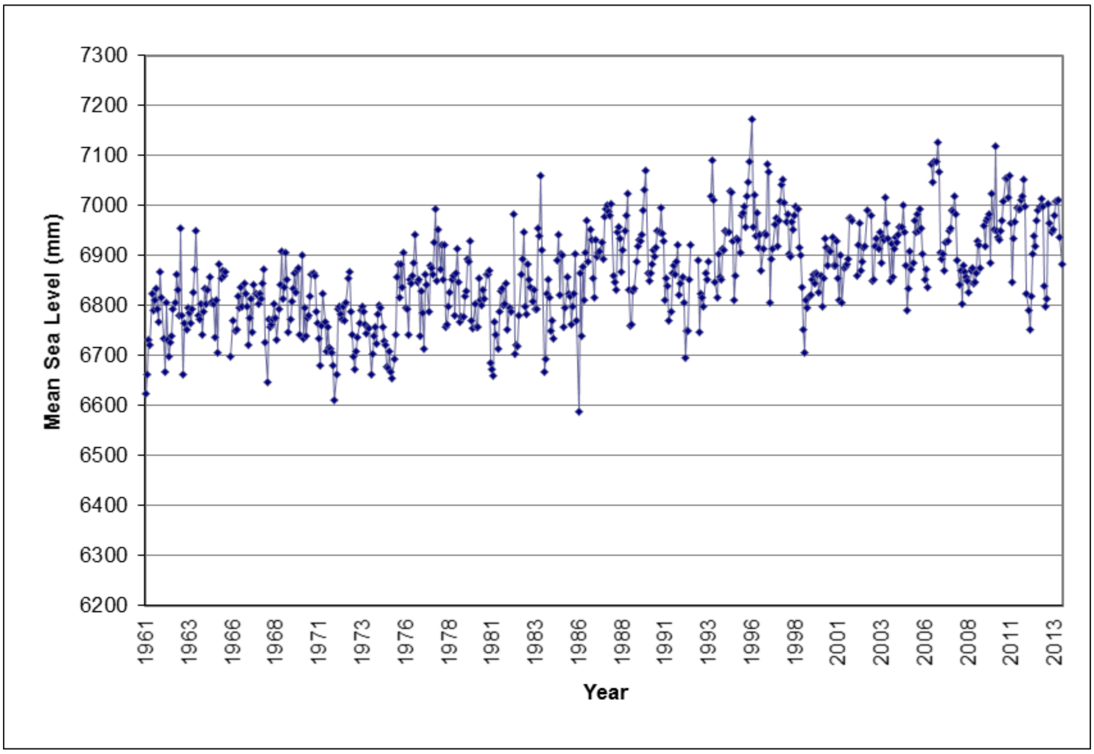


Figure A-15. Regional Sea Level Trend for selected series (1971-2010)

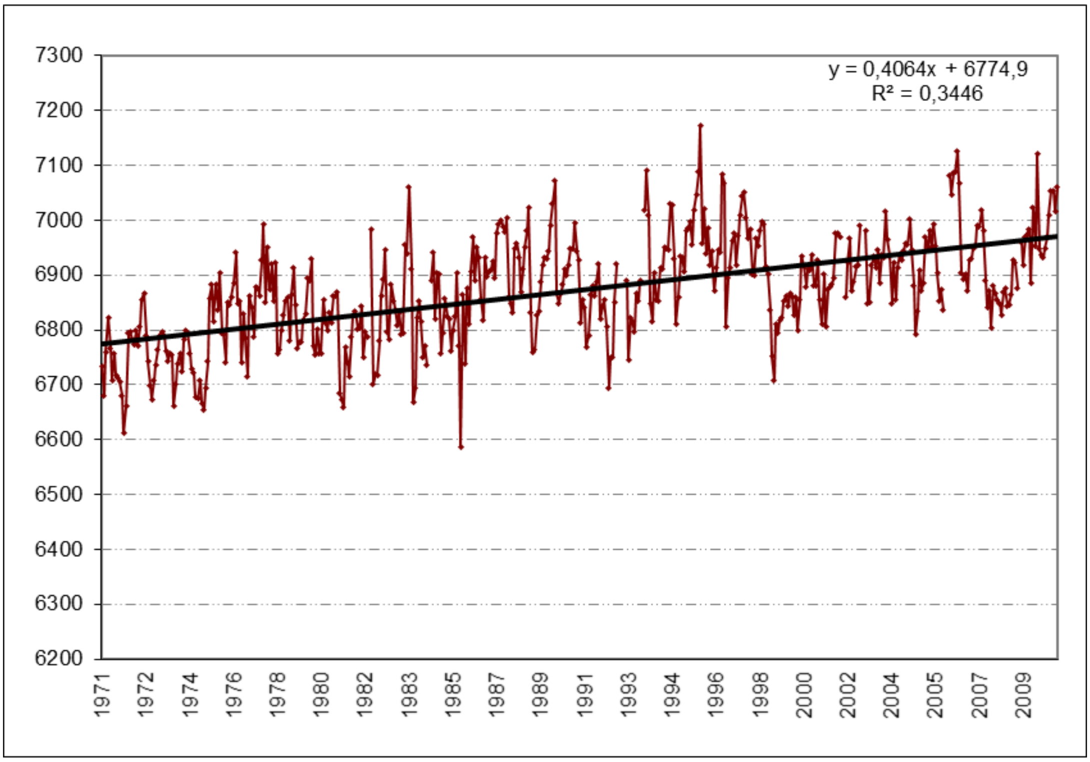
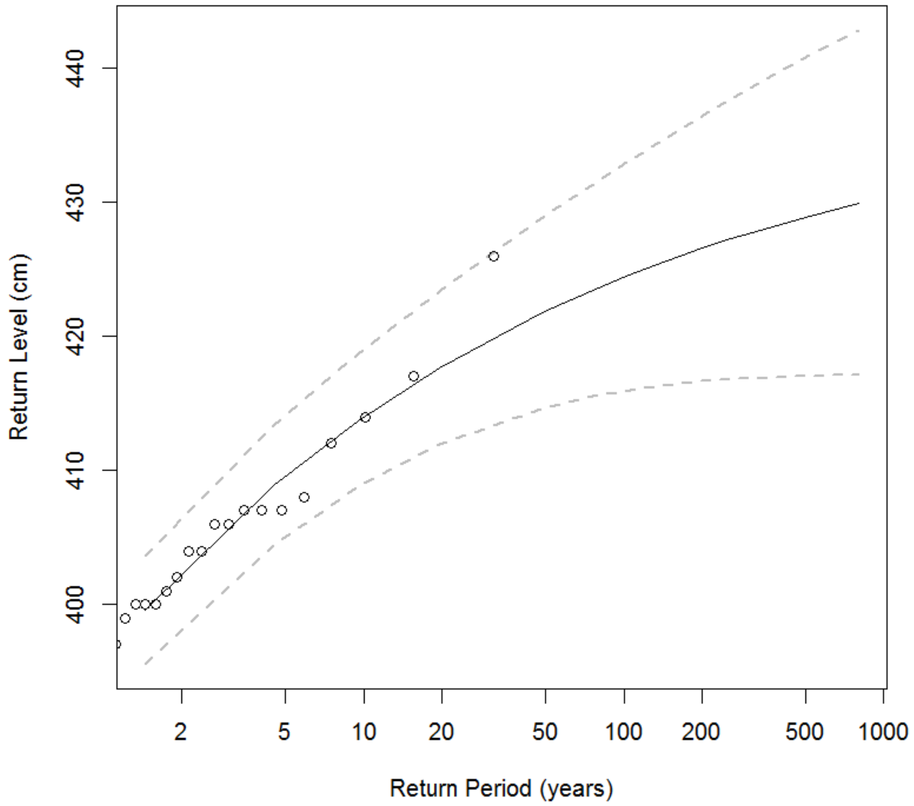


Fig. A-15 and A- 16 Data source: Permanent Service for Sea-Level Rise. Cadiz III Station (Self-elaboration)

Figure A-16. High Water Level extremal analysis: Return Period



Extremal analysis for High Water Levels performed in this thesis. Data for ‘total sea level’, i.e. meteorological and astronomical components of the tides. Methodology after, in R model ‘in2extremes’. Original data provided by the Spanish National Ports Authority; only for research purposes. Buoy Huelva Code 3326 (Geo. Coord: -6.830 E; 37.130 N) (Self-elaboration.)

Function parameters:

- Location: 396.0105786
- Scale: 10.1820404
- Shape: -0.2395717

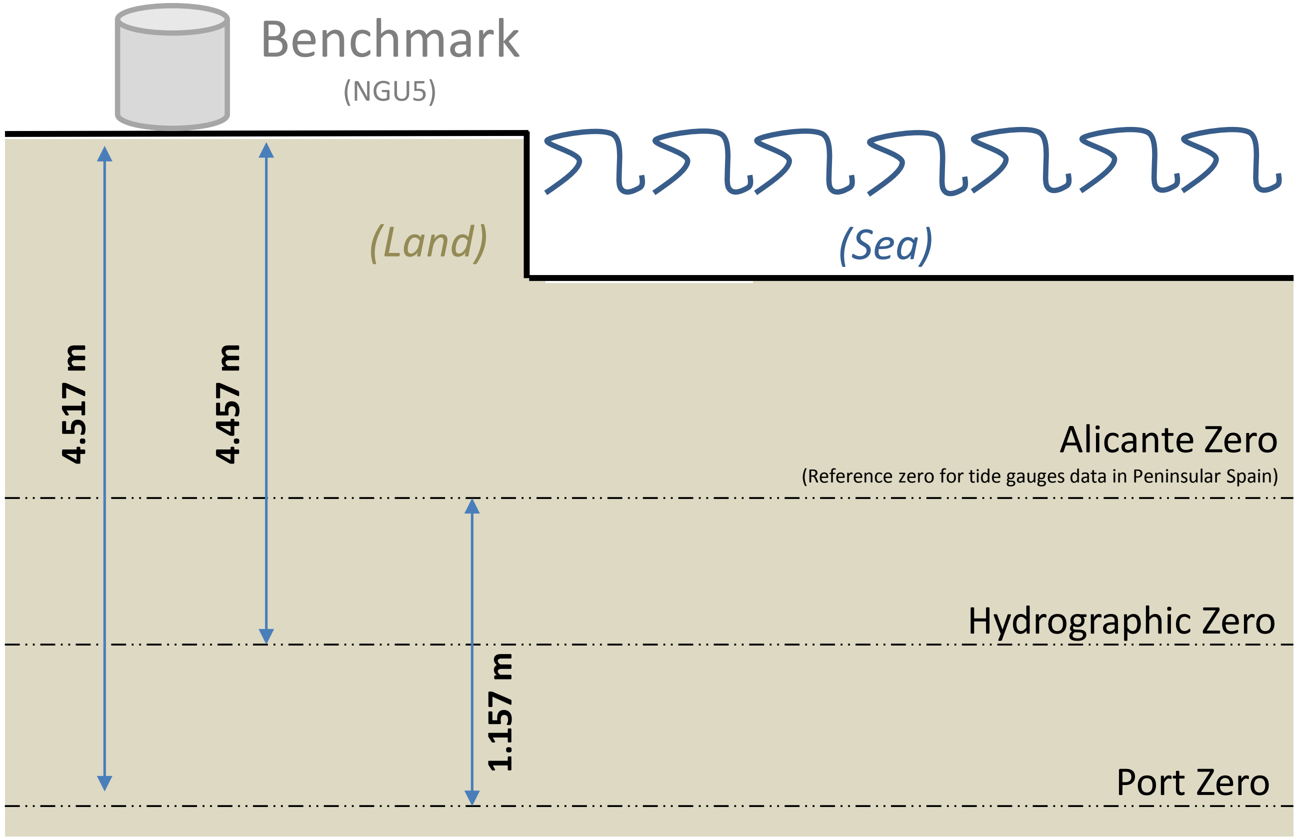
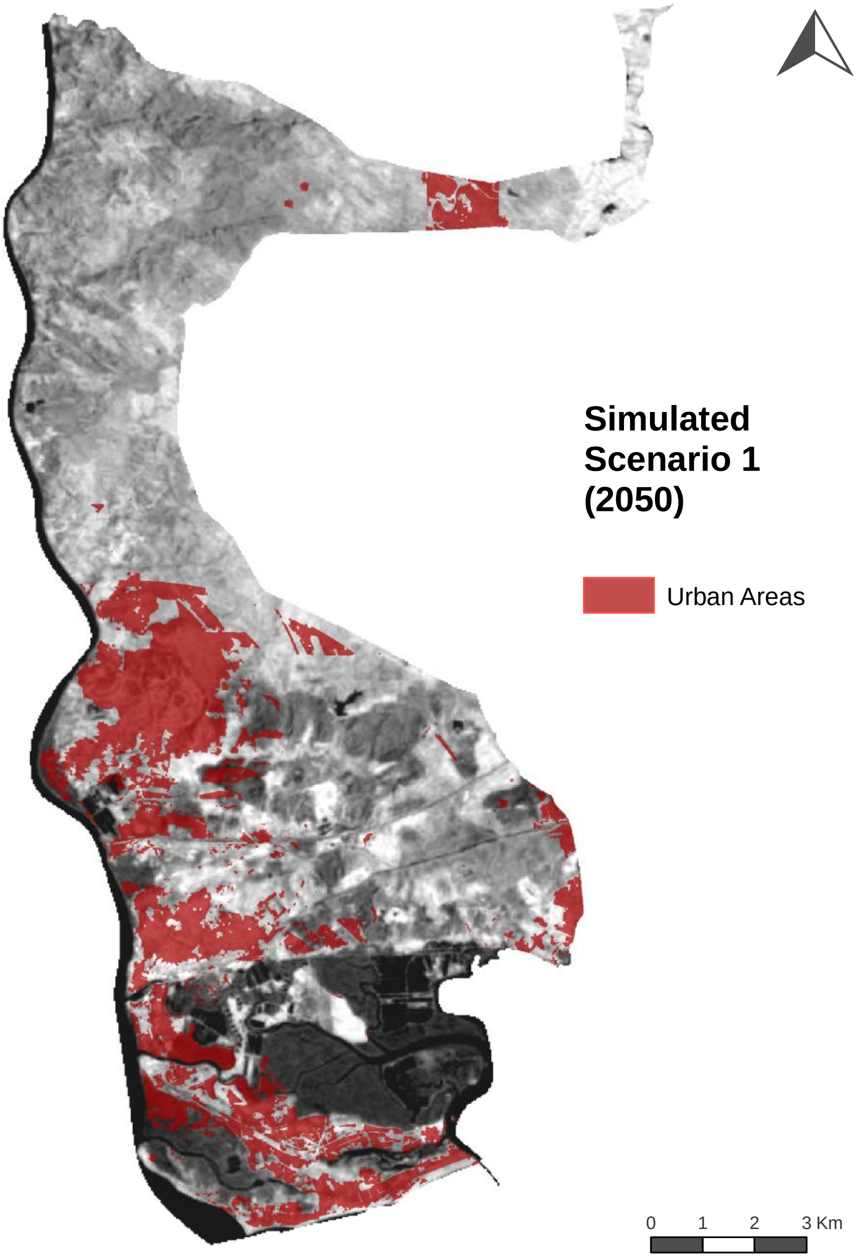


Figure A-17. Datum adjustment diagram. Benchmark geodetic station NGU5. Data source: Spanish National Port Authority (Self-elaboration)

Figure A-18. Future location of urban areas under Scenario 1 (2050).



(Self-elaboration)

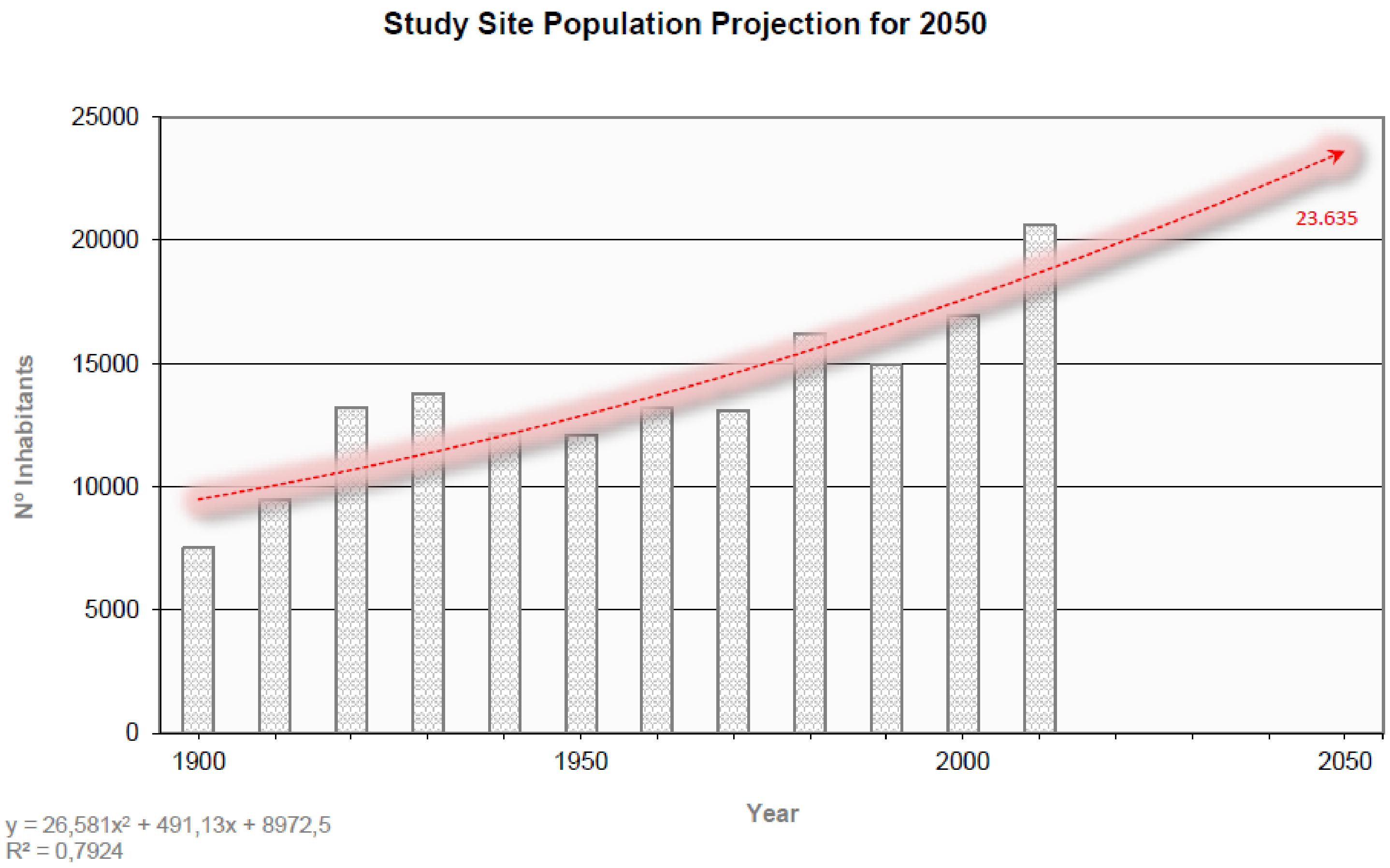


Figure A-19. Population projection for the study site on 2050. Quadratic polynomial projection model. Baseline data source (1900-2010) : National Institute of Statistics (INE, 2014) and Andalusian Statistics and Cartographic Institute (ICA, 2014) (Self-elaboration)

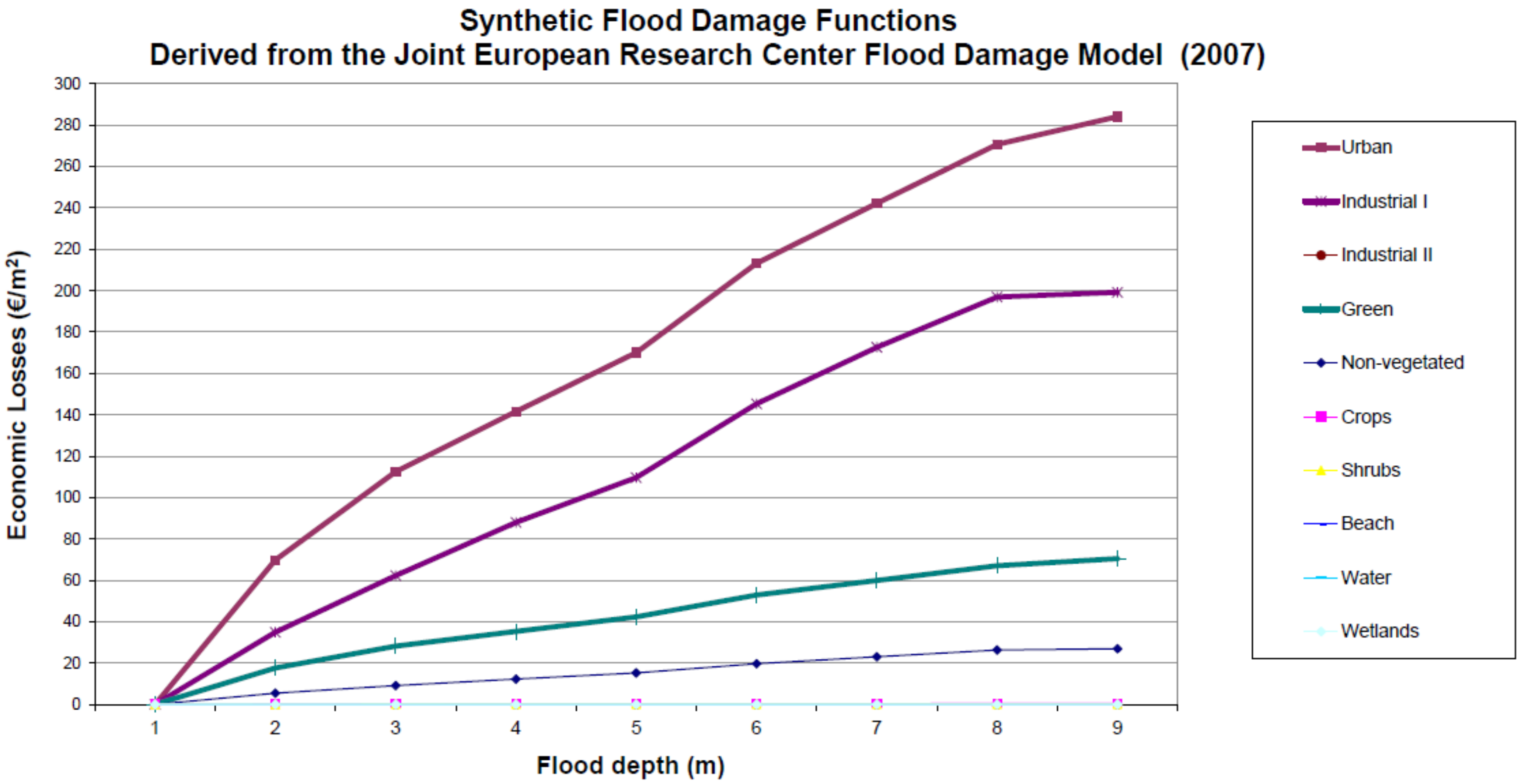
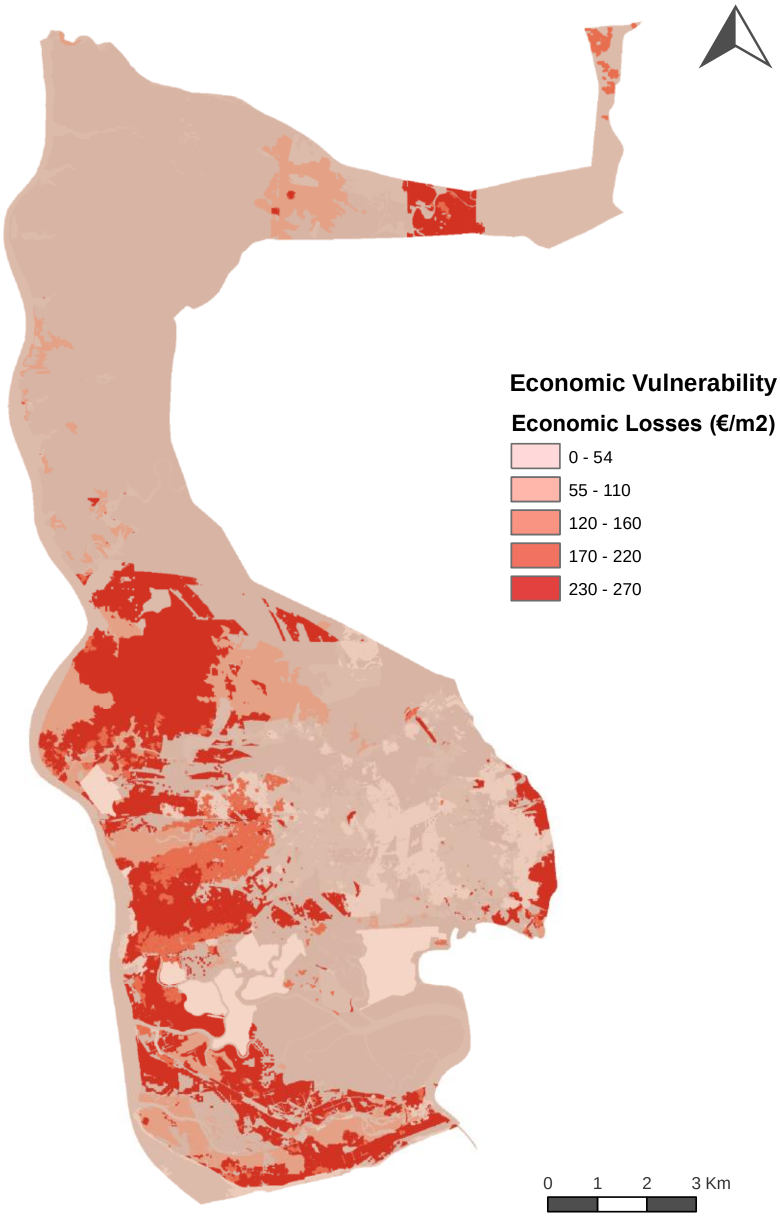


Figure A-20. Synthetic flood-damage functions derived from the JRC model (2007) (Self-elaboration)

Disclosure: original flood-damage data and model provided by the JRC *only* for research purposes. The synthetic functions herby presented have been generated for the 10 land uses analyzed in this thesis. Data should be considered preliminary results. Not authorized for further use or distribution.

Figure A-21. Prospective economic vulnerability map for the study site under Scenario 1

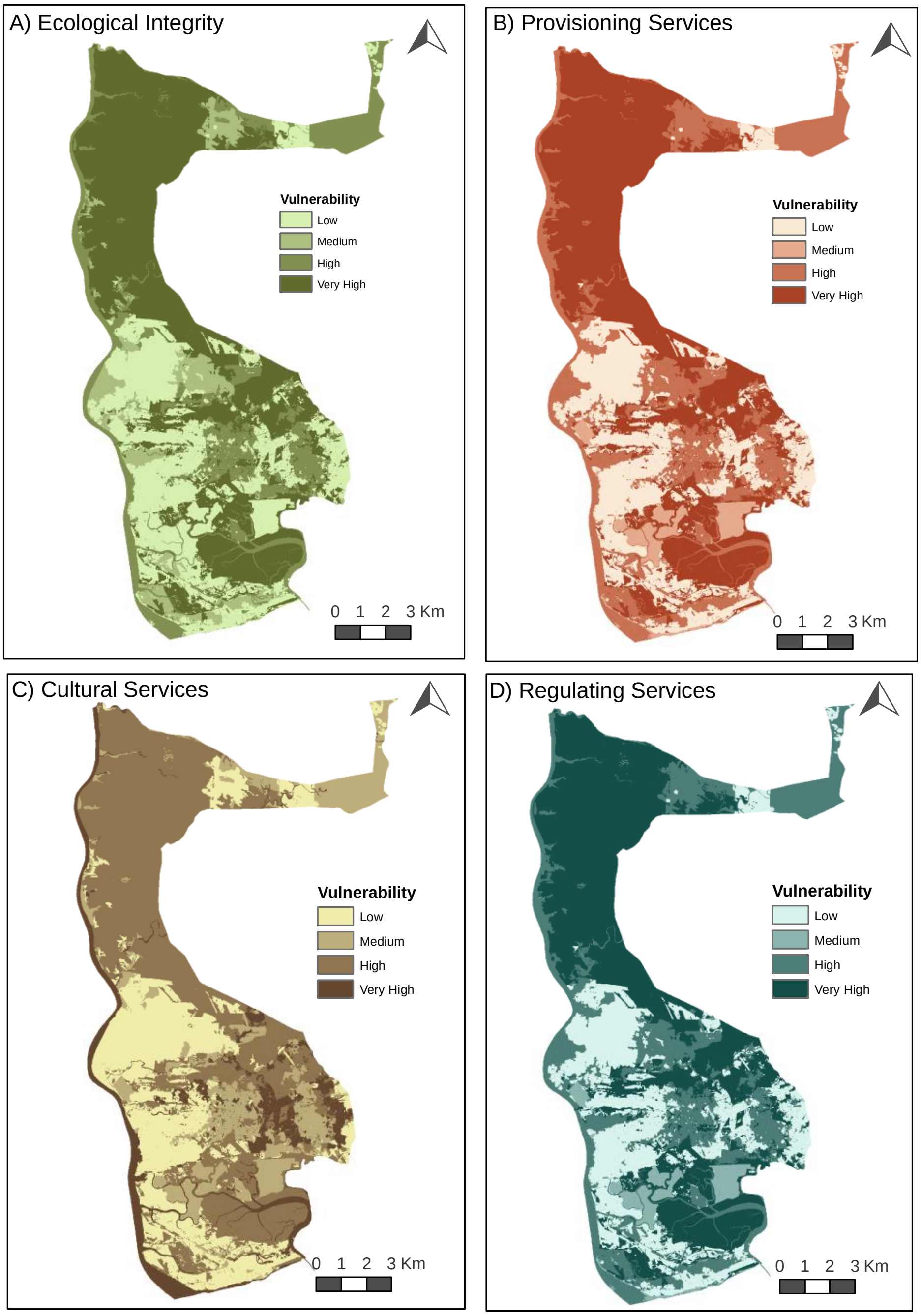


(Self elaboration)

Land Use	**Ecological Integrity**	Abiotic heteregeneity	Biodiversity	Biotic waterflows	Metabolic efficiency	Exergy capture (radiation)	Reduction of nutrients loss	Storage capacity (SOM)	**Provisioninng services**	Crops	Livestock	Fodder	Capture fisheries	Aquaculture	Wild Foods	Timber	Wood Fuel	Energy (Biomass)	Biochemicals/Medicine	Freshwater	**Regulating services**	Local climate regulation	Global climate regulation	Flood protection	Groundwater recharge	Air quality regulation	Erosion regulation	Nutrient regulation	Water purification	Pollination	**Cultural services**	Recreation and aesthetic value	Intrinsic value of biodiversity	**Summatory**
Urban	3,5	0,5	0,5	0,5	0,5	0,5	0,5	0,5	1,5	0,5	0,0	0,5	0,0	0,0	0,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**5,0**
Green/ Recreational	17,0	2,5	2,5	2,0	1,0	4,0	3,0	2,0	1,0	0,0	0,0	0,0	0,0	0,0	0,5	0,0	0,5	0,0	0,0	0,0	10,0	1,5	1,0	0,0	2,0	1,0	1,5	1,0	1,0	1,0	4,0	4,0	0,0	**32,0**
Industrial 1	2,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**2,0**
Industrial 2	2,0	1,0	1,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,0	2,0	0,0	**6,0**
Crops	19,7	3,1	2,4	3,4	2,3	3,9	1,4	3,1	16,4	4,4	2,6	2,4	0,0	0,0	0,4	1,6	3,0	1,4	0,6	0,0	9,9	2,3	1,4	1,0	1,3	0,9	1,4	0,3	0,6	0,7	2,9	2,4	0,4	**48,9**
Shrubs	28,0	2,8	4,0	4,0	4,0	4,5	4,3	4,3	13,8	0,0	1,7	1,3	0,0	0,0	3,0	2,5	2,8	0,0	2,5	0,0	25,0	3,2	2,7	1,8	1,3	2,5	4,0	3,3	3,3	2,8	7,2	3,8	3,3	**74,0**
Wetlands	27,0	2,8	3,3	4,3	3,8	4,0	4,0	5,0	8,8	0,0	1,0	1,5	0,0	0,0	1,3	1,3	1,3	1,3	1,3	0,0	21,3	3,0	2,8	3,8	1,8	1,3	1,3	3,5	2,3	1,8	5,3	3,0	2,3	**62,3**
Beach	10,0	3,0	3,0	1,0	1,0	1,0	0,0	1,0	2,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,0	0,0	0,0	6,0	0,0	0,0	5,0	1,0	0,0	0,0	0,0	0,0	0,0	7,0	5,0	2,0	**25,0**
Water	19,3	3,3	3,3	0,0	3,8	3,8	3,3	2,0	12,8	0,0	0,0	0,0	4,0	2,5	3,0	0,0	0,0	0,8	0,0	2,5	9,8	1,5	1,5	1,5	0,8	0,0	0,0	3,0	1,5	0,0	8,0	4,5	3,5	**49,8**
Non-vegetated	4,5	2,0	1,7	0,0	0,0	0,0	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	1,0	0,0	0,0	0,7	0,2	0,0	0,0	0,0	0,2	0,0	0,8	0,8	0,0	**6,3**

Table A-14. Ecosystem Services Matrix (Burkhard et al., 2012) adapted to the study site (Self elaboration)

Figure A-22. Prospective environmental vulnerability map for the study site under Scenario 1 on 2050



(Self-elaboration)

Questionnaire Q- 1. Stakeholders’ identification and analysis

Stakeholder’s name……………………………………………………………………………………………………
Date………
Place………

Primary Information
1. Could you indicate your occupation and/or relationship to Ayamonte’s coastal area?
2. Do you / your entity belong to any organisation/ group /institution?
Yes / No (Name of the group :………………………………………………………………..)
Official/ Not official group
3. Please specify scale of action of your formal/not formal entity: Local/ Provincial/ Regional /National / International / Other
4. Could you specify who the responsible / principal member of the entity?
Secondary Information
5. How do you use the coastal area/Which kind of activities do you conduct on it? (**a**)
6. Do you consider you depend on Ayamonte’s coastal area?
Data for the Snowball Sampling Method and Connections with other stakeholders
7. Could you please name stakeholders (**b**) related to Ayamonte coastal area?
8. Do you have contact/relationship with any of these persons/groups/organisations?

Clarifications:	
a)	On the context of this interview, ‘coastal area’ includes the sea, beaches, sand bars and dunes, coastal hinterland, Guadiana and Carreras rivers and associated channels, river banks, wetlands and saltmarshes.
b)	Any kind of institution, group, organization, entity or citizens, connected to the coast of Ayamonte, that is, those who live, work, enjoy, have political (either formal and informal) influence, or use in any other way the area of study.

Questionnaire Q- 2. Driving forces identification by stakeholders

Q2_Questionnaire for Driving Forces Identification by Stakeholders

Stakeholder's name………………………………………………………………………………………………
Date……
Place……

1. In your opinion, which are the main drivers of change* on Ayamonte coast? (*) Clarification: in the context of this work, 'drivers of change' refer to political, economic, social, physical or biological factors that have generated/are generating/will generate changes in the area.
a…………………………………………………Importance of the driver: Very high / High / Medium / Low
b…………………………………………………Importance of the driver: Very high / High / Medium / Low
c…………………………………………………Importance of the driver: Very high / High / Medium / Low
d…………………………………………………Importance of the driver: Very high / High / Medium / Low
2. In your view, which are the main economic activities/sectors affecting Ayamonte?
No
Sí
a…………………………………………………Importance of the driver: Very high / High / Medium / Low
b…………………………………………………Importance of the driver: Very high / High / Medium / Low
c…………………………………………………Importance of the driver: Very high / High / Medium / Low
d…………………………………………………Importance of the driver: Very high / High / Medium / Low
3. There is any policies -at the international, national, regional, local levels- which you consider a driver of change for Ayamonte?
No
Sí
a…………………………………………………Importance of the driver: Very high / High / Medium / Low
b…………………………………………………Importance of the driver: Very high / High / Medium / Low
c…………………………………………………Importance of the driver: Very high / High / Medium / Low
d…………………………………………………Importance of the driver: Very high / High / Medium / Low
4. In your view, which bio-physical processes generate changes in Ayamonte?
a…………………………………………………Importance of the driver: Very high / High / Medium / Low
b…………………………………………………Importance of the driver: Very high / High / Medium / Low
c…………………………………………………Importance of the driver: Very high / High / Medium / Low
d…………………………………………………Importance of the driver: Very high / High / Medium / Low
5. Do you believe there is any social / cultural factors that have/are/will generate changes in Ayamonte?
a…………………………………………………Importance of the driver: Very high / High / Medium / Low
b…………………………………………………Importance of the driver: Very high / High / Medium / Low
c…………………………………………………Importance of the driver: Very high / High / Medium / Low
d…………………………………………………Importance of the driver: Very high / High / Medium / Low
6. Do you believe climate change already is / will generate changes in Ayamonte?
Sí
No

Questionnaire Q- 3. Scenarios validation and storylines enrichment

Stakeholder's name……………………………………………………………………………………………………
Date………
Place……

Block 1: Views on scenarios plausibility
1. Do you think the four scenarios represent possible futures for Ayamonte?
2. Do you believe these scenarios could take place in Ayamonte? (please specify yes/no for each scenario)
3. Which scenario do you consider to be the most feasible for 2050? Why?
4. Which scenario do you consider as the least feasible for 2050? Why?
5. Which scenario do you think could bring higher economic growth to the municipality? And the one that bring less economic growth?
6. If you could choose, which scenario would you prefer to happen?
7. Do you think there are any other possible future that should have been taken into account?
8. Do you think that the touristic sector is the only possible economic alternative for this municipality?
Block 2: Perception on foresight methods to support decision-making and planning
9. Do you think that these kind of exercises (foresight/participatory based) could help in the decision-making and planning of a coastal area like Ayamonte?
10. (Control question: contrast to Question 1) Do you think that the driving forces taken into account in this study are indeed the most important in Ayamonte? Would you say any is missing?
11. Do you believe coastal areas decision-making/planning should include participatory processes?
Block 3: Climate change
12. Do you believe that climate change should be taken into account in coastal areas planning?
13. Which scenario do you think is more vulnerable to climate change effects?
14. (Control question: contrast to Question 6). If you were a decision-maker, which of the hereby-discussed future scenarios would you promote?