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Summary

Climate change impacts in coastal areas (CA) have exposed coastal ecosystems to unprecedented conditions. System dynamic modelling (SD) has been used as a powerful tool to improve climate change adaptation (CCA) strategies. However, until now there are no review papers that summarize how academic literature that employs SD modelling has addressed CCA in CA. Hence, the main objective of this study is to provide an overview of the state of the art of this field. A systematic literature review was chosen as the main method of analysis, which was complemented with a bibliometric analysis and a categorization of the main contents of the papers selected. Our results suggest that the literature is clustered in three groups: physical or social impacts, water and agriculture management, as well as ecosystem services. Following the classification of key representative risks (KRK) of the IPCC, some topics have been addressed more than others. Most papers focus on Disaster Risk Reduction (DRR) compared to adaptation to slow onset hazards. Besides, research in developing countries remains scarce, except for the case of Vietnam. One group of models seem to be in an advanced stage or abstract enough to be applied in other areas, whereas another group is better suited for local modelling. Quantitative SD modelling has been preferred compared to qualitative or mixed approaches. Finally, Stella and Vensim seem to be the most popular platforms to run simulations.

Keywords: Climate change adaptation, Coastal areas, System dynamics modelling, Environmental modelling, Literature review

JELClassification: C61, C63, Q54

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System Dynamics modelling and Climate Change Adaptation in Coastal Areas: A literature review

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Abstract

Climate change impacts in coastal areas (CA) have exposed coastal ecosystems to unprecedented conditions. System dynamic modelling (SD) has been used as a powerful tool to improve climate change adaptation (CCA) strategies. However, until now there are no review papers that summarize how academic literature that employs SD modelling has addressed CCA in CA. Hence, the main objective of this study is to provide an overview of the state of the art of this field. A systematic literature review was chosen as the main method of analysis, which was complemented with a bibliometric analysis and a categorization of the main contents of the papers selected. Our results suggest that the literature is clustered in three groups: physical or social impacts, water and agriculture management, as well as ecosystem services. Following the classification of key representative risks (KRK) of the IPCC, some topics have been addressed more than others. Most papers focus on Disaster Risk Reduction (DRR) compared to adaptation to slow onset hazards. Besides, research in developing countries remains scarce, except for the case of Vietnam. One group of models seem to be in an advanced stage or abstract enough to be applied in other areas, whereas another group is better suited for local modelling. Quantitative SD modelling has been preferred compared to qualitative or mixed approaches. Finally, Stella and Vensim seem to be the most popular platforms to run simulations.

Keywords: Climate change adaptation – Coastal areas – System dynamics modelling - Environmental modelling – Literature review

JEL Codes: C61, C63, Q54

1) Introduction

Climate change impacts in coastal areas have exposed oceans and coastal ecosystems to unprecedented conditions, leading to a dramatic change of its functioning and future adverse scenarios (Cooley et al., 2022). Heatwaves in marine ecosystems lasting several months have put species into a very dangerous area, beyond their tolerance levels. In an extreme case, warming levels beyond 2°C by 2100 might exert the extirpation, extinction collapse of diverse ecosystems: according to historical records, an increase of more than 5.2°C might lead to mass extinction of marine species. If it is not possible to limit the increase of global warming below 1.5°C, sea-level rise could increase the risk of coastal erosion and submergence of coastal land, loss of coastal habitat and ecosystems and worsen salinization of groundwater, compromising humans and natural ecosystems alike.

Different adaptation strategies have been put in place to cope with the foregoing issues, but its efficacy has been hindered by different factors. Indeed, adaptation planning and implementation strategies to reduce vulnerability and exposure from climate change have increased in at least 170 countries (Pörtner et al., 2022). Important adaptation actions have also been taken with respect to marine systems, but transformational and structural adaptation actions would be required to cope with high-emissions scenarios (Cooley et al., 2022). Most of the observed adaptation strategies remain fragmented, small-scale and focused to respond to current impacts or short-term risks. Additionally, available adaptation options are not able to cope with the impacts of climate change on marine ecosystems and its services. Nevertheless, multilevel solutions that consider different social, ecological and economic scales, combined with urgent and ambitious mitigation actions might meaningfully mitigate climate change impacts.

There are several tools and methods available to improve the capacity of decision makers to better adapt to the future impacts of climate change. In recent years, an increasing body of economics literature has moved beyond traditional optimization and cost-benefit analysis, towards more structural modelling approaches (Scrieciu et al., 2013). This has been the case of Agent Based models (ABM), GIS[1] models and System Dynamics (SD) models. These types of modelling have become a bridge between natural and social scientists to deal with the interconnectedness of social, economic and environmental issues. Out of these methodologies, SD stands out as a well stablished modelling approach to deal with a wide range of complex socio-ecological issues. This approach was developed by a team of researchers led by Jar Forrester and it has been implemented in different fields such as population, agriculture, etc. (Forrester, 1999). The book *The Limits to Growth* is a seminal document that analyzed in a holistic manner social, economic and ecological issues by employing a system dynamics approach (Meadows, 1982). The efficacy of this modelling approach to understand complex phenomena has been advocated in recent years by Herrington (2021) and Jackson & Webster (2016). According to them, the original model of the *Limits to*

[1] Geographical information systems.

Growth has been accurate enough to predict current growth trajectories, which call for prompt action to avoid the overshoot of social and ecological systems.

Until now there are some review papers that have addressed the relationship between SD modelling and general climate change issues. For instance, the work of Datola et al. (2022) studies how SD models have dealt with the concept of resilience, whereas Zomorodian et al. (2018) have focused on integrated water resources modelling. Another strand of literature has analyzed how different modelling approaches have addressed climate change mitigation rather than adaptation issues, such as the work of Scriecu et al. (2013). However, at a more particular level there are few papers that employ SD modelling to study climate change adaptation (CCA) in coastal areas (CA), (see Karamouz & Olyaei, 2017; Ko, 2012; Sahin, 2013; Tran, 2021). More importantly, until now there are no review papers that categorize and summarize how academic literature that employs SD modelling has addressed CCA in CA.

For this reason, it results relevant to conduct a literature review of SD modelling practices for the case of CCA in CA. The main objective of this study is to provide an overview of the state of the art of the field. The goal is to identify the main contents and novelty of each paper: most explored and underexplored topics, common case studies evaluated, main research questions addressed and future research directions identified by the authors. It would be also relevant to identify some technical features like methodologies employed, software(s) used to perform the simulations and some useful modelling features. For this reason, the paper is structured as follows: Section 2 presents the research method employed to conduct this literature review. The results are found in Section 3, which summarizes the most important thematic and technical contents of the papers selected. Section 4 is the Discussion section, in which the main results of the present work are identified and put into context. Finally, section 5 presents the general conclusions of this paper.

2) Methodology

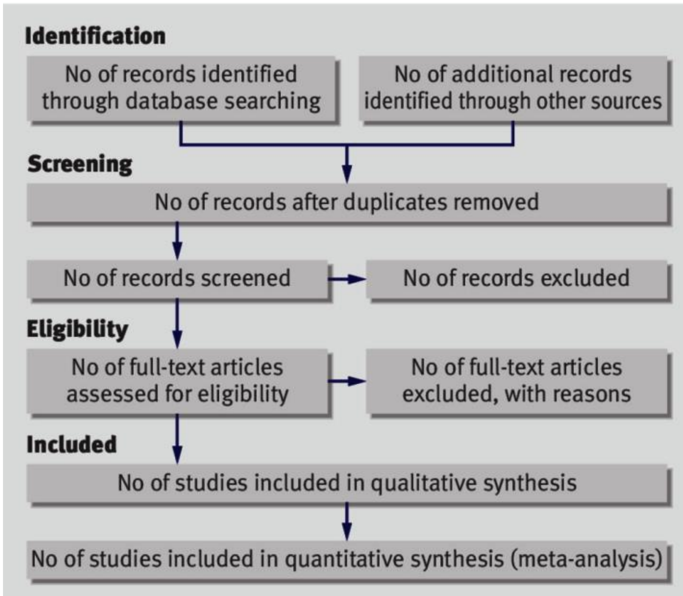
For the present research, a systematic literature review was chosen as the main method of analysis, which was complemented with a bibliometric analysis and a categorization of the main contents of the papers selected. Given its relevance and replicability, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) was chosen as the main method of analysis. Additionally, the search for papers was conducted with two main datasets: Scopus and ScienceDirect. To facilitate the selection of the papers, RAYYAN software was used to screen for relevant papers after retrieving the bibliometric data from the two sources mentioned earlier. The next step was to create interactive graphs and plots to summarize key bibliometric information with the open-source software Bibliometrix. At this point, a group of papers were selected to be studied and its main features were summarized in an spreadsheet file, according to different criteria coming from the sixth report assessment of the IPCC (Cooley, 2022). Finally, graphs were constructed to summarize key features of the final list of papers included.

There are normally two types of review articles found in the literature, narrative and systematic literature reviews (Terezinha Rother, 2007). On the one hand, narrative reviews are publications that describe the state of the art within a given topic or domain, by focusing on a theoretical or contextual point of view. However, this approach does not allow for the replication of the data neither it answers quantitative research questions. On the contrary, a systematic literature reviews "*is a well-planned review to answer specific research questions using a systematic and explicit methodology to identify, select, and critically evaluate results of the studies included in the literature review* (Terezinha Rother, 2007, p.1)". Hence, systematic literature reviews have a more robust methodological approach in comparison to traditional narrative literature reviews.

Given the objective of providing an overview of the state of the art of SD modelling of CCA in CA, the PRISMA method was chosen to conduct the systematic literature review. This procedure was initially published in 2009 by Moher et al. (2009) and it represents an improvement of a previous methodology named QUORUM (Quality Of Reporting Of Meta-analyses). These guidelines were born with the objective of addressing deficiencies in the reporting process of meta-analysis. Indeed, Mulrow (1987) analyzed 50 review articles published in leading medical journals between 1985 and 1986, discovering that these articles do not regularly use scientific methods to identify, assess and synthesis information. More importantly, none of these papers employed all the eight scientific criteria identified by Mulrow (1987).

On this regard, the PRISMA framework represents a novel set of guidelines to scientifically conduct a systematic literature review or meta-analysis, as presented in Figure 1. A broad selection of papers is made from an initial search carried out in bibliometric datasets and other sources. Afterwards, the information coming from different datasets and sources is consolidated, and duplicated results are eliminated. An inclusion criterion is set to decide whether to include or exclude some papers. The selected papers that meet the criteria will be the basis for qualitative or quantitative analysis, whereas for the excluded papers it will be necessary to explain the reasons for rejection. Finally, from those papers selected it should be indicated which of them will be the basis of qualitative and/or quantitative or meta-analysis.

Figure 1. A description of the PRISMA framework.



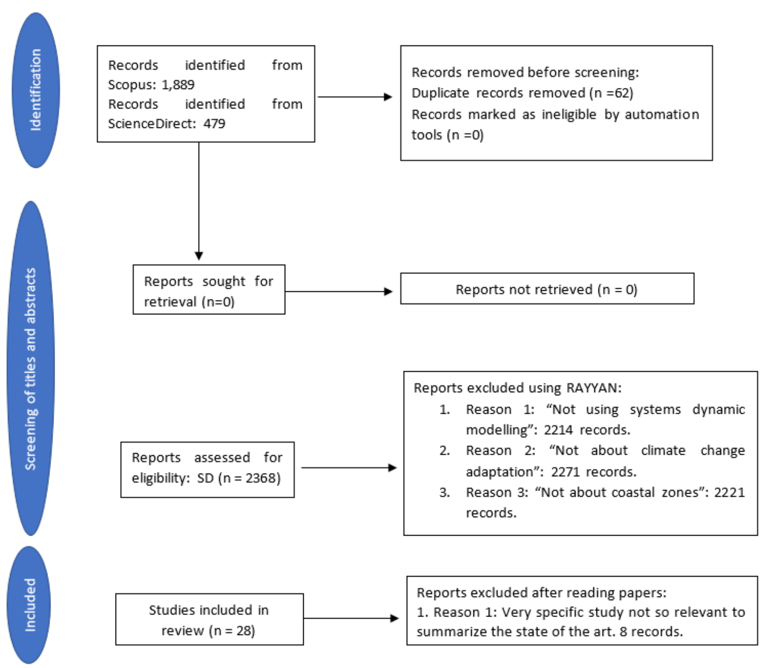
Source: Taken from Moher et al. (2009).

For the present work, this procedure was carried out by relying on two main datasets: Scopus and ScienceDirect. Two strings were built to perform an identical search within these two datasets. However, the languages and syntaxis of the strings differs between the datasets. Consequently, two different scripts were constructed according to the specificities of its own language. Both can be found at the end of this document, labelled as Annex 1. At least three types of keywords were included in these strings: those that relate to the methods employed (system dynamics modelling), the thematic domain (Climate Change Adaptation) and the particular topic (Coastal Areas). Some other keywords were included since they represent important issues of Climate Change Adaptation in Coastal Areas (floods, storms, erosion, sea level rise, etc.). Results were further restricted to English academic papers published in peer reviewed journals or book chapters.

The results of applying the PRISMA procedure are explained in Diagram 1. During the identification process, 1889 papers were retrieved from Scopus, whereas 479 papers came from Science Direct. To analyze these papers, its bibliometric data was downloaded and processed with the RAYYAN software. This software relies on artificial intelligence to accelerate the process of selecting relevant papers during the literature review. Since papers were retrieved from two different sources, this software was employed to eliminate duplicated papers. In this case, 62 duplicated papers were found and discarded for the analysis. Therefore, at the end 2,368 papers were retrieved for further analysis.

Later, abstracts, titles and keywords were screened by using the RAYYAN software to select those papers that were relevant for our study. The selection criteria relied on three main points: whether the paper employed system dynamics modelling; if it discussed climate change adaptation; and more particularly, adaptation in coastal areas. At this point, 2214 papers were excluded since they did not used the system dynamics modelling approach, 2271 papers did not discuss about climate change adaptation and 2221 did not focus on coastal areas. Therefore, at the end only 36 papers were selected as the final part of the PRISMA process. After reading the 36 papers selected, 8 of them were discarded because they tackled very particular phenomena. Hence, at the end of the process only 28 papers were selected for the analysis.

Diagram 1. Description at each state of the PRISMA process of the systematic literature review.



Source: Own elaboration.

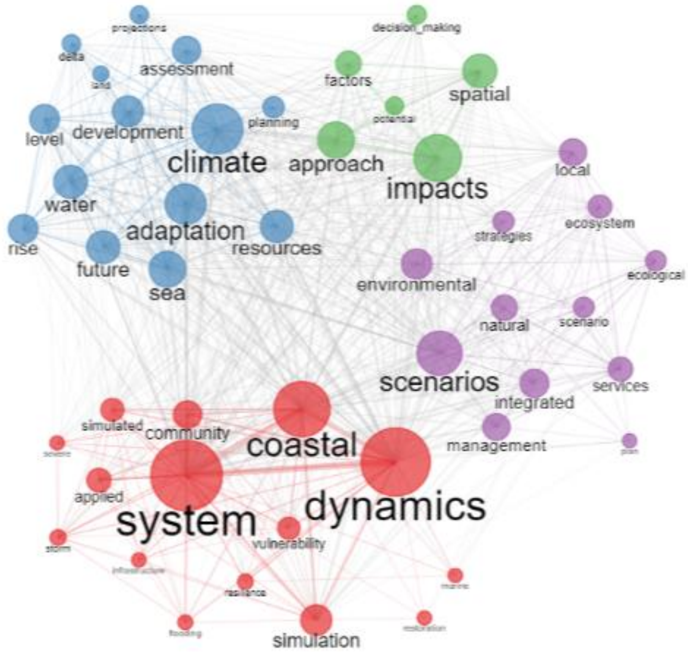
3) Results

a. Bibliometric overview

The bibliometric data of the 28 papers selected was retrieved from Scopus to construct bibliometric pictures to summarize the state of the art. The Bibliometrix package of R software was used through this process. It was decided to employ this software since it is open source and it is specialized in quantitative bibliometrics research. To provide an overview of the state of the art it was decided to construct three plots: a co-occurrence network map of keywords, a graph presenting the most relevant authors, and another one about the most global cited documents.

Picture 1 presents the co-occurrence network map of keywords. Unigrams were selected as the preferred unit of analysis, since the results obtained with bigrams and trigrams difficulted the analysis of the state of the art. A list of repeated or not relevant words was uploaded to the software to enhance the presentation of the co-occurrence network map (see Annex 2). At a first glance, it is relevant to notice the presence of three broad clusters (red, blue and purple) and a narrow one (green). The red cluster highlights the presence of studies that focus either on the physical impacts of climate change (flooding, storms) or on social issues (vulnerability, resilience, community-adaptation). The blue cluster might indicate that there are studies that focus on assessment, planning and projections to improve adaptation practices of water and land sectors, possibly against certain impacts of climate change such as sea level rise. In relation to the purple cluster, another strand of literature has focused on environmental management of ecosystem services and scenario building of local case studies. According to the green cluster, a less common strand of literature has employed spatial approaches to enhance decision-making practices.

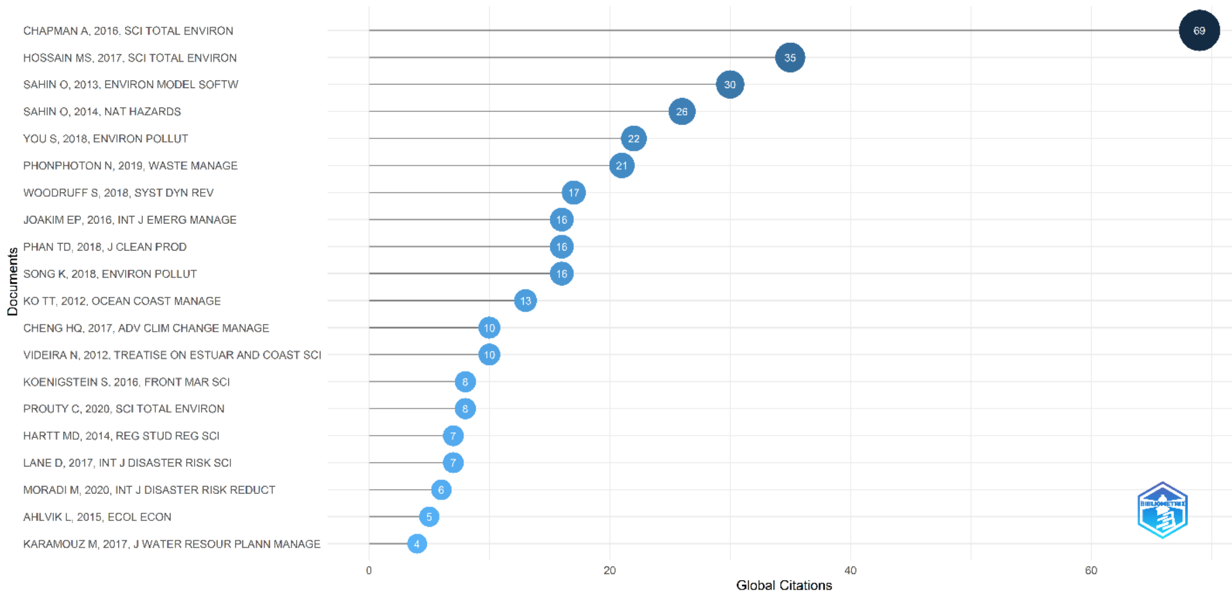
Picture 1. Co-occurrence network map of SD modelling of CCA in CA



Source: Own elaboration with bibliometric data from Scopus and ScienceDirect, plot with Bibliometrix software.

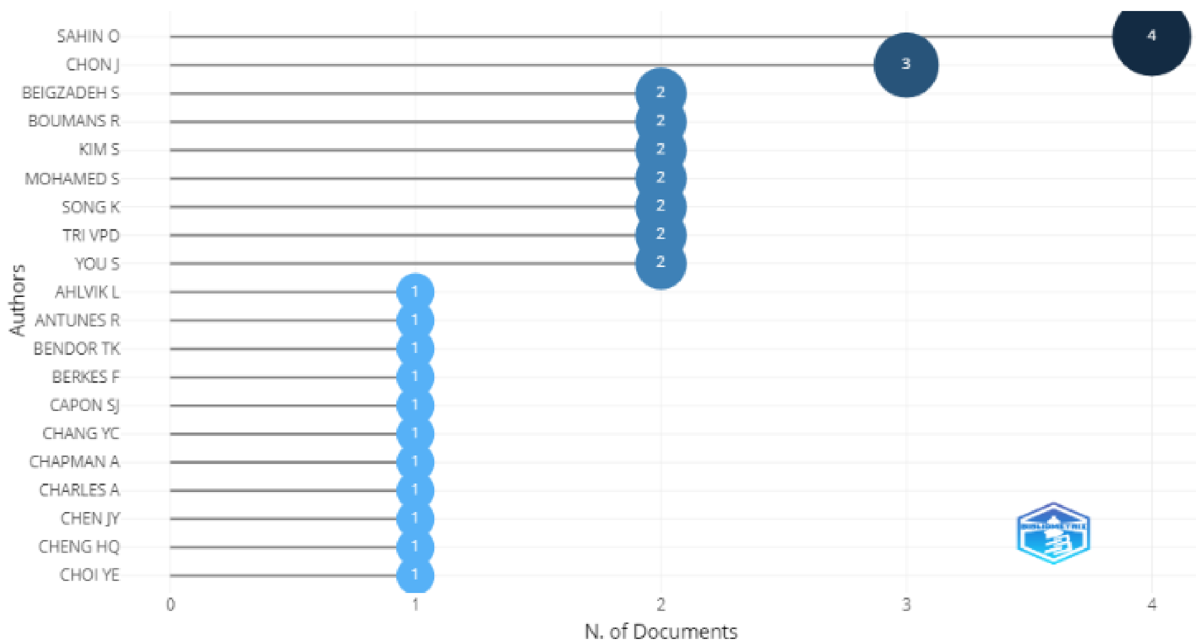
Graphs 1 and 2 present the most global cited documents and the most relevant authors, respectively. With respect to the first graph, at least three clusters are identified: Those with more than 20 citations; another between 10 and 20 citations and a final group with less than 10 citations. The paper written by Chapman A. (2016) stands out as the most cited paper, which deals with adaptation strategies for rice agriculture in the Vietnamese Mekong Delta. The papers of Hossain et al. (2017), Sahin (2013) and Sahin (2014) also represent an important part of the literature, since they have more than 20 citations each. The topics raised by these authors are related to coastal vulnerability to sea level rise and the concept of “safe operating space” (Rockström et al., 2009). With regards to the most relevant authors, Sahin and Chon have the authorship of the greatest numbers of papers individually, followed by a group of seven authors who either participate as authors or co-authors of two papers each. Finally, there is a group of 11 authors which only have the authorship of only one document each.

Graph 1. Literature of SD modelling of CCA in CA: Most global cited documents.



Source: Own elaboration with bibliometric data from Scopus and ScienceDirect, plot with Bibliometrix software.

Graph 2. Literature of SD modelling of CCA in CA: Most relevant authors.



Source: Own elaboration with bibliometric data from Scopus and ScienceDirect, plot with Bibliometrix software.

b. Categorization of the literature and main thematic features

The literature was classified according to criteria coming from the sixth assessment report of the IPCC, as well as other categories such as main objectives and limitations identified by the authors and geographical scope. To this end, all the papers selected were read and its information was stored in a spreadsheet file that contained the categories introduced earlier. Qualitative and quantitative answers were provided depending to the type of criteria: in some cases, quantitative and dichotomous answers were used, whereas qualitative or extended answers were also provided. An in-detail description of how the information was processed can be found in Annex 3.

A broad categorization of the literature by sectors is presented in Graph 3. This table is divided into six different categories, which represent Representative Key Risks (RKR) according to sixth assessment report of the IPCC (Pörtner, et al., 2022). According to Chapter 16 of this report, a key risk is defined as "*as a potentially severe risk and therefore especially relevant to the interpretation of 4 dangerous anthropogenic interference (DAI) with the climate system (O'Neill et al., 2022, p. 56)"*. Originally, 8 risks were considered, however it was decided to omit the first two ("Risk to low lying coastal socio-ecological systems and risks to terrestrial and ocean ecosystems"), because they overlap with KRK 7 and 8. Moreover, papers were not classified according to KRK 8 (Peace & mobility), since no papers reviewed this issue. Instead, a new category was created named "Community adaptation", given the considerable number of papers that tackled this issue. Therefore, Graph 3 classifies the papers found according to KRK C to G as presented in O'Neill et al. (2022), in addition to the new category community adaptation**.** Each paper was classified in a non-mutually exclusive way according to each category. As a result, one paper might discuss one or more KRK if this was the case within the research questions or objectives of the paper.

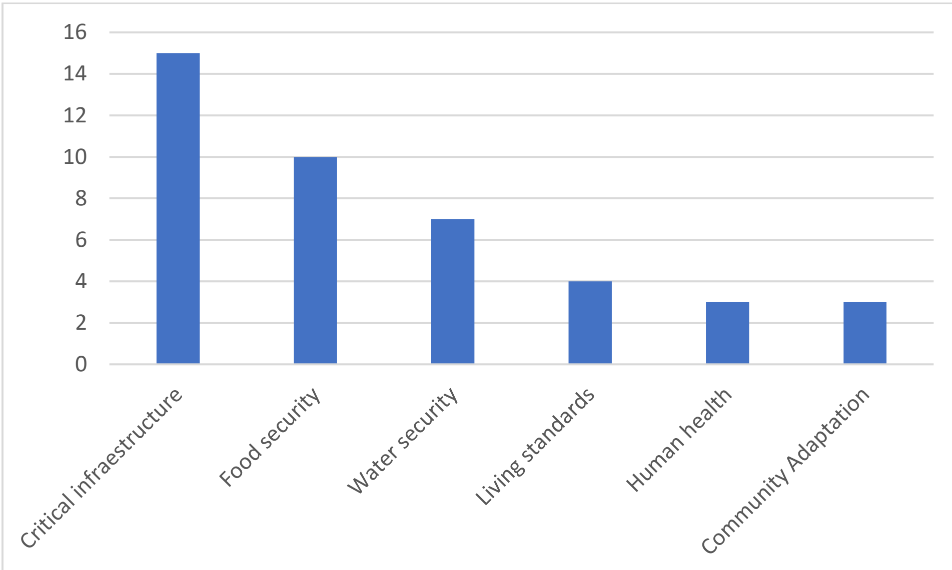
According to Graph 3, it is possible to identify 3 different groups of papers according to its popularity. Critical infrastructure[2] and Food Security[3] seem to be the most popular topics, given that there are 15 and 10 papers that discuss each topic respectively. Water security stems as a topic with intermediate relevance, because there are 7 papers revolve around this issue. Finally, the least

[2] Critical infrastructure refers to "Systemic risks due to extreme events leading to the breakdown of physical infrastructure and networks providing critical goods and services (O'Neill et al., 2022, p. 58-59)."

3 This type of risks refers to the breakdown of food systems due to climate change effects on land or ocean resources (O'Neill et al., 2022).

explored topics are Living standards[4], Human Health[5] and Community adaptation, which only discussed 11 papers in total.

Graph 3. Classification of papers according to KRK of the IPCC ARC WG2 report, number of papers that discuss each issue.



Source: Own elaboration with different sources.

Diagram 2 presents a more in-depth analysis of the research questions, objectives and particular topics addressed by each of the papers found. Each paper was classified according to the six-fold categorization presented earlier. As it was discussed before, each paper might belong to one or more categories. However, to facilitate the exposition, in Diagram 2 each paper was classified into only one out of the six risks, the one that it was chosen to be more relevant for each paper. In addition, for category of critical infrastructure the topics were further divided into four sub-categories: green infrastructure, ecosystem services, spatial land use planning and storm surges. Papers dealing with human health issues contains those papers which mostly address urban pollution and municipal waste.

[4] Economic impacts across scales, including impacts on Gross Domestic Product (GDP), poverty, and livelihoods, as well as the exacerbating effects of impacts on socio-economic inequality between and within countries (O'Neill et al., 2022).

[5] Human mortality and morbidity, including heat related impacts and vector-borne and water-borne diseases (O'Neill et al., 2022).

Papers classified within the critical infrastructure section seem to address green or grey infrastructure for coastal defense protection, as well as spatial land-use planning. Firstly, papers that tackle green infrastructure focus on the analysis of coral reefs (Hafezi et al., 2021) or urban infrastructure such as green roofs, infiltration storage facilities, infiltration reservoir, and porous pavement (Song & Chon, 2018). Another strand of literature focus on the measurement of ecosystem services for the case of tourism (Oliveira et al., 2022), as well as for integrated assessment process and land-use management (Videira et al. 2012; You et al. 2018). The case of spatial land-use planning is explored for the case of the wetlands in South Korea by Song et al. (2021), whilst Ko (2012) presents a more general framework to be used in different coastal areas. Finally, four papers deal with the relationship between grey infrastructure and the impacts of storm surges. By employing system dynamics modelling and geographical information systems, Moradi & Kabiri (2020) assess the impacts of storm surges in Iran, meanwhile Hartt (2014) focuses on the case of the Prince Edward Island in Canada. The work of Karamouz & Olyaei (2017) simulates the impacts of water level variation during storms on the coastal infrastructure of New York. Woodruff et al. (2018) investigate community adaptation strategies and infrastructure investment against sea level rise induced by storms.

Food security remains as an underexplored topic, whereas research about water security has been more extensive. For instance, for the case of food security there are only two papers that mainly deal with this issue. On the one hand, the work of Chapman (2016) studies the impacts of rice-sediments in the agriculture development of Vietnam. On the other hand, Zhao et al. (2022) use an integrated land-sea dynamics model to study the complex relationship between tourism, fisheries, transportation and sustainable development. Papers dealing with water security have mostly studied cases in Vietnam, either focusing on coastal freshwater systems (Phan et al. 2018), surface water resources (Tuu et al. 2020) or water scarcity induced by agricultural practices (Thanh et al. 2020).

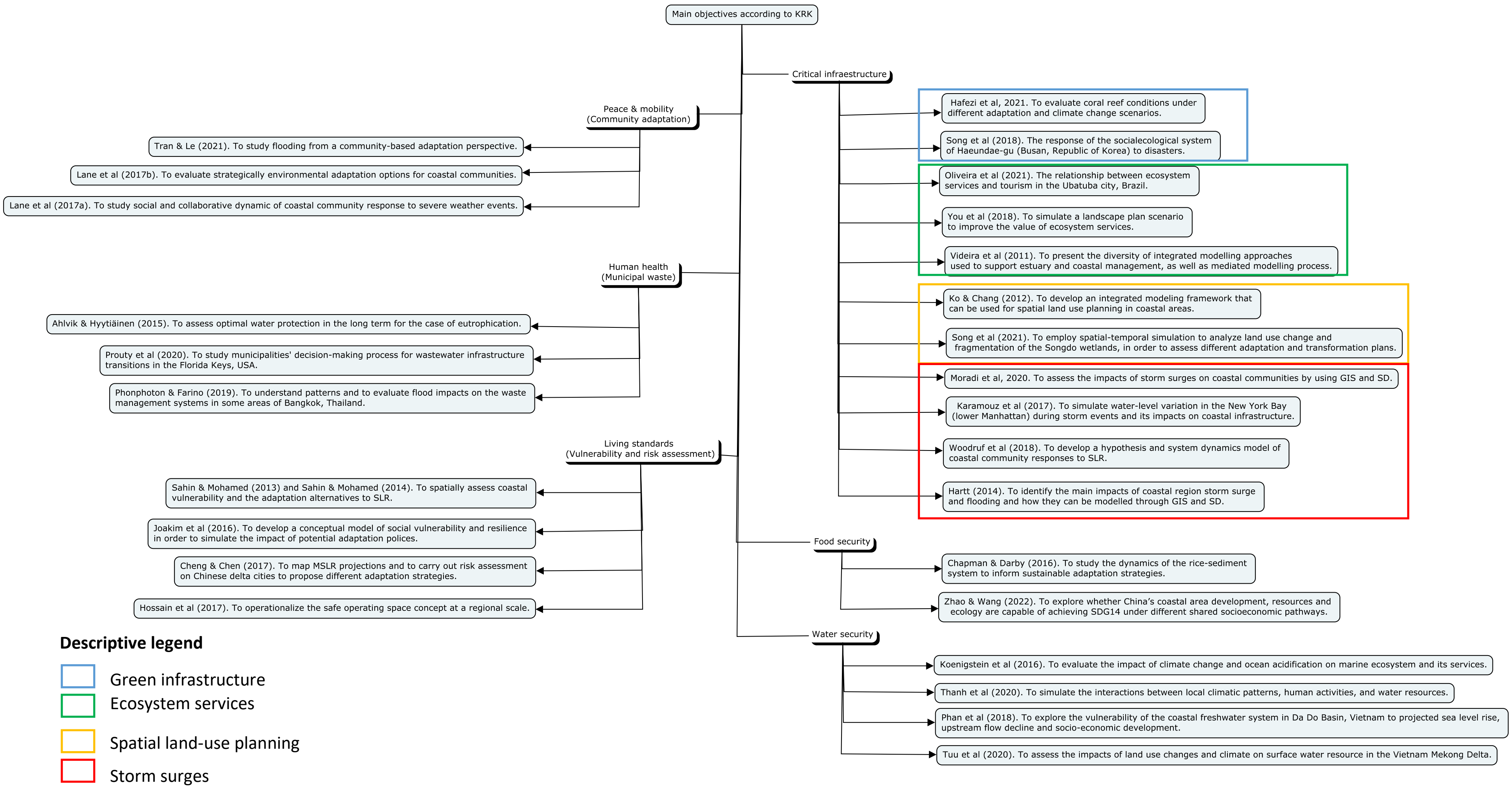
Papers that revolve around living standards have mostly focused on the analysis of vulnerability, risk assessment and resilience. Sahin (2013) & Sahin (2014) have developed different ways to measure coastal vulnerability against sea level rise, either by using SD modelling, GIS or a combination of both. Cheng (2017) has mapped mean sea level rise projections to carry out risks assessments, whilst Joakim et al. (2016) have focused on the measurement of social vulnerability and resilience by including a broad group of social variables (poverty, social networks, mobility, household structure, etc.). The work of Hossain et al. (2017) further contributes to the study of resilience, by operationalizing the concept of safe operation space across water and agriculture sectors for the case of Bangladesh.

With regards to the human health section, most of the papers tackled the issue of municipal waste. The waste-water infrastructure transition is analyzed for the case of Florida Keys by Prouty & Zhang (2020), whereas the impacts of floods in this type of infrastructure is studied by Phonphoton

(2019). A different approach is taken by Ahlvik & Hyytiäinen (2015), who develop an integrated assessment model to study eutrophication processes in the Baltic sea.

Papers dealing with community adaptation are still in early stages, as long as only 3 papers discuss this type of issues. For instance, the paper written by Tran (2021) study different community adaptation strategies to respond to flood events. Lane & Moll (2017) and Lane et al. (2017) offer novel approaches about how to model community social capacity and social networking in the light of extreme events, particularly severe storms.

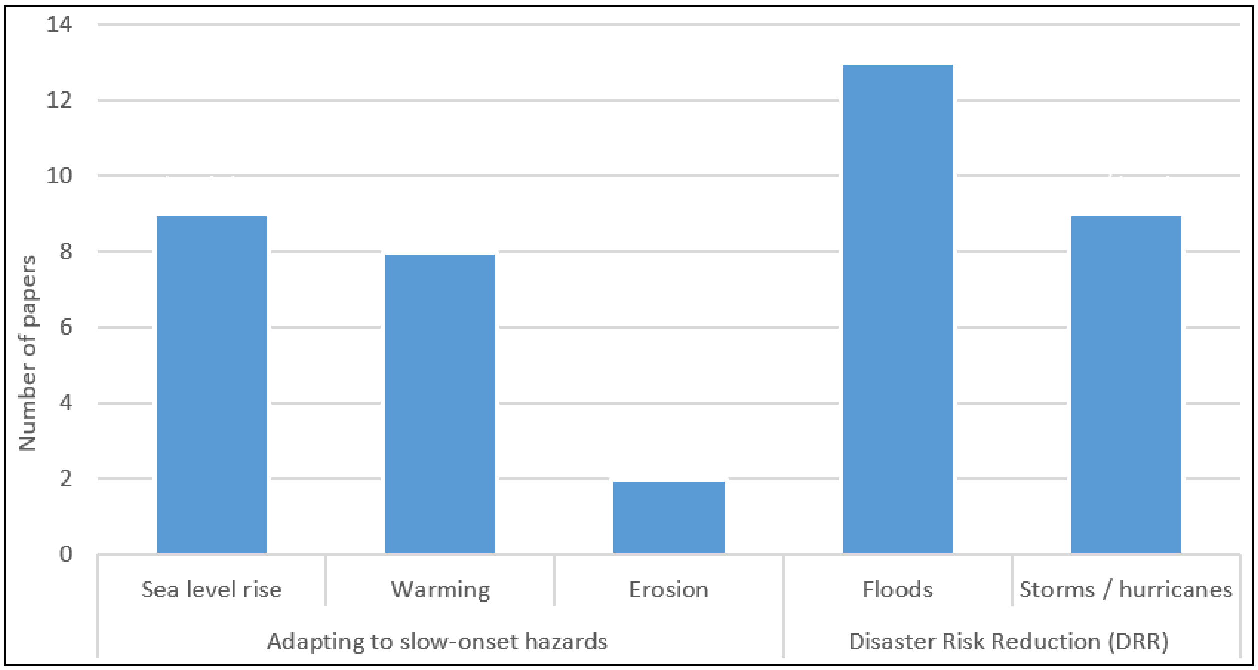
Diagram 2. Main objectives of the papers found sorted by KRK and subcategories.



Source: Own elaboration with different sources with the software CmapTools.

Another useful categorization stems from the distinction made by the Cooley et al. (2022) between two different adaptation strategies: adaptation to slow onset hazards (SOH) and that of climate variability and disaster risk reduction (DRR). The first group of adaptation strategies encompasses those process that would gradually have an impact along coastal areas, such as sea-level rise, warming of oceans and erosion. On the other hand, an increase of climate variability expected in the coming years might increase the frequency and intensity of some extreme weather events, like floods, storms and hurricanes. Graph 4 classifies the papers according to two adaptation strategies mentioned earlier. It is interesting to notice that both categories SOH and DRR have been more or less equally addressed by researchers using SD modelling, since there are a similar number of papers that discuss each of these issues. Nevertheless, within hazards classified as SOH, sea level rise and warming issues are among the most explored. Erosion issues have not gained much attention since only two papers address this topic. With regards to DRR, floods are the most studied topic followed closely by storms and hurricanes.

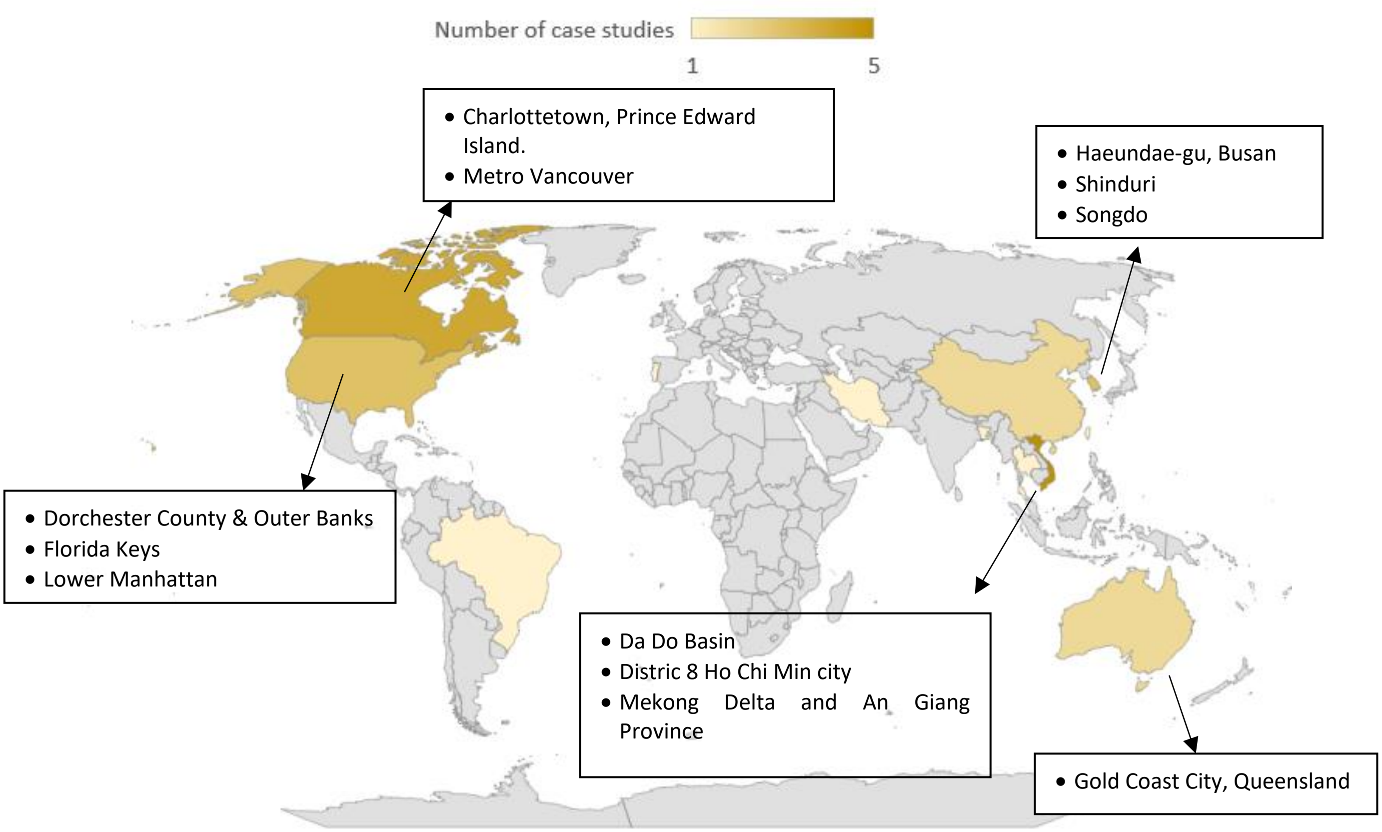
Graph 4. Type of risks analyzed in each paper, number of papers that discuss each issue.



Source: Own elaboration with different sources.

An overview of the most important case studies analyzed around the world is presented in Map 1. The countries that have been studied the most in terms of numbers of papers published are Vietnam, Canada, Korea and the USA which respectively have 5, 4, 3 and 3 papers (countries colored in strong yellow). The most important regions or local cases studies studied within these countries are located in black boxes. A second group of countries consists of Australia and China, with two papers each one (medium yellow). Another category that it is not depicted in this map belongs to those papers that investigate a region that compasses two or more countries. That is the case of 2 papers that address the cases of the Baltic Sea, the Barents Sea and the Northern Norwegian Sea. Finally, the group of countries colored in light yellow are those for which there is only one paper that studies a region or local area within the country. This is the case of Bangladesh, Brazil, Iran, Portugal, Taiwan, Thailand and the island of Vanuatu.

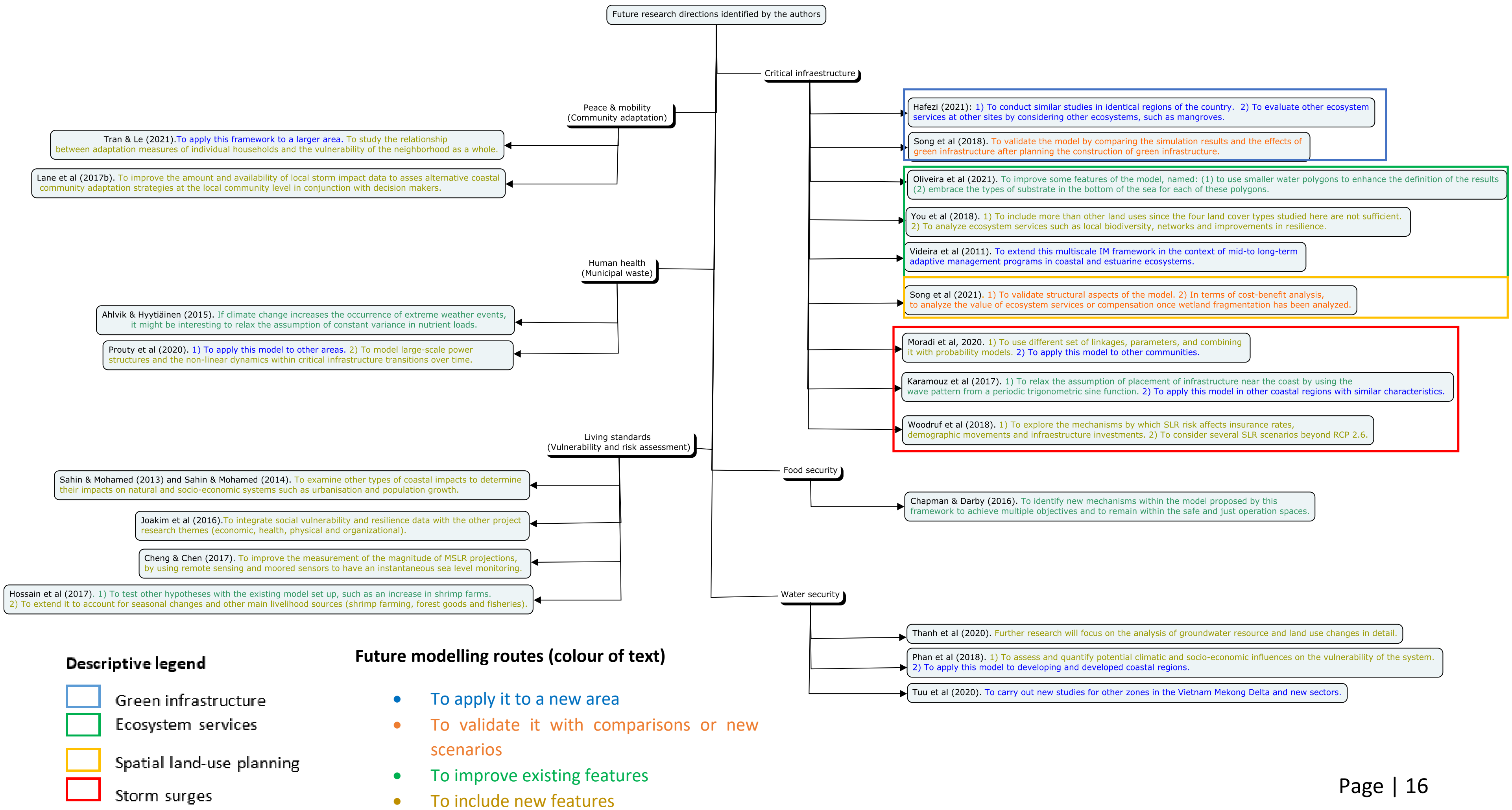
Map 1. Geographical scope of the papers selected. Number of local or regional case studies by country. Important regions or case studies within black boxes.



Source: Own elaboration with different sources.

Diagram 3 was constructed to identify the potential modeling routes proposed by the authors themselves. The future research directions of each paper were classified according to the six KRK utilized before, whenever they were identified by the authors. Overall, four modelling routes were proposed: to apply the model to a new area (blue color), to validate it with new scenarios or comparisons, to improve existing features of the model or to include new ones. Firstly, within the category "Critical infrastructure", a great number of authors propose to apply their models to other regions or to include new features. This might signal that those models dealing with risks to critical infrastructure might be in a later stage of development, or that they are abstract enough to be applied in a broader context. Models dealing with water security issues also follow this trend, whereas those tackling food security are still scarce to draw some insights. It seems that authors working on living standards and peace & mobility topics usually aim to include new features for their existing models. Models classified within the human health category propose different routes, such as applying them to new areas, including new features and refining existing ones.

Diagram 3. Main future research directions sorted by KRK and its subcategories.

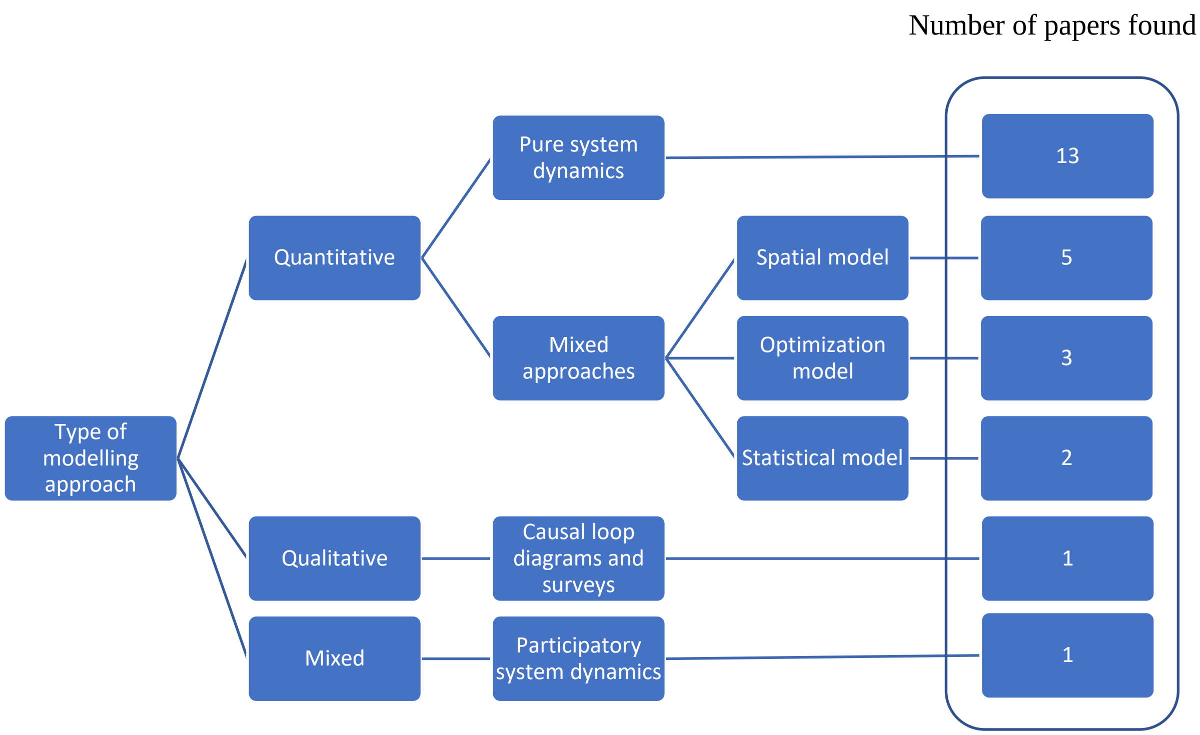


Source: Own elaboration with different sources with the software CmapTools.

c. The most relevant methods and technical features

System dynamics models have employed different types of modelling approaches, such as quantitative, qualitative or mixed approaches. Diagram 4 summarizes the papers retrieved according to the type of SD modelling approach followed by the authors. It is worth noting that most of the papers found have been quantitative and they have not been complemented with other methods. In total 13 papers that meet this criterion were found. However, an increasing body of literature has developed more complex models that complement the capacities of SD modelling with spatial, optimization or statistical modelling. SD models that take a spatial approach are those of Song et al (2021), Moradi et al (2020), Sahin (2013a & 2013b), Ko & Chang (2012). SD models have also been complemented with different optimization models, such as analytical Hierarchy Procecess (Sahin, 2013a), multi-objective objective programming (Ko & Chang, 2012) and stochastic dynamic programing (Ahlvik & Hyytiäinen, 2015). With respect to those that include statistical methods, Hafezi (2021) complements SD modelling with Bayesian networks, whilst Ahlvik & Hyytiäinen (2015) add Bayesian learning in a stochastic dynamic programing problem. Only one paper followed a qualitative approach that consisted in causal loop diagrams and interviews for integrated coastal area management in Egypt (Sano, 2014). Finally, the work of Dao & Huong, 2021 present a mixed approach: a participative system dynamics model to deal with community-based adaptation against flooding.

Diagram 4. Main SD modelling approach employed; number of papers retrieved for each category.



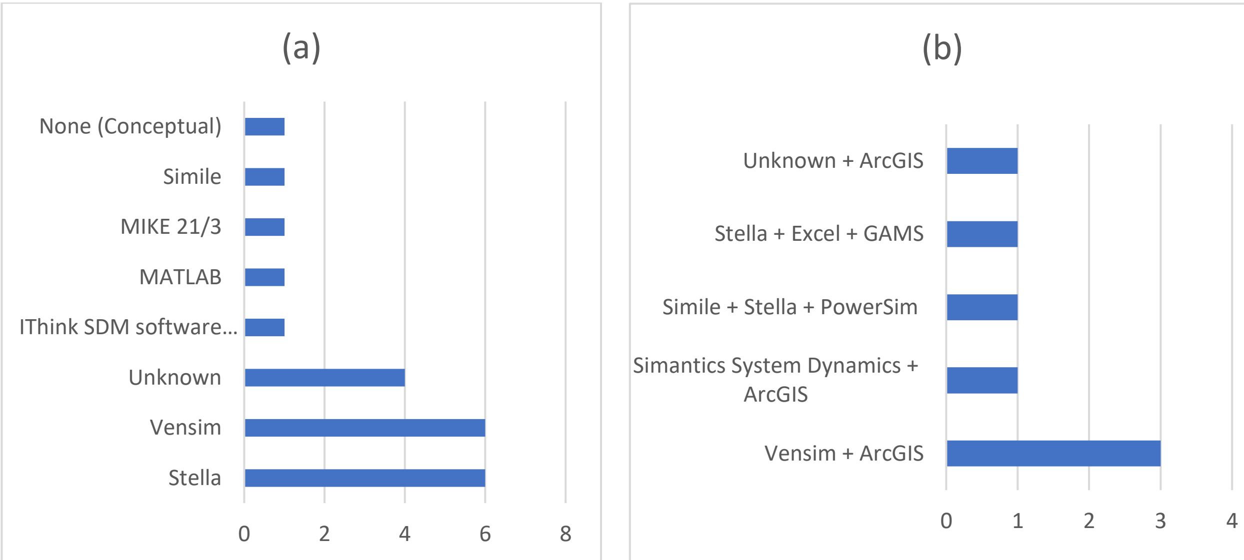
Source: Own elaboration with different sources.

One of the most important technical features of the models reviewed was the software(s) that they employ to carry out their simulations. For this reason, all the models were classified in two types: pure system dynamics models (PSDM) and hybrid system dynamics models (HSDM). PSDM encompasses all those models that only employ one software through the research, as well as that they do not employ any other complementary modelling approach, such as optimization, ABM, spatial or statistical modelling. On the contrary, HSDM usually employ more than one software, as well as one or more of the methods mentioned earlier. According to this classification, 21 papers followed a PSDM approach, whereas 7 papers relied on HSDM.

Graph 5 summarizes the different type of software used for both PSDM and HSDM. As presented in Graph 5a, Stella and Vensim appear as the most used software for the case of PSDM. The extensive number of models and previous work created with this platform might be a reason behind this. Secondly, an important number of papers do not report what type of software was employed for the simulations. This is an important drawback, since it discourages collaborative efforts to put forward the research carried out by these authors. Some marginal alternatives in terms of software are also available, such as Ithink, MATLAB, MIKE 21/3 and Simile. Some of them might be better suited to work with platforms different from Windows like Linux or Mac. One of the papers that used a PSDM followed a qualitative approach, since this work developed a conceptual model. A description of the different type of HSDM employed is shown in Graph 5b. Overall, it seems that the main purpose of having more than one modelling software is to carry out spatial analysis. This is reflected by the fact that the most popular combination of software used is that of Vensim and ArcGIS. Besides Vensim, other SD software have been used in conjunction with a GIS, such as Simile or Stella. Some other models combine SD software with other types of software to carry out optimization process, such as GAMS[6]. In this case, Microsoft Excel worked as an intermediary platform to exchange information between the simulations conducted in the SD software and the optimization software. The same issue of underreporting of software identified for PSDM is also present for HSDM, but with a significantly less importance.

[6] General Algebraic Modeling System.

Graph 5. Type of software used for the case of PSDM (a) and HSDM (b), number of papers for each software.



Source: Own elaboration with different sources.

4) Discussion

In recent years, global warming has accelerated at an increasing peace, endangering the stability of human and environmental ecosystems. The consequences of this process have been already documented, and they are expected to worsen without decisive actions at different levels. For this reason, adaptation to the future impacts of climate change becomes a worldwide priority, particularly for vulnerable areas such as coastal areas. Nevertheless, adaptation strategies for marine ecosystems remain fragmented and they lack a transformational approach, which considers the complexity of the complex evolution of socio-ecological ecosystems. System dynamics modelling approaches have been developed to deal with this type of complex phenomena. However, until now there are no studies that document how this modelling approach has addressed Climate Change Adaptation for Coastal areas. Therefore, this paper tries to fill this gap by conducting a systematic literature review, which can categorize the existing literature according to different thematic and technical criteria.

According to the bibliometric analysis conducted with the software Bibliometrix, at least two important results were obtained. According to the analysis of co-occurrence of keywords, there exist three types of broad literature clusters: one referring to either physical or social impacts; another that discuss planning for water management; and another one that discuss ecosystem services and management. An emerging cluster of literature has tried to integrate spatial modelling with SD for decision making practices. At a more particular level, the work of Chapman (2016) represents the most cited paper globally, which deals with water and agriculture adaptation strategies in Vietnam. An important concentration in the production of papers is observed within this field, since only 9 authors have published 75% of all the papers analyzed for this study (21 out of 28 papers).

A relevant finding of this work is the existence of explored and under-explored topics according to the categorization of KRK of the IPCC (ARW, G6). According to this criterion, the literature analyzed has covered more issues related to critical infrastructure, as well as food and water security. However, few papers have tackled human health, living standards and community adaptation issues. Papers classified within the critical infrastructure section seem to address green or grey infrastructure for coastal defense protection, as well as spatial land-use planning. Food security remains as an underexplored topic compared to water security, according to the number of papers published within each category. Papers that revolve around living standards have mostly focused on the analysis of vulnerability, risk assessment and resilience. With regards to the human health section, most of the papers have tackled the issue of municipal waste. Papers dealing with community adaptation are still in early stages, because only three papers discuss this type of issues. Furthermore, by employing another classification, more papers have been published that focus on Disaster Risk Reduction (DRR) compared to adaptation to slow onset hazards. Within the first category, floods and storms have been the most documented topics, whereas sea level rise and warming appear as the most relevant topics with regards to the second category.

With respect to the geographical aim of the papers, most papers have studied cases in developed countries, whereas research in developing countries remains scarce except for the case of Vietnam. Indeed, one third of the papers have analyzed cases in Canada, USA or South Korea. Within developed countries, some local areas have been studied extensively, such as the Prince Edward Island in Charlottetown (Canada) or the Gold Coast City (Austrialia). On the contrary, the research on developing countries have put emphasis in Vietnam, particularly the study of the Mekong Delta. Research has also been conducted for the case of Iran, Thailand, Brazil, Bangladesh, Taiwan and the island of Vanuatu. Nevertheless, only one paper for each country has been identified. There is also a lack of studies that focus on regional studies that encompasses one or more countries, since only two papers found followed this approach.

Models dealing with critical infrastructure issues, water security and human health seem to be in an advanced maturity stage and able to be applied in other areas, whereas those tackling food security, living standards and community adaptation issues are better suited for local modelling. By analyzing the future research directions identified by the authors, four different types of modelling routes were identified: To apply the model to other region, to validate it with new scenarios, to improve existing features or to add new features to the model. According to this classification, the authors of models found within the critical infrastructure, water security and human health propose to apply them to other regions or to validate them with new scenarios. On the contrary, authors of models within the categories of food security, living standards and community adaptation normally propose to improve existing features or to include new ones.

Regarding technical modelling issues, quantitative SD modelling has been preferred compared to qualitative or mixed approaches. The greatest share of quantitative SD models are “pure” SD models, but mixed approaches have emerged as interesting alternatives. SD models have had a better integration with spatial modelling practices, followed by optimization and statistical models. Qualitative works are very scarce, since only one model follows a purely qualitative approach by developing causal-loop diagrams, whilst another one employs a mixed approach (quantitative-qualitative) to build a participatory SD model by involving stakeholders throughout the process.

Finally, Stella and Vensim seem to be the most popular platforms employed for PSDM, while Vensim and ARCGIS have been the most relevant combination of software used for HSDM. Indeed, 57% of the papers classified as PSDM used either Vensim or Stella to run the simulations of their models. Underreporting has been considerable, since 20% of the papers does not indicate the software being used. A group of alternative software has been used, but it only represents isolated cases such as Ithink, MATLAB, Simile and MIKE 21/3. With regards to HSDM, 42% of the papers found used a combination of Vensim and ARCGIS and as much as 71% of the papers employ a combination of any SD software and ARCGIS. This reveals the relevance of the integration between SD and spatial modelling approaches. On the other hand, those models that complement SD with optimization modelling have employed Stella, Excel and GAMS to run their simulations. In this case, Excel has served as an intermediate platform to transfer the results obtained in Stella with the GAMS software and vice versa. Simile, Stella and PowerSIM have also been employed for the case of participatory modelling exercises, to facilitate the interaction with non-modelling experts and stakeholders.

5) Conclusions

This paper analyzed the evolution and state of the art of the scientific literature of climate change adaptation in coastal areas that employs SD modelling. To this end, a systematic literature review was conducted with information retrieved from two scientific datasets: ScienceDirect and Scopus. The PRISMA methodology was employed for this literature review, as well as the software RAYYAN. Later, a bibliometric analysis was conducted with the software Bilbiometrix, as well as a categorization with criteria coming from the IPCC AR6 W2 report (Cooley et al., 2022).

Seven results were obtained from the thematic analysis of the papers chosen for the analysis. Firstly, the literature seems to be clustered in three broad groups: physical or social impacts, planning for water and agriculture management, as well as ecosystem services and management. Secondly, following the KRK criteria of the IPCC, critical infrastructure, food and water security seem to be the most explored topics, but human health, living standards and community adaptation issues remain unexplored. Thirdly, more papers have been published that focus on Disaster Risk Reduction (DRR) compared to adaptation to slow onset hazards. Fourthly, most papers have studied cases in developed countries, whereas research in developing countries remains scarce except for the case of Vietnam. Fifthly, models dealing with critical infrastructure issues, water security and human health seem to be in an advanced stage or abstract enough to be applied in other areas, whereas those tackling food security, living standards and community adaptation issues are better suited for local modelling. Sixth, regarding technical modelling issues, quantitative SD modelling has been preferred compared to qualitative or mixed approaches. Finally, Stella and Vensim seem to be most popular platforms employed for PSDM, while Vensim and ARCGIS have been the most relevant combination of software used for HSDM.

Some important limitations are also worthwhile mentioning with respect to the present work. This literature review was limited to English written academic papers found in either ScienceDirect or Scopus datasets. Nevertheless, interesting papers might be already developed in other languages or datasets, particularly for the study of developing countries which seems to be scarce. Furthermore, the thematic categorization of the literature was based on different criteria coming from the latest report of the IPCC upon CCA. However, other criteria to classify the literature might be better suited to study particular challenges of Coastal areas, such as criteria coming from the 2021 EU Strategy on Adaptation to Climate Change (European-Comission, 2021). Finally, an analysis and comparison of the structure of each of the models found was omitted. The diversity of the topics found makes it difficult to compare the models, since some of them are directed towards local case studies whereas others focus on more aggregated issues.

To conclude, some future research directions are proposed to improve this literature review. Firstly, it would be interesting to analyze the modelling properties of each of the models, such as its most important modules, stocks, flows and parameters. As a second step, a comparative analysis between the models might shed light on potential intersections or complementarities between models. However, this would require a previous classification of the models, since as mentioned earlier it might become difficult to compare models that tackle different topics or that are aimed at different levels of analysis. At an advanced stage, a comparison across other types of modelling approaches might be very useful (such as ABM, GIS, etc), to identify synergies between different approaches for a given set of topics or levels of analysis.

6) References

1. [H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. O. (eds.). (2022). IPCC, 2022: Summary for Policymakers. In B. R. (eds.). [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (Ed.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (p. 40). Cambridge University Press. In Press.
2. Ahlvik, L., & Hyytiäinen, K. (2015). Value of adaptation in water protection - Economic impacts of uncertain climate change in the Baltic Sea. *Ecological Economics*, *116*, 231–240. https://doi.org/10.1016/j.ecolecon.2015.04.027
3. Chapman A., D. S. (2016). Evaluating sustainable adaptation strategies for vulnerable mega-deltas using system dynamics modelling: Rice agriculture in the Mekong Delta's An Giang Province, Vietnam, *559*.
4. Cheng H.-Q., C. J.-Y. (2017). Adapting cities to sea level rise: A perspective from Chinese deltas, *8*(2).
5. Cooley, S., D. Schoeman, L. Bopp, P. Boyd, S. Donner, D.Y. Ghebrehiwet, S.-I. Ito, W. Kiessling, P. Martinetto, E. Ojea, M.-F. Racault, B. Rost, and M. S.-M. (2022). 2022: Ocean and Coastal Ecosystems and their Services. In: Climate Change 2022: Impacts, Adaptation, and Vulnerability. In *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem,* (p. 236). Cambridge University Press. In Press.
6. Datola, G., Bottero, M., De Angelis, E., & Romagnoli, F. (2022). Operationalising resilience: A methodological framework for assessing urban resilience through System Dynamics Model. *Ecological Modelling*, *465*(May 2021), 109851. https://doi.org/10.1016/j.ecolmodel.2021.109851
7. European-Comission. (2021). *COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS*. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021DC0082&from=EN
8. Forrester, J. W. (1999). *Principles of systems*. Waltham, MA: Pegasus Communications, Inc.
9. Hafezi, M., Stewart, R. A., Sahin, O., Giffin, A. L., & Mackey, B. (2021). Evaluating coral reef ecosystem services outcomes from climate change adaptation strategies using integrative system dynamics. *Journal of Environmental Management*, *285*(February), 112082.

https://doi.org/10.1016/j.jenvman.2021.112082

10. Hartt, M. (2014). An innovative technique for modelling impacts of coastal storm damage, *1*(1).
11. Herrington, G. (2021). Update to limits to growth: Comparing the World3 model with empirical data. *Journal of Industrial Ecology*, *25*(3), 614–626. https://doi.org/https://doi.org/10.1111/jiec.13084
12. Hossain M.S. Eigenbrod F., Johnson F.A., D. J. A. (2017). Operationalizing safe operating space for regional social-ecological systems, *584*.
13. Jackson, Tim, Webster, R. (2016). *LIMITS REVISITED. A review of the limits to growth debate*. Surrey. Retrieved from http://limits2growth.org.uk/revisited/
14. Joakim E.P. Oulahen G., Harford D., Klein Y., Damude K., Tang K., M. L. (2016). Using system dynamics to model social vulnerability and resilience to coastal hazards, *12*(4).
15. Karamouz M. Olyaei M.A., Z. Z. (2017). Application of dynamic simulation modeling approach and load-resistance concept to water-infrastructure interactions in coastal areas, *143*(8).
16. Ko T.-T., C. Y.-C. (2012). An integrated spatial planning model for climate change adaptation in coastal areas, *66*.
17. Lane D. Moll R., B. S. (2017). Adaptation Decision Support: An Application of System Dynamics Modeling in Coastal Communities, *8*(4).
18. Lane D.E. Beigzadeh S., O'Sullivan T., Berkes F., Kuziemsky C., Charles A., M. R. H. H. (2017). A system model of collaborative community response to environmental emergencies, *9*(3).
19. Meadows Club of Rome., D. H. (1982). *The Limits to growth : a report for the Club of Rome's project on the predicament of mankind*. New York: Universe Books.
20. Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ*, *339*, b2535. https://doi.org/10.1136/bmj.b2535
21. Moradi M. Kabiri K., K. M. H. (2020). Integration of Geographic Information System and system dynamics for assessment of the impacts of storm damage on coastal communities - Case study: Chabahar, Iran, *49*.
22. Mulrow, C. D. (1987). The medical review article: state of the science. *Annals of Internal Medicine*, *106*(3), 485–488. https://doi.org/10.7326/0003-4819-106-3-485
23. O'Neill, B., M. van Aalst, Z. Zaiton Ibrahim, L. Berrang Ford, S. Bhadwal, H. Buhaug, D. Diaz, K. Frieler, M. Garschagen, A. Magnan, G. Midgley, A. Mirzabaev, A. Thomas, and R. W. (2022). 2022: Key Risks Across Sectors and Regions. In B. R. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem (Ed.), *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of*

Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (p. 173). Cambridge University Press. In Press.

24. Oliveira B.M. Fath B.D., Harari J., B. R. (2022). Socio-ecological systems modelling of coastal urban area under a changing climate – Case study for Ubatuba, Brazil, *468*.
25. Phan, T. D., Smart, J. C. R., Sahin, O., Capon, S. J., & Hadwen, W. L. (2018). Assessment of the vulnerability of a coastal freshwater system to climatic and non-climatic changes: A system dynamics approach. *Journal of Cleaner Production*, *183*, 940–955. https://doi.org/10.1016/j.jclepro.2018.02.169
26. Phonphoton N., P. C. (2019). A system dynamics modeling to evaluate flooding impacts on municipal solid waste management services, *87*.
27. Prouty C. Zhang Q., M. S. (2020). Extreme weather events and wastewater infrastructure: A system dynamics model of a multi-level, socio-technical transition, *714*.
28. Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., … Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475. https://doi.org/10.1038/461472a
29. Sahin O., M. S. (2013). A spatial temporal decision framework for adaptation to sea level rise, *46*.
30. Sahin O., M. S. (2014). Coastal vulnerability to sea-level rise: A spatial-temporal assessment framework, *70*(1).
31. Scrieciu, S., Rezai, A., & Mechler, R. (2013). On the economic foundations of green growth discourses: The case of climate change mitigation and macroeconomic dynamics in economic modeling. *Wiley Interdisciplinary Reviews: Energy and Environment*, *2*(3), 251–268. https://doi.org/10.1002/wene.57
32. Song K. Chon J., Y. S. (2018). Simulation modeling for a resilience improvement plan for natural disasters in a coastal area, *242*.
33. Song K. Han H.-J., Chon J., C. Y.-E. (2021). Adaptation and transformation planning for resilient social-ecological system in coastal wetland using spatial-temporal simulation, *789*.
34. Terezinha Rother, E. (2007). Revisão sistemática X revisão narrativa. *Acta Paulista de Enfermagem. Escola Paulista de Enfermagem, Universidade Federal de São Paulo*, *20*(2), 5–6.
35. Thanh T.N. Kim S., Phuong T.N., Mong T.L., Tuan P.V., T. V. P. D. (2020). A subregional model of system dynamics research on surface water resource assessment for paddy rice production under climate change in the Vietnamese mekong delta, *8*(3).
36. Tran T., L. L. (2021). System dynamics approach for understanding scheme of Community-Based Adaptation to flooding: The case of a flood-prone district in Vietnamese urban city.
37. Tuu N.T. Kim S., Tri V.P.D., Kim H., Kim J., L. J. (2020). Surface water resource assessment of

paddy rice production under climate change in the Vietnamese mekong delta: A system dynamics modeling approach, *11*(2).

38. Videira N. Antunes R., Santos R., Boumans R., van den B. M. (2012). Integrated Modeling of Coastal and Estuarine Ecosystem Services, *12*.
39. Woodruff, S., BenDor, T. K., & Strong, A. L. (2018). Fighting the inevitable: infrastructure investment and coastal community adaptation to sea level rise. *System Dynamics Review*, *34*(1–2), 48–77. https://doi.org/10.1002/sdr.1597
40. You S. Lee J., Chon J., K. M. (2018). Coastal landscape planning for improving the value of ecosystem services in coastal areas: Using system dynamics model, *242*.
41. Zhao Y. Wang X., L. Y. (2022). The land-sea system dynamics model with shared socioeconomic pathways can identify the gaps in achieving Sustainable Development Goal 14, *181*.
42. Zomorodian, M., Lai, S. H., Homayounfar, M., Ibrahim, S., Fatemi, S. E., & El-Shafie, A. (2018). The state-of-the-art system dynamics application in integrated water resources modeling. *Journal of Environmental Management*, *227*, 294–304. https://doi.org/https://doi.org/10.1016/j.jenvman.2018.08.097

7) Annexes

Annex 1

Scopus String

((TITLE-ABS-KEY (system-dynamics AND {sea level} AND ris*) OR TITLE-ABS-KEY ({system dynamics} AND {sea level} AND ris*) OR TITLE-ABS-KEY (sd AND {sea level} AND ris*) OR TITLE-ABS-KEY (sdm AND {sea level} AND ris*) OR TITLE-ABS-KEY (system-dynamics AND sea-level AND ris*) OR TITLE-ABS-KEY ({system dynamics} AND sea-level AND ris*) OR TITLE-ABS-KEY (sd AND sea-level AND ris*) OR TITLE-ABS-KEY (sdm AND sea-level AND ris*) OR TITLE-ABS-KEY (system-dynamics AND slr) OR TITLE-ABS-KEY ({system dynamics} AND slr) OR TITLE-ABS-KEY (sd AND slr) OR TITLE-ABS-KEY (sdm AND slr) OR TITLE-ABS-KEY (system-dynamics AND flood*) OR TITLE-ABS-KEY ({system dynamics} AND flood*) OR TITLE-ABS-KEY (sd AND flood*) OR TITLE-ABS-KEY (sdm AND flood*) OR TITLE-ABS-KEY (system-dynamics AND storm) OR TITLE-ABS-KEY ({system dynamics} AND storm) OR TITLE-ABS-KEY (sd AND storm) OR TITLE-ABS-KEY (sdm AND storm) OR TITLE-ABS-KEY (system-dynamics AND erosion) OR TITLE-ABS-KEY ({system dynamics} AND erosion) OR TITLE-ABS-KEY (sd AND erosion) OR TITLE-ABS-KEY (sdm AND erosion)) AND TITLE-ABS-KEY (adapt*)) OR (TITLE-ABS-KEY (system-dynamics AND coast*) OR TITLE-ABS-KEY ({system dynamics} AND coast*) OR TITLE-ABS-KEY (sd AND coast*) OR TITLE-ABS-KEY (sdm AND coast*)) AND (LIMIT-TO (SRCTYPE , "j") OR LIMIT-TO (SRCTYPE , "b")) AND (LIMIT-TO (LANGUAGE , "english"))

ScienceDirect String

- ("system dynamics" OR sd OR sdm) AND (coast OR coastal)
- ("system dynamics" OR sd OR sdm) AND ((adapt OR adaptation) AND ("rising sea level" OR "sea level rise" OR ("sea level" AND rise)))
- ("system dynamics" OR sd OR sdm) AND ((adapt OR adaptation) AND (flood OR flooding OR storm OR erosion))
- ("system dynamics" OR sd OR sdm) AND ((adapt OR adaptation) AND (ecosystem))

Annex 2. List of repeated and excluded words from the co-occurrence network map

Developed	systems
Social	analysis
Economic	modelling
Results	modeling
Developed	model
Sd	models
Study	study
Data	paper
Based	papers
Change	results
research	framework
current	communities
dynamic	

Annex 3. Spreadsheet to categorize and classify each paper selected for the analysis

Once that the PRISMA method is carried out, a final set of papers was analyzed through a different series of criteria coming from the IPCC sixth assessment report, as well as other information that it was deemed relevant. An online version of this dataset can be accessed here: https://www.dropbox.com/scl/fi/m9k172kl9dz0uwybxldcq/Paper-SD-modelling-Clean-Excel-file-for-Working-Paper.xlsx?dl=0&rlkey=zpxze1yqdki5z5ybc3sbdpzen. Table A summarizes the categories used to classify the papers, the type of variables and how the information was processed. The criteria highlighted in blue depicts those variables or information that are quantitative and that usually were obtained directly from the source. Criteria in green color has a qualitative nature and it usually was obtained by reading each of the papers. Information highlighted in yellow represent information that has a quantitative and dichotomous nature; however it was left to the author to decide whether each paper met or not those criteria. As a result, variables in yellow have a strong subjective nature and hence they might be subject of debate.

Table A. Description of the criteria used to classify each paper selected for the literature review. Quantitative variables highlighted in blue color, qualitative ones in green, dichotomous & subjective variables in yellow.

Criteria	Description of variable or information
Main information	ID
	Authors
	DOI
	Publication Year
General overview	Document type
	SDGs 2021 (As retrieved from Scopus)
	Is it a literature review (1/0) ?
	Is it Empirical (1) or Theoretical (0) ?
	Research questions
	Main Results
	Is it SES (Socio-ecological system) model (1/0) ?
General modelling features	Is it an IAM (Integrated Assessment Model), (1/0) ?
	Modelling technique described in the Methods Section (ABM/SD/combination.)
	Is it a Pure system dynamics model (1) or is it hybrid system dynamics model (0) ?
	Is it a spatial model (1/0) ?
	Model's name, if available
	Partnerships (institutions, authorities, organizations..)
Particular modelling features	Software used
	Is the code freely available (1/0) ?
	Can it be generalized (1/0) ?
Inclusion criteria	Is it related to Climate Change Adaptation (1/0) ?
	Is it related to coastal areas (1/0) ?
Geography	Scale of analysis (local, regional, global)
	If local, geographic area
	Country

Adapting to slow-onset hazards	Warming (1/0) ?
	Sea level rise (1/0) ?
	Erosion (1/0) ?
Disaster Risk Reduction (DRR)	Floods (1/0) ?
	Storms / hurricanes (1/0) ?
Representative Key Risks (RKRs)	Critical infrastructure (1/0) ?
	Living standards (1/0) ?
	Human health (1/0) ?
	Food security (1/0) ?
	Water security (1/0) ?
	Peace and Mobility (Community adaptation) (1/0) ?

Source: Own elaboration.

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“NOTE DI LAVORO” PUBLISHED IN 2022

1. 2022, Daniele Crotti, Elena Maggi, Evangelia Pantelaki, Urban cycling tourism. How can bikes and public transport ride together for sustainability?
2. 2022, Antonio Acconcia, Sergio Beraldo, Carlo Capuano, Marco Stimolo, Public subsidies and cooperation in research and development. Evidence from the lab
3. 2022, Jia Meng, ZhongXiang Zhang, Corporate Environmental Information Disclosure and Investor Response: Empirical Evidence from China's Capital Market
4. 2022, Mariagrazia D'Angeli, Giovanni Marin, Elena Paglialunga, Climate Change, Armed Conflicts and Resilience
5. 2022, Davide Antonioli, Claudia Ghisetti, Massimiliano Mazzanti, Francesco Nicolli, The economic returns of circular economy practices
6. 2022, Massimiliano Mazzanti, Francesco Nicolli, Stefano Pareglio, Marco Quatrosi, Adoption of Eco and Circular Economy-Innovation in Italy: exploring different firm profiles
7. 2022, Davide Antonioli, Claudia Ghisetti, Stefano Pareglio, Marco Quatrosi, Innovation, Circular economy practices and organisational settings: empirical evidence from Italy
8. 2022, Ilenia Romani, Marzio Galeotti, Alessandro Lanza, Besides promising economic growth, will the Italian NRRP also produce fewer emissions?
9. 2022, Emanuele Ciola, Enrico Turco, Andrea Gurgone, Davide Bazzana, Sergio Vergalli, Francesco Menoncin, Charging the macroeconomy with an energy sector: an agent-based model
10. 2022, Emanuele Millemaci, Alessandra Patti, Nemo propheta in Patria: Empirical Evidence from Italy
11. 2022, Daniele Valenti, Andrea Bastianin, Matteo Manera, A weekly structural VAR model of the US crude oil market
12. 2022, Banchongsan Charoensook, On Efficiency and Stability in Two-way Flow Network with Small Decay: A note
13. 2022, Shu Guo, ZhongXiang Zhang, Green credit policy and total factor productivity: Evidence from Chinese listed companies
14. 2022, Filippo Bontadini, Francesco Vona, Anatomy of Green Specialisation: Evidence from EU Production Data, 1995-2015
15. 2022, Mattia Guerini, Fabio Vanni, Mauro Napoletano, *E pluribus, quaedam*. Gross domestic product out of a dashboard of indicators
16. 2022, Cinzia Bonaldo, Fulvio Fontini, Michele Moretto, The Energy Transition and the Value of Capacity Remuneration Mechanisms
17. 2022, Giovanni Marin, Francesco Vona, Finance and the Reallocation of Scientific, Engineering and Mathematical Talent
18. 2022, Anna Laura Baraldi, Erasmo Papagni, Marco Stimolo, Neutralizing the Tentacles of Organized Crime. Assessment of Anti-Crime Measure in Fighting Mafia Violence
19. 2022, Alexander Golub, Jon Anda, Anil Markandya, Michael Brody, Aldin Celovic, Angele Kedaitiene, Climate alpha and the global capital market
20. 2022, Jlenia Di Noia, Agent-Based Models for Climate Change Adaptation in Coastal Zones. A Review
21. 2022, Alberto Gabino Martínez-Hernández, System Dynamics modelling and Climate Change Adaptation in Coastal Areas: A literature review

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