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The impacts of Climate Change on Agriculture and other economic activities in coastal areas: the case of Grado-Marano lagoon.

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Climate Change (CC) poses significant threats to coastal areas, with the main impacts being sea-level-rise (SLR) and the consequent loss of land. Much work has been done to evaluate effective adaptation strategies, but further research is needed. This paper aims at analyzing the costs of CC and SLR in the Grado-Marano lagoon, and at proposing an example of methodology based on an economic evaluation of damages related to: loss of land on the basis of different land-uses (i); loss of non-use values (ii); losses in productivity/use values via Bayesian Networks (iii); and on a multi-criteria-analysis able to integrate different (monetary and non-monetary) criteria focused on three pillars of sustainability (iv) to compare adaptation-strategies. We find that the larger impacts are on residential and tertiary sectors, even if most of the area has an agricultural vocation, and that the best adaptation-strategy is beach-nourishment even if rankings depend on criteria weights.





1. Introduction

Coastal areas and their local communities are particularly vulnerable to the expected future effects of climate change (CC) which must be carefully evaluated in order to optimize strategies of risk management. Indeed, societies in such areas are faced with the double effort of having to both mitigate and adapt to climate change. In this context, it is important to have not only projections on future climate evolution (by the scientific community), but also information on the type and extent of socio-economic impacts that this change may have, in order to define present and future policies against the negative impacts of CC.

In this context, the quantification of the costs related to the impacts of climate change is needed to support decision-making for the management of the potential risks/impacts expected and of the possible intervention strategies. This is made particularly complex by:

- the uncertainties related to future scenarios of global climate change;
- the resulting uncertainties in predicting the environmental effects of such changes;
- the interdependencies between the environmental effects and the impacts on communities and socio-economic systems at the local, regional, national and global levels;
- the strong multi-disciplinary nature of the impacts.

Moreover, strategies may be ex-ante and aimed at mitigating the causes of CC, or ex-post to better adapt to the effects and minimize the damages. Even just focusing on so-called adaptation measures, there is a large range of alternative strategies that could be adopted by the various economic sectors and institutions involved, and such actions can be taken at different territorial levels (Travisi, 2007).

Decision-makers are thus called, first, to assess whether a certain risk/impact of climate change requires adaptation actions and, secondly, should this be deemed necessary, to evaluate which option of adaptation is preferable (Breil et al., 2009; Travisi, 2007). The perspective adopted in this work is to choose the strategy that is expected to provide the highest benefit to the community (in terms of risks/impacts avoided) compared to the its costs. Nevertheless, if on the one hand the costs of mitigation and adaptation can be estimated with relative ease, the same



AGRICULTURE IN AN INTERCONNECTED WORLD

cannot be said for the estimated costs related to potential damages or, in the case of benefits, the estimated value of the damage avoided by actions of adaptation and/or mitigation.

The monetary quantification of the possible costs of CC is therefore a complex process, which may require the use of a broad range of estimation techniques, sometimes costly, depending on: the impact analyzed, the level of detail to be achieved, and the accessibility and the degree of uncertainty of the available data (Travisi et al., 2005). Moreover, the quantification of costs is made even more difficult by the methodological issues of assigning a monetary value to impacts on public or non-market goods, i.e., goods whose value is not (fully) expressed in the markets by the interaction of supply and demand.

Large research efforts at the international level have been devolved to study effective adaptation strategies (Feenstra et al., 1998; Klein et al., 2001; Bosello et al. 2007; EEA, 2007; Travisi, 2007; Breil et al., 2009; Catenacci, 2009; Barron et al., 2012; IPCC, 2014; etc.), but the evaluations of such measures are inherently based on assessments at the local level, which individually do not cover the full range of possible impacts of climate change in coastal areas and are strongly influenced by local conditions. This work focuses on one of the main impacts of CC for coastal areas that is sea-level rise (SLR) and proposes a methodology that is applied to the Grado-Marano lagoon on the north-eastern coast of Italy, a unique wetland ecosystem that is particularly sensitive and vulnerable to the impacts of sea-level rise in relation to its natural characteristics and anthropogenic pressures. Indeed, the methodology adopted is affected by the local characteristics and conditions, but it aims at being an example that can be adapted to other case studies.

More in detail, the aim of the research is fivefold: i) analyze the possible costs of SLR on the basis of risk scenarios of soil loss by 2100; ii) estimate the monetary value of the area that is exposed to a potential risk of permanent flooding; iii) include in the estimation impacts on non-market goods; iv) implement a participatory processes for the identification of the most significant impacts on the economic activities in the area at risk, and of the possible adaptation strategies; v) compare three different alternatives of adaptation.

The paper is structured as follows: Section 2 presents the area under evaluation; Section 3 describes in detail the methodology adopted; Section 4 reports the results, and the last section presents the concluding remarks.



2. Description of the area under investigation

The Grado and Marano lagoon is located at the northernmost part of the Mediterranean basin, it is one of the most important wetlands in the Mediterranean, and it is of considerable scientific interest both at the national and at the international level. It is indeed part of the network of wetlands recognized by the Ramsar Convention, and the national network of areas to be protected. The lagoon system stretches out for about 16,000 ha, with a length of nearly 32 km between the rivers Isonzo and Tagliamento and has an average width of 5 km; it is separated from the sea by a long shore bar of small islands and sand banks.

From an environmental point of view, the lagoon presents a highly complex and diversified territory, whose coenosis reflect the variety of salinity conditions in soil and water. It has a unique habitat, rich in endogenous fish and bird species, and halophyte plants that tolerate high salinity values (Catenacci, 2009).

Moreover, on the coast of the lagoon there are several economic activities and residential centers, which almost double their population during the warm season. Fishery in the lagoon used to represent the most important economic activity; now it continues to be relevant, even if in recent years it has showed a negative trend, mainly due to the reallocation of several operators to other activities, such as aquaculture, fish farming and tourism (IMW, 2001; Catenacci, 2009). Aquaculture is diffused, although the cultivated surface has progressively been reduced, as a consequence of the massive land reclamation interventions and of the degradation of water quality in the lagoon. Peculiar to this area, is a particular type of aquaculture, named 'vallicoltura', that is located where parts of the lagoon are separated by banks from the rest of the lagoon (Catenacci, 2009). Most of the area under examination is dedicated to agriculture, and part of the wetlands have been transformed in cultivated land through reclamation processes. About 90% of the agricultural land is arable, and is cultivated with crops like soybean, sugar beet and cereals (wheat, barley, corn). Vineyards and fruit orchards occupy 4% of the agricultural surface. The rest of the area is occupied by woods and arboriculture. Tourism has grown of importance in the last decades, with about 4,000,000 visitors per year (IMW, 2001). More recently, Eco-tourism has developed and it mainly involves the WWF Oasis for avifauna and the natural reserve of Valle Canal Novo, with an annual presence of about 15,000 visitors



(Catenacci, 2009). The industrial sector prevailing in the area, in particular in the area of the river Aussa-Horn, is the chemical one, both for operators and for the surface area occupied.

Indeed, the lagoon of Grado and Marano is a highly vulnerable area to the impacts of sea level rise (SLR) in relation to its geomorphological characteristics (sedimentary low-lying coast, migrant morphology, etc.) and the coastal human activities which impose pressures on the shore and decrease the natural resilience and adaptivity of the system (Catenacci, 2009).

3. Methodology

The magnitude of the impact depends largely on the specific characteristics of the territory affected by CC: ecological characteristics, nature and landscape, productive activities or existing tourism, the characteristics of the urban and residential areas, etc. The cost analysis of the effects of CC in this case must be conducted through the identification of all the 'values' present in the area, and involves the prediction of changes in the values of land, of activities, as well as other use-values, such as for example aesthetic, scenic and cultural values. This is the reason why we start with a strictly monetary approach and then extend the evaluation to adopt a multi-criteria approach, combining monetary and non-monetary variables.

3.1 Impact scenario

The area analyzed is depressed and is particularly vulnerable to risks related to sea-level rise (ENEA, 2007). In particular, the main impacts relate to the possible flooding of certain areas of land and the consequent permanent loss of soil (Antonioli, 2003). Our analysis builds on the risk assessment for 2100 made for the Grado-Marano lagoon by ENEA. Figure 1 reports the area that is estimated to become permanently flooded by 2100.

3.2 Property loss assessment

The main impact of CC in the Grado-Marano lagoon is considered to be the permanent loss of soil caused by the risk of sea level rise. This generates in turn a number of effects on the territory, which may qualify as costs for the local system and can be estimated in monetary terms (when possible), such as:



- loss of agricultural land;
- loss of land devoted to industrial or commercial activities;
- loss of property in a residential area;
- loss of recreational sites;
- loss of soil with natural habitats;
- impacts on infrastructure (residential, industrial, transport).

In other words, in this first part of the work we evaluate the damage resulting from the impact of SLR as the economic value of the land at risk of flooding, assuming that, in the case of absence of adaptation, the whole area that by 2100 will be under the sea level will be lost (permanent flooding).

The commercial value of the area varies depending on the type of land use (agricultural land, built-up urban areas, industrial zones, etc.). The starting point for estimating the costs of land loss is therefore the analysis of the territory according to the intended use of the land. In particular, the analysis takes into account the classification of land use CORINE land cover and uses its geo-referenced data for the study area.

The monetary value of the change of the stock at risk is calculated on the basis of current market values for each type of land use. The unit values (per square meter) are estimated based on market data at the municipal level. In particular: i) the values of urbanized land for residential, industrial or commercial activity are obtained from the online database on real estate prices of the Italian Ministry of Infrastructure and Land; ii) the values of farmland are estimated referring to the Average Agricultural Value (in Italian, 'Valore Agricolo Medio' – VAM) defined by provincial laws for the different agrarian regions for each type of culture; iii) the value of beaches (coastal public lands) is estimated considering concession fees for touristic and recreational beaches, established at ministerial level.

After having identified the monetary value per unit of land impacted (by type of land use), the analysis proceeds with the calculation of the total losses. All monetary amounts are then transformed into the same unit of measure using the coefficients provided by Istat (2014).

The monetary value of the damage, by type of land use is calculated as:

$$\text{Damage}_{2100} (\text{€}) = \text{Unit value } [\text{€} / \text{m}^2] * \text{Area } [\text{m}^2] \quad (1)$$



The damage for each type of land use is expressed in real-value terms in current prices, and at face value, using two different discount rates (1 and 3 percent). The nominal value allows to have an idea of what could be the possible cost in 2100.

Note that this approach is not able to account for changes in land use that might have occurred for reasons other than SLR.

3.3 Benefit-transfer as a mean to evaluate non-use values

The assignment of a monetary value for environmental goods or damages to natural habitats is a complex issue and it is not just limited to property values, since the damage to this type of goods are only partially quantified in market value. Thus, it is necessary to try to express in monetary terms also the natural and social services provided by the different types of land use.

An exhaustive measure of the total economic value of possible future damages to the natural heritage of the Lagoon of Grado and Marano would need an entire ad hoc study by means of specific surveys in the field and assessments, however, a first estimate can be provided on the basis benefit-transfer methods that use values calculated in pre-existing estimations.

In particular, we base our estimates for wooded areas subject to flooding on a study conducted within the project COPY "Cost of Policy Inaction. The case of not meeting the 2010 biodiversity target" (Braat et al, 2008). This study allows us to assign a monetary value to woodlands considering the following functions:

- Recreational activities;
- Passive use;
- Economic activities (e.g., timber production);
- Sequestration of carbon dioxide.

For wetlands, marshes and lagoons, we assign a monetary value based on the work of Ghermanti et al. (2007). This work builds on a meta-analysis that analyzed 383 studies assigning a monetary value to wetlands, including the assessment of several services offered by these areas, such as cultural services, support, supply of goods, stabilization and protection of natural systems. More in detail, the value that we use (0.0009125 €/mq/year) refers to the aggregated value – across the different services – for Italian wetlands.



In the area at risk there are also archeological sites. We value such areas taking values from a detailed study of the archaeological site of Paestum (Riganti et al., 2004), rescaling them to account for the different field range. In particular, the study by Riganti et al. (2004) estimated the willingness to pay for different services in the archaeological site of Paestum; of these we were able to only take into account the marginal value of additional opening hours.

Note that the monetary values discussed above are to be added to the value related to property loss.

3.4 Damages in relation to activity loss

3.4.1 Expert elicitation

To estimate the costs of future impacts of climate change on the productivity of the different land uses – to extend the analysis of the value losses due to SLR - it is necessary to analyze and make some assumptions about future conditions of the climate, the natural system and the socio-economic system that will be potentially impacted. To do so, we implemented a participatory process that involved thirteen experts from different fields of research with the aim of identifying the most significant impacts on the economic activities in the area at risk, and the possible adaptation strategies. The participatory approach is based on the NetSyMoD (Network Analysis, Creative System Modelling, Decision Support) methodology, which uses a range of tools aimed at facilitating the involvement of experts and/or stakeholders in decision-making processes (Giupponi et al., 2008; Giupponi et al., 2006).

In particular, we relied on the set of experts to fill the information gaps on the system components and dynamics. We developed a conceptual model of the system under evaluation based on the shared view of the causal links between the elicited components of the system by means of brain storming sessions. To identify the most important vulnerabilities of the area (Table 1), we used constrained ranking exercises – where each expert had to distribute 100 points among all the impacts of the list, assigning a higher or lower score to each one according to its relative importance in the area of study – followed by discussion sessions.

Then, the discussion turned to the possible options in terms of adaptation strategies. Firstly, the options were grouped into four categories, according to certain common features that emerged during the discussion (Catenacci, 2009):



- ‘natural expansion inland of lagoon water, without human intervention;
- rigid interventions on the coast or offshore, to stop or prevent the expansion of water;
- controlled expansion of water, by increasing the power of water pumps, by recreating the irregular morphology of the lagoon bed, or by applying a planning strategy which destined specific areas to the expansion of water;
- management of the sediment balance in the lagoon, by reconstructing salt marshes, by refilling the external sand bars with sediments from continental platforms or from dams cleaning, or by constructing levees along the rivers’.

The discussion that followed was aimed at finding a consensus on the best three adaptation strategies. Experts focused mainly on the real-life applicability of the different management options and on the potential benefits and the negative consequences arising from their implementation. The selected strategies were:

1. reconstruction of salt marshes: a work of reconstruction of the salt marshes of 200 ha in line with the scenario of SLR of 1 m by 2100.
2. beach nourishment: action nourishment of 10 linear km of coastline, the corresponding extension of the urbanized coast in the area under analysis;
3. no adaptation action.

For a more detailed description of the participatory activities and on the elicitation protocol, please see Catenacci (2009).

3.4.2 Bayesian Networks

After having identified and organized in a causal map the conceptual model of the system, the most important variables were selected to obtain a synthetic model that could be populated and used as a decision support tool. More in detailed, we developed an *ad hoc* Bayesian Network model (BN), able of providing probabilistic relationships between direct and indirect impacts of SLR, and to evaluate the effectiveness of alternative adaptation strategies.

The BN is a mathematical model represented in graphical form, and applied for reasoning under uncertainty. The Bayesian approach considers the probability of an event as a function of the state of knowledge (the "confidence level") that a person has with regard to the occurrence of the specific event, given all the information available to this person. Therefore, the Bayesian



approach is called 'subjective' to distinguish it from the 'objective' of frequentist statistics (Catenacci and Giupponi, 2010).

The BN model provides a graphical user-friendly user interface, able to communicate the interactions between the variables of the system, the causal relationships and dependencies between the variables, and the strength of the relations. Graphically, the BN consists of nodes that represent the factors of the system, and arcs, which define the probabilistic dependency relationships among the factors. Each node in the network is described by a finite set of mutually exclusive states. Nodes can represent: different variables of the system (chance nodes), alternative choices or policies (decision nodes), or measure the utility or value resulting from the implementation of a particular intervention (node value).

The quantitative potential of BN is given by the tables of conditional probabilities (CPTs). Each node is described by a different CPT indicating the probability that the given 'child' node is in one of its states, given the states of its 'parent' nodes. The probability given by the knowledge of the subject before the research is defined prior. When new data or information arises, the 'prior' is updated, allowing for an 'adaptive' management approach, which can change its performance in a flexible manner in the presence of new information on the results of certain actions.

Since the objective of this study is to define a methodology for the evaluation and selection of alternative strategies for adaptation to the impacts of SLR, we structured a decisional Bayesian network model (BDN), which considers the impacts of different scenarios of SLR, and the presence or absence of specific adaptation measures on environmental and socio-economic factors of the study area. Such model is able to measure the effectiveness of different adaptation by means of node values and to highlight the option that maximizes the expected value or utility. Figure 2 depicts the BDN for the case of beach nourishment, BDNs were also constructed for the other two options. The CPTs of BDN were compiled using subjective probability judgments elicited from experts using specific questionnaires. The use and processing of expert judgments made it possible to handle the problem of shortage or lack of data, and have facilitated a process of fruitful interaction between experts from different fields of study, in order to establish a shared model of the system in analysis.

The structuring and completing of the BN have resulted in a fully functional model for decision support, whose findings have been used to compare and evaluate the effectiveness of alternative



policies to adapt. For more details please see Catenacci (2009), while for a discussion of the potentials and limitations of the methodology proposed see Catenacci and Giupponi (2010).

3.5 Multi-Criteria Analysis for the evaluation of adaptation strategies

In the last part of this work we carried out a Multi-Criteria Analysis (MCA) that is a comparative analysis of different adaptation strategies able to include a variety of evaluation criteria that are not only based on monetary values.

More in detail, MCA is a methodology developed in order to internalize in economic assessments factors that are not strictly economic, and therefore not quantifiable (or difficult to quantify) in monetary terms (Jassen and Munda, 2000). MCA analysis has been developed to manage the complexity of decision-making processes that need to take into account not only economic efficiency, but also other criteria targeting environmental sustainability and social equity. Indeed, for climate change related evaluations other factors may be important. Simple examples are the issues related to: the irreversibility of mitigation or adaptation measures, equity, risk and uncertainty and the degree of support for policy choices (Travisi, 2007). In this context, MCA consists of defining a framework to integrate scorings about all of the selected multi-disciplinary criteria, without necessarily predicting a monetary estimate for all factors, through a system of scoring and weighting.

The analysis was conducted using a multi-criteria decision support software developed by Fondazione Eni Enrico Mattei in two projects funded by the Fifth Framework Programme (FP5) of the European Commission. The software is MULINO: MULti-sectoral INtegrated and Operational decision support system for the sustainable use of water resources at the catchment scale. The MCA conducted compares the three adaptation measures identified as the most promising and/or feasible by the expert elicitation.

3.5.1 Evaluation criteria

The evaluation criteria taken into account in the analysis are listed in Table 2. Given the nature of the MCA it has been possible to consider quantifiable and non-quantifiable evaluation criteria with different units of measurement.



The criteria considered relate to the three main macro-areas of sustainability (economy, society and environment) that are difficult to compare with traditional assessment tools.

More in detail, the first five criteria (E1-E5) are taken directly from the results emerging from the expert elicitation and BN analysis. In addition, we included other purely economic criteria related to the investment and management costs needed to implement the adaptation strategies considered (E6-E8). Moreover, we added two criteria that consider the social effects of the strategies analyzed, and in particular the impact on the usability of the preserved public property (S1-S2). Finally, we considered also environmental criteria referring to the characteristics of the adaptation options considered to be the most effective in terms of impact by the experts involved in the elicitation (Env1-Env4).

To take into account these criteria, we built an evaluation matrix associating each adaptation strategy (response) with values for each evaluation criterion (impact). More in detail, the values for the first five impacts (E1-E5) follow directly from the results of the two Bayesian networks. Regarding the strategy "no adaptation", the estimated values related to the event that no defense strategy or adaptation is implemented.

Investment costs related to the adaptation strategies under consideration are reported in Table 3. In particular, the values for the reconstruction of the salt marshes are the result of discussions with experts during the expert elicitation and are based on the technical costs arising from similar interventions in the Venice lagoon.

For beach nourishment we considered the average value of the costs of several artificial nourishment interventions made in the Veneto, Emilia Romagna and Lazio Regions (Barsanti et al., 2003). The estimated costs for the implementation of these adaptation strategies have a high variability determined by morphological, environmental and socio-economic specificities of the interventions. The technical costs may, in fact, vary greatly, for example, depending on the sediments used, the mode of transport, amplitude of the intervention and the need to support complementary measures. In order to take account of this variability in the MCA, we conducted a sensitivity analysis of the results to changes in the average cost of nourishment interventions, considering: i) the average cost of operations in the three regions described above; ii) the average cost of only the works carried out in the Veneto region. The sensitivity analysis showed that the



preference ranking of different adaptation options does not change considering either cost i) or ii). The results here reported are based on the overall average cost of nourishment interventions.

As regards the remaining evaluation criteria, their quantification was made using an ordinal scale, which reflects their relative values between the different alternatives of adaptation. Note that in multi-criteria analysis it is not the absolute value that is taken into account, but only the relative distance between the values assigned to the various response options under investigation; therefore, the focus is not on numerical values but on their relative sizes. For example, the assignment of values for operating costs is based on the fact that reconstructions of salt marshes is more complex to design and implement (start-up), but once the colonization of biotic communities has been triggered, the process of naturalization is self-feeding. Nourishment interventions instead need continuous maintenance after start-up.

For each non-economic evaluation criterion a value function was created to allow the normalization of the values for the three adaptation strategies analyzed. Those values go to make up the so-called evaluation matrix in which all the values related to the different evaluation criteria have the same scale, and in particular are distributed over the range [0,1].

3.5.2 Relative-weight scenarios

After putting together the evaluation matrix it becomes possible to directly compare the adaptation options considered, and to obtain the relative ranking of preferability. Such ranking reflects the "performance" of each adaptation option with respect to all evaluation criteria considered: economic, social and environmental. It also depends on the relative weight, or importance, given to the different evaluation criteria.

In this analysis, we considered two main cases:

- 1) uniform weights for all criteria, whereby all of the criteria are assigned equal weights in the final decision on the preferability ranking of the different adaptation options;
- 2) not equal weights for the different criteria, whereby each evaluation criteria is attributed a different importance in the final decision on the preferability of the different adaptation options. In particular, we analyzed the following assumptions on weights:



- a) three possible weights for the overall economic cost compared to the other factors in the decision to choose the type of adaptation action: 15, 40 and 70%;
- b) two possible distributions of weight between investment costs and costs of management:
 - a. 50% of investment costs - 50% operating expenses;
 - b. 30% of investment costs - 70% of operating expenses;

within operating expenses we gave 30% weight to the start-up phase and 70% to the maintenance one.

The relative weights assigned to the decision criteria other than implementation and management costs are taken from the results of the expert elicitation. The elicited weight values were then normalized so that their total weight was 85, 60, 30% of the total, in line with the three scenarios of varying degrees of importance attributed to the direct costs of adaptation measures.

The choice to explore different scenarios is intended to capture the degree of subjectivity typical of the decision-making process, which has to manage the conflict between the demands of the various players involved.

4. Results

4.1 *Economic evaluation of damages in relation to land value*

4.1.1 Aggregated results

The economic assessment has allowed us to quantify the direct impacts of climate change resulting from sea level rise in the Grado-Marano lagoon, considering the scenario of 1 m SLR in 2100. This part of the analysis has taken into account only the economic impacts of loss of land in the areas considered at risk of flooding using the value of land for the different uses. Table 4 reports the aggregated values of damage considering the administrative divisions (municipalities) in the Lagoon of Grado and Marano. The damage values refer to year 2100, however, for a better understanding of the extent of the impacts, the results are reported with reference to current real prices. To get an idea of what could be the future monetary costs, the tables also show the nominal values assuming a 1% or 3% discount rate.



What we find is that the most affected municipalities would be those of Grado (3.701.711.903 €), Lignano Sabbiadoro (3.014.595.631 €) and Latisana (1.423.752.876 €). The town of Grado is the one that occupies the larger area within the area at risk (21.4%), while Latisana and Lignano Sabbiadoro occupy only small portions of such area (Table 6). Lignano Sabbiadoro and Grado are also the municipalities that, together with Marano, have the longest shoreline of the lagoon; while Latisana is located in a more inner position.

Figure 3 reports the scatter plot comparing the percentage surface included in the area at risk with the estimated damage at 2100 for the fourteen municipalities. The municipalities that are most distant from the bisector are the ones for which a high deviation between the two percentage values is evident. In particular, in the upper left part of the graph are the municipalities characterized by a high economic damage compared to the surface in the area at risk; in the lower right part we find the municipalities characterized by the opposite situation (low economic damage with respect to the surface occupied). Finally, along the bisector are the municipalities for which the percentage economic damage reflects the percentage geographical impact. Note that this latter type of municipalities presents low values of both surface and estimated damage.

Table 5 reports the estimated-damage values aggregated for the different types of land use in the area. The residential sector is the one that will suffer the greater damage. The loss is estimated at € 4.8 million, representing 43.1% of total damage. The other most damaged sectors will be tertiary activities and natural habitats with estimated damages amounting to 3 and 1.6 million euros, respectively.

Figure 3 shows how agriculture shows a low monetary value of land compared to the surface occupied. Indeed, the comparison between the geographical incidence and the economic incidence rate is very interesting (Table 7). It can be seen that agriculture occupies 77.4% of the territory, but represents only 3.7% of the economic damage. In contrast, the residential sector covers only 1.9% of the area at risk, but it is responsible for 43.1% of the damage in monetary terms. Similarly, the services sector has 2.0% of the geographical incidence and 26.9% of economic impact. Natural habitats represent 14.5% of the territory and 15.3% of the economic loss.



The significant deviation of some data points from the bisecting line highlights the difference between economic and geographical incidence, and, consequently, the need and the importance of a detailed analysis that takes into account the different land uses and their economic values.

4.1.2 Detailed sectorial results

Agriculture

The loss of agricultural land by rising sea levels in the study area would lead to repercussions on the productivity of arable land, which covers the larger part of the surface of the area at risk, together with some complex cropping systems, as well as crops of excellence such as wine. For all types of crops the direct damage in the area is estimated to be of € 413,315,603. The most substantial losses can be attributed to arable land (€ 392,620,606). The other crops that suffer significant losses, even if much lower, are: vineyards, complex cropping systems and orchards.

It should however be borne in mind that the above amounts refer to the loss of value of the land subject to flooding, and do not include indirect or financial losses suffered by the firms subject to relocation whose production stops for the time required for the production of new plants to arise on new ground. The same value also does not discount the possibility that the land in question can change over the years the intended use, moving - as is happening in other municipalities in the region - from agricultural land to building land. In this case, the damage caused by the effects of climate change would be even greater.

Natural habitats

The assignment of a monetary value to environmental goods or to the damage to natural habitats is particularly complex, since, as already pointed out, there is no economic market for such goods, i.e., such goods are not directly bought and sold in markets. For this type of goods, the use of estimation methods based on market values (in particular the VAM) is only a partial estimate, not able to express the total economic value of the damage related to their possible loss. The damage values given below should therefore be interpreted in this light.

In the Grado-Marano lagoon, the extent of damage related to the loss of land characterized by natural vegetation is rather modest. It is estimated that as a result of the effects of rising sea level,



the damage would amount to a value of about 1.7 billion Euros. Among the types of ground included in the area and in the analysis are: deciduous and coniferous forests, heathlands and scrub, wetland areas and lagoons. As mentioned above, however, the monetary value per unit applied to this type of areas is certainly an underestimate, since it only considers the value of use, without capturing instead its real ecological function (linked, for example, to habitat preservation, ecological corridors etc.). The same applies to the assessment of damages to coastal portions. Note that beaches are evaluated in the subsection considering tourism, thus focusing only on the economic value of land considering the potential for an economic activity and not, for example, their biological or aesthetical values.

Residential sector

The possible future damages to residential land in the study area, defined as loss of land with real estate value, amounts to about EUR 4.8 billion and it is the main item of the total estimated damage for the entire study area.

In this analysis we consider four types of purely residential land use (continuous and dense settlements, continuous and moderately dense areas, discontinuously populated areas, and highly discontinuous settlements) plus parking spaces. The damage caused to the last two of categories of residential use is the most significant in monetary terms. The total damage can therefore be attributed mainly to discontinuous residential settlements.

The municipalities that would experience the greater damage are Lignano Sabbiadoro, Grado and Latisana with land losses for residential use with a value exceeding one billion euro. Also in this case the economic evaluation of the damage does not consider the indirect damages that may occur in time. For example, the indirect damage caused to buildings in the long term by increased soil landslides induced by preferential pathways of underground water, or the decrease in the market-value of property as a result of the increased risk of flood and landslide. This approach is also not able to capture any value related to the historical and architectural value of buildings.

Industry

Considering the potential loss of soil used for industrial activities, the damage caused by the effects of climate change would be around € 1.1 billion. As mentioned for other sectors, the



evaluation of the damage to industrial activities is limited to the estimation of the value of a possible loss of land currently devoted to industrial activities, it does not include any consequential damages in terms of lost productivity, damage to equipment over time, or even the costs of a possible relocation of plants.

More in detail, the study area includes: industrial areas (that show the highest damage, around 444 million euros), ports and dockyards. In particular, agri-food related industrial activities would suffer an estimated damage of about 270 million euros.

Tertiary activities

As for the activities grouped under what we define as the 'tertiary sector' (commercial areas, private and public services, sport and leisure activities, public transport parking areas), the estimates on the loss of land indicate a total estimated damage of around € 3.0 billion.

In particular, the economic damage is attributable in large part to the loss of sports and leisure activities. This type of land use occupies, in fact, the most significant portion of territory. Also in this case the economic evaluation of the damage does not consider the indirect damage that may occur over time or the losses related to the activities.

Tourism and costal shoreline

Moving to the economic damage caused by climate change in the coastal zone, we considered the loss of value attributable to beaches and sand dunes that characterize the coast of the Lagoon of Grado and Marano. According to the estimates of risk related to the year 2100, the damage for the loss of land occupied by beaches and sand dunes would be around EUR 31.6 million.

It is, however, an underestimate, because the assessment does not take into account any consequential damages related to the loss of beaches (e.g., spillovers for recreational and food-related tourism, commercial, craft and the services industry), or the intrinsic values of beaches, independent of their use (for example, the aesthetic value and cultural history of the coast).

Other types of land-use

Other types of land-use are also at risk of flooding, in the area such uses include: roads, canals, railways and archeological sites. Total losses are around 83 million €, with transport



infrastructure showing the highest monetary value with an estimated damage of about 81.5 million €. The value of roads and railways includes only the cost of construction and not the social and economic benefits that their presence implies.

Moving to archaeological sites, in this part of the report - designed to measure the pure value of the property at risk – these are assessed on the basis of a green urban or a meadow land, resulting in very low losses; Section 4.2 will instead take into account the intrinsic value of such areas.

4.2 Economic evaluation of non-use values

In Section 4, we assigned a monetary value to the loss of land estimated for 2100 as a result of rising sea levels. This value was calculated considering only the market value of the land, depending on the type of use. In this section, we include an economic evaluation of non-use values.

On the basis of the results by Braat et al. (2008) we estimated the annual damages induced by the loss of woodland areas.

Table 8 reports the annual values ascribable to wooded areas, and in particular to deciduous and coniferous forests in the area at risk, for each type of service provided to the population. The function that has the highest value in monetary terms is by far the capacity of forests to capture carbon dioxide from the atmosphere. This is an important function in the light of concerns about climate change and the resulting policies to reduce emissions of carbon dioxide. More in detail, total annual losses amount to about 242,000 euro. This damage - expressed in annual terms - should be aggregated in time and added to the economic damage in terms of real estate value - expressed as the total value up to 2100 - calculated in Section 4.

For wetlands, marshes and lagoons, we assigned a monetary value based on the work of Ghermanti et al. (2007). What emerges is a total annual damage - that would occur in the case of the disappearance of wetlands - of 13,945 €.

We also assign a non-use value to the archaeological sites located in Aquileia, Grado and Palazzolo dello Stella, based on cultural and recreational services and on the estimations by Riganti et al. (2004), considering the marginal value of additional opening hours. The resulting annual value associated with the archaeological sites in the area is equal to 10,601 euro. Again, this amount is to be added to the value of the property calculated in Section 4.1.



4.3 *Economic evaluation of damages in relation to activity loss*

Table 9 reports the quantitative results from the Bayesian Network that will be used as inputs for the last part of the analysis (Section 4.4). In particular, the table shows the values of the different economic activities present in the study area in the absence and presence of SLR in the case of the implementation of each of the three adaptation strategies considered. It should be noted that in the case of aquaculture and fisheries expected values imply economic gains in the presence of the SLR.

The results from the three BDNS can be viewed directly to define scenarios and to guide policy decisions regarding the implementation of adaptation strategies, or they can be further processed and compared in the context of cost-benefit analysis, or multi-criteria analysis.

The aggregated values in the nodes at the base of the three BDNS, reported synthetically in Table 9, seem to suggest that an intervention of beach nourishment could lead to a greater benefit in terms of avoided economic damage, compared to that resulting from the reconstruction of the salt marshes.

The nourishment intervention would limit the erosion process of the coastline outside the lagoon, and reduce the risk of flooding, thus increasing the value of the beaches with a consequent benefit to the tourism sector, which is the business with the greatest weight in the local economy. However, the marginal benefit resulting from the implementation of this adaptation strategy would tend to decrease in the presence of higher SLR scenarios, which may negatively affect the defensive capacity of the intervention.

The reconstruction of the salt marshes could be an effective form of adaptation, especially in the presence of scenarios with limited sea level rise, thanks to the self-adaptive behavior of salt marshes, which can trap and redistribute sediments, creating the irregular shape of the bottom of the lagoon and reducing wave strength and expansion of the inland lagoon. However, such actions would lose effectiveness in the case of high SLR scenarios, and should in any case be accompanied by other complementary adaptation strategies.

At the sectoral level, what emerges is that clams cultivation would actually benefit from the increase in sea level. The marginal benefit would be reduced considering higher SLR scenarios, probably because this type of activity requires quite low water levels to allow clam emergence and their collection. The benefit would increase in the presence of larger areas of salt marsh,



which would control the marine ingression and the process of salinization of the lagoon. Fishing in the lagoon would also benefit from SLR assuming that species would adapt to the new environment. Benefits are reduced in the presence of the two adaptation strategies. Agriculture would instead suffer negative impacts, and the damage would be slightly reduced by the implementation of the measure of reconstruction of salt marshes. Even the tourism business would be greatly affected by SLR, but the damage would be contained through beach nourishment interventions. Finally, the value of the lagoon ecosystem would suffer significant losses in the presence of SLR, which could be partially controlled by a reconstructive surgery of the salt marshes, while it would not benefit from beach nourishment.

4.4 Multi-Criteria Analysis for the evaluation of adaptation strategies

If we were to consider only the evaluation criteria that can be expressed in monetary terms, looking at tables 3 and 9, it is clear that the strategy of coastal nourishment would be the winner, followed at a distance by the reconstruction of salt marshes. However, in this last part of the analysis we decided to broaden the scope of the investigation to include qualitative considerations related to social and environmental aspects.

Figure 4 shows the output of the MCA software where it is possible to see the scores achieved by the various alternatives analyzed, the preference ranking, and the distance from the first position expressed as a percentage. Figure 4 refers to the case where equal importance has been assigned to the 14 evaluation criteria included in the analysis. In this case it is possible to note how - according to these assumptions - the intervention of beach nourishment is preferable compared to the two alternatives of reconstruction of salt marshes and no adaptation. In particular, the performance of the option of salt marsh reconstruction is superior to that of non-adaptation and reaches a score of about 80% of what obtained by nourishment interventions.

The criteria that contribute the most to the success of this adaptation strategy are: productivity in the tourism sector, usability of the public good (both landscape and use), protection of the lagoon through the wave damping, control with respect to erosion and salinization. It should be noted that the productivity of the tourism and fishing contribute significantly only to the option of beach nourishment, while the criteria linked to the loss of natural habitat, the operating expenses



in the maintenance phase, the maintenance of habitat and lagoon productivity of aquaculture are those who favor the option of reconstruction of the salt marshes.

For the cases with not-equal weights, Table 10 reports the rankings for the cases analyzed. What emerges is that the option of beach nourishment is preferable when the weight given to economic costs is medium-low. The performance of the reconstruction of the salt marshes increases as the relative importance given to the operating expenses increases with respect to investment costs. However, it never emerges as strongly preferable. In the extreme cases where the importance of the overall economic cost of the adaptation strategy becomes very important, the preferred option becomes that of not taking any action and just allow the loss of land.

5. Conclusions

This paper aims at evaluating the costs of climate change in the Grado-Marano lagoon and at proposing a four-point methodology to tackle such problems. The methodology is in some parts easily transferable to other case-studies and in some other it needs to be adapted to the specific local conditions, but it is general enough to be useful for further research.

The methodology proposed, firstly, assesses the value of direct damage related to property loss and then extends its scope to consider also a set of indirect impacts and values that are not strictly “market”. Furthermore, it also aims at evaluating the losses in terms of productivity and use-values of the activities via the definition of a Bayesian Network, built with the co-participation of a pool of multi-disciplinary experts of the lagoon environment. Finally, on the basis of the previous results the proposed approach adopts a multi-criteria analysis to compare different possible adaptation strategies by means of multi-disciplinary quantifiable and non-quantifiable evaluation criteria.

The reference scenario assumes a sea level rise of 1m by 2100 as the only element of risk. Given this environmental risk, the main direct impact on the territory relates to the possible loss of land. In particular, this study estimates the monetary value of possible future damage, in terms of: (first part) loss of properties in residential areas; loss of agricultural land; loss of land devoted to industrial or commercial activities; loss of recreational sites and soil loss with natural habitats; (second part) loss of non-market value related to recreational use, passive use, supply of primary



resources, carbon sequestration, wetland services, cultural and historical value; (third part) loss of productivity for agriculture, aquaculture, fisheries and tourism, loss of natural habitat.

The methodology for estimating the first set of costs considers the variability of the damage due to the different types of land use and applies conventional methods of assessment based on current market values. The main findings of the estimate of possible future damage are summarized below. The total estimated damage for the reference scenario by 2100, considering only the property values, amounts to about € 11.1 billion in terms of current real prices. The municipalities mostly affected are those of Grado, Lignano Sabbiadoro and Latisana.

As regards the different types of land use, those that suffer the most by rising sea levels would be the areas intended for residential settlement, although they are for the most part of the discontinuous type. The loss of these areas would cause damage estimated at € 4.8 billion, or 43% of the total economic damage. The second sector to suffer is the so-called tertiary one, with an estimated loss of €3.0 million, followed by natural habitats with a potential loss of 1.6 million Euros. This fact highlights the need to carry out detailed analyzes that take into account the different land uses and their economic values.

The above estimates are then updated by adding the values emerging from studies that take into account other relevant issues for calculating the 'total economic value' of the damage. Especially when assessing the value of the damage for natural habitat it is too restrictive to consider only the real estate value of these areas. In this report, the assessment of the value of land for permanent flooding include values of "use" and "non-use". Taking into account the different services that the areas with forest cover and wetlands provide, it has been estimated that, as a first approximation, the annual damage caused by the loss of these services would amount to € 256,700. A similar argument was made for the archaeological sites in the cities of Aquileia, Grado and Palazzolo dello Stella. The annual value associated with the intrinsic values of these areas, calculated using the willingness to pay for additional hours of opening, is estimated at € 10,618.

We also consider changes in productivity of agriculture, aquaculture, fisheries, and tourism, finding that losses are in the order of 85-100 million €, depending on the adaptation strategy considered. This part of the analysis was conducted with a participatory approach by means of a multi-stage expert elicitation and was focused around the definition of a conceptual map



highlighting the most important aspects and their causal relations. The output was used to build a Bayesian Network to quantify the potential effects of three different adaptation strategies on the main impacts in the area under evaluation, namely: 1) a process of reconstruction of salt marshes; 2) beach nourishment interventions; 3) no adaptation.

On the basis of the outcomes of the economic evaluations, expert elicitation, BN analysis and other issues we were able to carry out a MCA analysis considering the following criteria: changes in the productivity of aquaculture; changes in the productivity of fisheries; changes in the productivity of the agricultural sector; changes in the productivity of tourism; loss of natural habitat; investment costs; initial management charges; management charges for the maintenance; usability of public assets in landscaping; usability of public assets to the level of use; protection of the lagoon through erosion control; protection of the lagoon through damping of the waves; protection of the lagoon habitat by maintaining the lagoon; protection of the lagoon compared to salinization.

The multi-criteria analysis was conducted by analyzing several scenarios where the weights assigned to evaluation criteria varied. The option of beach nourishment seems to be preferable when the weight assigned to economic cost is medium-low compared to the full range of criteria included. The performance of the reconstruction of the salt marshes strategy increases with the relative importance given to investment costs. However, it is never strongly successful. In extreme cases where the importance given to overall costs becomes very important the preferred option is to not take any adaptation measure. This highlights the importance of the weights assigned to the different criteria and therefore of building tools to support the decision-making processes with a participatory approach.

These results bring to light the importance of strategic analysis of the possible future impacts of CC and the need for tools to support the decision-making process. In particular, in this case-study the usefulness of implementing a participatory processes for the identification of the most significant impacts on the economic activities in the area at risk, and of the possible adaptation strategies was proved to be very strong as it allowed to overcome significant gaps in the available data. Moreover a multi-criteria approach for a comparative analysis of different adaptation strategies that can include very diverse and multi-disciplinary evaluation criteria has also proved to be crucial. This approach is particularly important when making assessments



supporting decision-making processes that need to take into account simultaneously several multi-disciplinary aspects of a problem.

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Tables and Figures

Table 1: Indexes for the results of the ranking exercise

Impacts	Average
Change in ecosystems	12.11
Change in lagoon morphology	9.15
Marinization of the lagoon	7.81
Loss of dry land	7.6
Coastal evolution	7.5
Modification of avifauna	6.97
Loss and creation of habitat	6.38
Modification of fish species	4.89
Reduced availability of drinkable water	4.63
Damages to infrastructures and buildings	4.5
Change in aquaculture productivity	3.77
Change in agricultural productivity	3.68
Saltwater intrusion	3.44
Damages to health	3.22
Change in soil quality	3.17
Change in fishery productivity	2.95
Change in touristic productivity	2.73
Change in commercial productivity	1.89
Change in industrial productivity	1.84
Impacts of transport infrastructure	1.76

Table 2: Evaluation Criteria for the MCA analysis

EVALUATION CRITERIA	TYPE - NAME
Aquaculture productivity change	Economic - E1
Fishery productivity change	Economic - E2
Agriculture productivity change	Economic - E3
Tourism productivity change	Economic - E4
Loss of natural habitat	Economic - E5
Investment costs	Economic - E6
Start-up costs	Economic - E7
Maintenance costs	Economic - E8
Fruition of the public good in terms of landscaping	Social – S1
Fruition of the public good in terms of use	Social – S2
Protection of the lagoon through erosion control	Environmental - Env1
Protection of the lagoon through damping of waves	Environmental - Env2
Protection of the lagoon habitat by maintaining the lagoon;	Environmental - Env3
Protection of the lagoon from salinization.	Environmental - Env4

Table 3: Investment costs for adaptation strategies in analysis

	Size	Unit cost	Total cost
Adaptation Strategy	scenario: 1m SLR in 2100		
Recreation of salt marshes	200 ha	200 €/ha	40.000.000 €
Beach nourishment	10 Km	1416 €/m	14.163.720 €
No Adaptation	-	-	0 €

Table 4: Estimated aggregated damage values in 2100 for each municipality under the 1m SLR in 2100 scenario

Municipality	Damage at 2100 (current real prices)	Damage at 2100 (nominal prices) 1% rate	Damage at 2100 (nominal prices) 3% rate
	€	€	€
Aquileia	513.862.472	1.270.843.044	7.568.927.585
Carlino	267.958.338	662.692.858	3.946.887.285
Fiumicello	69.730.226	172.451.147	1.027.090.050
Grado	3.701.711.903	9.154.774.046	54.524.295.604
Latisana	1.423.752.876	3.521.110.290	20.971.141.107
Lignano Sabbiadoro	3.014.595.631	7.455.453.736	44.403.429.435
Marano Lagunare	500.120.058	1.236.856.419	7.366.508.957
Muzzana del Turgnano	16.709.750	41.325.201	246.125.949
Palazzo dello Stella	245.827.377	607.960.357	3.620.909.709
San Canzian d'Isonzo	241.863.313	598.156.754	3.562.521.098
San Giorgio di Nogaro	464.074.481	1.147.711.417	6.835.576.306
Staranzano	140.758.178	348.111.725	2.073.294.926
Terzo di Aquileia	184.493.308	456.273.905	2.717.490.695
Torviscosa	351.895.226	870.278.769	5.183.234.085

Table 5: Estimated aggregated damage values in 2100 for type of land use under the 1m SLR in 2100 scenario

Land use	Damage at 2100 (current real prices)	Damage at 2100 (nominal prices) 1% rate	Damage at 2100 (nominal prices) 3% rate
	€	€	€
Agriculture	413.315.603	1.022.178.672	6.087.924.374
Natural habitats	1.667.989.872	4.125.137.446	24.568.625.330
Industry	1.099.827.713	2.720.004.814	16.199.891.531
Residential sector	4.792.673.974	11.852.853.072	70.593.600.822
Tertiary sector	2.991.762.456	7.398.984.577	44.067.108.616
Turism	31.642.497	78.255.661	466.077.563
Other	113.417.985	280.496.173	1.670.588.062
Totale	11.110.630.098	27.477.910.414	163.653.816.298

Table 6: Municipal surfaces included in the area at risk for the 1m SLR in 2100 scenario

Municipality	Included surface	Percentage incidence
	m ²	%
Aquileia	23.606.051	11,60%
Carlino	12.692.318	6,20%
Fiumicello	7.169.268	3,50%
Grado	43.510.765	21,40%
Latisana	13.415.763	6,60%
Lignano Sabbiadoro	7.020.981	3,40%
Marano Lagunare	11.295.770	5,50%
Muzzana del Turgnano	2.566.927	1,30%
Palazzo dello Stella	14.382.321	7,10%
San Canzian d'Isonzo	12.013.297	5,90%
San Giorgio di Nogaro	6.124.262	3,00%
Staranzano	8.022.498	3,90%
Terzo di Aquileia	22.191.162	10,90%
Torviscosa	19.650.446	9,60%

Table 7: Comparison of percentage economic damage with percentage geographic incidence for the different land-uses for the 1m SLR in 2100 scenario

Sector	Economic damage (%)	Geographic Incidence (%)
	m ²	%
Agriculture	3,72%	77,40%
Natural habitats	15,01%	14,44%
Industry	9,90%	1,90%
Residential sector	43,14%	1,91%
Tertiary sector	26,93%	2,04%
Turism	0,29%	0,07%
Other	1,02%	0,85%
Not included land-uses	n.d	1,40%
Total	100%	100%

Table 8: annual damage attributed to non-market values of woods

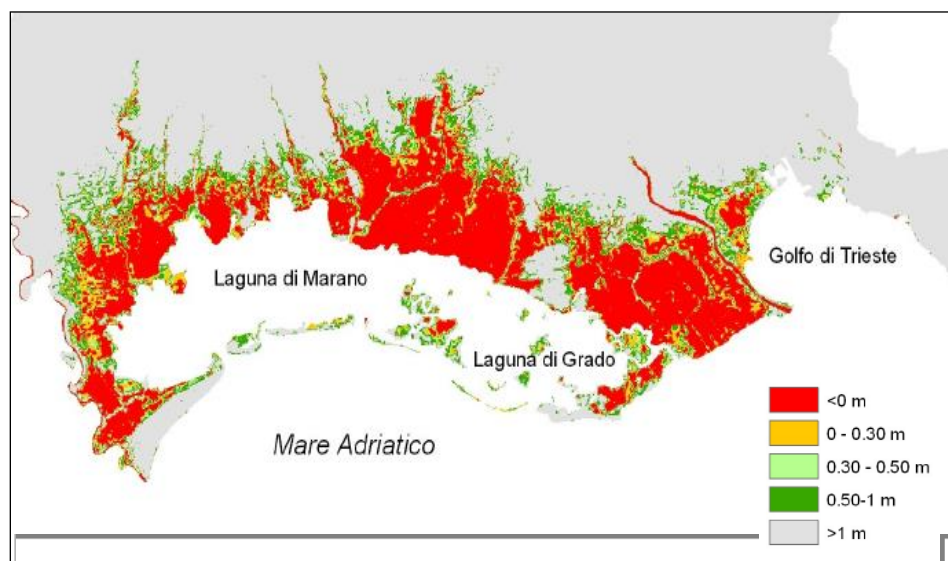
Land use	Area (m ²)	ANNUAL DAMAGE (€/year)			
		Recreational value	Passive use value	Supply of primary resources	Carbon sequestration
Coniferous woods	480.766,55	63,94	5.240,36	5.985,54	14.951,84
Deciduous woods	3.966.611,36	527,56	43.236,06	49.384,31	123.361,61

Table 9: Expected damage to activities/use values in the study area

Expected losses due to SLR (Million €)			Adaptation Strategies		
			1 m		
			No adaptation	Reconstruction of Salt Marshes	Beach Nourishment
Evaluation criteria	Impact	Changes in the productivity of aquaculture	0,33	0,38	0,35
		Changes in the productivity of fisheries	-21,16	-19,83	-20,05
		Changes in the productivity of agriculture	0,04	0,03	0,04
		Changes in the productivity of tourism	-76,21	-75,25	-66,02
		Loss of natural habitat	-1,76	-1,44	-1,76

Table 10: Scorings for the three adaptation strategies under the 1m SLR at 2100 scenario with non-uniform weighting of the evaluating criteria.

RANKING	Cost weight: 15%				Cost weight: 40%				Cost weight: 70%			
	inv/o&m 50-50		inv/o&m 30-70		inv/o&m 50-50		inv/o&m 30-70		inv/o&m 50-50		inv/o&m 30-70	
1°	B. Nourish.	100	B. Nourish	100	B. Nourish	100	Salt Marsh	100	No Adapt	100	No Adapt	100
2°	Salt Marsh	86	Salt Marsh	91	Salt Marsh	83	B. Nourish	98	B. Nourish	69	Salt Marsh	66
3°	No Adapt	28	No Adapt	29	No Adapt	72	No Adapt	77	Salt Marsh	55	B. Nourish	58



Source: ENEA

Figure 1: Area with an elevation below 1m that is estimated to be flooded by 2100

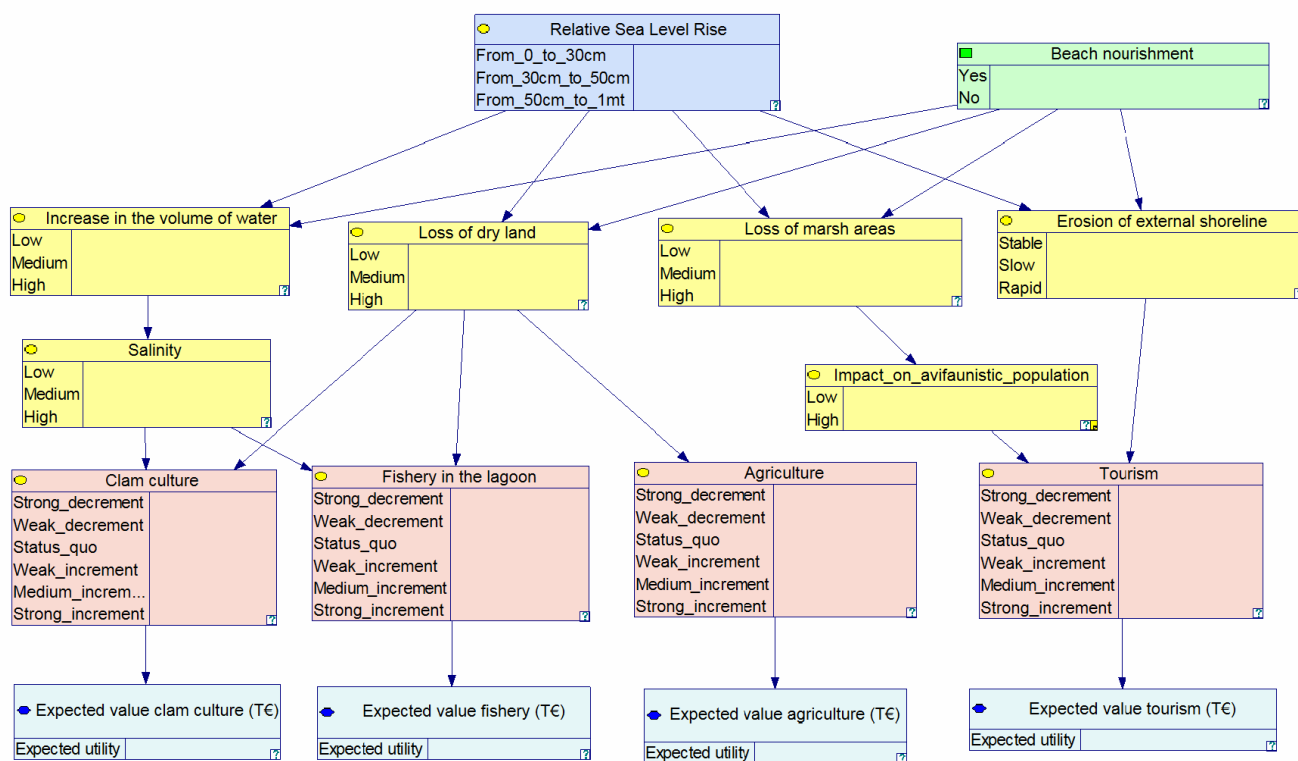


Figure 2: Example of BN representing the simplified decision model for the option of beach nourishment

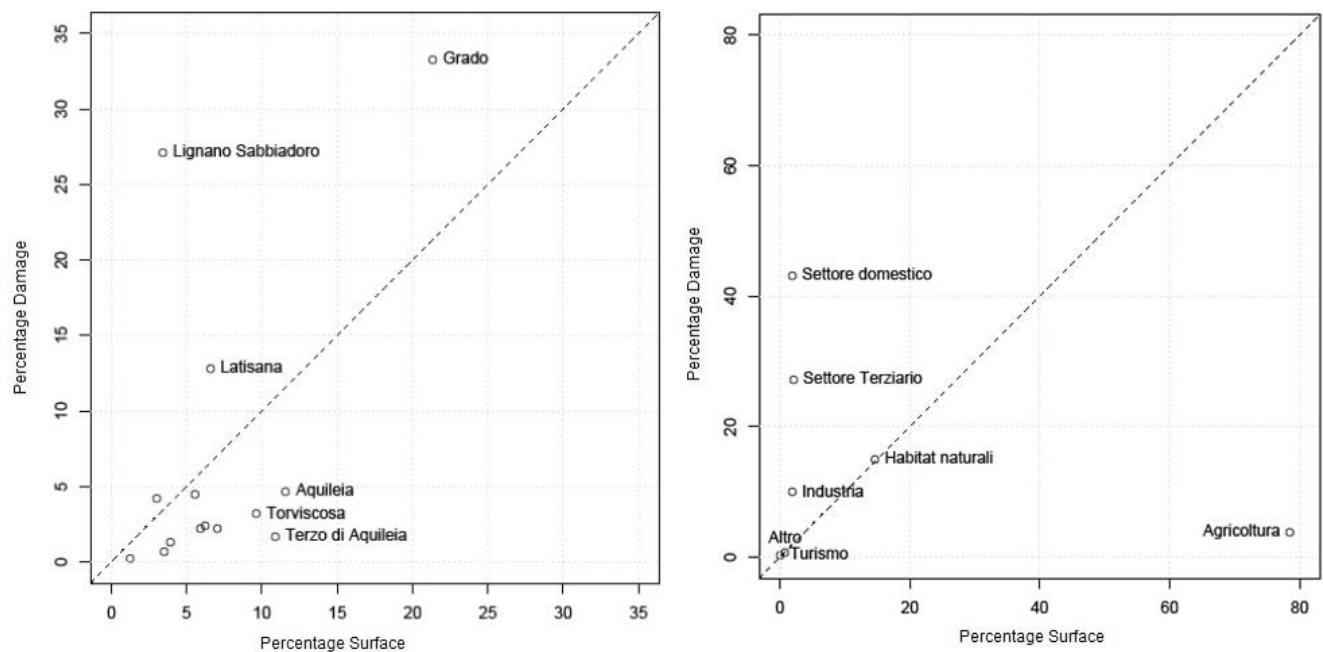


Figure 3: Comparison of percentage economic damage with percentage of surface of the study area for the different municipalities and land-uses for the 1m SLR in 2100 scenario.

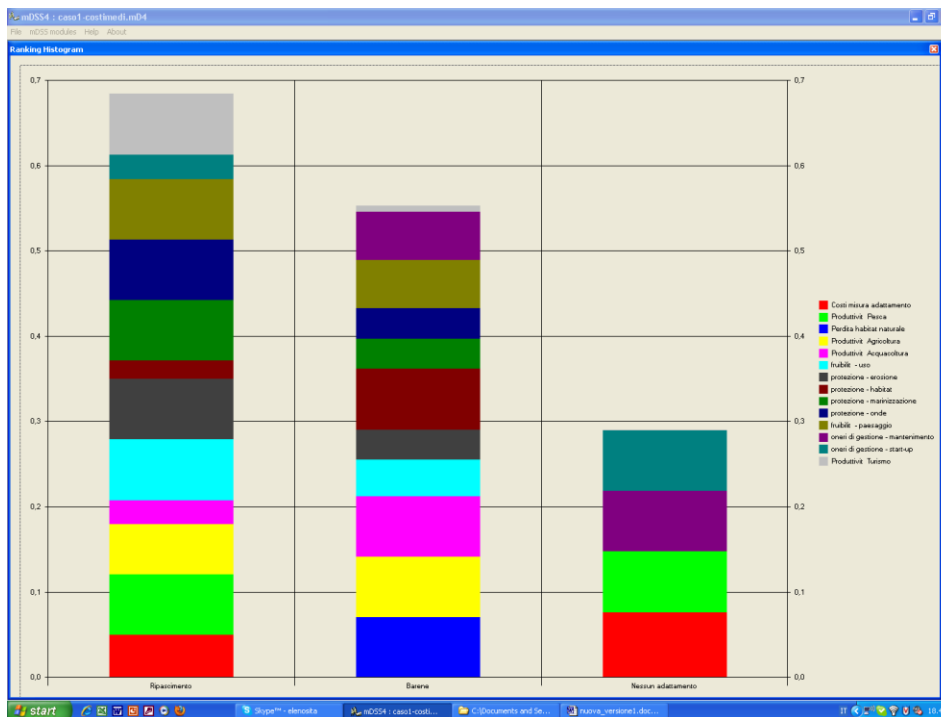


Figure 4: Screen-shot from the software MULINO showing the scoring for the three adaptation strategies under the 1m SLR at 2100 scenario with uniform weighting of the evaluating criteria.