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Socio-Economic Assessment of Ecosystem-Based and Other Adaptation Strategies in Coastal Areas: A Systematic Review

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Abstract: Coastal areas are highly vulnerable to climate-change hazards (e.g., sea-level rise, flooding, coastal erosion), which can lead to significant impacts at the ecosystem and societal level. Interest in ecosystem-based adaptation (EbA) is gaining importance due to its potential multiple benefits, including social and environmental aspects, when compared to more traditional approaches such as hard engineering interventions. When assessing EbA strategies, further understanding of the nature–society functions, processes, values, and benefits is needed to increase its application. This study contributes to better knowledge of EbA and other adaptation strategies by developing a systematic literature review of studies performing socio-economic assessments of climate-change adaptation in coastal areas. The analysis of 54 publications revealed that cost–benefit analysis was applied in most studies, followed by multi-criteria analysis and other techniques. Hybrid adaptation strategies based on different combinations of hard, soft, and EbA interventions were considered as potential optimal solutions in a significant part of the assessments. This study shows some potential co-benefits of EbA, such as livelihood diversification or biodiversity conservation, but also stresses the need for further research on this topic, as well as on evaluating how EbA performs in the long term under changing climate-condition scenarios.

Keywords: climate-change adaptation; coastal cities; ecosystem-based adaptation (EbA); socio-economic assessment; systematic literature review

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1. Introduction

The effects of climate change on both human and natural systems include loss and damage to ecosystems, infrastructure, environment, and populations worldwide. Coastal areas greatly contribute to socio-economic activities, concentrating approximately 40% of the world's population, with forecasts indicating that this percentage will continue to increase in the upcoming decades [1]. Sea-level rise, coastal flooding, erosion, storm surges, and landslides are some of the most relevant hazards affecting coastal areas [2,3]. These coastal hazards and associated impacts have compounding consequences for both society and the economy. Therefore, climate-change adaptation—alongside mitigation—is a necessary response on which decision-makers must take action in their local and regional context.

According to the Intergovernmental Panel on Climate Change (IPCC), adaptation can be defined as the "process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities" [4]. Several authors make the distinction between different types of adaptation options, suggesting various ways of grouping them [5–7]. The analysis presented in this article aligns with the following categories:

(i) *Hard adaptation*—mainly based on physical and structural adaptation with the implementation of grey infrastructure (i.e., engineering-based approach), often in the form of artificial stabilization structures [7–10] and with the purpose of addressing climate impacts such as flooding or coastal erosion (e.g., levees, technical shading, irrigation systems) [11].

(ii) *Soft adaptation*—includes initiatives aimed at encouraging adaptative behavior [11], social adaptation, awareness-raising, and institutional adaptation and capacity building [12], or strategies to strengthen building codes in the form of wetproofing, dryproofing, and building elevation [13–15], among others.

(iii) *Ecosystem-based adaptation* (*EbA*)—refers to an integrative approach focused on sustainable management, conservation, and restoration of ecosystems with the purpose of providing services that support adaptation to climate change along with social, economic, and cultural co-benefits for local communities [16,17]. Ref. [18] made use of the ecosystem-service cascade model presented in ref. [19] to identify the main EbA components, namely, (a) ecological structures (e.g., watersheds, forests, gardens, and green roofs), (b) ecological functions and processes (e.g., how wetlands provide flood protection), (c) adaptation benefits (e.g., flood protection and reduced climate-related mortality and morbidity), (d) valuation (e.g., avoided costs or improved quality of life), and (e) ecosystem-management practices (e.g., community-based monitoring of a forest or a new green-space law). EbA has been categorized under the umbrella term of "nature-based solutions" (NbS) [20,21], which has a wider scope including actions that protect, sustainably manage, or restore natural or modified ecosystems, while simultaneously addressing societal challenges beyond climate-change adaptation. Human health and food-and-water security are some examples [22]. EbA was initially applied in the agriculture and forestry sectors [23,24], but its interest as a cost-effective and comprehensive multi-functional approach is rising in the context of urban areas [18]. Moreover, EbA solutions have been recently advocated in the sixth Assessment Report of the IPCC [4] as part of coastal defense strategies against flooding, storm surge, and sea-level rise. Despite some authors considering EbA part of soft adaptation [5,25,26], others consider it an independent category due to its potentially central role in strategic-adaptation planning [11] and its ability to increase the capacity of territories to reduce climate risks by enhancing the provision of ecosystem functions and services [27].

(iv) *Hybrid adaptation*—based on any combination of the previous adaptation options.

The main aim of this paper is to develop a systematic literature review of studies performing socio-economic assessments, or, in other words, evaluation or appraisal, of climate-change adaptation in local and regional coastal areas. The research is designed to address three main objectives: (i) to identify the most frequently used socio-economic methods to assess adaptation strategies and measures, and to characterize those methods in terms of their main aim, timing, and stakeholders' involvement; (ii) to describe the adaptation context in which the assessment methods were applied, notably by looking at the climate-change hazards and impacts addressed in the selected studies, the climate-change scenarios applied, and the adaptation strategies and measures assessed; and (iii) to understand and describe how the different adaptation strategies and measures assessed in the studies performed under a socio-economic perspective (e.g., cost-efficiency, generation of societal benefits) in the context of various hazards.

This study's main contribution is twofold. First, it provides important information about a diverse set of socio-economic methods that can be used in the analysis of adaptation strategies and measures. Socio-economic assessment tools are very relevant to evaluating aspects such as the desirability and economic efficiency of different adaptation options. Second, it gives an overview of measures capable of addressing different climate hazards affecting local and regional coastal areas while indicating some of their corresponding benefits and drawbacks. Despite focusing on various types of adaptation strategies, this review gives particular importance to EbA, with the purpose of contributing to better knowledge of the benefits of introducing EbA solutions to climate change, either alone or in combination with other adaptation strategies. A better understanding of adaptation options and methods for the assessment of their socio-economic performance can facilitate local and regional planners and decision-makers in the selection of actions to implement.

The following sections explain the methodology followed in the systematic literature review (Section 2) and present the main results of the review (Section 3), as well as the discussion and conclusions (Section 4).

2. Methodology

The systematic literature review of socio-economic assessment studies applied to climate-change adaptation follows the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA 2020) methodology [28]. PRISMA ensures consistency of the research process and quality of the results, minimizing bias by following a standardized protocol and identifying gaps and future research paths [29,30].

In this review, consistency, and standardization of the PRISMA methodology are reflected in three main stages: (i) identification of studies that fulfil the eligibility criteria in the selected databases, (ii) screening process of the selected records to be consistent with the stated research questions, and (iii) inclusion of records for literature-review analysis.

2.1. Identification of Studies

The identification of studies was conducted by searching Web of Science (WoS) and Scopus because of their large databases of scientific peer-reviewed literature, Zenodo as an open repository of scientific and non-scientific literature, the Community Research and Development Information Service (CORDIS) as an important database for EU-funded project publications, and the European Climate Adaptation Platform Climate-ADAPT due to its relevance as a database of quality checked information about climate change. The process of identifying and selecting the studies for the analysis was conducted in November and December of 2021. The search string was designed to capture a broad scope of studies that performed different types of socio-economic assessments of adaptation measures or strategies for climate change in coastal, and mainly urban, areas. This allowed a broad overview of the most frequently used methods to be obtained. The search string had the following configuration: ("socio-economic" OR "socioeconomic" OR "economic" AND "assessment" OR "analysis" OR "evaluation" AND "climate change" AND "adaptation" AND "coastal" OR "urban" OR "city"). For the identification of studies, the search was limited to scientific articles written in English and published between 2010 and 2021 that contained the search-string words within their title and abstract. This search resulted in 6501 records identified in the five databases. From this number, 4501 records were duplicated and removed before the screening, and 24 additional records were removed for other reasons (studies not written in English, or full references not published), making a total of 1976 eligible records for screening.

2.2. Screening Process

The resulting entries were filtered based on four additional eligibility criteria: (i) case studies developed in coastal areas, (ii) local and/or regional spatial scale of the analysis, (iii) implementation of socio-economic assessments, and (iv) studies addressing climate-change-related impacts and specific adaptation strategies and/or measures. The full list of the eligibility criteria applied in the stages of identification and screening is presented in Table 1.

The screening process involved two steps. First was the screening of the title and the abstract, which led to the exclusion of 1367 out of 1976 records due to their non-compliance with the eligibility criteria. Second, another 461 studies were excluded in the full-text screening due to not fulfilling the eligibility criteria or being irrelevant to the stated research questions. Moreover, a final revision of duplicates led to the removal of a further 102 records. This process resulted in 46 eligible studies for the literature-review analysis.

Table 1. Eligibility and exclusion criteria applied in the literature review.

Criterion	Eligibility Criteria	Exclusion Criteria
Timeline or period	2010–2021	Pre-2010
Language	English	Non-English
Type of publication	Peer-reviewed scientific articles	Others
Publication status	Published	Non-published
Geographical context	Coastal areas	Others
Spatial scale	Local, regional	National, continental, global
Type of assessment	Socio-economic	Non-socioeconomic
Environmental issue/action	Studies focused on climate-change-related impact and specific adaptation strategies/measures	Not related to climate-change impact and adaptation

As a final step, the identification and screening stages were repeated for the references cited in the 46 eligible studies. A total of 23 records were first identified, and then screened, leading to eight additional eligible studies. As a result, 54 articles were included in the literature-review analysis. Figure 1 provides an overview of the results of the identification and screening stages through the PRISMA 2020 diagram.

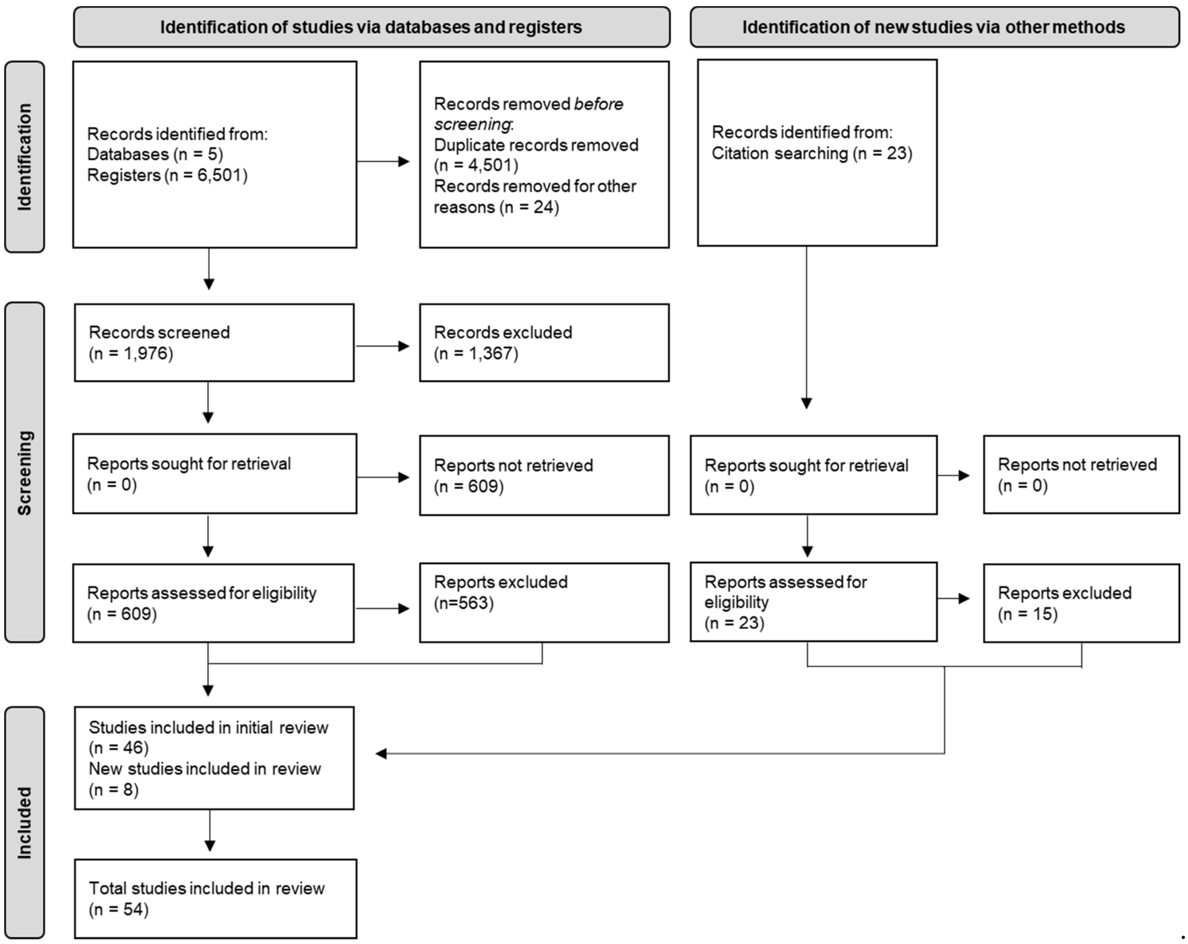

Figure 1. PRISMA 2020 flow diagram. Results overview. Source: Adapted from ref. [28].

2.3. Literature-Review Analysis

The final stage of the PRISMA methodology was to review the selected studies through a full-text reading. This process was based on the analysis of a group of variables that allowed the studies to be characterized and the stated research questions to be answered (Table 2).

Table 2. Variables analyzed in the full-text assessment.

No.	Coding Fields
A.	Basic information
1	Article ID
2	Authors
3	Year of publication
4	Article title
5	Name of journal
6	Article keywords
7	Geographical scale of the analysis (A—Regional/provincial; B—Urban/peri-urban; C—District/neighbourhood/ street)
8	Location of the study area
9	Period of the analysis
B.	Socio-economic assessment methods
1	Assessment method (A—Cost–benefit analysis; B—Multi-criteria analysis; C—Others; If others, please specify)
2	Timing of the assessment (A—Ex-ante; B—Interim; C—Final or ex-post evaluation)
3	Aim of the assessment method
4	Stakeholders involved (A—Citizens and citizen groups; B—Public authorities; C—Researchers/Academia; D—Private sector)
5	Type of stakeholder involvement
C.	Climate-change impact and adaptation context
1	Climate hazards addressed in the study (A—Sea-level rise; B—Coastal erosion; C—Flooding; D—Multi-hazards; E—Others; If multi-hazards/others, please specify)
2	Sectoral climate impacts addressed in the study (A—Risk to tourism; B—Loss of cultural heritage; C—Damage to commercial buildings; D—Damage to residential buildings; E—Energy networks; F—Agriculture stress; G—Loss of wetlands; H—Loss of animal habitat; I—Damage to civil infrastructure; J—Risk to local economy; H—Others; If others, please specify)
3	Climate-change and socio-economic scenarios applied
4	Type of adaptation strategies assessed (A—EbA; B—Hard; C—Soft; D—Hybrid)
5	Specific adaptation strategies assessed
D.	Performance
1	Main results of the assessment
2	Main recommendations provided by the study

3. Results

The following sub-sections summarize the main results of the systematic literature review, presenting basic information in the articles, identifying and characterizing the socio-economic methods used to assess climate-change adaptation and the main hazards and impacts addressed in the studies, and ending with the main results of the assessments and the recommendations provided in the reviewed studies. The full set of results is provided as Supplementary Materials (S1).

3.1. Basic Information

The analysis of the 54 selected studies targeted the period 2011–2021. More than 50% of the selected references were published between 2018 and 2021. Since the research focuses on how adaptation interventions are undertaken at the local and regional scale, selected publications were grouped if the case studies were mainly conducted at the regional/provincial scale (50% of analyzed records), urban/peri-urban scale (39%), or district/neighborhood level (11%). A total of 21 countries were represented in the selected references, with EU and non-EU countries accounting for 29 and 27 case studies, respectively (Figure 2).

Figure 2. Geographical location of case studies.

3.2. Socio-Economic Methods Used to Assess Climate-Change Adaptation

(a) Types of assessment methods

The literature review revealed that cost–benefit analysis—CBA was the most frequent option (24 studies), followed by multi-criteria analysis—MCA (seven studies) and a third category grouping other types of methods with lower frequency (23 studies). Table 3 summarizes the number of studies reviewed per method. Details of the authors reviewed in each category are available as Supplementary Materials (S2).

(b) Aim and timing of the assessment methods

More than half of the analyzed records (32 out of 54) had the main aim of evaluating the most effective or preferred adaptation measures/strategies. Comparing interventions to assess their effectiveness or the highest preference is particularly relevant in studies performing CBA and MCA, with about 50% of studies performing the first assessment method having this aim and the percentage going up to 60% for the second category. The remaining studies focused on different objectives: examining the effects of climate change in the study area and the implementation of the adaptation strategies (12 articles); defining different scenarios to compare the value of the damage losses, the investment needs in adaptation, or the benefits of the different interventions proposed (3); determining the timing to initiate adaptation strategies (2); incorporating flexibility and uncertainty when evaluating adaptation strategies (1); developing a planning framework to adapt to climate hazards (2); determining economically efficient protection standards (1); and testing the vulnerability associated with the adaptation measures considered (1).

Most of the studies (80%) assessed the adaptation measures/strategies before being implemented (ex-ante analysis), offering a range of optimal solutions to mitigate negative effects of climate change. The remaining studies performed an interim evaluation (10%), a final or post evaluation (6%), and a mixed of ex-ante and interim evaluation (4%).

Table 3. Assessment methods applied in the reviewed studies.

Type of Method			**Studies**
CBA			24
MCA			7
Other methods	Adaptive regional input–output (ARIO)		1
	Demonstrate ecosystem services enabling innovations in the water sector (DESSIN)		1
	Ecosystem-based ranking (EBR)		1
	Effectiveness assessment with scenario-based approach		2
	Expected annual damages (EAD)		1
	Gains and losses in ecosystem services		1
	Hydrodynamic and optimization model		1
	Input–output model		1
	Real-options Analysis (ROA)		2
	Strengths–weaknesses–opportunities–threats (SWOT)		1
	System dynamics (SD) modeling		2
	Integrated approach	Benefit assessment and hazard modelling	1
		CBA—cost effectiveness	1
		CBA/MCA	1
		Framework combining Sustainable Development Goals (SDG) and Sustainability Impact Score (SIS)	1
		NPV and ROA	1
		Qualitative modelling and Bayesian belief networks (BBN)	1
		Risk assessment and a decision-making approach	1
		Value-at-risk (VAR) and ROA	1
		Vulnerability assessment and evaluation	1

(c) Stakeholder involvement

Stakeholders such as citizens and citizens groups, public authorities, researchers and academics, and representatives from the private sector were involved in different stages of the assessments in 21 of the 54 reviewed studies. These included all eight studies performing MCA or combining it with CBA, six CBA studies, and seven studies applying other types of methods. For example, in refs. [31–33], stakeholders participated in the definition of the climate problem and the identification of adaptation strategies. Other studies included the participation of stakeholders in the development and evaluation of the decision criteria for the selection of adaptation options (e.g., refs. [34–36]) and in the estimation of the economic impact related to the selected adaptation strategies [34,37,38].

3.3. Climate-Change Impact and Adaptation Context

(a) Climate-change hazards and sectoral impacts

Flooding was the climate-change hazard most addressed in the socio-economic assessments. It was analyzed as a single hazard in 24 out of 54 studies, but when considering studies dealing with multiple hazards, flooding was addressed in almost 50% of the studies (Table 4). Studies applying other types of methods approached a wider list of hazards. Accounting for all hazards, i.e., including studies addressing single and multi-hazards, flooding was the most repeated threat (32 studies), followed by sea-level rise (13), storms and rainfall events (11), coastal erosion (7), temperature-related hazards and ocean warming (5), and other types of hazards such as saltwater intrusion and high waves (5). Regarding the geographical location of the top three hazards, flooding was addressed in all countries analyzed, except for France, Greece, Italy, India, and Thailand. Sea-level rise was considered in case studies of Denmark, France, Greece, the USA, China, and Thailand, and storms and rainfall events in Australia, Canada, India, Thailand, the USA, Uruguay, the UK, Spain, Denmark, and France.

Table 4. Number of reviewed studies per climate-change hazard and socio-economic method.

Climate-Change Hazard		CBA	MCA	Other	Total
Single hazards	Sea-level rise (SLR)	2	-	3	5
	Coastal erosion	2	1	-	3
	Flooding	14	2	8	24
	Saltwater intrusion	-	1	-	1
	Urban heat island (UHI)	-	1	-	1
	Storms	-	-	2	2
	Extreme heat events	-	-	1	1
	Ocean warming	-	-	1	1
Total (single hazards)		18	5	15	38
Multi-hazards		6	2	8	16
	Total	24	7	23	54

The top three climate-change sectoral impacts addressed in the studies were damage to residential buildings (19 studies), followed by damage to commercial buildings (16 studies) and damage to civil infrastructure (14 studies). Flooding, sea-level rise, and heavy precipitation were recurrent triggers of these impacts. Other relevant impacts were related to the local economy and tourism activity, appearing in seven studies each. These impacts were mainly associated with the climate hazards of coastal erosion, sea-level rise, and storms.

(b) Period of analysis and climate change and socio-economic scenarios

The reviewed articles considered different periods of analysis. Twenty-four studies developed projections up until a particular year (e.g., 2030, 2050, 2070, 2100), 14 studies included more than one end-year, and the remaining 16 studies did not specify a period of analysis. The three most frequent time horizons represented in the assessments were 2100 (23 studies), followed by 2050 (14) and 2030 (4).

A total of 26 studies relied exclusively on the IPCC's representative concentration pathways (RCP)—from the lowest to the highest greenhouse emission concentrations in 2100 (RCP2.6 (421 ppm), RCP4.5 (538 ppm), RCP6.0 (670 ppm), and RCP 8.5 (936 ppm) [39]). Some studies used the four RCP scenarios (e.g., refs. [40,41]), whereas others focused on three (e.g., refs. [5,6]), two (e.g., refs. [42,43]), or only one RCP (e.g., refs. [7,44]). Only four of these 26 studies did not consider the extreme scenario (RCP8.5) in their modeling [38,44–46]. In addition to the RCP scenarios, 13 studies developed climate projections with the support of data from national and regional institutions (e.g., refs. [37,39,47]) and 12 studies relied on projections elaborated in previous research (e.g., refs. [46,48,49]). Three studies did not apply any type of climate-change scenario [8,31,50].

Furthermore, some studies applied shared socio-economic pathways (SSP) alone or in combination with RCP. SSP considers five pathways of socio-economic global changes up to 2100 (SSP1 ("Sustainability"—low challenges for mitigation and adaptation); SSP2 ("Middle of the Road"—moderate challenges); SSP3 ("Regional Rivalry"—high challenges); SSP4 ("Inequality"—low challenges for mitigation and high for adaptation); SSP5 ("Fossil-fueled Development"—high challenges for mitigation and low for adaptation) [51,52]). Refs. [5,53] combined RCP with all SSP for their prediction models, whereas refs, [54,55] relied only on the five SSP for their estimations. Other authors refs. [56–60] considered IPCC's Special Report on Emissions Scenarios (SRES), which preceded the RCP scenarios. SRES combine demographic change, social and economic development, and broad technological developments in four different families (A1, A2, B1, B2) (A1 (rapid economic growth), which includes three subsets (A1FI—fossil-fuel intensive, A1B—balance across energy sources, and A1T—predominantly non-fossil fuel); A2 (regionally oriented economic development in a very heterogenous world); B1 (global environmental sustainability); and B2 (local environmental sustainability) [59]). SRES considered within this review included A1F1 [60], A1B [56], A2 [57], and A2 together with B2 [58].

(c) Adaptation strategies and measures

Table 5 shows that most of the studies focused on the analysis of hybrid adaptation strategies (40 out of 54 studies), followed by studies only addressing hard-based approaches (9), soft strategies (3), and EbA (2). Seventeen articles assessed hybrid interventions including EbA. From these, 12 studies combined EbA with hard and soft measures, four included EbA and soft options, and one study considered EbA and hard-based adaptation. Dykes and seawalls were the hard measures most frequently analyzed (16 studies), followed by measures to improve drainage systems (e.g., pipe enlargement, pumping stations) (8). Beach nourishment was the most analyzed soft measure (9), followed by land elevation (8) and building-quality upgrades (including wetproofing of buildings) (5). Green roofs (3), permeable pavements, dune restoration, and wetland restoration (2) were the most recurrent EbAs.

Table 5. Number of reviewed studies per adaptation strategy and socio-economic method considered.

Adaptation Strategy		CBA	MCA	Other	Total
Hard		6	-	3	9
Soft		1	1	1	3
EbA		-	1	1	2
Hybrid	Hard and soft	12	2	9	23
	Hard and EbA	1	-	-	1
	Soft and EbA	1	-	3	4
	Hard, soft, EbA	3	3	6	12
	Total	17	5	18	40
Total		24	7	23	54

When grouping the studies according to the socio-economic method considered, CBA mainly addressed hybrid strategies (17 studies), followed by hard (6) and soft (1) forms of adaptation. The analysis of EbA as the only considered strategy appeared in one MCA, as well as in another study implementing a SWOT analysis to define the measures to be part of the urban-planning strategy based on ecosystem-service improvement. Examples of specific measures associated with the previous categories are provided in Table 6.

The correspondence between climate-change hazards and adaptation strategies in Figure 3 shows that the combination of hard and soft measures was the most frequently assessed option in the reviewed studies. Flooding was the only hazard addressed by all types of strategies (hard, soft, EbA, and hybrid). Specific measures for flooding included hard-based interventions such as dykes, seawalls, levees, breakwaters, and drainage systems; soft measures like beach nourishment and road, building, and land-elevation plans; and EbA dealing with open urban drainage systems (OUDS) and the restoration of mangroves, wetlands, and barrier and oyster reefs. Optimal hybrid strategies identified combined barrier (hard) and wetland (EbA) alternatives.

In the face of sea-level rise, some relevant measures included hard (e.g., dykes, breakwaters, seawalls, pumping stations), soft a (e.g., beach nourishment, floodproofing of buildings, land-elevation or -adaptation plans), and EbA approaches (e.g., bioswales, mangrove restoration). Examples of strategies combining hard and soft or hard and EbA could be the case of sea-dyke construction and mangrove-forest rehabilitation, or a breakwater together with sediment replacement. Beach nourishment and floodproofing of buildings in the short term followed by a strategy including dyke, seawalls, groins, and building elevation to address more extreme scenarios in the next decades were proposed in beach areas with high tourism activity.

Table 6. Examples of adaptation measures addressed in the reviewed studies.

Adaptation Strategies	Examples of Specific Adaptation Measures
Hard	- Dykes, groins, and seawalls - Breakwaters - Stormwater-pumping stations - Storm-surge dams - Drainage systems - Pipe enlargement - Removing constructions
Soft	- Plans to restriction permission/forbid coastal constructions - Land-use change - Increased access to health care - Floodplain zoning - Flood-proofing of buildings - Early warning systems - Land-elevation planning - Sand nourishment
EbA	- Wetland restoration - Rehabilitation of coastal dunes - Restoration of barrier/oyster reefs - Rehabilitation of mangrove forests - Green roofs - Urban parks - Detention basins - Earthen dykes - Green areas as drainage systems
Hybrid	- Revegetation on dunes (EbA), wetland restoration (EbA), beach-access management (soft), dykes (hard) - Sea dykes (hard) and mangrove-forest rehabilitation (EbA) - Green roofs (EbA), bioretention cells and detention basins (EbA), permeable pavements (EbA), and infiltration trenches (soft)

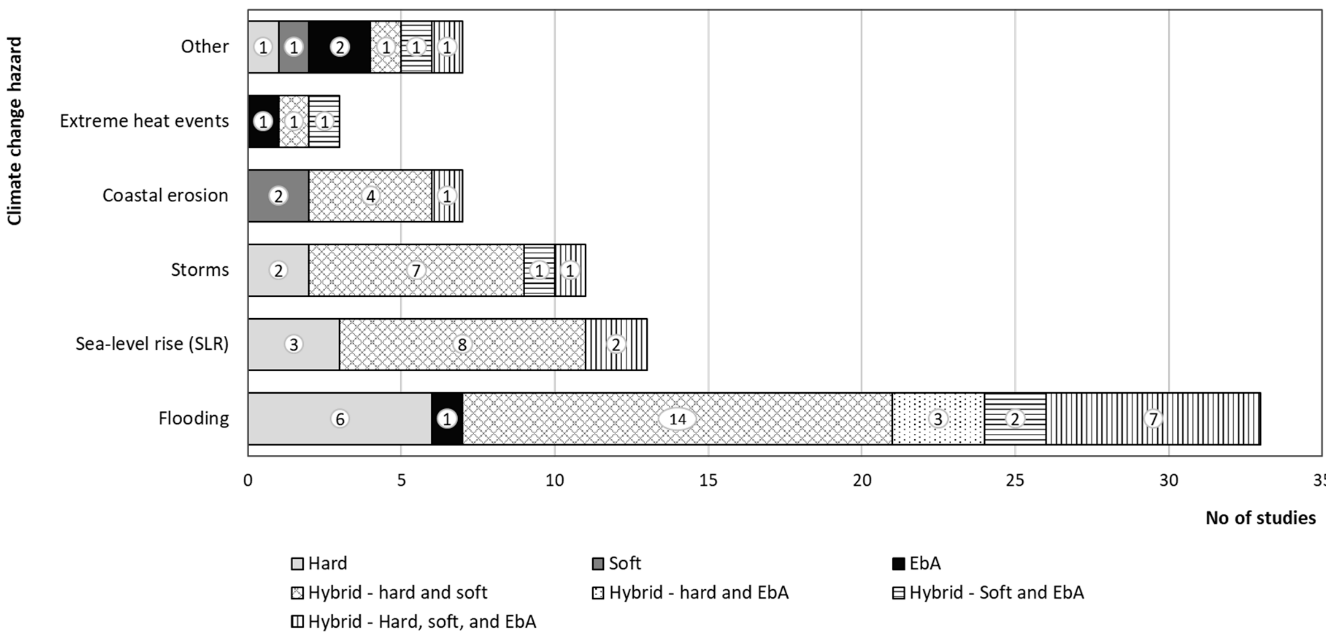

Figure 3. Adaptation strategies addressing climate-change hazards (number of studies).

Regarding storms and heavy rainfall events, some examples of measures included the implementation of green roofs, the installation of water-storage tanks, and the use of permeable pavements and infiltration trenches. The combination of rainwater harvesting and floodproofing buildings was also highlighted as an effective measure to address sea-level rise and storms. Moreover, measures assessed in studies focusing on coastal erosion included artificial beach nourishment and hard structures (e.g., breakwaters, groins), whereas EbAs associated with the increase of green and shaded areas were applied in the case of extreme heat events in urban areas.

3.4. Performance

(a) Main results of the assessments including EbA adaptation measures

This section and Table 7 present the results of the studies that compared the performance of EbAs with other alternatives for adaptation. In the case of studies performing CBA, or CBA in combination with other methods, EbA alternatives were often considered as cost-effective options. This was the case of wetland restoration when addressing the problem of coastal flooding in the Gulf Coast of the United States, showing USD 10.5 billion of net benefits under most conservative estimates [61]. This measure also had the best economic performance to reduce flood risk in Shanghai (China) when comparing initial investment and maintenance costs and the reduction in expected annual damage [5]. Ref. [62] stressed the better technical performance of hard measures such as pipe enlargement to address flooding. Nonetheless, OUDS was found to be a cost-effective alternative if potential co-benefits like landscape improvement and recreational opportunities were also considered.

When comparing green roofs to other adaptation measures, ref. [9] found that the highest B/C ratio corresponded to the implementation of pipes when flood-damage reduction was singly considered (primary benefit), and to rainwater barrels when both primary and co-benefits (air quality, building-temperature reduction, carbon sequestration, rainwater harvesting, and heat-stress reduction) were integrated into the analysis. Ref. [63] estimated the potential benefits of green infrastructure (GI) in terms of flood reduction, water-quality improvement, and additional benefits (added aesthetic value, air-quality improvement, habitat provision, and reduction of UHI and energy consumption). The study identified positive NPV results of implementing green roofs, bioretention cells, and retention and detention basins in the city of Barcelona 10 years after its implementation. More information summarizing the main results of CBA in the articles that applied this method is provided as Supplementary Materials (S3).

Different assessment criteria can be defined to perform MCA and rank the adaptation measures to show stakeholders' preference. Ref. [35] highlighted the need to assess the co-benefits of EbA to capture its full impact in addition to the main adaptation purpose. This study grouped the criteria into flood-reduction reliability, cost reduction, and co-benefits (biodiversity enhancement, aesthetic values) to compare hard and EbA strategies for flood mitigation. Results showed open-detention basins as the most preferred option when the reduction of flood risk was singly considered. When other benefits such as aesthetic value and biodiversity enhancement were integrated into the analysis, other strategies including rainwater barrels and porous pavements, or rainwater barrels together with porous pavements and pipes, were preferable.

Ref. [36] considered nine criteria to assess a set of adaptation measures to address coastal erosion and flooding, namely, (1) "no regrets," which refers to the capacity of the adaptation interventions to generate co-benefits; (2) "robustness" to indicate the effectiveness of the measure regardless of the climate-change scenario considered; (3) flexibility/reversibility; (4) short decision horizon; (5) synergy with mitigation; (6) immediate benefits; (7) possible impacts on other risks; (8) self-sufficiency; and (9) life expectancy. In the case-study area of the Aquitaine region (France), the adaptation measures selected were grouped according to the number of criteria fulfilled. This was to highlight that the authors selected four measures considered essential to be implemented when applying a climate-change adaptation strategy: creation of a surveillance/observation network, construction of removable buildings, creation of climate services, and communication via the media.

Additionally, they identified measures to be implemented within a short decision horizon, which could change and adapt to the ecosystem as environmental conditions do so. Some examples are sand fences, plant cover on dunes and cliffs, dune restoration, beach nourishment, beach drainage, and sealed buildings. During the prioritization procedure, ref. [36] found that hard measures were ranked in lowest position when including stakeholder preference. Participants in the study prioritized the capacity of EbA measures to generate co-benefits related to, inter alia, biodiversity increase, aesthetic values, and recreational opportunities. In the case of soft measures, these were found to be effective regardless of the climate-change scenario considered by these same authors. On the contrary, the main disadvantage related to the soft-based options was the difficulty of quantifying the long-term societal changes that might derive from their implementation.

Ref. [31] assessed the level of sustainability of adaptation solutions to coastal flooding, notably through their potential impact in terms of SDGs. The authors analyzed two types of coastal areas. First were locations with a varying geology (e.g., wetlands, dunes, cliffs, sandy coastline) in the USA, Colombia, Australia, Vietnam, and the Netherlands. Flood-protection measures such as wetland and mangrove restoration, barrier reefs, sedimentation, and sand nourishment were considered for these areas. Second, five sites of the Dutch North Sea coast with one type of geology (sandy coastline) were identified, where the implementation of sand nourishment was assessed based on different pumping techniques. The results indicated that the geographical characteristics of the sites studied might influence the selection of the SDG used in the assessment. When calculating the level of sustainability of the locations with varying coastal geology, the Netherlands, the USA, and Australia obtained the highest scores, whereas Colombia and Vietnam obtained the lowest values within the following SDGs: disaster-risk reduction, sustainable tourism, knowledge and innovation, CO_2-emission reduction, flood awareness, and biodiversity abundance. Regarding the sites with one type of geology in the North Sea region (the Netherlands), the following SDGs were rated as highly relevant: water quantity and quality, economic productivity, CO_2-emission reduction, knowledge and innovation, air quality, flood awareness, and coastal erosion.

Ref. [64] assessed flood-prone coastal areas defended by flood-protection systems and ranked them based on the extent to which these protection systems were nature-based. The flooding-protection measures were assessed in the North Sea coast of Belgium, the Netherlands, and Germany. To evaluate whether the measures were nature-based, two criteria were considered: whether they maintained the ecosystem in a healthy, productive, and resilient condition, and whether they provided the necessary ecosystem services. The results revealed natural dunes to be in the first place of the ranking, followed by engineered dunes (rank 2) and dykes in dunes. Hard structures such as dykes, dams, and storm-surge barriers ranked the lowest (rank 5).

Table 7. Studies comparing EbA with hard and/or soft adaptation measures.

Study	Method	Hazard	Adaptation Measures and Strategies																									
			Hard							Soft								EbA										
			Cliff Drainage	Concrete Dykes	Dams	Engineering Dunes	Floodwalls/Storm-Surge Barriers	Local Levees	Pipes/Pipe Enlargement	Beach-Access Management	Enhanced Building Codes	Home-Elevation Policy	Infiltration Trenches	Permeable Pavements	Rainwater Barrels	Sandbags	Sand Nourishment/Sedimentation	Bioretention Cells	Detention Basins	Dune Restoration	Earthen Dykes	Green Roofs	Mangrove-Forest Rehabilitation	OUDS	Oyster-Reef Restoration	Plant Cover of Cliffs	Retention Basin	Wetland Restoration
Ref. [5]	CBA	Flooding					■				■																	+
Ref. [63] [1]	CBA	Flooding, overflow, runoffs											+	+				+	+			+					+	
Ref. [7]	CBA	Flooding		+																	■		+					
Ref. [62]	CBA	Flooding							■				■											+				
Ref. [61]	CBA/CEA	Flooding		■				■				■				■	■								■			+
Ref. [35]	MCA	Flooding							+					+	■				■									
Ref. [36]	MCA	Flooding, coastal erosion	■				■			■	■					■	■			■						■		■
Ref. [9]	MCA/CBA	Flooding							+					■	+				■			■						
Ref. [64]	Other (EBR)	Flooding		■	■	■	■													+								
Ref. [31]	Other (SDG, SIS)	Flooding														+	■						+		+			+

Legend: Cells marked in grey show the adaptation measures included in the studies, and the sign (+) indicates which ones were considered the best adaptation options. Notes: [1] This study assessed the joint performance of this set of measures in relation to the co-benefits considered.

In relation to studies addressing only EbA, ref. [33] developed an MCA to evaluate the perception of the inhabitants of the municipality of Catania (Italy) of EbAs to be implemented in the context of the definition of the city's adaptation plan to climate change. The analysis focused on urban green areas (e.g., uncultivated green spaces, sports areas, urban-design areas, urban parks) with the purpose of guiding the city's government on the design and implementation of new resilient urban development. The authors designed three alternative scenarios of green strategies to improve air quality and mitigate the urban heat-island effect (UHI): "Hypothesis 1. Inclusive—creation of green areas with inclusive and social functions (equipped with parks, urban gardens, etc.), Hypothesis 2. Resilient—creation of urban green spaces with non-usable landscape function but as a climate-change adaptation measure, and Hypothesis 3. City—conservative recovery, cleaning, and maintenance of the current green." Environmental, social, climate, economic, and landscape objectives were used to define the 20 evaluation criteria in this process. The creation of green areas, avenues, and urban gardens within the "inclusive" strategy (Hypothesis 1) was the most preferred and strategic option for the choices of urban green investments due to its social, landscape, and economic aspects.

Regarding examples of other types of methods, ref. [50] applied a SWOT analysis to support the development of urban-planning strategies. The authors addressed a set of EbA solutions to prevent flooding and mitigate water scarcity and heatwaves in the city of Faro (Portugal). Permeable soils were proposed for runoff mitigation and to improve water supply; planting trees to shade streets, pavements, and buildings for urban-temperature regulation; and green roofs in buildings as a water-management solution for flooding.

(b) Recommendations provided

Regarding final recommendations in the assessed studies, socio-economic-oriented analysis of adaptation strategies centered on cost-efficiency was considered a sub-optimal approach for decision-making [62]. There is a need for developing exploratory forms of governance that favor learning and innovation [65]. This involves new analytical tools and models to help engineers, managers, and policymakers with the decision-making process when comparing adaptation measures and strategies [35,38,43,49,60,66,67].

Long-term planning perspectives [6,31,65], the adoption of flexible and dynamic adaptation strategies [32,43], and the implementation of hybrid strategies to lower future uncertainty risks [5] should be considered when developing public policies or management plans. Moreover, any decision related to adaptation options should involve an in-depth and careful analysis of the local and context-specific environment [6,36,57,67].

The design of the metrics assessing adaptation options could be made more robust by using a multi-method approach to formulate precise assessment objectives [68]. When evaluating adaptation strategies, scenario-based cost–benefit analyses (or delayed-investment CBAs) should be integrated with adaptation pathways into their frameworks [14,15], together with an evaluation of the environmental impact of the planned interventions before implementation [40].

Further research effort is needed in developing strategic analysis [6], targeting other potential drivers of individual vulnerability (e.g., education and pre-existing medical conditions) and of institutional adaptive capacity (e.g., effectiveness of early warning systems and inter-agency cooperation) [41]. Moreover, the policy-making process will potentially benefit from the different research objectives, inter alia: the analysis of the feasibility and acceptability of the different adaptation options by the local population [69], the assessment of socio-economic inequalities derived from the different adaptation options through different methods other than CBA [62], and a better understanding of the impact of hazards on coastal ecosystems (e.g., groundwater, beaches and dunes, lagoons and wetlands) as well as at the socio-economic level (e.g., insurance sector, local economy, immigration and emigration patterns) [41,69].

4. Discussion and Conclusions

This study reported the results of a systematic literature review of studies published between 2010 and 2021 that performed a socio-economic assessment of climate-change adaptation in local and regional coastal areas. The main objectives of the review were to identify and characterize the methods applied in the assessments; to describe the climate change hazards, impacts, and adaptation solutions addressed in the reviewed studies; and to gather the main results obtained from the assessments, with a particular interest in the performance of EbA in comparison with hard- and soft-based approaches.

A total of 54 studies was selected following the PRISMA 2020 methodology. A further analysis of these studies indicated a growing importance of the research topic in recent years, with most of the studies being published after 2018. All continents were documented in the case studies except for Africa and South America. Most of the studies had the main aim of evaluating the most effective or preferred adaptation measure/strategy by means of a CBA. This method has been widely used in the field of environmental economics. Some examples include the analysis of welfare implications and environmental impacts from investment projects in different sectors, such as the transport and energy sectors [70,71], the quantification of economic benefits of different waste-treatment options [72], the impact assessment of tourism and recreational activities [73], and the evaluation of the sustainability of renewable-energy systems [74]. When applied to assess climate-change adaptation alternatives, this method facilitates a straightforward examination, allowing their monetary costs and benefits to be compared, for instance, in the form of C/B ratios. Nonetheless, when considering long-term planning and defining the most viable adaptation strategy, the decision-making process could benefit from the use of complementary evaluation methods that are not driven only by cost-efficiency criteria, as suggested in ref. [62].

The review verified that there is a high number of other available tools and methods to evaluate adaptation options. Multi-criteria analysis (MCA) was the second most applied method after CBA in the reviewed studies, followed by other options such as SWOT analysis, impact analysis, and ROA. MCA is used as a tool to identify and select alternatives in different fields of knowledge and sectors. Some examples of its application include the selection of renewable-energy projects [75], in the transport sector and intermodal transport chains to select among the most efficient alternatives [76], within social-sciences disciplines to compare business performance [77], or the acceptance of certain policies [78–80], among others. The participatory-based approach that is possible to follow with an MCA allows for the involvement of different stakeholders in the evaluation of adaptation interventions that, when implemented in a balance and inclusive way, can support the legitimization and acceptance of the decision process by all parties involved. Moreover, another advantage is the possibility to integrate a wide number of potential (monetary and non-monetary) criteria for evaluating various adaptation alternatives. Applying one or another assessment method might influence the understanding of EbA and other adaptation options' performance, and even its nature by the involved parties in the analyses. Whereas CBA greatly relies on economic criteria, complementary performance assessments based on MCA or other participatory-based approaches might bring new insights about the multidimensional characteristic of adaptation measures, and particularly EbA, thus affecting stakeholder's knowledge and stated preferences. Integrated-approach methods are therefore recommendable to follow up on the assessment of adaptation measures.

The analysis also showed that flooding and sea-level rise were the most common climate-change hazards addressed in the studies, which was somewhat expected, as these represent some of the main hazards affecting coastal areas. Most of the assessments focused on multiple hazards, which included the previous two hazards along with others, such as storm surge, coastal erosion, and extreme heat events. Damage in residential and commercial buildings, as well as in civil infrastructure, were the climate-change sectoral impacts most often documented in the studies and were usually associated with flooding, sea-level rise, and storm surges. This highlights the vulnerability of coastal, and mainly urban, areas to climate change, as different natural and societal elements coinhabit in these areas, some of which present a high rigidity towards more permanent solutions like relocation.

To alleviate the sectoral impacts mentioned above, the authors reviewed in this study identified and evaluated the performance of a wide number of adaptation options. Built on that analysis, Table 8 provides some insights about the main advantages and disadvantages of implementing hard, soft, or EbA strategies, which decision-makers could consider when developing their adaptation strategies.

Table 8. Potential advantages and disadvantages of implementing hard, soft, and EbA measures.

Adaptation-Strategy	Advantages	Disadvantages
Hard	- Long life expectancy of the project, with low maintenance costs due to the application of long-lasting materials. - Needed for the large-scale management of certain hazards (e.g., the role of urban sewage systems on flood control). - Several adaptation options are cost-efficient from a financial perspective. - Availability of data for the estimation of financial costs and benefits.	- Requirement of high investments. - Low flexibility towards structural changes. - Generally oriented towards climate-risk reduction, potentially overlooking detrimental effects on the environment, including ecosystems and natural processes. - Often requires the input of materials such as cements that have a high carbon footprint and are not renewable. - Maintenance of some structural interventions might require multilevel governance.
Soft	- They are more flexible in the context of the adaptation-planning process. - Some soft measures can be independent of the local context (e.g., risk awareness, management, and protection plans). - Embed social-adaptation actions related to educational, informational, and behavioral contexts.	- Long-term societal changes that might derive from the implementation of these measures can be hard to quantify. - Life expectancy of soft measures related to plans might need to be updated whenever climate, technology, or environmental conditions do so.
EbA	- They are context specific so they can be flexible towards changes in climate and environmental conditions. - Application of renewable and low-impact materials. - Promotes a wide range of social and environmental co-benefits in addition to the main adaptation purpose (e.g., capacity to enhance different ecosystem services, biodiversity improvement, aesthetic values, carbon capture, job creation). - Wide variety of solutions targeting different hazards. - Potential synergy with the purpose of climate-change mitigation.	- Some co-benefits might be complex to quantify. - Depending on the measure implemented, it may not represent an effective standalone solution to deal with large-scale hazards. - Potential detrimental side effects, such as green gentrification. - Potential fragility of measures in the face of extreme events. - Requires a more complex knowledge integrating natural and societal processes. - Institutional support is required to ensure long-term monitoring and co-benefits.

In addition to the strategies in Table 8, this review revealed that the consideration of hybrid adaptation strategies, based on different combinations of hard, soft, and EbA measures, not only widens the portfolio of potential adaptation solutions but also could represent a viable option, as shown in several case studies. Whenever EbA interventions were assessed together with soft and/or hard options, the literature review showed positive results for the former alternatives. Evidence suggests that EbA could be most effective when used in combination with other measures and as part of an overall strategy of adaptation to climate change. Taking the example of flooding, dyke construction and heightening of seawalls were some frequent examples of hard measures, which were also often combined with sand nourishment (soft) and wetland restoration (EbA) for flood prevention. Green roofs combined with detention basins [63] or porous pavements with pipes and rainwater barrels [35] could improve the management of urban flooding and overflow hazards.

One of documented strengths of EbA is the potential to generate various co-benefits besides the main purpose of adaptation. These include, inter alia, the potential improvement in ecosystem-service provision (e.g., food provision, carbon storage, water, and air quality), biodiversity conservation, and livelihood diversification. Indeed, if additional co-benefits are considered, EbA can provide cost-effective measures and reveal greater preference by stakeholders against traditional engineering approaches. Nonetheless, considering the low number of reviewed studies focusing only on EbA, these findings will benefit from further research. There is room for improvement in providing evidence on the assessment of the pros and cons provided by EbA in comparison with more traditional strategies, including effectiveness and other potential benefits. A deeper understanding of EbA performance, alone and in combination with other adaptation solutions, combining economic, social, and environmental dimensions with stakeholder preference, would help decision-makers and planners to make better-informed decisions. Further research is also needed to assess the impact of climate change itself on proposed EbAs under high-risk scenarios, modeling their performance in the long term under changing environmental conditions. Moreover, it is important to understand whether some EbA interventions may or may not also lead to environmental and societal detrimental impacts. Similarly, knowledge is still limited when assessing the co-benefits EbA can bring into the local context in terms of livability, social interaction, or job opportunities, among others.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jmse11020319/s1, Table S1: Main results of the full-text assessment; Table S2: Assessment methods and authors applied in the reviewed studies; Table S3: Main results of the CBA studies. References [81–92] are cited in the supplementary materials.

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