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By Sara Floriana Zanini
(Department of Management, Ca' Foscali University and Fondazione Eni Enrico Mattei)

Summary

This mixed-method systematic review is motivated by the willingness to identify the efforts of the most recent developments of the literature on the understanding of water challenges in socio-ecological systems, particularly coastal ones. The attention, in the exercise, is directed at the analysis of individual and collective decision-making processes concerning the use of the environmental good. This is because ultimately, if it is true that water resources are affected by external trends and shocks, it is also relevant how distinct paths of local and regional level responses impact on resource status. The inquiry, departs from a conceptual point of view mainly pinpointing scholars' already proposed method- ological solutions for the concern, being them mostly participatory modelling excercises, bayesian net- work analyses, multi-agent games and experiments and finally integrated assessment models. Even if methodological tools with a potential to explicitly represent human decision-making coupled with its connection with the natural environment do exist, these methods are found to be relatively superficially articulated in interdisciplinary water management analyses. Particularly, the study explores to what extent is the human behaviour, in relation to water resources, included into the extant analyses.

Keywords: human behaviour, decision-making process, climate change adaptation, water resources

JEL Classification: D80, D90, Q25, Q54

***Address for correspondence*:**
Sara Floriana Zanini
PhD Candidate, Department of Management
Ca' Foscari University
Cannaregio 30135 Venice (VE), Italy
e-mail: sara.zanini@unive.it

Water challenges in socio-ecological systems: is human decision-making accounted for in the analysis of climate change adaptation options?

Sara Floriana Zanini[a*]

[a]Department of Management, Ca' Foscari University, Venice, Italy

[*]Corresponding author; sara.zanini@unive.it

Abstract

This mixed-method systematic review is motivated by the willingness to identify the efforts of the most recent developments of the literature on the understanding of water challenges in socio-ecological systems, particularly coastal ones. The attention, in the exercise, is directed at the analysis of individual and collective decision-making processes concerning the use of the environmental good. This is because ultimately, if it is true that water resources are affected by external trends and shocks, it is also relevant how distinct paths of local and regional level responses impact on resource status. The inquiry, departs from a conceptual point of view mainly pinpointing scholars' already proposed methodological solutions for the concern, being them mostly participatory modelling excercises, bayesian network analyses, multi-agent games and experiments and finally integrated assessment models. Even if methodological tools with a potential to explicitly represent human decision-making coupled with its connection with the natural environment do exist, these methods are found to be relatively superficially articulated in interdisciplinary water management analyses. Particularly, the study explores to what extent is the human behaviour, in relation to water resources, included into the extant analyses.

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1 Introduction

Coastal areas are complex systems of assembled and interlinked value, characterized by specific geophysical attributes, the presence of on one side, the marine environment and on the other, of limited land with water also supplied by inland bodies. In the centuries, their features acted as *a magnet for a miscellany of human activities* with demands and expectations for them, also in terms of economic exploitation, increasingly intensified (Hossain, Gain, & Rogers, 2020; Ridolfi E., 2010: 71).

These fundamental variables allow to conceptualize them not only as socio-ecological system (SES; Ostrom, 2009), but before as complex adaptive systems. They are constituted relationally, show adaptive capacities, their components' behaviour is a result of dynamic processes, they are determined contextually and novel qualities of them emerge through complex causality (Preiser, Biggs, De Vos, & Folke, 2018: 46). If it is true that this complexity can only be tackled through the overcoming of fragmentation, the path for a comprehensive understanding of coastal SES is to be seen in complementation, not by the rejection of reductionism (Newell & Meek, 2003). Indeed, new system-level properties or dynamics may emerge by agents interaction with one another leading to changes in the institutional, economic and ecological context for subsequent human actions and ecosystem dynamics (Heylighen, Cilliers, & Gershenson, 2006). As an example of the key feature characterizing these variable - the interactions between the parts rather than the properties of its isolated components (Anderson, 1972) - the social diffusion of water overexploitation behaviour through the patterns of social interaction can be taken (Mirzaei & Azarm, 2022).

On this purpose, research is evolving toward an ampler and more integrated understanding of the nature-human complexes so that to embody economic and societal challenges into broader interconnectedness with the natural environment. This is because it is urgent to understand how the natural or human induced threats to the stability of coastal SES root, by focusing on the dynamics characterizing the specific local system - assuming also they might not be the same of another one.

Indeed, the communities, and the surrounding environment they depend on, are exposed to exogenous changes through direct and indirect impacts on the interrelated components of SES (Perry, Ommer, Barange, & Werner, 2010). Changes may occur simultaneously and at different scales and speeds and their outcome can be drastically different for communities of different shapes and different places (Tuler et al., 2008). Even though the majority of the literature focuses exclusively on climate change or global environmental change as the driver of change, also multi-scalar and multi-temporal, social, political and economic changes play a role (Bennett, Blythe, Tyler, & Ban, 2016).

Out of any doubt, climate change is to be considered one mayor important exogenous driver of change in coastal SES; it is recognised as a threating trend for which it is likely to have devastating consequences for both social systems and natural resources, the extent to which depends on the regions under the lens

(Cooley et al., 2022; Glavovic et al., 2022).

Among them, water stress[1] is certainly a crucial one (Caretta, Arfanuzzaman, Morgan, Kumar, et al., 2022).

Impacts on the resource may arise in residential water demand, supply and management; water utilities will be confronted with changes in the availability of supplies, water quality and saltwater intrusion into aquifers in coastal areas, due to higher temperatures, altered streamflows, drier conditions, increased storm runoff and sea level rise as well (Caretta et al., 2022). Many low-lying coastal aquifers risk to be contaminated by increased salinity, and the other reasons above mentioned. Increases in precipitation from tropical cyclones and associated high tide are also expected to exacerbate coastal flooding (Caretta et al., 2022).

But the research setting spotlighted, i.e. water stressed coastal areas, is also urged by other specifically associated dynamics (Bennett et al., 2016). These are represented, as anticipated, by shortly exacerbating demographic, socio-political, economic, cultural, or technological shocks, acting as external drivers theirselves (Kaplan-Hallam, 2016) (or sometimes being paths of response emerging within the affected system). As an example of this, water demand by humans and the economic activities they run is increasing, with the consequence of creating risks as the imbalance between available resources and needs; one case is the tourism sector seasonally concentrated overconsumption in peaking coastal destination. Water stress can indeed be a function of physical conditions, but also caused by population' consumption levels within artificially-defined territorial limits, as well as induced by technological and institutional capabilities that change over time (Ridolfi E., 2010).

As a consequence, attention shall be given to all the risks posed by the exogenously induced water challenges. They refer to ecosystem services, people, livelihoods and key infrastructure, networks and services providing critical goods and services; living standards, through economic impacts across scales, can also be threaten as well as food security and clearly water security itself including water quality deterioration (O'Neill et al., 2022). These risks has already been recognise as research scopes guiding a close literature to that addressed in this work (Martínez-Hernández, 2022).

It is pointed out by Ludwig, Hilborn, and Walters (1993) that managing natural resources, rather than being about dealing with only the environmental goods themselves, it is also about understanding people attitudes in their use. Follows that the impacts on local water resources should be explored by also taking account of the decision-making processes of the actors involved into the dynamics of this complex systems, being them simply affected stakeholders or contributors to the complication.

On these lines, envisioning the decision-making process of individuals is crucial in the comprehension of emergent phenomena since their anticipation strategies, adaptive behaviour, and social interactions

[1] Water stress is defined as *a region's difficulty in meeting human and/or ecological demands for freshwater due to water resource challenges including water availability, water quality, and accessibility to water* Schulte and Morrison (2014)

play a role in it (Huber et al., 2018). The synergy of agents with the natural environment is the fundamental link to be uncovered (Ostrom, 2009) because agents involved in SES have different interests to pursue; one is surely economic but there could be something more subtle. Not only external influences are to be taken into account: when the goal is a positive interaction with natural resources and a changing environment, there is a requirement in exploring internal influences (Addo, Thoms, & Parsons, 2018) through the analysis of behavioural individual and collective models. These can be, for instance, the attitudes or the habits of the stakeholders, mainly guided by own environmental cognitions, of the resource itself and on the impact of the external forces (e.g., climate change) on it. In SES there is indeed acknowledgement that environmental cognition influence individuals' behaviour which in turn modifies the environmental systems and, closing a cycle, the subsequent emergent outcome feedbacks on environmental cognition of agents again (Holling, 2001).

All these challenges upscale the need for water management strategies to be refined and possible interventions tested to let on one side, the implications of agents' behavioural barriers emerge before undesirable impacts of drivers of change would take root and, on the other, to inform adaptation paths.

In the attempt to help communities coping with these changes, a number of strategies can be brought into play: building adaptive capacity, facilitating and increasing adaptive learning, strengthening institutions, integrating knowledge from different stakeholders, recognise differential impacts, exploring the feasibility of adaptation strategies, activating cooperative and adaptive management, among the others (Bennett et al., 2016; Moser, 2010). This is one reason why it is troublesome to define boundaries for a research stream aimed at the analysis of the interaction between exposures and endogenous adaptation to it. Indeed, multiple methods of analysis targeted at surfacing SES responses to change and at finding solution paths to them, can be suited, being them not only quantitative but enriched with qualitative integrations and an interdisciplinary view; a broader lens would allow deepening into the understanding of communities' reactions to proposed challenges (Huber et al., 2018). Surely, mainstream economic models cannot be solely taken into consideration being them centered on aggregated agents and adopting only neoclassical economics assumptions (Huber et al., 2018). The observation of autonomous adaptation processes demonstrates that perfect rationality of the agents should be abandoned favouring a combination with bounded rationality assumptions, mainly theorized in the fields of behavioural economics and related. The extant literature show that however, scholars do not easily integrate behavioural theories to explain agents' decision-making processes and in support of derived architectures of choice (Huber et al., 2018; Groeneveld et al., 2017); this choice, if taken[2], is dependent on a series of elements to be accounted

[2]In the agent-based modelling literature, one of the first to implement a behavioural theory - theory of planned behaviour (Ajzen, 1991) - has been Andreas M. Ernst (Ernst, 1999), formalizing it in an ABM of a fishery socio-ecological system (Jager, 2021).

for, which complicate their inclusion. Behaviours need to be understood for theories to be associated and involved in the analyses; mapping everyday decisions may imply to build on theories of habits, or a choice need to be taken on the inclusion of memory and learning in the decision process. The researcher, in addition, should consider what are the outcomes and patterns of interest, what are the characteristics of the situation in which agents decide, what decision-making processes are important in the given decisional situation, which decision-making elements are relevant to the purpose and context of the model, what theories should be combined if there is the need to - as by exploiting the Consumat approach which addressed habits, imitation, social comparison and optimisation processes as well (Schwarz et al., 2020: 11).

Dealing with these issues requires a new generation of models in which the human dimension is carefully considered together with accurate simulation of the physical and environmental dimensions (Giupponi, Borsuk, de Vries, & Hasselmann, 2013).

1.1 Contribution and research question

According to the above, the attention of this work is directed at the understanding of individual and collective decision-making processes, concerning the use of the water resources. This is because ultimately, if it is true that resource status – in terms of quantity and quality – is affected by external trends and shocks it is also relevant how direct and indirect uses of water by local agents (from individuals such as consumers and tourists to entities as firms and public institutions) determine an impact on it.

Even if tools with a potential to explicitly represent human decision-making coupled with its connection with the natural environment may help in this effort, some of these methods are found not to be widely used in interdisciplinary water management analyses [3], such as ABMs (Gain et al., 2021).

Notably, a review of agents' decision-making in SESs, focused on external drivers' induced water challenges, is lacking. The inquiry, as above suggested, will develop both from a conceptual and a methodological point of view, additionally pinpointing scholars' already proposed solutions for the concern. The wanderings of the review can be translated into two research questions (RQs):

1. What is the research interest guiding the identified literature when it comes to the analysis of external drivers' induced water challenges in coastal SESs?

2. How is the agent's behaviour characterized from the point of view of the decision architecture and the behavioural theories brought into play?

The material below is organized as follow: Section 2 explains the methodological framework, section 3 surfaces the results and, in the end (section 4 and section 5), conclusive remarks can be found.

[3] Gain et al. (2021) consider as potential for both analysing and implementing interdisciplinary water paradigm approaches eight advanced methods of SES analysis: participatory workshop; role-play game; multi-criteria analysis; agent-based models; system dynamics; network analysis; integrated assessment; bayesian approach

2 Method

Once the interest on the topic has been clarified being not only an issue explored through a single research method, what is an automatic consequence is to broader the analysis to the multiple ways scholars have explored the challenges related to water resources into SESs.

Because of this reason and based on Grant and Booth (2009) and Lizarondo et al. (2022), the selected method of analysis is that of a mixed-method systematic review, which allows the strengths of a critical review where different types of research evidence are combined within a single framework, following a comprehensive search process. Both quantitative and semi-qualitative methodologies have been taken into consideration, carrying out the first part of the analysis with a common basis - answering to RQ1 - deepening then only quantitative methodologies on the second part of the analysis - being the answer to RQ2. For this reasons results will not be presented as a unique corpus but they will be partially differentiated by grouping similar studies.

Scopus [4] and Web of Science[5] have been used as literature sources by deriving two different search strings based on the same identified query's keywords, as each database follows specific rules but the search need to be homogeneous across them; two samples of journal articles were obtained through the search on *"Article title, Abstract and Keywords"* for Scopus[6] and other two were extracted from the *"Topic"* search (i.e., title, abstract, author keywords, and Keywords Plus) for Web of Science[7]. The samples extracted from each of the database were two because once the search has been done by including the keyword *"Coast*"* as an additional requirement but it was then dropped in the subsequent searches because of the limitations; since only meager literature could be found on coastal areas, these were paid attention but not exclusively deepened.

Screening was done using the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA[8]) protocol (in Figure 1; Page et al., 2021), which is an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses (Moher, Liberati, Tetzlaff, & Altman, 2009).

Standard method was used to record and assess the eligibility of all identified articles and other information. The sample of articles was screened with the support of Ryyan software (Ouzzani, Hammady, Fedorowicz, & Elmagarmid, 2016). It was narrowed through the elimination of duplicates and by the

[4] Scopus, 2022. Elsevier.

[5] Web of Science, 2022. Clarivate.

[6] String: TITLE-ABS-KEY ((agent-based OR agent AND based OR ab OR abm) OR ((model* OR simulat* OR game* OR role-play OR (participatory AND approach*) OR (multi-criteria AND analys*) OR (system AND dynamics) OR (network AND analys*) OR (integrated AND assessment) OR (bayesian AND approach*)) AND (agent* OR human* OR person OR people OR actor OR individual* OR collectiv* OR communit* OR (local AND population) OR locals OR turis* OR touris* OR farm* OR fisher* OR firm* OR household* OR resident* OR bank* OR insurance*) AND ((decision* AND theor*) OR behav* OR decision-making OR (decision* AND (mak* OR process)))) AND (climat* AND chang*) AND (*water* OR *hydro*))

[7] Composed string: (agent-based OR agent based OR ab OR abm) OR (model* OR simulat* OR game* OR role-play OR participatory approach* OR multi-criteria analys* OR system* dynamic* OR network analys* OR integrated assessment* OR bayesian approach*) (Topic) and agent* OR human* OR person OR people OR actor OR individual* OR collectiv* OR communit* OR local population OR locals OR turis* OR touris* OR farm* OR fisher* OR firm* OR household* OR resident* OR bank* OR insurance* (Topic) and decision* theor* OR behav* OR decision-making OR decision* mak* OR decision* process* (Topic) and climat* chang* (Topic) and *water* OR *hydro* (Topic).

[8] For a more suited recall of this method to research literature review's objectives see Martínez-Hernández (2022)

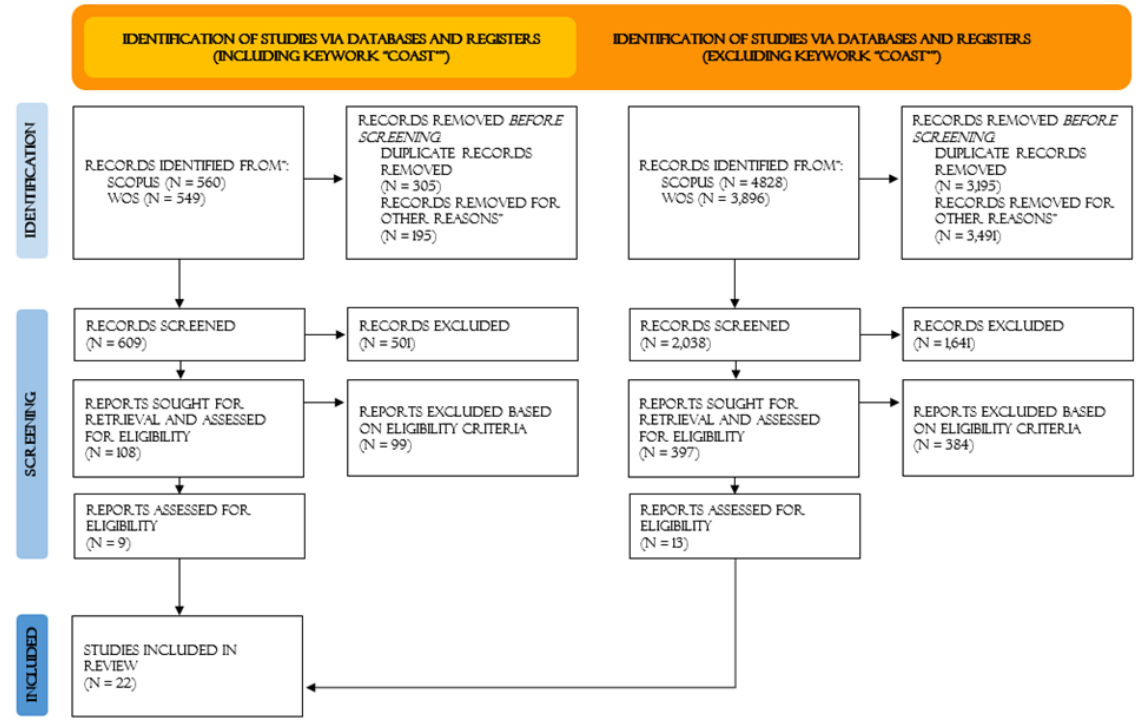

Figure 1: Author's adaptation of PRISMA 2020 flow diagram

definition of inclusion criteria: the impact of external drivers as reason for the study to be focused on adaptation option (RQ1); the account of a socio-psychological dimension - either as a formalized assumption or as an element of investigation - in relation with the natural environment (RQ2); a research question defined by the need of managing changes in water resources status either directly or through the adaptation of dependent services and activities (all RQs).

The investigation proceeded thus on a sample of 22 articles (Table 2) deepening the understanding of them through a structured scrutiny, whose framework is explained in the next subsection.

2.1 Review criteria and papers' categorization

The need of identifying relevant categories for the analysis of the studies has been guided by some compelling literature reviews attentive to the modelling of the agents' decisional process (which to the best of the author's knowledge is greatly focused on agricultural settings, Huber et al., 2018; Kremmydas, Athanasiadis, & Rozakis, 2018; Groeneveld et al., 2017), on water management and flood risks Gain et al., 2021; Simmonds, Gómez, & Ledezma, 2020; Taberna, Filatova, Roy, & Noll, 2020; Zhuo & Han, 2020), or climate change (di Noia, 2022; Martínez-Hernández, 2022; Balbi & Giupponi, 2010)). By gathering review criteria previously adopted in the literature and, if necessary, by adapting them to the specific needs, a framework of analysis - for the literature dedicated to the understanding of water-

related impacts of external drivers as the reason for the study to be focused on adaptation option, within SESs - has been developed. This framework is structured into seven categories (as numbered in Table 1: (1)*"Studies' overview"*, (2)*"Exogenous drivers of change"*, (3)*"Adaptation options"*, (4)*"Agents' characteristics"*, (5)*"Decision architecture"*, (6)*"Theories of human behaviour"*, (7)*"Modelling features"*). Some of them are built suitable for the whole sample of papers while other have only been set aside for ABMs and assimilable approaches (Categories (4), (5), (6) and (7)). Papers' categorization elements are listed in Table 1; specified in that are the details of each categorical variable considered with associated references if relevant [9].

[9]* Similar to Martínez-Hernández (2022) taken from (O'Neill et al., 2022; page 2455) and Pörtner et al. (2022), respectively; ** From di Noia (2022); *** All sub-categories of categories 4) and 5) have been selected from Huber et al. (2018); the categorization has only been partially modified so that to better fit the sample of this analysis; **** Adapted from Schwarz et al. (2020).

Table 1: Categorization elements

Category	Sub-category	Details
1) Overview	**Geography**	**Territory**: Rural or Urban; **Scale of analysis**: Regional or Local; **Country name**; **Type of country**: Developing or Developed; **Geographical setting**: Coast or Inland
	Research interest	**Research question**; **Representative key risk (RKR) addressed***: Risk to low-lying coastal socioecological systems (Risks to ecosystem services, people, livelihoods and key infrastructure in low-lying coastal areas and associated with a wide range of hazards, including sea level change, ocean warming and acidification, weather extremes (storms, cyclones) and sea ice loss, for example); Risks associated with critical physical infrastructure, networks and services (Systemic risks due to extreme events leading to the breakdown of physical infrastructure and networks providing critical goods and services); Risk to living standards (Economic impacts across scales, including impacts on GDP, poverty and livelihoods, as well as the exacerbating effects of impacts on socioeconomic inequality between and within countries); Risk to food security (Food insecurity and the breakdown of food systems due to climate change effects on land or ocean resources); Risk to water security (Risk from water-related hazards (floods and droughts) and water quality deterioration; focus on water scarcity, water-related disasters and risk to Indigenous and traditional cultures and ways of life); **Water resources addressed**; **Role of water resources**: water represents the element of risk or the resource impacted, to be managed.
	Discussion and conclusion	**Management/policy implications**; **Future directions**
2) Exogenous drivers of change (RQ1)	**Social drivers**	
	Environmental drivers	**Type of event***: Slow Onset Hazard or Extreme Events
	Policies	
3) Adaptation options (RQ1)	**Nature of adaptation****	Planned or Autonomous
	Type of adaptation**	Management (e.g., land use policies, relocation or eco-buffer and ecosystem preservation measures) or Defence (i.e., hard and/or soft and engineering-based solutions, both at community level and at individual level)
4) Agents' characteristics (RQ2)	**Agents Heterogeneity**	
	Emotions***	**Scores**: 0 (Not mentioned); 1 (Mentioned but not formalized); 2 (Included as state of agents (e.g. for different activities)); 3 (Integrative modelling of emotions in farmers' decision-making)

Category	Sub-category	Details
	Goals/needs* **	**Scores**: 0 (Not mentioned); 1 (Optimization towards one goal (e.g. income maximization)); 2 (Multiple goals with simple prioritization rules (e.g. income maximization with additional objectives in the constraints or lexicographic preferences)); 3 (Multiple goals with empirically derived weighting between goals (multi-goal programming));
	Values* **	**Scores**: 0 (Not mentioned); 1 (Mentioned but not formalized); 2 (Consideration of values as a state variable); 3 (Consideration of values determining preferences / beliefs);
5) Decision architecture (RQ2)	**Perception, Interpretation, Evaluation*** **	**Scores**: 0 (Not mentioned); 1 (Agents are assumed to simply know variables); 2 (Memory of past decisions: Agents change decisions over time as consequence of their experience (socio-economic or biophysical environment)); 3 (Explicit representation of the mechanism of how agents perceive and interpret the socio-economic or biophysical environment and how agents change decisions over time as consequence of their experience)
	Social learning* **	**Scores**: 0 (Not mentioned); 1 (No memory or knowledge about other behaviour); 2 (Agents have knowledge about other agent behaviour and adjust behaviour); 3 (Learning i.e., agents change their decisions over time as consequence of their observation of other behaviour)
	Uncertainty in decision-making* **	**Scores**: 0 (Not mentioned); 1 (Not considered i.e., no risk management); 2 (Risk management based on simple rules or buffers); 3 (Consideration of risk-aware decisions i.e., stochastic dynamic programming)
	Decision-making rule* **	**Scores**: 0 (Not mentioned); 1 (One rule for all agents i.e., random, optimizing, satisficing); 2 (Decision rule based on agent (or agent-type)); 3 (Complex structures i.e., two step procedures (e.g. consumat approach))
	Time horizon of decisions* **	**Scores**: 0 (Not mentioned);1 (Annual decisions only); 2 (Annual and investment decisions); 3 (Intertemporal decisions i.e., consideration of the optimal point in time of an investment)
	Structural change* **	**Scores**: 0 (Not mentioned); 1 (Not considered / random); 2 (Empirical based exit / entry probabilities); 3 (Model endogenous representation of structural change)
	Social interactions* **	**Scores**: 0 (Not mentioned); 1 (Mentioned but not formalized); 2 (Considering other agent behaviour i.e., imposed network); 3 (Emerging interactions based on social networks)
6) Theories of human behaviour (RQ2)	**Theory**	
	Decision Making Theory** **	Rationality (theories which are very close to expected utility theory, usually with farmers as optimality seekers – as in the case of choices based on price optimization) or bounded rationality (deviating from one or more of the assumptions of rationality - as in the case when quasi-hyperbolic discounting is allowed as a distortion from rationality)
	Theory type	Individual vs collective
	Theory origin	Literature; Literature within; Case study previous; Case study within (as both case-based theory or theories grounded in the literature can be qualitatively explored and specified on the case study examined in the studies, if that was the case the information has been recorded as within)
7) Modelling	**features**	Is the model geographically explicit? Software/model/coding used Standard reporting protocol

3 Results

3.1 The whole sample

3.1.1 Studies' overview

It is by following the described selection process that 22 journal articles have been selected. They are reported in Table 2 with basic information associated to them.

The number of publications has increased over the period 2012-2022. The studies are representative of 15 countries; the analyses are spread around the world with four studies in Italy (the most represented one) and three in Bangladesh; United States follows in terms of number of publications.

As Figure 2 highlights, most of the studies (14) are located in developed countries while 8 of them in developing ones and as also visible, is the rural environment to be a preferred territory for exploring water challenges, than the urban (or peri-urban one); this is true for those analyses whose geographical setting is both the coastal environment and inland areas. The category of studies exploring coastal rural research issues is mainly associated with developing countries while inland rural water challenges are studied in developed ones.

Table 2: Overview of reviewed studies

Reference	Title	Journal	Model type	Country
Blackett et al. (2022)	Marae-opoly: supporting localised Maori climate adaptation decisions with serious games in Aotearoa New Zealand	Sustainability Science	Seriuous Game-Flood model (hydrological model)	New Zeland
Laatabi et al. (2022)	LittoSIM-GEN: A generic platform of coastal flooding management for participatory simulation	Environmental Modelling and Software	Agent-based model-Participatory simulation	France
Mirzaei and Azarm (2022)	Evaluation of farmers' participatory behavior and compensation policy for agricultural water-saving	Frontiers in Water	economic-environmental programming model-agent-based model	Iran
Noor et al. (2022)	A methodological framework for modeling sustainability visions: A case study of groundwater management in Faizpur distributary, Pakistan	Agricultural Water Management	Stepwise participatory modeling framework (Case study)	Pakistan
Okura, Budiasa, and Kato (2022)	Exploring a Balinese irrigation water management system using agent-based modeling and game theory	Agricultural Water Management	Agent based model-game theory	Indonesia
Reinhard, Naranjo, Polman, and Hennen (2022)	Modelling choices and social interactions with a threshold public good: Investment decisions in a polder in Bangladesh	Land Use Policy	Investment behaviour model-Agent-based model	Bangladesh
Rojas et al. (2022)	Participatory and Integrated Modelling under Contentious Water Use in Semiarid Basins	Hydrology	Agent-based model-Participatory modelling	Chile
Egerer, Cotera, Celliers, and Costa (2021)	A leverage points analysis of a qualitative system dynamics model for climate change adaptation in agriculture	Agricultural Systems	Leverage point analysis-System dynamics	Germany
Mills, Ruggiero, Bolte, Serafin, and Lipiec (2021)	Quantifying uncertainty in exposure to coastal hazards associated with both climate change and adaptation strategies: A U.S. pacific northwest alternative coastal futures analysis	Water (Switzerland)	Agent-based model	US

Reference	Title	Journal	Model type	Country
Phan, Bertone, Pham, and Pham (2021)	Perceptions and willingness to pay for water management on a highly developed tourism island under climate change: A Bayesian network approach	Environmental Challenges	Bayesian network	Vietnam
Zagaria, Schulp, Zavalloni, Viaggi, and Verburg (2021)	Modelling transformational adaptation to climate change among crop farming systems in Romagna, Italy	Agricultural Systems	Agent-based model	Italy
Ji, Wu, Xie, Huang, and Sun (2020)	A novel two-stage fuzzy stochastic model for water supply management from a water-energy nexus perspective	Journal of Cleaner Production	Two-stage fuzzy stochastic programming approach	China
Michaelis, Brandimarte, and Mazzoleni (2020)	Capturing flood-risk dynamics with a coupled agent-based and hydraulic modelling framework	Hydrological Science Journal	Agent-based model	Italy
Phan et al. (2020)	Identifying and prioritising adaptation options for a coastal freshwater supply and demand system under climatic and non-climatic changes	Regional Environmental Change	Bayesian network	Vietnam
Abebe, Ghorbani, Nikolic, Vojinovic, and Sanchez (2019)	Flood risk management in Sint Maarten: A coupled agent-based and flood modelling method	Journal of Environmental Management	Agent-based model	Sint Marteen
Merloni, Camanzi, Mulazzani, and Malorgio (2018)	Adaptive capacity to climate change in the wine industry: A Bayesian Network approach	Wine Economics and Policy	Bayesian network	Italy
Dubbelboer, Nikolic, Jenkins, and Hall (2017)	An agent-based model of flood risk and insurance	Journal of Artificial Societies and Social Simulations	Agent-based model	UK
Yu, Sangwan, Sung, Chen, and Merwade (2017)	Incorporating institutions and collective action into a socio-hydrological model of flood resilience	Water Resources Research	Polder social system model-Flood model	Bangladesh
Lázár et al. (2015)	Agricultural livelihoods in coastal Bangladesh under climate and environmental change - A model framework	Environmental Science: Processes and Impacts	Agent-based model	Bangladesh

Reference	Title	Journal	Model type	Country
Raheem (2015)	A common-pool resource experiment in acequia communities	International Journal of the Commons	Common pool resource experiment	US
Balbi, Bhandari, Gain, and Giupponi (2013)	Multi-agent agro-economic simulation of irrigation water demand with climate services for climate change adaptation	Italian Journal of Agronomy	System dynamic multi-agent model	Italy
Becu (2012)	Effects of rainfall variability on farm income disparity and inequity in a small catchment of Northern-Thailand: A multi-agent simulation investigation	Territoire en Mouvement	Multi-agent model	Thailand

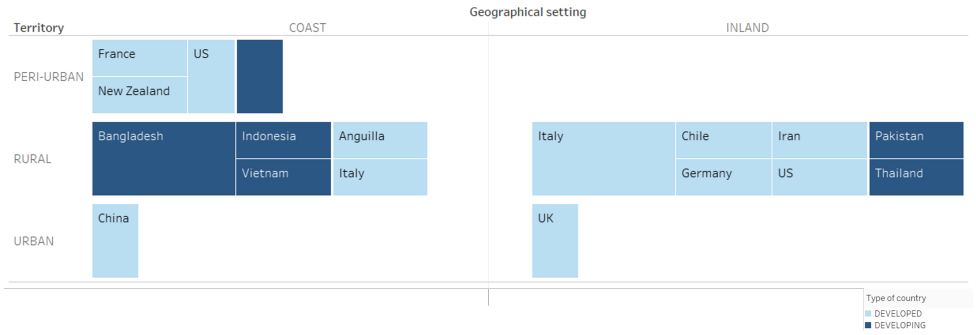

Figure 2: Publications' setting

3.1.2 Exogenous drivers of change and adaptation options

In the attempt to answer RQ1, in the following is presented the information collected for the Category *"Exogenous drivers of Change"* and *"Adaptation"*. The complete information collected for these categories are reported in Table 3 in the Appendix.

Overall, slow onset hazards as the raise in temperature, salinization and changes in water supply availability (vs extreme event such as floods) are the main environmental exogenous drivers considered by the authors. Management as an adaptation strategy is only explored in slow onset hazard cases, i.e. when the exogenous driver of change has long-run evidence, whereas when extreme events hit the analysed approach is that of implementing defensive measures. As shown in Figure 3, when slow onset hazards threat the SESs as exogenous drivers of change, adaptation is mainly planned with defence as the main strategy. In general, defence is the main strategy analysed. In one of the studies falling within this classification, Phan et al. (2020) explore whether it is possible and which are the most appropriate adaptation options for freshwater management under both current and likely future conditions. The planned defence mechanisms of adaptation are represented by the attempt to increase the river storage capacity, build a water supply plant, build a salinity prevention gate, build pumping station and increase water price.

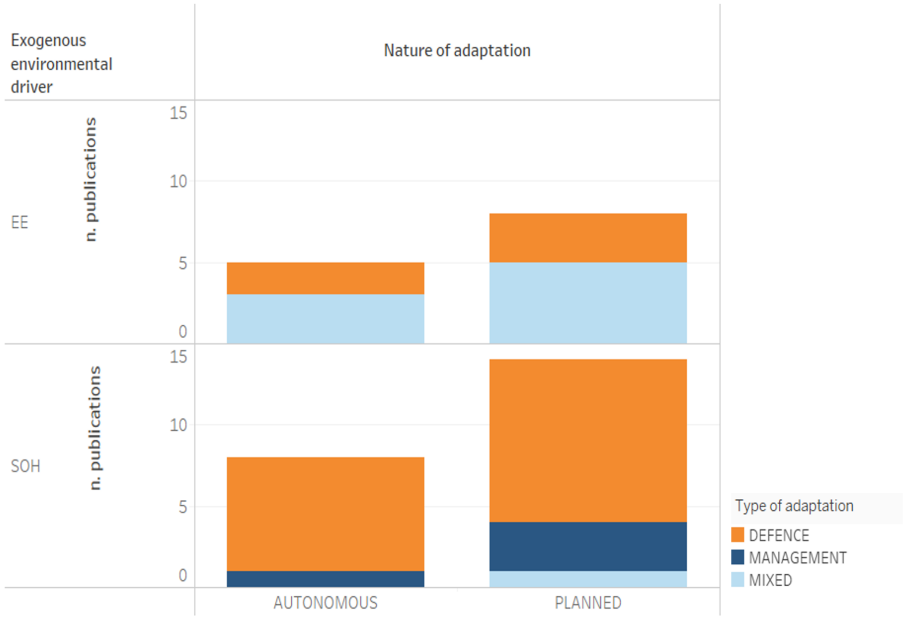

Figure 3: Adaptation characteristics

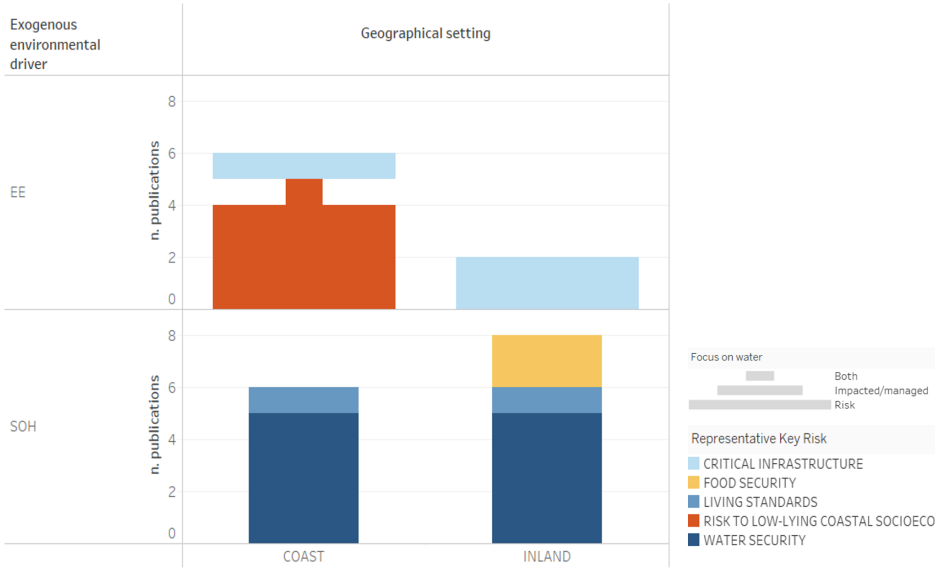

Figure 4: Exogenous drivers of climate change

Figure 4 brings into the picture some additional elements. With no surprise, when extreme events are studied, water is the element of risk which impact on the SESs, being a threat for the critical infrastructure or having broader impacts for the whole communities required to adapt through integrated approaches. This is the case of Mills et al. (2021) that address the risk to low lying communities by exploring, among other elements, how hazard exposure uncertainty vary through time in response to human or physical drivers. Both the RKRs (which as listed in Table 1 are the elements of focus of each study's research question) are addressed in coastal environment while inland areas are only explored for critical infrastructure issues, such as in Michaelis et al. (2020) that study how changes in the vulnerability of individuals influence community flood-risk dynamics by modelling individual households' decision-making process which comprises the possibility of avoid reacting to flood risk, implement individual flood protection measures (water barriers) or file a complaint to the government that itself decides about reinforcing the levee system. In the case of slow onset hazards, the leading research interest is water security followed by living standards and food security; the latter is only addressed for what concern inland environment. For all these three RKRs water resources are not assigned the role of exogenous drivers of change but they are studied as those elements which bear the impacts of external forces and must be managed to optimize the use and solve raised challenges. In this group of papers the work of Reinhard et al. (2022) can be found; the objective of their analysis is to provide insights necessary to increase food production in by modelling the decision-making process of buying a pump collectively to discharge water to the river and reduce waterlogging.

3.2 Modelling of human behaviour

Answering RQ2 required a more detailed focus on the Categories of Category, *"Agents' characteristics"*, *"Decision architecture"* and *"Theories of human behaviour"*. For this part of the analysis only 15 papers have been included as the methodology attempt to understand the formalization of human behaviour into the exercise. Bayesian network analyses and studies based on only participatory approaches (i.e. not integrated with suiter methodologies. such as ABMs) have been excluded. Table 4 in the Appendix list all information collected for these categories.

3.2.1 Agents' characteristics

In Figure 5 one can find the evidence that, in the analysed sample, the agents involved into ABMs and similar modelling exercise are mainly farmers. They are followed by a considerable number of papers involving not only one category of agents but many; this is the case of Laatabi et al. (2022), Egerer et al. (2021) and Abebe et al. (2019), among the others. Water security RKR is the research question focus that all agent types have been considered to face, with the exception of Mills et al. (2021) that model policy scenarios as agents of their model, dealing with broader risks to low-lying coastal communities

issues, i.e. outcomes and tradeoffs occurring when when decision-making entities and their policies are part of evolving landscapes. Farmers are associated with many RKRs (food security, living standards, risks to low-lying coastal communities and water security) excluding critical infrastructure.

When it comes to the characteristics of the modelled agents, it is in Figure 6 that we can identify a few elements. There is not a clear trend of improvement in the score over time; emotions is the feature which is almost always disregarded and only in three cases it takes the poor value of 1, when extreme events are addressed as exogenous environmental drivers. Values are slightly more taken into account by authors; anyway 7 studies do not consider them. However, there are 4 studies considering it a very important agents' characteristic in the determination of preferences and beliefs guiding choices (score 3 is for example assigns to Zagaria et al. (2021), using the theory of basic values - i.e. openness to change, environmental conservation, collaboration and ambition to distiguish among four farmer types). Almost the same is true for goals and needs, which never reach the subjectively assigned score of 3 while often being included as a simple optimization towards one goal.

3.2.2 Decision architecture and theories of human behaviour

In Figure 7 is depicted the account of different elements of agents' decision making process defining the characteristics of decisional rules. Uncertainty in decision making (i.e. the management of risk and risk awareness) and decision making rule (i.e. the complexity of decisions, up to structures as consumat Approach) are the elements which lead the modelling of agent's behaviour with structural changes and time horizon as the least accounted for. Social learning is the only element of choice architecture which is not considered when both critical infrastructure and living standards RKRs are analysed. Living standards and food security RKRs are the research question focus for which the authors have developed the least articulated choice architecture; additionally, these RKRs are always dealt with autonomous adaptation which does not foresee a deep account of structural changes social learning and social interactions. Indeed only elements of individual choice are explored in these cases.

For what concern the origin and type of decision making theories, we can say there is no prevalence of one single theory in the explanation of agents' adaptation processes. To mention some, consumat approach enriched by the account of prosocial behaviour in the choice of cooperation (Reinhard et al., 2022), social norms for collective actions (accounting also for collective memory) (Yu et al., 2017), cultural theory (Rojas et al., 2022), protection motivation theory (Michaelis et al., 2020), theory of basic values (Zagaria et al., 2021) and altruism and inequity (Raheem, 2015) are used to model agents' decision-making process. Mostly, theories are not applied as they are designed but they are adapted to the modelled case study. In Figure 8 it is shown that bounded rationality theories are the reference for both collective and individual theories. When rationality is considered, the theories, either developed for the case study or derived by literature, are declined precisely for the example tested through empirical data collected on

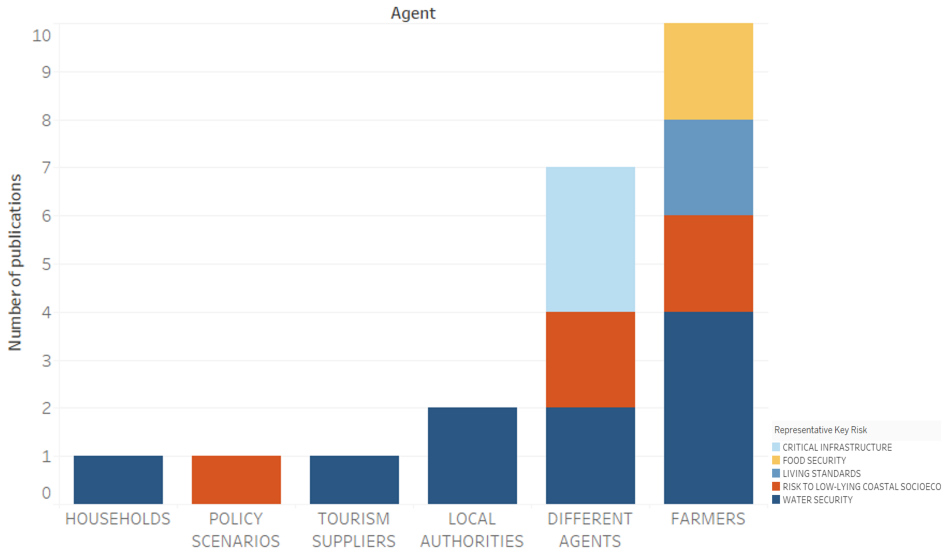

Figure 5: Environmental drivers faced by agent type

Figure 6: Agents' characteristics

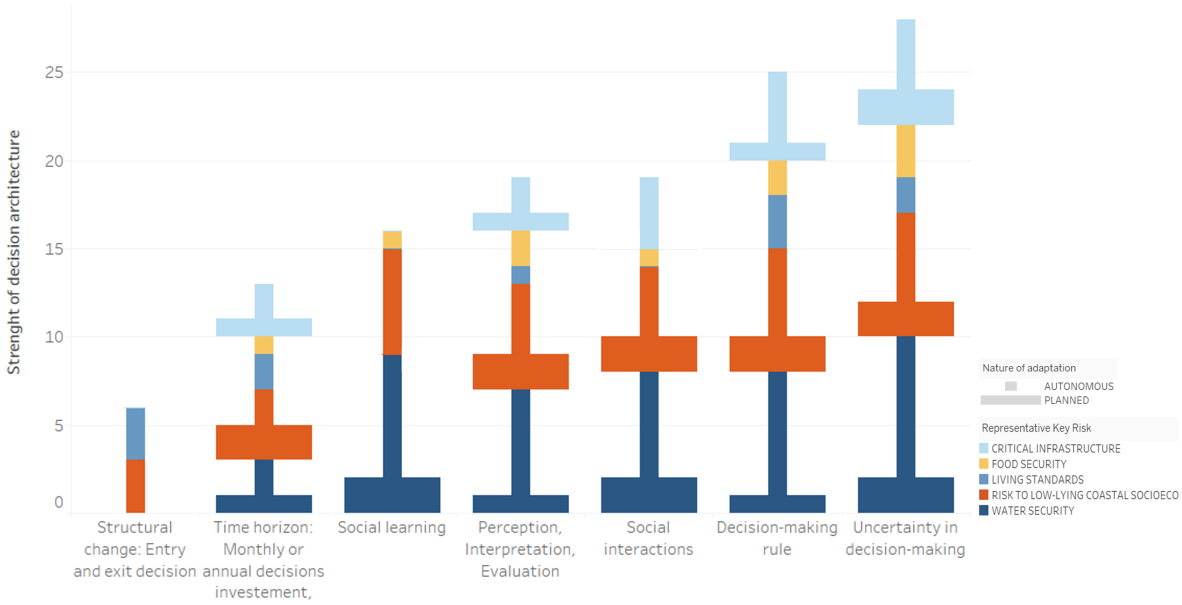

Figure 7: Account of elements of choice architecture by environmental driver

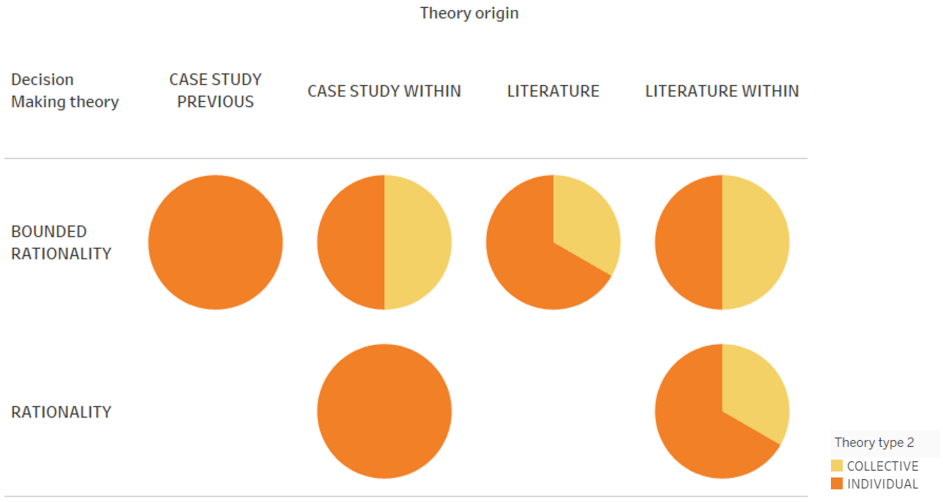

Figure 8: Behavioural theories

purpose and for the study itself.

3.2.3 Data sources and modelling features

There are 15 studies that can be labelled as integrated assessment models, with different methodologies used as components in the simulations, from ABMs coupled with game theoretical basis, hydrological models, common-pool games experiment, investment models and other.

It is only in nine cases that a Geographical Information System (GIS) has been used to represent spatially the simulations. For what concern the software used, Netlogo is twice used but no other software is considered more than once. The reporting protocols (either ODD Protocol by Grimm et al. (2006) or ODD+D Müller et al. (2013) Protocol or ODD+2D Protocol Laatabi, Marilleau, Nguyen-Huu, Hbid, and Babram (2018)) is used in only five studies.

The other information collected for this category are reported in Table 5 in the Appendix.

4 Conclusions

To give a conclusive picture of the findings from RQ1, the following Figure (Figure 9) is derived. As emerged, rural environment is the setting where research has mainly focused, specifically in coastal areas, for what concerns developing countries, while is the inland to be studied in developed ones. Whilst conducting the analysis, three types of exogenous drivers were considered; the exogenous social drivers of change and the policy ones, however, turned out not to be relevant in this literature. Social drivers of change can be detected in the sample, when changes in demand for water are also causing some differences in the availability and management of the resources, but these are often considered alongside the main exogenous environmental drivers. The exogenous threating trend of climate change, emerging as both sudden extreme events or slow onset hazards, is differentiated in the adaptation strategies that tackle it as, not surprisingly, defence is only explored in the first case, while management is applied to avert the impacts of the second one. On the former side, when extreme events are studied, water is the element of risk which impacts on the SESs while on the latter side, water resources are assigned the role of those elements which bear the impacts of external forces and must be managed to optimize the use and solve raised challenges.

Follows from the areas targeted by the studies that farmers are the main modelled agents. When it comes to the characteristics of them that are taken into account to map their behaviour, it appear that there is no improvement in the depth with which emotions, values and goals and needs are accounted for. Over time: emotions is almost always disregarded, values are slightly more taken into account and a simple optimization towards one goal is the main targeted objective in most of the cases. Better results

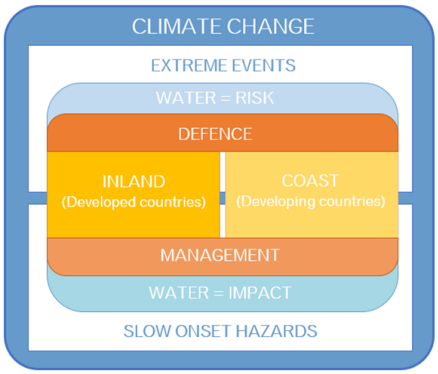

Figure 9: Summary of results

are obtained for the elements of agents' decision making process delineating the characteristics of the defined decisional rules. It is the management of risk and risk awareness which obtain the highest degree in the level of complexity with which decisions are mostly examined. However, the architecture of choice is still a weak element in the analysed sample. Overall, since the sum of the points for each category could reach up 66, it is possible to detect a lack of account for the elements, which at most reaches 28 as a score, each. An optimistic aspect is instead the contextualization to the modelled case study of the behavioural theories (even derived by the literature), rather than their application without a minimum adaptation.

5 Discussion

Section 3 summarizes the main results obtained by conducing this analysis which, however, should be red in the light of some weaknesses.

One important remark on the analysis cannot but be mentioned: there is a limitation in the collection and categorization of this information in that they are carried out on a subjective basis and without interviewing the author of the studies for a more accurate attribution of the categories. This is to be underlined because, even though literature reviews, to different extents, are the result of the author's critical process, it is in Huber et al. (2018) that we notice a more appropriate association of the variables also used for the categorization of this work, made possible by an *"iterative exchange between model developers, experts on decision-making and a core writing team"* (Huber et al., 2018: 146). To solve this lack would be an added value for the whole process but, at the moment, its existence must be taken into account in the reading of results and these conclusions. Also, results would be more significative in the case of an extension of the sample which, in this work account, for only 22 studies.

Generally, even though there is a huge focus of researchers on agricultural settings, we can notice

from Caretta et al. (2022) and O'Neill et al. (2022) that other sectors and types of risks are worth of investigation, given the expected impacts related to water resources.

The answer to the first research question (RQ1) highlights gaps in the literature that inquisitive researchers can consider to enhance. One unexplored issue is climate change induced water challenges in coastal areas, relatively to developed countries, as the extant literature has mainly concentrated on the inland environment. In addition, modellers can consider to go deep into the possibilities that both types of adaptation strategies, management and defence, are implemented in response of both extreme events and slow onset hazards.

Results from RQ2 highlight the evidence that the analysed sample partially recognise bounded rationality as a step forward to overcome the shortcomings of the formalization of agents as only rational actors. This is an advancement with respect to the findings of preview reviews focusing on agents' behavioural processes; Groeneveld et al. (2017) found theories supporting human sub-models in their sample were rarely regarded, mainly ignoring alternative theories than those based on rationality assumptions. However, results also strongly confirm the extant literature in supporting that: even though complexity of human behaviour is increasingly recognized, its integration into formal exercises remains superficial (Jager, 2021; An, 2012). As Schlüter et al. (2017) highlight, outdoing this limitation is challenging even also because many are the theories available across the social sciences, they often represent only a single aspect of decision-making processes, not to mention the difficulties in the formalization of them.

To facilitate a broader inclusion of theories on human decision-making in formal models, experts have provided tools and suggested a path toward a common language to facilitate implementation, as MoHuB (Modelling Human Behavior; Schlüter et al., 2017) framework or the step-wise methodology of Elsawah, Guillaume, Filatova, Rook, and Jakeman (2015), which go beyond the scope of this work but can be consider for new applications.

References

Abebe, Y. A., Ghorbani, A., Nikolic, I., Vojinovic, Z., & Sanchez, A. (2019). Flood risk management in sint maarten–a coupled agent-based and flood modelling method. *Journal of environmental management*, *248*, 109317.

Addo, I. B., Thoms, M. C., & Parsons, M. (2018). Household water use and conservation behavior: A meta-analysis. *Water Resources Research*, *54*(10), 8381–8400.

Ajzen, I. (1991). The theory of planned behavior. *Organizational behavior and human decision processes*, *50*(2), 179–211.

An, L. (2012, mar). Modeling human decisions in coupled human and natural systems: Review of agent-based models. *Ecological Modelling*, *229*, 25–36. DOI: 10.1016/J.ECOLMODEL.2011.07.010

Anderson, P. W. (1972). More is different: broken symmetry and the nature of the hierarchical structure of science. *Science*, *177*(4047), 393–396.

Balbi, S., Bhandari, S., Gain, A. K., & Giupponi, C. (2013). Multi-agent agro-economic simulation of irrigation water demand with climate services for climate change adaptation. *Italian Journal of Agronomy*, *8*(3), e23–e23.

Balbi, S., & Giupponi, C. (2010). Agent-based modelling of socio-ecosystems: a methodology for the analysis of adaptation to climate change. *International Journal of Agent Technologies and Systems (IJATS)*, *2*(4), 17–38.

Becu, N. (2012). Effects of rainfall variability on farm income disparity and inequity in a small catchment of northern-thailand: a multi-agent simulation investigation. *Territoire en mouvement Revue de géographie et aménagement. Territory in movement Journal of geography and planning*(14-15).

Bennett, N. J., Blythe, J., Tyler, S., & Ban, N. C. (2016). Communities and change in the anthropocene: understanding social-ecological vulnerability and planning adaptations to multiple interacting exposures. Retrieved from https://digitalarchive.worldfishcenter.org/handle/20.500.12348/751 DOI: 10.1007/s10113-015-0839-5

Blackett, P., FitzHerbert, S., Luttrell, J., Hopmans, T., Lawrence, H., & Colliar, J. (2022). Marae-opoly: supporting localised māori climate adaptation decisions with serious games in aotearoa new zealand. *Sustainability Science*, *17*(2), 415–431.

Caretta, A. M. M. A., Arfanuzzaman, R. B. M., Morgan, S. M. R., Kumar, M., et al. (2022). Water. in: Climate change 2022: Impacts, adaptation, and vulnerability. contribution of working group ii to the sixth assessment report of the intergovernmental panel on climate change.

Cooley, S., Schoeman, D., Bopp, L., Boyd, P., Donner, S., Ito, S.-i., ... others (2022). Oceans and coastal ecosystems and their services. In *Ipcc ar6 wgii.* Cambridge University Press.

di Noia, J. (2022, aug). Agent-Based Models for Climate Change Adaptation in Coastal Zones. A Review. *FEEM Working Papers*. Retrieved from https://ideas.repec.org/p/ags/feemwp/322810.html

DOI: 10.22004/AG.ECON.322810

Dubbelboer, J., Nikolic, I., Jenkins, K., & Hall, J. (2017). An agent-based model of flood risk and insurance. *Journal of Artificial Societies and Social Simulation*, *20*(1).

Egerer, S., Cotera, R. V., Celliers, L., & Costa, M. M. (2021). A leverage points analysis of a qualitative system dynamics model for climate change adaptation in agriculture. *Agricultural Systems*, *189*, 103052.

Elsawah, S., Guillaume, J. H., Filatova, T., Rook, J., & Jakeman, A. J. (2015). A methodology for eliciting, representing, and analysing stakeholder knowledge for decision making on complex socio-ecological systems: From cognitive maps to agent-based models. *Journal of environmental management*, *151*, 500–516.

Ernst, A. M. (1999). Resource dilemmas, computer simulated actors and climate change? a methodology to investigate human behavior in a complex domain. *Complex problem solving: Cognitive psychological issues and environmental policy applications*, 95–105.

Gain, A. K., Hossain, S., Benson, D., Di Baldassarre, G., Giupponi, C., & Huq, N. (2021). Social-ecological system approaches for water resources management. *International Journal of Sustainable Development and World Ecology*, *28*(2). DOI: 10.1080/13504509.2020.1780647

Giupponi, C., Borsuk, M. E., de Vries, B. J., & Hasselmann, K. (2013). Innovative approaches to integrated global change modelling. *Environmental Modelling & Software*, *44*, 1–9.

Glavovic, B. C., Dawson, R., Chow, W., Garschagen, M., Haasnoot, M., Singh, C., & Thomas, A. (2022). Cross-chapter paper 2: Cities and settlements by the sea. In *Ipcc ar6 wgii*. Cambridge University Press.

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health information & libraries journal*, *26*(2), 91–108.

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., ... others (2006). A standard protocol for describing individual-based and agent-based models. *Ecological modelling*, *198*(1-2), 115–126.

Groeneveld, J., Müller, B., Buchmann, C. M., Dressler, G., Guo, C., Hase, N., ... others (2017). Theoretical foundations of human decision-making in agent-based land use models–a review. *Environmental modelling & software*, *87*, 39–48.

Heylighen, F., Cilliers, P., & Gershenson, C. (2006). Complexity and philosophy. *arXiv preprint cs/0604072*.

Holling, C. S. (2001). Understanding the Complexity of Economic, Ecological, and Social Systems. *Ecosystems 2001 4:5*, *4*(5), 390–405. Retrieved from https://link.springer.com/article/10.1007/s10021-001-0101-5 DOI: 10.1007/S10021-001-0101-5

Hossain, M. S., Gain, A. K., & Rogers, K. G. (2020). Sustainable coastal social-ecological systems: how

do we define "coastal"? *International Journal of Sustainable Development and World Ecology*, 577–582. DOI: 10.1080/13504509.2020.1789775

Huber, R., Bakker, M., Balmann, A., Berger, T., Bithell, M., Brown, C., ... others (2018). Representation of decision-making in european agricultural agent-based models. *Agricultural systems*, *167*, 143–160.

Jager, W. (2021, dec). Using agent-based modelling to explore behavioural dynamics affecting our climate. *Current Opinion in Psychology*, *42*, 133–139. DOI: 10.1016/J.COPSYC.2021.06.024

Ji, L., Wu, T., Xie, Y., Huang, G., & Sun, L. (2020). A novel two-stage fuzzy stochastic model for water supply management from a water-energy nexus perspective. *Journal of Cleaner Production*, *277*, 123386.

Kaplan-Hallam, M. (2016). Social shocks in social-ecological systems : the impacts of sea cucumber booms for coastal communities in Mexico. Retrieved from https://open.library.ubc.ca/soa/cIRcle/collections/ubctheses/24/items/1.0339982 DOI: 10.14288/1.0339982

Kremmydas, D., Athanasiadis, I. N., & Rozakis, S. (2018, jul). A review of Agent Based Modeling for agricultural policy evaluation. *Agricultural Systems*, *164*, 95–106. DOI: 10.1016/J.AGSY.2018.03.010

Laatabi, A., Becu, N., Marilleau, N., Amalric, M., Pignon-Mussaud, C., Anselme, B., ... others (2022). Littosim-gen: A generic platform of coastal flooding management for participatory simulation. *Environmental Modelling & Software*, *149*, 105319.

Laatabi, A., Marilleau, N., Nguyen-Huu, T., Hbid, H., & Babram, M. A. (2018). Odd+ 2d: An odd based protocol for mapping data to empirical abms. *Journal of Artificial Societies and Social Simulation*, *21*(2).

Lázár, A. N., Clarke, D., Adams, H., Akanda, A. R., Szabo, S., Nicholls, R. J., ... others (2015). Agricultural livelihoods in coastal bangladesh under climate and environmental change–a model framework. *Environmental Science: Processes & Impacts*, *17*(6), 1018–1031.

Lizarondo, L., Stern, C., Apostolo, J., Carrier, J., de Borges, K., Godfrey, C., ... others (2022). Five common pitfalls in mixed methods systematic reviews: lessons learned. *Journal of Clinical Epidemiology*.

Ludwig, D., Hilborn, R., & Walters, C. (1993). Uncertainty, resource exploitation, and conservation: lessons from history. *Science*, *260*(5104), 17–36.

Martínez-Hernández, G. A. (2022, aug). System Dynamics Modelling and Climate Change Adaptation in Coastal Areas: A Literature Review. *FEEM Working Papers*. Retrieved from https://ideas.repec.org/p/ags/feemwp/322836.html DOI: 10.22004/AG.ECON.322836

Merloni, E., Camanzi, L., Mulazzani, L., & Malorgio, G. (2018). Adaptive capacity to climate change in the wine industry: A bayesian network approach. *Wine Economics and Policy*, *7*(2), 165–177.

Michaelis, T., Brandimarte, L., & Mazzoleni, M. (2020). Capturing flood-risk dynamics with a coupled

agent-based and hydraulic modelling framework. *Hydrological Sciences Journal*, *65*(9), 1458–1473.

Mills, A. K., Ruggiero, P., Bolte, J. P., Serafin, K. A., & Lipiec, E. (2021). Quantifying uncertainty in exposure to coastal hazards associated with both climate change and adaptation strategies: A us pacific northwest alternative coastal futures analysis. *Water*, *13*(4), 545.

Mirzaei, A., & Azarm, H. (2022). Evaluation of farmers' participatory behavior and compensation policy for agricultural water-saving. *Frontiers in Water*(4).

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. (2009). Preferred reporting items for systematic reviews and meta-analyses: the prisma statement. *Annals of internal medicine*, *151*(4), 264-269.

Moser, S. C. (2010). Now more than ever: the need for more societally relevant research on vulnerability and adaptation to climate change. *Applied geography*, *30*(4), 464–474.

Müller, B., Bohn, F., Dreßler, G., Groeneveld, J., Klassert, C., Martin, R., ... Schwarz, N. (2013). Describing human decisions in agent-based models–odd+ d, an extension of the odd protocol. *Environmental Modelling & Software*, *48*, 37–48.

Newell, W., & Meek, J. (2003). Complexity and interdisciplinarity. *Knowledge management, organizational intelligence and learning, and complexity, Encyclopedia of Life Support Systems. Available online at http://www. eolss. net. Oxford, UK: EOLSS Publishers*.

Noor, R., Inam, A., Zahra, S. M., Shoaib, M., Riaz, R., Sarwar, A., ... Ahmad, S. (2022). A methodological framework for modeling sustainability visions: A case study of groundwater management in faizpur distributary, pakistan. *Agricultural Water Management*, *271*, 107822.

Okura, F., Budiasa, I. W., & Kato, T. (2022). Exploring a balinese irrigation water management system using agent-based modeling and game theory. *Agricultural Water Management*, *274*, 107951.

O'Neill, B. C., van Aalst, M., Zaiton Ibrahim, Z., Berrang-Ford, L., Bhadwal, S., Buhaug, H., ... others (2022). Key risks across sectors and regions.

Ostrom, E. (2009, jul). A general framework for analyzing sustainability of social-ecological systems. *Science*, *325*(5939), 419–422. DOI: 10.1126/SCIENCE.1172133/SUPPL$_F$*ILE*/*OSTROM.SOM.PDF*

Ouzzani, M., Hammady, H., Fedorowicz, Z., & Elmagarmid, A. (2016). Rayyan — a web and mobile app for systematic reviews. *Systematic reviews*, *5*, 210.

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., ... others (2021). The prisma 2020 statement: an updated guideline for reporting systematic reviews. *Systematic reviews*, *10*(1), 1–11.

Perry, R. I., Ommer, R. E., Barange, M., & Werner, F. (2010). The challenge of adapting marine social–ecological systems to the additional stress of climate change. *Current Opinion in Environmental Sustainability*, *2*(5-6), 356–363.

Phan, T. D., Bertone, E., Pham, T. D., & Pham, T. V. (2021). Perceptions and willingness to pay for

water management on a highly developed tourism island under climate change: A bayesian network approach. *Environmental Challenges*, *5*, 100333.

Phan, T. D., Smart, J. C., Sahin, O., Stewart-Koster, B., Hadwen, W. L., & Capon, S. J. (2020). Identifying and prioritising adaptation options for a coastal freshwater supply and demand system under climatic and non-climatic changes. *Regional Environmental Change*, *20*(3), 1–14.

Pörtner, H.-O., Roberts, D. C., Adams, H., Adler, C., Aldunce, P., Ali, E., ... others (2022). Climate change 2022: Impacts, adaptation and vulnerability. *IPCC Sixth Assessment Report*.

Preiser, R., Biggs, R., De Vos, A., & Folke, C. (2018). Social-ecological systems as complex adaptive systems. *Ecology and Society*, *23*(4).

Raheem, N. (2015). A common-pool resource experiment in acequia communities. *International Journal of the Commons*, *9*(1).

Reinhard, S., Naranjo, M. A., Polman, N., & Hennen, W. (2022). Modelling choices and social interactions with a threshold public good: Investment decisions in a polder in bangladesh. *Land Use Policy*, *113*, 105886.

Ridolfi E. (2010). *Water Challenges in Coastal Areas. Challenges in Water Resources Management Vulnerability, Risk, and Water Resources Preservation.* (Tech. Rep.). Venezia: Marie Curie Training Course.

Rojas, R., Castilla-Rho, J., Bennison, G., Bridgart, R., Prats, C., & Claro, E. (2022). Participatory and integrated modelling under contentious water use in semiarid basins. *Hydrology*, *9*(3), 49.

Schlüter, M., Baeza, A., Dressler, G., Frank, K., Groeneveld, J., Jager, W., ... others (2017). A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological economics*, *131*, 21–35.

Schulte, P., & Morrison, J. (2014). Driving harmonization of water-related terminology. *Discussion Paper*.

Schwarz, N., Dressler, G., Jager, W., Janssen, M., Wijermans, M., Groeneveld, N., ... Groeneveld, J. (2020, dec). Formalising theories of human decision-making for agent-based modelling of social-ecological systems: practical lessons learned and ways forward. *Socio-Environmental Systems Modelling*, *2*, 16340–16340. Retrieved from https://sesmo.org/article/view/16340 DOI: 10.18174/SESMO.2020A16340

Simmonds, J., Gómez, J. A., & Ledezma, A. (2020). The role of agent-based modeling and multi-agent systems in flood-based hydrological problems: A brief review. *Journal of Water and Climate Change*, *11*(4), 1580–1602. Retrieved from https://www.researchgate.net/publication/336814082_The_role_of_agent-based_modeling_and_multi-agent_systems_in_flood-based_hydrological_problems_a_brief_review DOI: 10.2166/WCC.2019.108

Taberna, A., Filatova, T., Roy, D., & Noll, B. (2020, dec). Tracing resilience, social dynamics

and behavioral change: a review of agent-based flood risk models. *Socio-Environmental Systems Modelling*, *2*, 17938–17938. Retrieved from https://sesmo.org/article/view/17938 DOI: 10.18174/SESMO.2020A17938

Tuler, S., Agyeman, J., Agyeman, J., da Silva, P. P., LoRusso, K. R., & Kay, R. (2008). Assessing vulnerabilities: Integrating information about driving forces that affect risks and resilience in fishing communities. *Human Ecology Review*, 171–184.

Yu, D. J., Sangwan, N., Sung, K., Chen, X., & Merwade, V. (2017). Incorporating institutions and collective action into a sociohydrological model of flood resilience. *Water Resources Research*, *53*(2), 1336–1353.

Zagaria, C., Schulp, C. J., Zavalloni, M., Viaggi, D., & Verburg, P. H. (2021). Modelling transformational adaptation to climate change among crop farming systems in romagna, italy. *Agricultural Systems*, *188*, 103024.

Zhuo, L., & Han, D. (2020, dec). Agent-based modelling and flood risk management: A compendious literature review. *Journal of Hydrology*, *591*, 125600. DOI: 10.1016/J.JHYDROL.2020.125600

6 Appendix

In the following are reported additional information on the analysed papers. Detailed descriptions are taken from the original works.

Table 3: Characteristics of reviewd studies - Aim and results

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Blackett et al. (2022)	Maori vital infrastructure and services are vulnerable to extreme weather events, including water flooding	Develop an indigenous climate change adaptation decision model that captured the key processes and stages involved for the community facing uncertain and complex climate change impacts. The excercise is implemented to bring together diverse knowledge, and provide a safe, culturally sensitive space, for participants to play and evaluate different adaptation strategies.	Decision on best adaptation option to implement among upgrading the stop bank, raising building floor level, build new land, new building or move to a new complex.	Serious games have the potential to navigate tensions and co-develop climate change adaptation resources. Considerable emphasis on relationship-building and the translation of knowledge into a meaningful marae-based resource has been detected.
Laatabi et al. (2022)	Risk of coastal flooding in low coastal zones, due the sea-level rise in concomitance with continental and pluvial flooding	The principal aim of LittoSIM-GEN is to help stakeholders and urban planners to improve their risk culture and awareness by discovering new ways of optimizing their decisions and collaborate with other stakeholders.	Adoption of adaptation strategy based on land use decisions (land can be assigned a purpose among natural, agricultural, authorized-for-urbanization, urban, adapted urban, urban-densification) and coastal defence decisions (dike, dune, pebble dike) in addition to three strategies by builders.	Discussions and debriefing during these format implemented by the study foster the social learning of participants by simulating scenarios where collaborative projects and collective management of the risk may be the efficient way to reduce flood damage and protect coastal populations and activities.
Mirzaei and Azarm (2022)	Decrease in the availability of water resources and intensification of the conflicts between users of water resources	Evaluation of participatory behavior of farmers with optimal patterns of water allocation and estimation of the necessary budget to compensate for the reduction of water consumption in agricultural areas	Water extraction to compensate water scarcity, and its allocation.	It was found that different forms of insistence on the individual behavior of farmers make it difficult to participate in optimal water allocation patterns with simultaneously providing economic and environmental goals.

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Noor et al. (2022)	Groundwater depletion due to absence of a well define groundwater management policy together with low social awareness level; groundwater sustainability is at risk in term of its quality and quantity.	Understanding different system processes and allows for a more comprehensive qualitative assessment of stakeholder proposed policies.	Water pricing, revise cropping pattern, gray water reuse, and construction of dams	Among other proposed policies water pricing is found to be the most effective policy in improving irrigation efficiency and hence helps in reducing groundwater extraction. The policy may face resistance from upstream farmers due to excessive and cheap availability of irrigation water in their area, but can help in water reallocation and shift traditional methods of farming to more advanced techniques.
Okura et al. (2022)	Irrigation sector compounded due to social issues such as climate change and urbanization-induced population dynamics	Analyze conflicts over surface irrigation water and harvesting labor and also aims to present solutions to increasing conflicts due to labor resource depletion owning to urbanization.	Optimize the use of water supply, land preparation, paddy growth and harvesting stage decisions	Social changes could accelerate farmers' noncooperative behavior; to resolve conflicts, cooperative relationships must be developed on a larger scale, but social issues go beyond the intra-community level and will require government intervention to efficiently use decreasing resource supply.
Reinhard et al. (2022)	Excess precipitation in monsoon season leading to waterlogging	The objective is to provide insights necessary to increase food production by modelling the decision-making process of buying a pump collectively to discharge water to the river and reduce waterlogging (i.e. promoting collective investments with public good characteristics - based on success from another case study).	Investing in a public good, i.e. private pumps for collective drainage system: they are used to drain water for rice production at plot level facilitating cultivation of crops in different seasons.	For more effective and efficient water management in the polder system, the current water management institutions (e.g. water management groups) could benefit from a system which contains more incentives for collaboration (nudges or economic incentives). Policies can thus support beliefs for the cooperation of their members.

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Rojas et al. (2022)	Water management in a semiarid basin under contentious water use.	Deploy an integrated modelling tool and digital platform (SimCopiapo) with the purpose of exploring alternative water management strategies to support scenario analysis and potential policy pathways with stakeholders.	Development of individual water management strategy among water use and right exchange, strenghtening of hydraulic infrastructure, opting for recharge management, and managing demand.	Results suggest that reductions of groundwater demand alone are not sufficient to capture stakeholders' interests and steer the system towards sustainable water use, and thus a portfolio of management strategies including exchanges of water rights, improvements to hydraulic infrastructure and robust enforcement policies is required as long as the establishment of an efficient enforcement policy to monitor compliance on caps imposed on groundwater use and sanction those breaching this regulation.
Egerer et al. (2021)	Availability of water resources as a consequence of climate change and intensified crop cultivation in a region with the highest irrigation intensity.	Identify leverage points for effective climate change adaptation measures and the potential of stakeholders to implement adaptation measures that correspond to the identified leverage points on different time scales.	Water withdrawal regulation, EU direct payments, water storage and reuse, humus enrichment, irrigation, crop cultivation, financial incentives, societal awareness	Results show that the most effective measures to adapt to climate change are the retaining of water by the construction of additional water storage, increasing financial incentives to support water-use efficiency and water retention, and raising societal awareness of water-use conflict in the region.
Mills et al. (2021)	Flooding, erosion, and recreational beach accessibility	Exploring outcomes and tradeoffs that result when decision-making entities and their policies are included as part of evolving landscapes; in particular it explores which human (policy) or physical drivers deviate the most from current conditions, and how does hazard exposure uncertainty vary through time.	Adoption of measures for adapting to flood risk, which comprise backshore protection structures, nourishment, easement, relocation, safest-site and hazard zone	Adaptation policies produced a greater deviation from baseline conditions, climate change produced the greatest variance through time. Based on the assumptions used in the modelling effort, the policies implemented in response to coastal hazards have a greater impact on community exposure than climate change.

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Phan et al. (2021)	Long-term water resource management satisfying a growing water demand, subject to climate change and tourism development.	Exploring the determinants affecting the respondents' perceptions and willingness to pay for building reservoirs and increasing water price to help decision-makers to adopt more effective practices to the sustainable development of water resources.	Building reservoirs and increase the water prices	Tourism development is found as the most influential factor affecting the respondents' willingness to pay for building reservoirs, while climate change impact is the most influential factor for respondents' willingness to pay for higher water prices.
Zagaria et al. (2021)	Transformational adaptations to water scarcity and water use informed by water policies	Aim to quantify how climate change, farmer behavior and water policies may influence strategic adaptation decision-making at the farm-level, the extent to which implemented adaptations represent transformations, and their impact on farm structure and wider socio-ecological change.	Increase or decrease the farm size, expand the irrigated area, upgrade the irrigation efficiency, adopt a diversification strategy (deepening or broadening) or change the crop production.	Under higher drought risk perception, farmers are motivated to explore a broader set of adaptations, including those outside of the trajectory determined by their farming strategy. This process particularly favors the implementation of transformational increases in farm size and irrigated area, eventually stimulating farmers to adopt an expansionist strategy. As transformative changes to farming strategy trigger farmers to engage in new path-dependencies, aims of water policies may therefore rebound into unintended effects, emphasizing the importance of accounting for transformational perspectives.
Ji et al. (2020)	Increasing water demand and freshwater shortages leading to utilization of unconventional water source.	The impacts of water resources availability on optimal allocation strategies is analyzed under different scenarios taking into account decision-makers' risk preferences; economic loss is also assessed.	Utilization of unconventional water source (seawater, brackishwater, and recyclewater) as part of a diverse water supply portfolio to meet increasing water demand.	Water scarcity would require more exploitation of groundwater and utilization of desalination water and recycle water, which would exacerbate environmental pressure and increase energy demand for water supply. Decision makers with a more pessimistic attitude would increase the water supply amount and consider more diverse water sources to guarantee system security to guarantee sufficient water supply rather than take a resource action later.

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Michaelis et al. (2020)	Surface flood-risk dynamics, flood insurance and risk communication on the development of flood risk over time.	How do changes in vulnerability of individuals influence community flood-risk dynamics? How do different parameters shape model outcomes and how significant is the role of individual decision making for flood-risk development?	Not to react to flood risk, implement individual flood protection measures (water barriers) or file a complaint to the government which decides about reinforcing the levee system, compromising between a cost-benefit analysis and filed complaints from households.	Changes of community and individual vulnerability over time affect community flood risk; the patterns emerge from individual and governmental decision making about flood protection measure implementation with flood experience and damage identified as the main drivers of these decisions.
Phan et al. (2020)	Securing adequate freshwater supply to meet rising demands, significantly affected by changes to both climatic and nonclimatic drivers.	Identify appropriate adaptation options for freshwater management under both current and likely future conditions	Increase river storage capacity, build a water supply plant, build a salinity prevention gate, build pumping station, increase water price.	Climate change and tourism development were found to be the strongest factors causing water shortage for building reservoirs and increasing water price, followed by occupation and monthly income. Support for long-term solutions is found.
Abebe et al. (2019)	Flash flooding from surrounding hills or extreme rainfall events such as thunderstorms in addition to coastal flooding.	Examine existing and proposed flood risk management policies.	Households urban building development based on compliance with institutions and implementation of flood hazard reduction by goverment	When there is strict enforcement of the policies, which are manifested in higher compliance thresholds, communities' exposure and vulnerability reduces as more people follow them. With a localized effect, the policy reduces the vulnerability of household agents located only in the delineated flood zones.
Merloni et al. (2018)	Changes in water availability, determined by hotter temperatures, decreasing precipitations and increase in extreme events	Assessment of factors influencing the behavior of wine producers and the strategies implemented by them, i.e. short and long-term adaptation measures.	Decisions on the most appropriate cultivation practice (phytosanitary treatment, leaf removal), soil management (irrigation, soil preparation etc.), harvesting practices (mechanical, manual), harvesting date (upfront, postponed) and wine making process (selected yeasts, blend).	The adoption of focused management and appropriate adaptation strategies, as well as appropriate policies with regard to regulation, incentives and support, are crucial issues for farmers to face the ongoing climatic challenge.

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Dubbelboer et al. (2017)	Vulnerability of homeowners to surface water flooding as one of the greatest short-term climate risks.	How adaptation and insurance decisions could affect future surface water flood risk in that dynamic.	Homeowner's decisions to move house and/or install measures to protect their properties from flooding coupled with the role of flood insurance.	Future development can exacerbate current levels of surface water flood risk. Investment in flood protection measures are shown to be beneficial for reducing surface water flood risk.
Yu et al. (2017)	Salinity influenced by flooding events and rainfall	Investigation on the critical general features that affect the capacity of an infrastructure-dependent socio-hydrological system to cope with hydrological variability in the presence of collective actions problems and increased incentives.	Maintenance (e.g., repair of embankment erosions and malfunctioning sluice gates, and cleaning up of debris in the canals) and emergency repair.	Flood management strategies that focus on structural measures to reduce flood risk may lead to loss of resilience in the long run thus, policymakers must balance the conventional measures with alternative strategies that enhance communities' adaptive capacity for resilience, likely involving investments into improved capacity for monitoring the system states and fostering of continuous learning and experimentation for increased adaptability or flexibility.
Lázár et al. (2015)	Water and salinity stress (in addition to atmospheric fertilisation by carbon dioxide and temperature stress)	Support agriculture and poverty-based analysis by simulating the net agriculture profit (evolution of food security indicators and poverty levels) in addition to map the decision-making process of agents that act to support their households.	Chosing a crop type, a type of work (farm or off-farm if more convenient) and accessing to loans for supporting the activity.	An increase in productivity do not translates into a worth increase in income for farmers with large increases not being enough to guarantee reduced poverty levels; the number of rural landless households is expected to increase with the consequence of seeking for off farm sources.
*Raheem (2015)*Reliability of water for irrigation as climate change predictions tend toward less reliable supplies	Testing if farmers traditional irrigators are better adapted to water scarcity and variability than other communities.	Change irrigation strategy to account for community needs	Despite predictions to the opposite, no significant difference is found between mean withdrawals or predictions of other players' behavior. On average, explored groups withdrew above the social optimum but below the Nash equilibrium with no better results for traditional irrigators.	

Reference	Water resources	Research interest and aim	Adaptation option considered	Results and management/policy implications
Balbi et al. (2013)	Irrigation water demand playing a crucial role in the sustainability of crop production and water consumption	Farmer's decision making-process is explored together with the consequent future irrigation water demand	Irrigation and crop management decisions (farming choices, e.g. allocation of utilised agricultural area to specific crops)	Bad forecasts may significantly affect farmers' incomes, in particular in those cases in which irrigation systems are characterised by high variable costs (e.g. energy required for irrigation pumps). Also, the interaction between various sources of stochasticity and uncertainty may affect aggregated and average results.
Becu (2012)	Inter-annual rainfall variability on income disparity among farms sharing water resource	Analysing farming systems by taking into account the multiplicity of situations, disparities between farms and by assessing inequity within the farm population and the effects of inter-annual rainfall variability and of alternative land uses.	Whether to plant, irrigate and harvest crops.	RStress events such as dry years tend to increase economic disparities among farms. Land-use change which increase irrigation demand, tend to increase farm inequity that would be positively correlated to the pressure on the resource.

Table 4: Characteristics of reviewed studies - Modelling of human behaviour

Reference	Agent	Heterogeneity	Behavioural theory
Laatabi et al. (2022)	DIFFERENT AGENTS	Players are mad of a mix of stakeholders.	Risk minimization
Mirzaei and Azarm (2022)	FARMERS	Cooperative and non-cooperative farmers	Social pressure (and the additional rule of government encouragement of farmer's cooperative behaviours)
Okura et al. (2022)	LOCAL AUTHORITIES	Cooperative and non-cooperative farmers	Cooperative and non-cooperative behaviours
Reinhard et al. (2022)	FARMERS	Farmers modelled are heterogeneous in their preferences for income satisfaction and risk aversion and social preferences. Each strategy defines an individual cognitive process.	Consumat approach enriched by the account of prosocial behaviour in the choice of cooperation
Rojas et al. (2022)	FARMERS	Four grid-group categories (Egalitarian–Hierarchist–Individualist–Fatalist)	Cultural Theory
Mills et al. (2021)	POLICY SCENARIOS	Status quo = Continuation of present-day policies; Hold the lines=Policies or decisions to preserve existing infrastructure and human activities; Realign= shifting development to suit the changing environment; Laissez-Faire=Current policies were relaxed.	not
Zagaria et al. (2021)	FARMERS	Four dimensions referencing the Theory of Basic Values: openness to change (vs. tradition), environmental conservation (i.e. self-transcendence, vs. selfenhancement), collaboration (vs. autonomy) and ambition (reflected within different aspired profits)	Theory of basic values
Ji et al. (2020)	LOCAL AUTHORITIES	Based on risk preferences: pessimistic (risk averse), optimistic (risk prone), and neutral (risk neutral) agents are considered.	Risk attitude

Reference	Agent	Heterogeneity	Behavioural theory
Michaelis et al. (2020)	DIFFERENT AGENTS	Different types of agents: individual households and a government.	Protection Motivation Theory
Dubbelboer et al. (2017)	DIFFERENT AGENTS	There are different types of agents: homowner, Insurer, Homebuyer, Local government, Developer, Bank	na
Yu et al. (2017)	FARMERS	All small-holders endowed with same knowledge and land extent but they can be either cooperators or defectors	Social norms for collective actions (accounting also for collective memory)
Raheem (2015)	FARMERS	Based on behavioural theories	Intergenerational altruism and sustainable development hypotesis and inequity aversion and reciprocal altruism are accounted for as characteristics for differentiating agents.
Becu (2012)	FARMERS	There are different types of agents: upstream and downstream farms using water to irrigate crops, drinking water company, and village household water consumption.	na

Table 5: Characteristics of reviewd studies - Models' features

Reference	Methodology	Is the model geographically explicit?	Software/model/coding used	Standard reporting protocol
Blackett et al. (2022)	Serious Game and flood model (hydrological model)	not	us	us
Laatabi et al. (2022)	Agent-based model (Participatory simulation coulpled with hydrodynamic model)	Use of GIS	GAML language under the Gama platform; hydrodynamic model (LIFSLOOD-FP)	ODD+2D
Mirzaei and Azarm (2022)	Agent-based model	not	Mathematical programming method and TOPSIS multi-criteria decision-making method	not
Noor et al. (2022)	Stepwise participatory modeling framework (Case study)	not	us	us
Okura et al. (2022)	Agent based model and game theory	Use of GIS	Adaptation of Lansing and Kremer ABM	not
Reinhard et al. (2022)	Investment behaviour model integrated into an agent-based model	Matrix environment	Netlogo V6	ODD
Rojas et al. (2022)	Agent-based model; Participatory modelling	Use of GIS	Digital platform (SimCopiapo), mostly in Python, including an API web and front-end HTML/JavaScript. DGA-HIDROMAS provides the surface water model implemented in the AQUATOOL software.	not
Egerer et al. (2021)	Leverage point analysis (Qualitative system dynamics models (QSDMs))	not	na	us
Mills et al. (2021)	Agent-based model	Use of GIS	Envision	not
Phan et al. (2021)	Bayesian network	not	na	us
Zagaria et al. (2021)	Agent-based model	Use of GIS	NetLogo version 5.3.1	not

Reference	Methodology	Is the model geographically explicit?	Software/model/coding used	Standard reporting protocol
Ji et al. (2020)	Two-stage fuzzy stochastic programming approach	not	na	us
Michaelis et al. (2020)	Coupled agent-based and hydraulic modelling framework	Use of GIS	Repast,1; LISFLOOD-FP hydraulic model used.	ODD
Phan et al. (2020)	Bayesian network	not	us	us
Abebe et al. (2019)	Agent-based model	Use of GIS	Model: CLAIM; Institutions are coded using the ADICO grammar within the institutional structure of MAIA; implemented using Java-based Repast Simphony modelling environment	not
Merloni et al. (2018)	Bayesian network	not	Netica software	us
Dubbelboer et al. (2017)	Agent-based model	Use of GIS	Netlogo V6	ODD
Yu et al. (2017)	Polder social system model and flood model (hydrological model)	not	na	na
Lázár et al. (2015)	Agent-based model	Use of GIS	FAO's CROPWAT 4.3 model re-coded in Matlab	Brief Overview
Raheem (2015)	Common pool resource experiment	not	na	us
Balbi et al. (2013)	System dynamic multi-agent model	not	Simile	ODD+D
Becu (2012)	Multi-Agent Simulation Investigation	not	CatchScape3	us

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Fondazione Eni Enrico Mattei
Corso Magenta 63, Milano – Italia

Tel. +39 02 403 36934

E-mail: letter@feem.it
www.feem.it

Fondazione Eni Enrico Mattei