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Protection by hard defence structures or relocation of assets exposed to coastal risks: Contributions and drawbacks of cost-benefit analysis for long-term adaptation choices to climate change

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ABSTRACT

Adapting to sea-level rise due to climate change involves new public policies that aim to relocate those assets most at risk from coastline erosion or flooding. It is no longer solely a question of studying the merits of a defence infrastructure project designed to prevent risks but of looking instead into a broader and longer-term project implying a whole new logic of land-use management for the areas concerned. In this context, the aim of the present article is to compare different adaptation scenarios and to show the need for evolving economic assessment and decision-making tools to include multidimensional and long-term aspects of adaptation policies. It is important to show the limitations of traditional Cost-Benefit Analysis (CBA) by integrating economic impact and non-market factors which are currently only assessed in multi-criteria approaches. Such assessments enable comparison of the Net Present Value (NPV) of a protection scenario using hard defence structures with various relocation scenarios, depending on whether the CBA includes only the direct damages avoided (classic CBA) or integrates the long-term tourist economy and environmental impacts (enhanced CBA). As costs of property purchasing are high, CBA may initially favour the protection scenario over relocations despite unfavourable tourist and environmental consequences. However, if one takes into consideration innovative land-purchase mechanisms which enable reduced investment costs in relocation scenarios, the latter measures may have a positive NPV. We therefore conclude that, in the long term, taking into account the local tourist economy and environmental benefits, the likely fall in prices of real estate at risk and the implementation of anticipatory schemes could enable relocation policies to become economically viable.

1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC, 2014), sea-level rise resulting from climate change will exacerbate the effects of storms and coastal flooding in coastline areas. These areas, often highly urbanized, are very vulnerable in terms of damage to infrastructure, property and human safety. Until now, coastal management doctrines have emphasized measures that attempt to stabilize the coastline, to protect it from erosion and coastal flooding. Faced with the prospect of increased risks, the current recommendations are for policies that 1) reduce sensitivity to risks through mitigation, and/or 2) reduce exposure to risks by relocation of assets (MEDDTL/DGALN, 2012). Even when policies adapt to the local situation by associating several kinds of measures, the costs and respective advantages of each may be called into question, especially for protection measures that involve hard defence structures such as riprap structures or seawalls, and recently recommended relocation policies whose political and social acceptability is problematical.

Cost-Benefit Analysis (CBA) is the emblematic decision-making tool for this type of public choice. It is used to rule upon the pertinence of a project or to arbitrate between several management strategies. However, in the field of river (or coastal) flood prevention, CBA is generally limited to the investment and maintenance

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costs of hard defence structures and to direct damages avoided (the latter being assessed through damage functions) (André et al., 2013). In the case of adapting to climate change, it seems useful to adopt a more global understanding and also include certain indirect avoided costs and long-term impacts such as repercussions upon the tourist economy and non-market effects upon the environment, which are not integrated into "classic" CBA. The aim of this article is to suggest ways to address these limitations. This leads us to envisage the CBA of a territorial project of urban development of a much broader scope than that of a project dedicated solely to risk prevention, and therefore one that is more attuned to the spirit of adaptation to climate change and to the urban and social transformations involved in relocation policies.

In this article, a CBA was carried out on the basis of five scenarios: (i) a reference scenario corresponding to minimal action against coastal risks, in line with present-day management (referred to as "reference situation"), (ii) a scenario corresponding to the construction of hard defence structures (known as "protection"), (iii) an initial relocation scenario using existing schemes (known as "standard relocation") and finally (iv and v) two relocation scenarios which integrate innovative compensation procedures which reduce the costs of asset repurchasing and facilitate social and political acceptance of the operation (Lambert, 2013; André et al., 2015). These are referred to as "relocation with division of ownership" and "relocation with buy and leaseback".

Our approach is intended to be both instructive and comparative so as to weigh up the various factors involved and the differences in results according to the scenario and the type of approach. To free ourselves from specific conditions, we have thus chosen to build our assessment upon a fictional site that constitutes an archetypal example of a seaside community of the French Mediterranean coastline. The use of such an archetypal reference site helps strengthen the instructive nature of our evaluation to local decision-makers. The site is representative of a dense urban area, located on a low, sandy coastline, faced with a considerable risk of erosion and coastal flooding. This is a very common situation in France and especially on Mediterranean coastal territories.

The aim of this study is to emphasize that decision-makers, facing to climate change, will have to rethink their overall planning by integrating numerous factors, including environmental, economic and tourism features, the latter being often the main source of income for Mediterranean territories. It is therefore important to identify the factors that enhance the interest of the relocation policies, such as the maintenance of beaches, as these are both a natural infrastructure of protection and an asset to the tourism sector. For this purpose, the use of a simplified case study facilitates a comprehensive approach, to compare the different protection and relocation scenarios, showing the interest of the division of ownership and the buy and leaseback procedures, which are the innovative elements introduced by the article. This fictional case study is a decision support for local decision-makers, who are today helpless with regards to those long-term horizon projects, with many uncertainties on both coastal natural hazards and evolution of economic market. Of course, in reality, the range of risk management actions is wider, the choice depending on local characteristics, which most often leads to combine several types of measures, which can be qualified of "hard" (defence structures like seawalls or breakwaters) or "soft" (dune management, beach nourishment, etc.). Our approach focuses on the study of the conditions of the economic feasibility of relocation policies, specifically for urban coastal areas where humans, urban assets and tourism issues are particularly significant.

The intention is not to provide accurate valuations but to enable sensitivity analyses which can grade results according to orders of magnitude. Unlike the usual practice in France of carrying out CBA assessments at a national scale, and thereby excluding effects that may balance each other out in spatial terms (in the transfer, for example, of tourist attractiveness between towns), our approach is deliberately focused on a local scale, the one at which adaptation projects are carried out after public consultation. Decisions taken at this level should take into account the whole range of relevant effects.

After examining in the second part to what extent climate change and associated adaptation policies involve methodological adjustments in relation to classic CBA, we present in the third part the details of our approach. The results are presented in the fourth part which compares the scenarios of classic and enhanced approaches. The fifth part is given over to discussion of the results and a sensitivity analysis for the main factors of specific impacts.

2. Renewing assessment tools to guide long-term decisions

2.1. Practices and limitations of traditional methods

Without wishing to open up an epistemological debate about the usefulness and relevance of economic or management science to decision-making, it is important to ask how adaptation to climate change implies a necessary development of its tools and above all of its procedures, given long-term prospects and the progressive nature of the logic which should characterize adaptation policy.

Sequential (Treich, 2000) or adaptive (Holling, 1978) approaches are appropriate for progressive action by what are known as "no-regrets" policies, i.e. ones that have positive impact during the phase of adaptation and are designed to avoid irreversible effects. These are policies of "act and see", creating pathways of adaptation that, in the continuously progressive spirit of sustainable development, allow action to be taken from a position of anticipation, adjusting it all the while as further knowledge becomes available, and giving priority to avoided costs. These are the sequential policies put forward by Treich (2000) for whom it is important not only to seek the "social acceptability of a level of risk or the choice of a reasonable investment to prevent the risk" but also to define "strategies of intermediate management that offer high degrees of flexibility for future generations". The transformations of the decision-making process towards greater flexibility should be accompanied, according to Treich (2000), by profound changes in laws and forms of governance. These changes also mean reconsidering the discount rate, whose single nature has been called into question and whose level in France has recently been reduced to increase long-term benefits, especially environmental ones (Quinet, 2013).

These debates also occur at a time of budget restrictions when CBA, bolstered by the principles of "new public management" (Bezes et al., 2011), has become increasingly used to rationalize and legitimize public action (Roy and Damart, 2002). It can be considered as the cornerstone for traditional economic calculations and decision-making practices, especially for valuing projects. In the last few decades, the implementation of more complex and interdisciplinary projects and policies, in the field of sustainable development for example, has affected the methods for assisting decision-making and valuations. This evolution concerns both metrics, with the surge of indicators and multi-criteria methods, and practices too, with the development of participatory evaluation (Plottu, 2005; Baslé, 2008; Rey-Valette and Mathé, 2012). However, CBA is actually used quite seldom in Europe (Laurans et al., 2013), especially in France where the culture of valuation is not widespread (Varone and Jacob, 2004; Banos and Rulleau, 2014).

Traditionally used for infrastructure projects (transport in particular), CBA has come to be employed more and more in natural hazard management. In the area of flood prevention, the incorporation into French law of the European “Floods” directive (Directive, 2007/60/EC) and the second generation in 2011 of the Flood Prevention Action Programs known in France as “PAPI” schemes (MEDDTL/DGPR, 2011) have generalized recourse to this approach, even if once again it remains underdeveloped in France (Erdlenbruch et al., 2008; Bourguignon, 2014). Faced with the diversity and scale of factors to be accounted for and the numbers of organizations involved (consulting firms, public bodies, state services, etc.), the need for rationalization and standardization of practices has led the French government, with the help of researchers and experts, to produce precise specifications and methodological guidelines, especially regarding the damage functions that are to be taken into account to value benefits (CEPRI, 2010; MEDDE/CGDD, 2014). In a context of policy-making that is geographically scattered and fraught with uncertainty, these guidelines allow results to be harmonized and, in doing so, facilitate comparisons and even arbitration at the national level. They also constitute a medium for transferring expertise and skills from research to consulting firms and stakeholders involved in policy-making. This standardized approach has however led to the exclusion of elements that might have introduced some degree of subjectivity. It is the case for impacts on non-market assets such as human safety, the environment and biodiversity through, for example, the maintaining of wetlands and beaches. To reintegrate these elements into the mix, a whole range of indicators were put forward in Multi-Criteria Analysis (MCA) so that Net Present Value (NPV) from CBA has tended to become just one of several decision criteria used in the processes of arbitration and deliberation - with varying degrees of explicitness as to the criteria chosen - . NPV is thereby losing its place in assisting policy-making.

In the more specific example of coastal risks, the results of the European project Theseus[1] show that, with the exception of the United Kingdom, use of CBA and MCA is still uncommon in Europe (Penning-Rowsell et al., 2014). In France, CBA and MCA have been mandatory in coastal flooding prevention projects since the Xynthia storm of 2010, especially in the case of hard defence structures within PAPI schemes. This trend is not without its own problems however as assessing the risk of coastal flooding in the context of climate change due to sea level rise is problematical, given the shortage in historical data and the interdependent relationship with coastal erosion. These uncertainties lead to technical problems for the inventory of assets threatened by damage and/or destruction, and therefore for the assessment of damages that could be potentially avoided by a project. Moreover, coastal risk management in the context of climate change recommends not only defence structures, but also relocation policies, for which there is no standard method of CBA. Projects for spatial restructuring of territories require considerable budgets (in particular for the purchase of assets at risk) and should therefore see their benefits for the economy and for tourism recognized, not to mention the non-market and long-term damages they avoid (human lives saved, environmental benefits etc.).

2.2. Diversity of cost and benefit factors of an adaptation policy

The originality of our approach comes from its focus on relocation policies and the fact that it views it as a project of territorial restructuring with a considerable number of implications (André et al., 2015). It thus enables losses avoided to be included and, following the logic as the “no-regrets” measures, allows for broader improvements in the local economy and environment to be considered.

Table 1 sums up the main advantages of a policy of adapting to sea level rise through relocation measures. It illustrates the diversity and the importance of its effects, thereby justifying the development of a global and integrated approach, even if certain effects can have no monetary value attached to them.

Obviously, relocation policies also have disadvantages. For example, they generate opposition of residents who will have to move, because of their attachment to their homes, their loss of integration into social networks in the neighbourhoods, and more generally their individual loss of well-being. This opposition generates a political risk for local decision-makers. Depending on the case, there may also be losses of utility due to urbanization of the retreat areas, especially if these are natural or agricultural lands, which would not have been directly affected by climate change.

3. Methodological details of the evaluation

3.1. Definition of the site representing a Mediterranean coastline community

We have chosen to argue in terms of an imaginary fictional site that is representative of a seaside town of the French Mediterranean coastline. This town is located in a lowland area, affected by chronic erosion, subject to shoreline retreat and flooding during storms. Its shoreline is 1.5 km long with a high building density (including the seafront) comprising individual houses and apartments as well as tourist-related businesses (shops, restaurants, hotels). For the test site construction, very specific characteristics, such as presence of coastal rivers, estuaries, or lagoons, that increase vulnerability (including involving river flooding in addition and combination to coastal flooding) and makes more complex the hazard assessment (Ashton et al., 2013; Samaras and Koutitas, 2014; Duong et al., 2016), were deliberately excluded. In some of these cases, the potential retreat areas could also be more difficult to identify, and are necessarily farther from the coast, decreasing the population acceptability of the relocation policy. Table 2 summarizes the main characteristics of this test site (based on average data observed in the regions of Languedoc-Roussillon and Provence-Alpes-Côte d'Azur), and Fig. 1 illustrates the type of territory with pictures of two real sites.

3.2. Presentation of the scenarios

The main characteristics of the reference situation and the adaptation scenarios for protection and relocation are summarized in Table 3.

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[1] http://www.theseusproject.eu.

[2] For simplification purposes, we have grouped together owners and occupiers, while aware that certain owners may not reside in the area and that certain occupiers may not be concerned by all of the effects.

[3] This is the current general rule in France by law, but it is very rarely observed in practice.

[4] In France, depending on the circumstances, property at risk from a major natural hazard can be purchased by the State and compensated for by national funding (“Barnier” funding) at market value without risk estimation. It is the case at present for assets exposed to coastal flooding, cliff collapse, but not to coastal erosion of sandy coastlines.

[5] In France, damage due to natural disasters is covered by an insurance system based on national solidarity, funded by an extra contribution that every inhabitant must pay in house and car insurance, regardless of the level of risk they face. We believe that this system of risk-pooling may change. If the present system is maintained, the effect should be taken into account for the whole society.

[6] We have used a period of 10 years to differentiate from the reference situation where, in the absence of protection, beach nourishment occurs every 5 years.

[7] We therefore place ourselves in a worst-case scenario. Many inhabitants may of course choose to stay in the town. In this case, the model would have to include the costs and effects of rebuilding in retreat zones. Many low-lying towns have little risk-free land available, which means rethinking ways to increase the density of existing areas (hence the need for a territorial reconstruction approach) and/or contemplating population (and tax) movements between towns, with hinterland communities for example.

Table 1
Identification of the main expected advantages of a relocation project.

Target	Damages avoided	Other expected advantages
Inhabitants at risk[2]	Depreciation in asset value making forward sale impossible, or even total loss with no compensation if the property is integrated into publically-owned coastline[3] (with the exception of cliffs eligible for "Barnier" funding[4]) Rise in insurance premiums, or even uninsurability of property (if change to present system[5]) Human loss (deaths), health consequences (injuries, stress, psychological impact of temporary flooding) Debts, individual bankruptcy, psychological impact of sudden property repossession	Improvements in quality of life through new and more functional housing, energy savings Scenic and recreational amenities after increase in size of beaches and wetlands
State and public bodies	Overdue expropriations with recourse to "Barnier" funding in the case of Imminent Danger Orders on eligible coastline Cost of legal action and litigation due to inaction of public authorities	Increased confidence in the future and in public policies
Whole of society	Direct damages (housing, business property, public buildings and infrastructure) and indirect damages (costs of crisis management, temporary rehousing, business disruption) due to temporary flooding General increase in insurance premiums if present system is maintained Economic losses if decline in area activity especially in tourism (business losses, employment, management of abandoned tourist zones etc.)	Revitalizing of economy and rise in tourist attractiveness Employment in real estate, building industry and public works Environmental gain from restoring and expanding beaches

3.3. *Definition of valuation time horizons and details of the logic behind relocation scenarios*

Annual cost and benefit modelling of the different scenarios is established on a time horizon of 50 years, as recommended in national guidelines (MEDDE/CGDD, 2014). This horizon corresponds to the minimal duration required for setting up progressive relocation policies. Their progressive nature befits adaptation policies in the sense that it facilitates social acceptance of relocation and enables the organization of territorial reconstruction (André

Table 2
Characteristics of the CBA test site.

Shoreline	1.5 km long
Beach width	30 m wide, so surface area of 4.5 ha
Population	6500 inhabitants
Individual houses	1000 of which 100 are to be relocated (110 m^2 on average)
Apartments	2000 of which 200 are to be relocated (60 m^2 on average)
Second houses	50% of accommodation
Economic activity	30 shops and 30 restaurants to relocate
Tourist accommodation capacity	230,000 nights spent/year (60% occupancy rate)
Environmental asset at risk	3 ha of *Posidonia* seagrass meadows

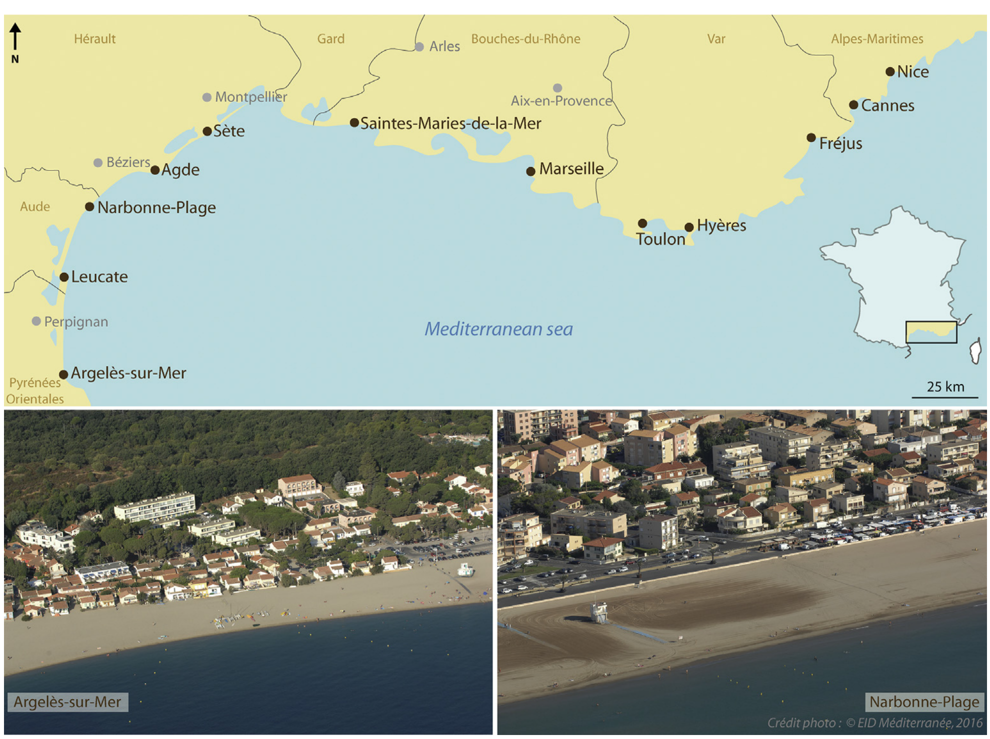

Fig. 1. Illustration of the reference area and of two sites with characteristics close to the test site.

Table 3
Main hypotheses characterizing the scenarios studied.

Reference scenario (i)	Minimal action for risk management ("business as usual") and maintenance costs due to beach nourishment every 5 years. Costs of repairs and crisis management due to temporary flooding after storms are high. Nota bene: as every 10 years, a limited but rising number of properties (from 2 in 2030 to 32 in 2070) face a too great risk and are purchased (through Barnier funding) to be demolished, we thus suppose that several unintended relocations will inevitably occur in this scenario.
Protection scenario (ii)	Installing on the foreshore a riprap structure for a 30-year duration with need for beach nourishment every 10 years.[6] This structure protects the seafront from probable 10-year and 50-year flood occurrences, but does not protect it from a 100-year storm which causes damage equivalent to the no-protection situation. We suppose that this structure accentuates erosion and in turn causes a reduction of two thirds of beach size (from 30 to 10 m), producing a decrease in the environmental and recreational value of the site and a drop in property values on the seafront, as well as in the number of users and tourist income (from 5% in 2030 to 10% in 2050).The construction also brings about a reduction of one third of the surface area of *Posidonia* seagrass meadows (from 3 to 2 ha).
Relocation scenarios (iii, iv et v)	Relocation of 100 individual houses, 200 apartments and 60 shops and restaurants. The average purchase prices for housing located on the seafront are based on the example of the town of Hyères-les-Palmiers in the Var area. Compensation is calculated at market prices without risk estimation and including 10% of incidental compensation (property transfer taxes, moving expenses). The costs of demolishing buildings are based on the experience of the Xynthia storm. The cost of renaturing the beach and dune system is included after each demolition phase. We suppose that the relocated inhabitants leave the town[7] (which implies taxation loss) but that business owners remain in the community. Relocation enables a gradual increase in the width of the beach from 30 to 60 m which then brings about a rise in tourist numbers of 10% after renovation of the seafront.

Table 4
Costs of implementing scenarios in euro (€ tax exc. 2015).

	Reference scenario (i)	Protection scenario (ii)	Relocation scenarios (iii, iv et v)
Riprap structures	–	5,631€/lm	–
Maintenance of structures (future or existing)	5% of the investment/year i.e. 282€/lm		282€/lm/year during 20 years for scenarios iv and v
Beach nourishment	338€/lm every 5 or 10 years		338€/lm every 5 or 10 years during 20 years for scenarios iv and v
Project design, project management, public survey	–	10% of investment	10% of structure maintenance and beach nourishment
Purchasing housing and businesses at risk	Market value (Barnier funding)	–	Houses: 3,636€/m^2 Apartments: 3,908€/m^2
Incidental compensation due to property transfer taxes, fees & moving expenses	10% of compensation value	–	10% of compensation value
Demolition of buildings	30,000€/house 5,000€/apartment	–	30,000€/house 5,000€/apartment
Demolition of infrastructure (roads, networks ...)	–	–	3,500€/lm
Renaturing the beach front (natural defence)	–	–	563€/lm
Property transfer & leasing management	–	–	1,000€/housing/year
Maintaining leased housing	–	–	1,500€/housing/year
Financial expenses	–	–	Loan at rate of 3,4% over 30 years + insurance risk loan representing 5% of yearly repayments

et al., 2015).

In the case of standard relocation (scenario iii), moving or demolishing assets occurs at the beginning of the time horizon, programmed for 2020 so as to account for the period required for the planning and setting up of the project. For scenarios iv and v, on the contrary, two successive phases of temporary occupation are considered. The approach put forward in André et al. (2015), is based on innovative land purchase mechanisms which allow the owners to continue to occupy their accommodation under certain conditions, for 20 or 40 years depending on the area. Division of ownership (scenario iv) consists of acquiring bare ownership and leaving usufruct to the former owners until the date agreed upon at the outset of the project. This reduces the cost of purchasing housing property since the cost of bare ownership is fixed at 30% of the value of the property.[8] Buy and leaseback (scenario v) involves purchasing the entire property at market prices with no risk estimation at the outset and then setting up a leasing system until a fixed date (via a temporary occupancy permit or a specific long-term lease). This generates income which partly compensates for the initial purchasing costs.

For both scenarios, property purchases take place at the start of the project and, since they represent a high initial outlay, we have supposed that they would not be financed solely by subsidies and that financial expenses due to loan repayments should be included in the CBA. For the buy and leaseback scenario, maintenance and management costs are accounted for throughout the operation. Lastly, as demolitions are planned for two periods, i.e. 2041 and 2061, and not at the outset, temporary protection costs are provided for over the first 20 years of the project. Moreover, the damages due to temporary coastal flooding are included right up until the actual demolition of the property at risk.

All values have been converted into euro excluding tax for the year 2015 (data from previous years has been corrected by an annual inflation rate of 2%). Following the recommendations of the French General Commission for Strategy and Planning, the discount rate has been set at 2.5%[9] (Quinet, 2013). As recommended in the general methodology for CBA of risk prevention in France, we have also taken as one of our principal assumptions that there will be no structural change of the assets during the period of the project.

[8] This calculation is based on the cash-flow method and supposes that the accumulated revenues from rents which the owners could have received over the agreed duration of usufruct represent 70% of property value.

[9] Discounting allows us to compare cash flows over time and relate them to the present by applying a rate that accounts for preference for the present and aversion to risk. This rate automatically and considerably reduces future flows and thereby the long-term costs and benefits. For example, the sum of a million euro in 50 years with a discount rate of 2.5% would be equal to 290,000€ at present. Many studies thus advocate low and declining rates in the long run to give greater weight to environmental benefits which also occur over the long term.

Table 5
Specific costs and benefits of scenarios (€excl. tax 2015).

	Reference scenario (i)	Protection scenario (ii)	Relocation scenario (iii, iv et v)
Avoided damages			
Crisis management	10% of direct building damages		
Psychological damage	Feedback from Nîmes 2002		
Additional damages			
Loss of property value from beach disappearance	–	10% of property value every 10 years (seafront property)	–
Loss due to reduction in beach size	–	Reduction of 2/3 of beach value, calculated via WTP/visit and average annual number of users	–
Reduction in tourist numbers	–	In the end, 10% loss of tourist expenditure/year	–
Deterioration of *Posidonia* seagrass meadows	–	1/3 reduction in value of meadow calculated according to bibliography	–
Fall in local taxation revenue due to property loss	1278€/accommodation/year	–	1278€/accommodation/year
Additional benefits			
Scenic, recreational and environmental gains (wider beach, more natural shoreline, landscape, biodiversity, etc.)	–	–	Multiplication by 2 of beach value calculated via WTP/visit and average annual number of users
Gain in tourist attractiveness due to community revitalization	–	–	In the end, 10% gain of tourist expenditure/year

3.4. Data and hypotheses of the costs and benefits in classic CBA

Valuing the costs and benefits for classic CBA was carried out following the usual practices. Valuing the different scenarios was done by comparing them with the costs and benefits of the reference situation and at maximum values for damages to assets. Table 4 sums up the costs of implementing the measures put forward in the scenarios.[10]

Avoided damages to property were valued using damage functions specific to coastal flooding (MEDDE/CGDD, 2014). Average Annual Damage (AAD) is calculated by weighting damages from each risk scenario according to the probability of their annual occurrence (10, 50 and 100 years). A gradual development of the risk due to sea level rise and the possible increase of the frequency and intensity of storm surges were included over the time horizon: an additional 30% coefficient was applied arbitrarily to all AAD after 30 years to account for climate change. The benefits counted in this classic CBA approach are only the damages from coastal flooding avoided by defence structures or relocation.

3.5. Data and hypotheses of specific costs and benefits in enhanced CBA

To account for the specifics of adaptation policies to climate change in coastal zones, our approach includes several effects and impacts that are not valued in classic CBA, i.e. depending on the scenario (1) changes to tourist numbers, (2) losses and gains in environmental and recreational value due to changes in beach size and (3) environmental loss due to surface reduction of *Posidonia* seagrass meadows. The scenarios thus have very varied damages and costs. The economic repercussions of tourist numbers were valued according to the average expenditure ratios (average figures from official publications of Languedoc-Roussillon and Provence-Alpes-Côte-d'Azur administrative regions) depending on the type of accommodation, multiplied by the number of nights observed for each type. The environmental and recreational value of the beaches was determined by multiplying the annual number of users by the average Willingness To Pay (WTP) for each visit to use this type of site. The number of beach users was estimated by applying a frequency rate per hectare per season (peak summer season of 30 days with high density, i.e. 1000 people/day/ha, and off season over 120 days with 300 people/day/ha), on the basis of countings on photography and video images. This method of calculation enabled us to count both tourists and daytrippers. Estimating WTP for beach conservation was taken from a meta-analysis of available data concerning recreational values of beaches. We have used an average value of 3€ (excl. tax) per person per visit (all the references used in order to summarise these data are provided in Appendix).

In the various relocation scenarios, the measures of purchasing, leasing and demolition of buildings impact local taxation revenue (property and local council taxes) that is included in the analysis. Finally, we have counted crisis management costs for storm events proportional to building damages, as well as the psychological impacts of coastal flooding. In the absence of monetary data for psychological costs, we have used costs related to the rise in consumption of psychotropic drugs observed after the 2002 floods in the town of Nîmes (Delavière, 2009), which potentially underestimates this impact. Table 5 summarizes the details of specific costs and benefits for each scenario.[11]

4. Results

4.1. Classic CBA results

Classic CBA is limited to investment and maintenance costs as well as direct damages avoided by installing hard defence structures and by standard measures of relocation. For the latter, it is mainly a question of the reduction in building damages caused in one case by installing defence structures, and in the other by

[10] For bibliographical sources and details, see the appendix (Supplementary Material).

[11] For bibliographical sources and details, see the appendix (Supplementary Material).

[12] Including incidental compensation, property transfer and financial expenses.

[13] Including incidental compensation, property transfer and leasing management of the project, financial expenses, but with deduction of incomes produced by leasing.

Table 6
Results of classic CBA for various scenarios (€ excl. tax 2015).

	Cumulative costs a	AAD b	AAD with climate change c	Cumulative damages d	Damages avoided e = d (ref scen) − d	NPV f = e − (a − a (ref scen))
Reference scenario (i)	17,897,319	1,549,763	2,014,692	54,113,472	–	–
Protection scenario (ii)	32,264,643	299,497	389,347	10,456,900	43,656,572	29,289,247
Standard relocation scenario (iii)	151,366,886	94,815	123,260	4,911,270	49,202,202	−84,267,365

removal of assets at risk from coastal flooding. The results (Table 6) show that protection and relocation scenarios enable a considerable reduction of damages compared to the reference scenario. Damages avoided by installing protection are high and the NPV indicates a positive result for this scenario, in the region of 29 million €. It must be remembered however, that in this classic analysis, the environmental consequences of loss of *Posidonia* seagrass meadows or beach are not included. The relocation scenario with current regulatory framework enables higher avoided costs but also involves heavy property purchasing costs (100 million €) since this is done at prices without risk estimation. In this case, relocation scenario NPV within existing legislation is highly negative even with greater avoided damages than the protection scenario.

4.2. Economic assessment of relocation depending on purchasing procedures

To take into account non-market benefits which lead to a more favourable assessment of relocation, our analysis was redone to include innovative property-purchase mechanisms (Table 7). These procedures considerably reduce relocation costs, but not sufficiently for NPV to be positive.

4.3. Results with enhanced CBA integrating tourist and environmental factors

As previously indicated, accounting for non-market factors allows inclusion of environmental costs for the protection scenario and environmental, social and economic benefits for relocation scenarios as well as the local economic impacts (tourist activity, taxation) of the different scenarios (Table 8).

The results show that with these new parameters, the NPV of the protection scenario is negative as well as that of relocation with current regulatory framework, even though the amount is considerably lower. On the contrary, the innovative asset-purchasing mechanisms, by greatly reducing the cost of acquiring assets, enable, together with the economic and environment benefits in CBA, to obtain a positive NPV for relocation scenarios with division of ownership or buy and leaseback. We then valuate the relative weights of the different costs, damages avoided and other benefits.

For the protection scenario (iii), Table 9 points up the importance of construction and maintenance costs of the hard structures but also of the additional damages identified in enhanced CBA (deterioration of Posidonia seagrass meadows, decrease in recreational and environmental value and drop in tourist numbers after beach size reduction). In a period when the prospects of tourist

Table 7
Comparison of NPV of relocation depending on asset purchasing mechanisms in classic CBA (€ excl. tax 2015).

	Cumulative costs a	Leasing income b	Actual cumulative costs c	Cumulative damages d	Damages avoided e = d (ref. scen) − d	NPV f = e − (c − a (ref. scen))
Standard relocation scenario (iii)	151,366,886	0	151,366,886	4,911,270	49,202,202	−84,267,365
Division of ownership relocation scenario (iv)	64,839,981	0	64,839,981	30,820,395	23,293,077	−23,649,585
Leasing relocation scenario (v)	166,432,996	103,764,440	62,668,556	30,820,395	23,293,077	−21,478,161

Table 8
Results of enhanced CBA for different scenarios (€ excl. tax 2015).

	NPV classic CBA f	Additional damages g	Additional benefits h	NPV enhanced CBA i = f − g + h
Protection scenario (ii)	29,289,247	38,769,714	0	−9,480,466
Standard relocation scenario (iii)	−84,267,365	0	52,814,500	−31,452,865
Division of ownership relocation scenario (iv)	−23,649,585	0	30,533,793	6,884,207
Leasing relocation scenario (v)	−21,478,161	0	30,533,793	9,055,632

Table 9
Relative weight of costs and for the protection scenario (ii).

Costs	Building defence structures	16,892,436€	21%	State & public bodies
	Maintenance of structures	12,400,024€	15%	
	beach nourishment	1,282,939€	2%	
	Project design	1,689,244€	2%	
Classic CBA damages	Building damages	9,504,530€	12%	Inhabitants at risk
	Psychological damages and crisis management	952,370€	1%	
Additional damages enhanced CBA	Decrease in property values (beach size)	1,099,974€	1%	
	Decrease in tourist numbers	10,263,636€	13%	Whole of society
	Decrease in recreational and environmental value (beach size)	12,112,519€	15%	
	Deterioration of *Posidonia* seagrass meadows	15,293,585€	19%	

Table 10
Relative weights of costs and benefits for the standard relocation scenario (iii).

Costs	Property purchases[12]	132,741,418€	63%	State & public bodies
	Demolition of buildings and infrastructure	6,036,078€	3%	
	Renaturing	1,563,212€	1%	
	Taxation loss	10,869,856€	5%	
Classic CBA damages	Damages to buildings	4,463,903€	2%	Inhabitants at risk
	Psychological damages and crisis management	447,366€	0%	
Additional benefits enhanced CBA	Rise in tourist numbers	12,088,340€	6%	Whole of society
	Rise in scenic, recreational and environmental values	40,726,160€	19%	

development lead to a priority for ecotourist or luxury products, and when society is increasingly in favour of maintaining biodiversity, the reduction of beach size constitutes a considerable constraint for a community's sustainable territorial development project.

On the other hand, for the relocation scenarios, the results of Tables 10 and 11 show the high cost of property purchases and additional benefits identified in enhanced CBA (rise in tourist numbers and environmental values), which underline the economic argument for implementing this type of adaptation policy. For the relocation scenarios with division of ownership or buy and lease back (iv and v), it is to be noted that the significant decrease in property purchasing costs compared with the standard relocation scenario (iii), via the innovative purchase mechanisms proposed, is partly compensated for by higher damages to buildings, since the buildings are only demolished after 20 and 40 years. Likewise, the additional benefits identified in enhanced CBA (rise in tourist numbers and environmental values) have lower values here since renaturing of the seafront is delayed, but the difference is nonetheless sufficient to make the NPV positive for the last two scenarios.

In all of the scenarios, the distribution of costs and benefits according to stakeholder category indicates the importance of public costs, while avoided damages, economic repercussions and environmental benefits are shared out among the whole of society, including private stakeholders (inhabitants, tourists, owners of housing or business activities etc.) Given the sums presented, implementation of these adaptation policies raises the question of their funding and of the necessary pooling of these costs at varying scales (Clément et al., 2015).

5. Discussion

Our approach goes beyond the mere assessment of damages avoided by defence works or planning changes. It also aims to assess different implementation procedures (purchasing tools, weight of financial expenses, etc.) and the different consequences of a project on the economy -tourism in particular-, on the environment and on social policy (the quality of life and the attractiveness of an area). We are not assessing a simple risk prevention project by a defence structure, but a territorial project, which means working outside current methodological frameworks by giving a monetary value to certain non-market impacts.

Given the contingent nature of certain non-market values, it is important to carry out a sensitivity analysis for those factors with a high relative weight in the results of this enhanced CBA.[14] The first stage of the sensitivity analysis consists in measuring the stability of the results depending on the value of the discount rate chosen. A rate of 1.5% instead of 2.5% would lead to an NPV of −7381 k€ for the protection scenario (ii), whereas a 4% rate would lead to an NPV of −10,376 k€; the NPVs of standard relocation (iii) would amount respectively to 13,377 k€ and −57,732 k€. These results show that adaptation policies, whose results are felt in the long term, are all the more interesting when the discount rate is low. The variation in results for the relocation scenario is greater than for the protection scenario because the benefits are felt throughout the time horizon, whereas the high purchasing costs are counted at the beginning of the period considered. For the relocation scenarios with division of ownership or buy and leaseback (iv and v), NPV are also negative at a discount rate of 4%; but the ranking of the different scenarios remains the same, the relocation scenario with innovative procedures being more cost-effective than the standard relocation scenario, itself more advantageous than the protection scenario.

Table 12 shows the robustness of the results of the CBA since changes in the NPV polarity are only observed with changes to the values of two variables, namely the price of housing and WTP of beach users. These changes moreover are only seen in the iv and v scenarios. For the relocation with buy and leaseback scenario (v), the change in the NPV sign may be put into perspective in the case of the change in housing prices because, in the simulation, only the purchasing cost was modified and not the revenue from leasing housing. However, the WTP value appears to be a critical parameter for analysis results in the two relocation scenarios. The interest of these innovative purchasing mechanisms is nonetheless underlined by the simulation, since the NPV of scenarios iv and v remain positive in the majority of cases.

Finally, calculation of the threshold from which NPV becomes positive is a strategic indicator for decision-making. A fall in real estate prices of 29%, for example, would enable this target to be reached for the standard relocation scenario (iii). This is a decisive result for adaptation decisions. Non-intervention, for instance, which led to a rise in damages to buildings at coastal flooding occurrences, could, in a mid-term perspective, also lead to a rise in insurance premiums which in turn would lower the value of property (Grislain-Letrémy and Villeneuve, 2015). The interest of relocation for property owners lies in avoiding a fall in real estate capital since the property purchasing in the different scenarios would occur as early as 2020. The sensitivity of NPV to property prices leads us to envisage the idea that, sooner or later, relocation policy will become self-evident, even when compared to protection policies. The main issue is thus to encourage stakeholders to anticipate them by demonstrating how economically effective they are, especially when they are based upon the specific purchasing mechanisms proposed in André et al. (2015). However, the emotional attachment of owners to their homes is such that information campaigns will be required to help inhabitants understand the advantages (even though most coastline property markets are still stable). Local decision-makers will also have to be informed so that concerted approaches are encouraged (Santoro et al., 2013). Another decisive variable is visitors' WTP for maintaining beach sizes. If this unit value varies significantly with each study (cf. Appendix), and especially with the method of economic assessment chosen, the variations are in every case smaller than

[14] Let us bear in mind here that our argument is based on a fictional site intended to be representative of French Mediterranean coastal communities, and that the ranking of factors could vary in other localities.

Table 11
Relative weights of costs and benefits for relocation scenarios with division of ownership and buy and leaseback (iv and v).

Costs	Property purchases[13]	40,185,402€	32%	State & public bodies
	Temporary maintenance of buildings	11,526,823€	9%	
	Temporary maintenance of defence structures and beach nourishment	5,512,647€	4%	
	Demolition of buildings and infrastructure	3,355,566€	3%	
	Renaturing	1,079,344€	1%	
	Taxation loss	3,072,263€	2%	
Classic CBA damages	Damages to buildings	28,011,579€	22%	Inhabitants at risk
	Psychological damages and crisis management	2,808,817€	2%	
Additional benefits enhanced CBA	Rise in tourist numbers	8,833,019€	7%	Whole of society
	Rise in scenic, recreational and environmental values	21,700,774€	17%	

Table 12
Sensitivity analysis of the key factors in the various scenarios.

Parameter variation	Protection scenario (ii)	Relocation scenarios		
		Standard (iii)	Division of ownership (iv)	Buy and leaseback (v)
Cost of defence structures and beach nourishment (±20%)	NPV still < 0	NPV still < 0	NPV still > 0	NPV still > 0
Purchasing price of housing (±20%)	NPV still < 0	NPV still < 0	NPV still > 0	NPV > 0 if rise < 8%, NPV < 0 if rise > 8%
Annual average damages (±20%)	NPV still < 0	NPV still < 0	NPV still > 0	NPV still > 0
Tourism income (±20%)	NPV still < 0	NPV still < 0	NPV still > 0	NPV still > 0
Number of beach users (±20%)	NPV still < 0	NPV still < 0	NPV still > 0	NPV still > 0
WTP for beaches (from 1 à 5€/visit)	NPV still < 0	NPV still < 0	NPV > 0 if WTP > 2€, NPV < 0 if WTP < 2€	NPV > 0 if WTP > 1€, NPV < 0 if WTP < 1€
Value of Posidonia seagrass meadows (±50%)	NPV still < 0	-	-	-

those observed when tourist numbers are estimated, owing to the high cost of monitoring which is infrequent as a consequence (Le Corre et al., 2012). However, visitor frequency, underestimated up to now, plays a major role in economic assessment. Recently installed camera surveillance systems have enabled more accurate calculations of tourist frequency and diversity throughout the year. (Balouin et al., 2014). These issues will need to be investigated further in future developments aiming to include non-market elements in CBA.

6. Conclusion

This article has sought to compare the effects in a coastal area of different types of scenarios for adapting to sea level rise, but also to show that decision-making tools must evolve to integrate the notion of long term and the multidimensional nature of climate change (Desmont et al., 2011), through the most integrated approaches possible. The aim of including a diversity of effects is, moreover, intended to show the advantage of adaptation policies, which are more complex than the setting up of a new infrastructure or an occasional protection measure. It confirms the necessity for understanding climate change adaptation within the framework of a global territorial project (Martínez de Anguita et al., 2008). It is important not to constrain assessments because of uncertainties (Patt et al., 2005) and to be able to apply a principle of anticipation, required by adaptation to climate change. We have shown that the results of CBA vary greatly depending on whether they only include direct costs and benefits or non-market elements, and also on the spatial scale considered, which allow or does not allow us to take into account the local economic benefits, especially in terms of tourism. Indeed, our results point up the advantage of widening the scope of effects included in CBA for measures dealing with adaptation to climate change when long-term risks are involved with impacts on multiple aspects of the economic and environmental capital of the area. So, even if confidence intervals of the estimators of non-market assets require us to be prudent in interpreting the results, the approach we have used allows for a more accurate and fairer ranking of the scenarios, as well as one that is more instructive and less contestable when decision-makers, confronted with difficult political support for relocation, must inform, justify and persuade residents of the advantages of their decisions. To refine the methodology even more, several lines of research are possible. These could involve the economic assessment of certain social aspects such as the psychological impact of coastal flooding. The indicator we have used, i.e. variation in the consumption of psychotropic drugs, does not reflect the full impact upon residents. Furthermore, as the sensitivity analysis showed, the results depend upon the “credibility” of the hypotheses put forward and the variables included in the analysis. Taking into account, for example, the effects of protecting human lives, should further strengthen the NPV differential in favour of relocation as opposed to protection, the latter remaining fallible for events with the lowest probability of occurrence but the most crucial for residents' safety.

Finally, focusing on several local effects of adaptation options, our approach is a valuable contribution to enhance the decision-making processes that guides strategic choices in public policies, by taking into account impacts that have been underestimated until now. The aim was to identify the conditions that would justify a relocation scenario, illustrating in an instructive manner the diversity of factors involved on economic cost-effectiveness assessment of these policies. Of course, the relative weight of different factors will be different depending on the area: our objective was not to provide a reference hierarchy of these factors, but rather to encourage, with a representative example of Mediterranean coastal communities, to expand the scope of the factors used to facilitate the long-term justification of the relocation policies. Our example shows that an enhanced CBA approach that includes a variety of non-market factors is feasible, and can be of interest. This article also offers methodological trails for future studies. Furthermore, our approach provides insight on comparing scenarios according to their ways of implementing, showing the advantage of introducing innovative property-purchasing mechanisms, which implies changes to the law and to practices; this further supposes strong action in terms of information and raising awareness among decision-makers, State services and the population. Division of ownership or buy and leaseback mechanisms will only work if the risks have been anticipated since they are based on long-term arguments. As Droege (2006) has pointed out, management practices today function on a mode of reaction. It is necessary to develop "exploratory" forms of governance (Duit and Galaz, 2008) that favour learning and innovation (Clark, 1998).

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.ocecoaman.2016.10.003.

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