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Article

Systematic Review of Socio-Economic Assessments of Climate Change Adaptation in Coastal Areas

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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 a better knowledge of EbA 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 most of the studies assessed adaptation solutions through cost-benefit analysis, 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 suggests the potential co-benefits of EbA in the form of ecosystem services, livelihood diversification or biodiversity conservation, but also stresses the need for further research on this topic, as well as on evaluating how EbA perform in the long-term under climate changing conditions scenarios.

Keywords: Climate change adaptation; Coastal cities; Ecosystem-based adaptation (EbA); Socio-economic assessment; Systematic literature review

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 world's population, with forecasts indicating this percentage will continue to increase in the upcoming decades (Neumann et al., 2015). Sea-level rise, coastal flooding, erosion, storm surges or landslide, are some of the most relevant hazards affecting coastal areas (Oppenheimer et al., 2019; Doust et al., 2021). 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. 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." (IPCC, 2022). Indeed, the goal of adaptation is to enhance adaptive capacity, strengthen resilience, and reduce vulnerability (UNFCCC, 2015).

Climate change adaptation covers several actions, ranging from social and institutional to physical and structural ones (IPCC, 2014). Social adaptation refers to educational, informational, and behavioural actions such as awareness-raising, early warning and response systems, household evacuation, retreat, and migration. Institutional adaptation encompasses economic options (e.g., insurance, subsidies, taxes), laws and regulations (e.g., water regulation agreements, land assessments and zoning), and policies and programmes (e.g., adaptation plans, mainstreaming). Physical and structural adaptation includes engineered-based interventions focused on, *inter alia*, coastal protection, storm drainage and wastewater management; technological innovation (e.g., early warning monitoring systems); services (e.g., emergency and health services, social safety nets); and ecosystem-based approaches to climate change adaptation, in short ecosystem-based adaptation (EbA).

EbA refers to an integrative approach combining biodiversity and ecosystem services within climate change adaptation planning to encourage urban capacities to adapt (adapted from the Convention on Biological Diversity, 2009). According to IPCC (2022), "adaptation in natural systems includes autonomous adjustments through ecological and evolutionary processes. […] It also involves the use of nature through ecosystem-based adaptation" (). This approach focuses 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 (Convention on Biological Diversity, 2009; Munang et al., 2013). EbA was initially applied in the agriculture and forestry sectors (Vignola et al., 2009; Doswald et al., 2014), but its interest as a cost-effective and comprehensive multi-functional approach is rising in the context of urban areas (Brink et al., 2016). The sixth Assessment Report of the IPCC (IPCC, 2022) advocates for the use of EbA as part of coastal defence strategies against flooding, storm surge or sea-level rise.

EbA has been categorised under the umbrella term of Nature-based solutions (NbS) (Naumann et al., 2011; Nesshöver et al., 2017; Pauleit et al., 2017). The concept of NbS was introduced by the World Bank and the International Union for Conservation of Nature (IUCN) towards the end of the 2000s to emphasise the importance of biodiversity conservation for climate change mitigation and adaptation (Cohen-Shacham et al., 2019). NbS refer to actions which protect, sustainably manage, or restore natural or modified ecosystems, whilst simultaneously addressing societal challenges such as climate change, disaster risk reduction, and human health (Cohen-Shacham et al., 2016). NbS have been defined by the European Commission as "actions which are inspired by, supported by, or copied by nature" (European Commission, 2013; European Commission, 2015) .

EbA focuses primarily on climate change adaptation, hence it is more limited in scope than NbS. EbA spans many systems, processes, and values within the nature-society domain. Brink et al. (2016) makes use of the ecosystem service cascade model presented in Haines-Young & Potschin (2010) to identify the main EbA components, namely: i) ecological structures (e.g., watersheds, forests, gardens and green roofs); ii) ecological functions and processes (e.g., how wetlands provide flood protection); iii) adaption benefits (e.g., flood protection and reduced climate-related mortality and morbidity); iv) valuation (e.g., avoided costs or improved quality of life); and v) ecosystem management practices (e.g., community–based monitoring of a forest or a new green space law).

Several authors make the distinction between different types of adaptation options, suggesting various ways of grouping them (Du et al., 2020; Lane et al., 2017; Oanh et al., 2020). The analysis presented in this paper aligns with the following categories: i) *hard adaptation* – mainly based on the implementation of grey infrastructure (i.e., engineering-based approach), often in the form of artificial stabilisation structures (Alves et al., 2018, 2019; Bloetscher et al., 2016; Oanh et al., 2020), and with the purpose of addressing climate impacts such as flooding or coastal erosion (e.g., levees, technical shading, irrigation systems) (Zölch et al., 2018); ii) *soft adaptation* – includes initiatives aimed at encouraging adaptative behaviour (Zölch et al., 2018), awareness-raising and institutional capacity building (Jones et al., 2012), or strategies to strengthen building codes in the form of wetproofing, dryproofing, and building elevation (Aerts et al., 2014; Scussolini et al., 2017; de Ruig et al., 2019); iii) *EbA* - includes adaptation interventions implemented at the ecosystem level, and focused on the ecological structure, functions, and services provided (Wamsler et al., 2016). Despite some authors considering EbA as part of soft adaptation (Kithiia & Lyth, 2011; Schoonees et al., 2019; Du et al., 2020), others considered it an independent category, due to its potentially central role in strategic adaptation planning (Zölch et al., 2018), or its ability to increase the capacity of territories to reduce climate risks by enhancing the provision of ecosystem functions and services (Wamsler et al., 2016); and iv) *Hybrid adaptation* - based on any combination of the previous adaptation options.

Socio-economic assessment tools are very relevant to evaluate the desirability and economic efficacy of different adaptation options, helping decision makers in the selection of different alternatives (Amadio et al., 2022). The main aim of this paper is to develop a systematic literature review of studies performing socio-economic assessments of climate change adaptation in local and regional coastal areas. The research is designed to address three main questions: i) *What are the most frequently used socio-economic assessment methods used to analyse adaptation strategies?*; ii) *In which adaptation context have these assessment methods been utilised?*; and iii) *How do the adaptation strategies studied perform?* The selected studies were characterised in terms of their basic information (e.g., year of publication, type of publication), socio-economic assessment methods applied (e.g., name and aim of the method, stakeholders' involvement), adaptation context (e.g., type of adaptation measures addressed, climate change impact considered in the studies), and performance of the assessments (e.g., main quantitative and qualitative results of the assessments, policy recommendations provided). Despite focusing on various types of adaptation strategies, this review gives particular importance to

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EbA, with the purpose of contributing to better knowledge of the benefits of introducing EbA solutions to climate change.

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 (Page et al., 2021). PRISMA ensures consistency of the research process and quality of the results, minimising bias by following a standardised protocol and identifying gaps and future research paths (Bueno et al., 2021; Sierra-Correa & Cantera Kintz, 2015).

In this review, consistency, and standardisation of the PRISMA methodology is 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 (Table 1) was designed to capture studies that performed socio-economic assessments of adaptation measures or strategies to climate change in coastal, and mainly urban, areas. For the identification of studies, the search was limited to English-written scientific articles published between 2010 and 2021 that contained the search string words within their title and abstract. This search resulted in 6,501 registers identified in the five databases. From this number, 4,501 records were duplicated and removed before the screening, and 24 additional records were removed for other reasons (non-English written studies, or full references not published), making a total of 1,976 eligible records for screening.

Table 1. Search string used for the literature review.

Field of analysis		Type of analysis		Environmental issue		Environmental action		Geographical context
socio-economic	**AND**	**assessment**	**AND**	climate change	AND	adaptation	AND	coastal
socioeconomic		analysis						urban
economic		evaluation						city

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 2.

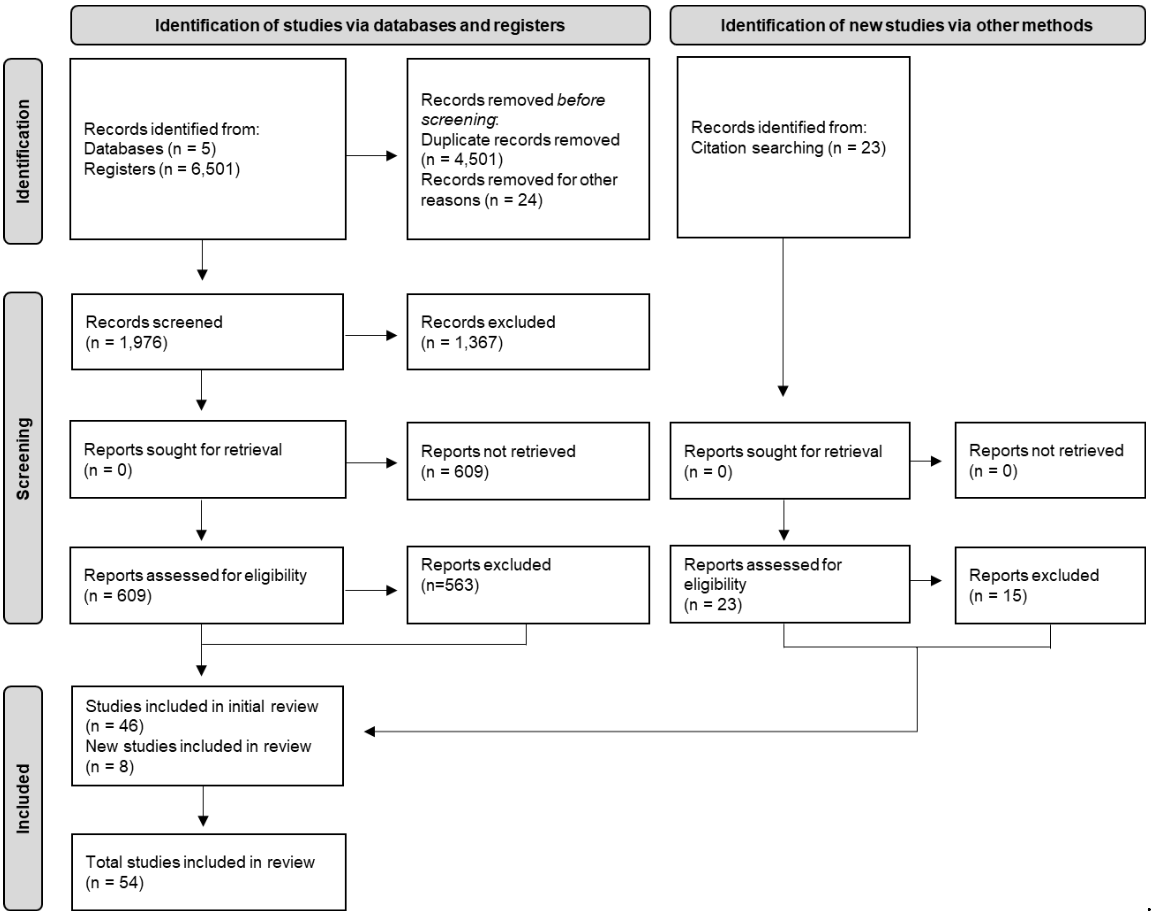
Table 2. Eligibility and exclusion criteria applied in the literature review.

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

The screening process involved two steps. First, the screening of the title and the abstract, which led to the exclusion of 1,367 out of 1,976 records due to their non-compliance with the eligibility criteria. Second, another 461 studies were excluded in the full-text screening by not fulfilling the eligibility criteria, or by 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.

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 Page et al. (2021).

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 to characterise the studies and to answer to the stated research questions (**Table 3**).

Table 3. Variables analysed 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 – Multi-criteria analysis; B – Cost-benefit analysis; C – Cost-effectiveness analysis; D – Others; If others, please specify)
2	Timing of the assessment (A – ex ante; B – interim; C – final or ex post evaluation)

No.	Coding Fields
3	Aim of the assessment method
4	Stakeholders involved (A – Citizens and citizens groups; B – Public authorities; C – Researchers/Academia; D – Private Sector)
5	Type of stakeholders' involvement
6	Main metrics applied in the study
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 summarise the main results of the systematic literature review, presenting basic information of the articles, providing information on the socio-economic methods used to assess climate change adaptation, the main hazards and impacts addressed in the studies, and ending with the main results of assessments and the recommendations provided in the reviewed studies. The full set of results are provided in the Supplementary Information.

3.1. Basic information

The analysis of the 54 selected studies targeted the period between 2011 and 2021. More than 50% of the selected references were published in 2018 to 2021. Since the research focuses on how adaptation interventions are undertaken at local and regional scale, selected publications were grouped if the case studies were mainly conducted at regional/provincial scale (50% of analysed records), urban/peri-urban scale (39%), or district/neighbourhood level (11%). Regarding the geographical location of the case studies, 29 belong to EU countries, and 27 are non-EU countries (**Figure 2**).

Figure 2. Geographical location of case studies.

3.1. 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 4** summarizes the methods and authors considered in this category.

Table 4. Assessment methods applied in the reviewed studies.

Type of method		Studies
CBA		**Abadie et al. (2020); André et al. (2016); Coelho et al. (2020); Du et al. (2020); Fletcher et al. (2016); Haer et al. (2017, 2018); He et al. (2020); Kind (2014); Locatelli et al. (2020) de Ruig et al. (2019, 2020); Löwe et al. (2017); McNamara et al. (2011); Oanh et al. (2020); Radhakrishnan et al. (2018); Ritphring et al. (2021); Scussolini et al. (2017); Tsvetanov & Shah (2013); van der Pol et al. (2021)Vousdoukas et al. (2020); Wagenaar et al. (2019); Zhou et al. (2012, 2013).**
MCA		Alves et al. (2018, 2020); Andreadis et al. (2021); Baills et al. (2020); Camare & Lane (2015); Nguyen & Bleys (2021); Sturiale & Scuderi (2019).
Other methods	Adaptive Regional Input-Output (ARIO)	Hallegatte (2016)
	Demonstrate Ecosystem Services Enabling Innovations in the Water Sector (DESSIN)	Ćulibrk et al. (2021)
	Ecosystem-Based Ranking (EBR)	van der Nat et al. (2016)
	Effectiveness assessment with scenario-based approach	Rohat et al. (2021)

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Type of method		Studies
Expected Annual Damages (EAD)		Löwe et al. (2018)
Gains and losses in ecosystem services		Kuhfuss et al. (2016)
Hydrodynamic and optimization model		Alves et al. (2016)
Input-Output model		Hallegatte et al. (2011)
Real Options Analysis (ROA)		Dawson et al. (2018) Kontogianni et al. (2014)
Strengths-Weaknesses-Opportunities-Threats (SWOT)		Berte & Panagopoulos (2014)
System Dynamics (SD) modelling		Lane et al. (2017); Woodruff et al. (2018)
Integrated approach	Benefit assessment and hazard modelling	Hérivaux et al. (2018)
	CBA – cost effectiveness	Reguero et al. (2018)
	CBA/MCA	Alves et al. (2019)
	Framework combining Sustainability Development Goals (SDG) and Sustainability Impact Score (SIS).	Schipper et al. (2021)
	NPV and ROA	Manocha & Babovic (2018)
	Qualitative modelling and Bayesian Belief Networks (BBN)	Metcalf et al. (2014)
	Risk assessment and a decision-making approach	Freire et al. (2016)
	Value-at-Risk (VAR) and ROA	Abadie et al. (2017)
	Vulnerability assessment and evaluation	Bloetscher et al. (2016)

a) Aim and timing of the assessment methods

More than half of the analysed 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, where about 50% of studies performing the first assessment method have this aim, and the percentage goes 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);

or testing the vulnerability associated to 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%).

a) Stakeholders' 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 Schipper et al. (2021), Metcalf et al. (2014) and Sturiale and Scuderi (2019), 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., Tonmoy et al., 2015; Alves et al., 2020;Baills et al., 2020), or in the estimation of the economic impact related to the selected adaptation strategies (McNamara et al., 2011; Tonmoy et al. 2015; Kuhfuss et al., 2016).

3.1. Climate change impact and adaptation context

a) Climate change hazards and sectoral impacts

Flooding was the climate change hazard mostly addressed in the socio-economic assessments. It was analysed 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 5**). Studies applying 'other' types of methods approached a wider list of hazards. Accounting 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).

Table 5. 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	-	-	1	**1**

Climate change hazard		CBA	MCA	Other	Total
	events				
	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 precipitations 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.

a) 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 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) (IPCC, 2013). Some studies used the four RCP scenarios (e.g., Ritphring et al., 2021), while others focused on three (e.g., Du et al., 2020; Lane et al., 2017), two (e.g., Haer et al., 2017; Radhakrishnan et al., 2018),(e.g., Woodruff et al., 2018; Oanh et al., 2020). Only four of these studies did not consider higher emission scenario (RCP8.5) on their modelling. In addition to RCP scenarios, 13 studies developed climate projections with the support of data from national and regional institutions (e.g., McNamara et al., 2011; Mostofi Camare & Lane, 2015; Ritphring et al., 2021), four studies relied on projections elaborated in previous research (e.g., Freire et al., 2016; Löwe et al., 2018; Coelho et al., 2020). Three studies did not apply any type of climate change scenario.

Furthermore, some studies applied Shared Socio-economic Pathways (SSP) alone or in combination with RCP. SSP considers five pathways of socioeconomic 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); and SSP5 ("Fossil-fuelled Development" – high challenges for mitigation and low for adaptation) (O'Neill et al., 2014, 2017). Du et al. (2020) and He et al. (2020) combined RCP with SSP1 to SSP5 for their prediction models, whereas Vousdoukas et al. (2020) and Wagenaar et al. (2019) relied only on the five SSP for their estimations. Other authors (Fletcher et al., 2016; Hallegatte, 2016; Kontogianni et al., 2014; Nakićenović, 2020; Nguyen & Bleys, 2021) considered IPCC's Special Report on Emissions Scenarios (SRES), which preceded 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) (Nakićenović et al., 2020). SRES considered within this review included A1F1 (Nguyen & Bleys, 2021), A1B (Fletcher et al., 2016), A2 (Hallegatte, 2016), and A2 together with B2 (Kontogianni et al., 2014).

a) Adaptation strategies and measures

Table 6. 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 analysed (16 studies), followed by measures to improve drainage system (e.g., pipe enlargement, pumping station) (8). Beach nourishment was the mostly analysed soft measure (9), followed by land elevation (8), and building quality upgrade (including wetproofing of buildings) (5). Green roofs (3), permeable pavements, dunes restoration and wetland restoration (2) were the most recurrent EbA.

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, and in another study implementing a SWOT analysis to define the measures to be part of the urban planning strategy based on ecosystem services improvement. Examples of specific measures associated with the previous categories are provided in **Table 7**.

Table 6. 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

Table 7. Examples of adaptation measures addressed in the reviewed studies.

Adaptation strategies	Examples of specific adaptation measures
Hard	- Dykes, groynes, and seawalls. - Breakwaters. - Stormwater pumping stations.

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Adaptation strategies	Examples of specific adaptation measures
	- Storm surge dams. - Drainage systems. - Pipe enlargement. - Remove constructions.
Soft	- Plans to restriction permission/forbid coastal constructions. - Land use change. - Increase access to health care. - Floodplain zoning. - Flood-proofing of buildings. - Early warning systems. - Land elevation. - Sand nourishment.
EbA	- Wetland's restorations. - Rehabilitating 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).

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, or drainage systems; soft measures like beach nourishment, or road, building and land elevation plans; and EbA dealing with the restoration of mangroves, wetlands, or barrier and oyster reefs. In face of sea-level rise, some relevant measures included hard (e.g., dykes, breakwaters, and seawalls) and soft approaches (e.g., beach nourishment, floodproofing of buildings, land elevation or adaptation plans). Regarding storms and heavy rainfall events, some examples of measures included the implementation of green roofs, installation of water storage tanks, and the use of permeable pavements and infiltration trenches. Moreover, measures assessed in studies focusing on coastal erosion included artificial beach nourishment and hard structures (e.g., breakwaters, groynes), whereas EbA associated with the increase of green and shaded areas was applied in the case of extreme heat events in urban areas.

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

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3.1. Performance

a) Main results of the assessments

This section and **Table 8** present the results of the studies that compare the performance of EbA with other alternatives for adaptation. In the case of studies performing CBA, or CBA in combination with other methods, EbA alternatives are shown to be cost-effective adaptation options. Wetland restoration were highly cost-effective measures when addressing the problem of coastal flooding in the Gulf Coast of the United States, showing 10.5 billion USD of net benefits under most conservative estimates (Reguero et al., 2018). This was also the measure with the best economic performance to reduce flood risk in Shanghai, when comparing initial investment and maintenance costs and the reduction in expected annual damage (Du, Scussolini, Ward, Zhang, Wen, Wang, Koks, Diaz-Loaiza, Gao, & Ke, 2020). Open Urban Drainage System (OUDS) was found to be a cost-effective alternative to pipe enlargement or water infiltration trenches, if besides flood damage reduction, other benefits such as landscape improvement were considered (Zhou et al., 2013).

When comparing green roofs to other adaptation measures, (Alves et al., 2019) 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 in the analysis. Locatelli et al. (2020)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 ten years after its implementation. More information summarising CBA main results in the articles that applied this method is provided in the Supplementary Information.

Different assessment criteria can be defined to perform MCA and rank the adaptation measures to show stakeholders' preference. Alves et al. (2020) 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 show open detention basin as the most preferred option when the reduction of flood risk is singly considered. If other benefits such as aesthetic value and biodiversity enhancement are integrated in the analysis, other strategies including rainwater barrels and porous pavements, or rainwater barrels together with porous pavements and pipes, were preferable. Baills et al. (2020) 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 Aquitaine region (France), adaptation measures selected were grouped according to the number of criteria fulfilled. It is to highlight authors select 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 identify measures to be implemented within a short decision horizon, which might change and adapt to the ecosystem. These adaptations as environmental conditions do so. Some examples are sand fences, plant cover on dunes and cliffs, dune restoration, beach nourishment, beach drainage or sealed buildings.

Schipper et al. (2021) assessed the level of sustainability of adaptation solutions to coastal flooding, notably through their potential impact in terms of SDGs. Authors analysed two types of coastal areas. First, 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 according to different pumping techniques. Results indicate 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, USA, and Australia obtained the highest scores, while 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.

Van der Nat et al. (2016) 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, Netherlands, and Germany. To evaluate if the measures were na-

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ture-based, two criteria were considered: if they maintained the ecosystem in a healthy, productive, and resilient condition, and if they provided the necessary ecosystem services. Results reveal natural dunes to be in the first position of the ranking, followed by engineered dunes (rank 2) and dykes in dunes. Hard structures such as dykes, dams or storm surge barriers rank the lowest position (rank 5).

Table 8. Studies comparing EbA with hard and/or soft adaptation measures.

Study	Method	Hazard	Adaptation measures and strategies																									
						Hard								Soft										EbA				
			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Du et al. (2020)	**CBA**	Flooding																										+
Locatelli et al. (2020) 1	CBA	Flooding, overflow, runoffs											+	+				+	+			+					+	
Oanh et al. (2020)	CBA	Flooding		+																			+					
Zhou et al. (2013)	CBA	Flooding																						+				
Reguero et al. (2018)	CBA/CEA	Flooding																										+
Alves et al. (2020)	MCA	Flooding							+					+														
Baills et al. (2020)	MCA	Flooding, coastal																										

Study	Method	Hazard	Adaptation measures and strategies																								
			Hard						Soft										EbA							
			u	·	e	ei	sto	lev	en	m	ild	va	.	pa	ter	,	t /	nti	on	res	-	n	est	U	ef	ve	o
		erosion	grey				grey			grey	grey					grey	grey			grey						grey	grey
Alves et al. (2019)	MCA/CBA	Flooding							grey +					grey	grey +				grey			light grey					
van der Nat et al. (2016)	Other (EBR)	Flooding		grey	grey	grey	grey													grey							
Schipper et al. (2021)	Other (SDG, SIS)	Flooding														grey +	grey						grey +		grey +		grey +

Legend: Cells marked in grey show the adaptation measures included in the studies, and the sign (+) indicates which ones were considered as the best adaptation options.

Notes: [1] This study assessed the join performance of this set of measures in relation to the co-benefits considered.

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Two reviewed studies assessed the EbA better perceived by citizens (Sturiale & Scuderi, 2019)or more robust (strong and generating greater opportunities) (Berte & Panagopoulos, 2014) when designing urban adaptation plans to climate change. Sturiale and Scuderi (2019) developed an MCA to evaluate the perception of the inhabitants of the municipality of Catania (Italy) concerning EbA in the context of defining the city's adaptation plan to climate change. The analysis focused on urban green areas (e.g., uncultivated green spaces, sport areas, urban design areas, urban parks) with the purpose of guiding the city's government on the design and implementation of new urban resilient 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." (p.17). Environmental, social, climate, economic and landscape objectives were used to define the twenty evaluation criteria in this process. The creation of green areas and 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, Berte and Panagopoulos (2014) 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 run-off 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.

a) Recommendations provided

Regarding final recommendations in the assessed studies, socio-economic oriented analysis of adaptation strategies centred on cost-efficiency was considered a sub-optimal approach for decision-making (Zhou et al., 2013). There is a need for developing exploratory forms of governance that favour learning and innovation (André et al., 2016). This involves new analytical tools and models to help engineers, managers and policymakers on the decision-making process when comparing adaptation measures and strategies (Alves et al., 2020; Andreadis et al., 2021; Coelho et al., 2020; Haer et al., 2018; Kuhfuss et al., 2016; Nguyen & Bleys, 2021; Radhakrishnan et al., 2018)

Long-term planning perspectives (André et al., 2016; Lane et al., 2017; Schipper et al., 2021), the adoption of flexible and dynamic adaptation strategies (Metcalf et al., 2014; Radhakrishnan et al., 2018),the implementation of hybrid strategies to lower future uncertainty risks (Du et al., 2020) 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 (Hallegatte, 2016; Lane et al., 2017; Haer et al., 2018; Baills et al., 2020).

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The design of the metrics assessing adaptation options could be more robust by using a multi-method approach to formulate precise assessment objectives (van der Pol et al., 2021). When evaluating adaptation strategies, scenario-based cost-benefit analyses (or delayed investment CBAs) should be integrated with adaptation pathways into their frameworks (Scussolini et al., 2017; de Ruig et al., 2019), together with an evaluation of the environmental impact of the planned interventions before implementation (Ritphring et al., 2021).

Further research effort is needed in developing strategic analysis (Lane et al., 2017), 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) (Rohat et al., 2021). 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 (Hérivaux et al., 2018); the assessment of socio-economic inequalities derived from the different adaptation options through different methods other than CBA (Zhou et al., 2013); and 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) (Hérivaux et al., 2018; Rohat et al., 2021).

3. 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 characterise the methods applied in the assessments; to describe the climate change hazards, impacts, and adaptation solutions addressed in the reviewed studies; and to draw 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 were 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 facilitates a straightforward examination of adaptation alternatives, allowing to compare their monetary costs and benefits, for instance, in the form 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 only driven by a cost-efficiency criteria as already suggested before in Zhou et al. (2013). 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, or ROA. The participatory-based approach

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that is possible to follow with a MCA allows to involve different stakeholders in the evaluation of adaptation interventions which, 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.

The analysis also showed that flooding and sea-level rise were the most common climate change hazards addressed in the studies, which is 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, or 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 cohabit in these areas, some of which presenting a high rigidity towards more permanent solutions like relocation.

Another aspect that this review revealed was 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 suggest that EbA could be most effective when used in combination with other measures and being part of an overall adaptation strategy 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 for flooding prevention (EbA). Green roofs combined with detention basins (Locatelli et al., 2020) or porous pavements with pipes and rainwater barrels (Alves et al., 2020) 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 services provision (e.g., food provision, carbon storage, water, and air quality), biodiversity conservation, or livelihood diversification. Indeed, if additional co-benefits are considered, EbA can be cost-effective measures and reveal greater preference by stakeholders against traditional engineering approaches. Still, due to the low number of reviewed studies focused only on EbA, there is room for improvement in providing evidence on the assessment of the effectiveness and other potential benefits brought by EbA in comparison with more traditional strategies and, further research is needed to assess the impact of climate change itself on proposed EbA under high-risk scenarios. Moreover, it is important to understand whether some EbA interventions could or not also lead to environmental and societal detrimental impacts. For instance, on assessing the potential relation between the creation of an urban park or green area restoration and the housing price increase in the surrounding area,

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or the greater affluence of tourists, which can be related to social exclusion and other impacts such as waste or noise pollution. Similarly, knowledge is still limited when assessing co-benefits EbA can bring into the local context, in terms of liveability, social interaction, or job opportunities, among others.

This study concludes that EbA could represent a win-win approach due to its potential to support an effective adaptation to climate change and to generate positive investment returns, not only from a monetary perspective but also in terms of multiple co-benefits. Nonetheless, more research is needed on assessing the pros and cons of these measures and their performance in the long-term under changing environmental conditions. A better knowledge about EbA performance alone and in combination with other adaptation solutions would help decision-makers and planners to make better-informed decisions.

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