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Review

Coastal Socio-Ecological Systems Adapting to Climate Change: A Global Overview

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Abstract: A systematic literature review was conducted on papers studying coastal socio-ecological systems (SESs) in adapting to climate change to support sustainable coastal management and contribute to achieving the UN SDGs. We selected, analyzed, and synthesized 173 peer-reviewed, English-language scientific publications using the PRISMA method. Firstly, we summarized and compared the selected literature; then, we explored its geographical distribution and respective coastal landscapes, and we identified and classified the adaptation strategies focused on different coastal landscapes. Furthermore, we processed the results obtained to develop a unique conceptual model based upon the DPSIR framework for coastal SESs adapting to climate change. This review shows a gradual increase in the number of published papers, particularly after the Paris Agreement, with an uneven distribution across the world. The number of papers and case studies was lower in highly vulnerable coastal areas, with the exception of Bangladesh. Most of the literature presented a local perspective rather than a national or transnational one, focusing more on vulnerability assessment than adaptation strategies. Recent studies have shown an increasing focus on ecosystem-based adaptation. Institutional and financial support are reported as the main constraints on ensuring long-term monitoring and beneficial impacts.

Keywords: coastal areas; landscapes; ecosystem services; climate change; SESs; vulnerability; adaptation; sustainability; DPSIR; SDGs

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1. Introduction

According to the Intergovernmental Panel on Climate Change (IPCC), the term 'coastal' can be used both for "the land near the sea" and for "that part of the marine environment that is strongly influenced by land-based processes" [1]. Unfortunately, the landward and seaward limits of coastal zones are not consistently defined across the globe, but from a functional viewpoint, coastal areas comprise the extent of a landscape affected by coastal processes and the ecosystems they support without limiting them to a particular geographical entity or spatial periphery [2]. Therefore, coastal areas can also be defined as complex and adaptive socio-ecological systems (SESs) near the sea. Coastal SESs are composed of social (e.g., coastal settlements, ports, seawalls, tourism, laws, and policies) and ecological (e.g., beaches, lagoons, estuaries, mangroves, and coral reefs) dimensions that interact continuously and at different scales [3,4]. These coastal systems constitute approximately 5% of the earth's surface [2] and provide essential ecosystem services (ESs) that contribute to individuals' well-being, supporting the development of the Blue Economy [5–7]. They provide habitat for about 40% of the world's population, who directly or indirectly depend on coastal ecosystem services (ESs) for their livelihoods and socio-economic welfare [8], and this percentage is expected to rise in the upcoming decades [9,10]. Coastal ESs include provisioning (e.g., food, fish, timber, fuel), regulating (e.g., carbon sequestration, storm and surge protection, erosion control), supporting (e.g., soil formation, nutrient cycling, water cycling, biodiversity conservation), and cultural services (e.g., recreation and tourism) [11]. For example, lagoons, saltmarshes, and estuaries provide critical nesting, foraging, and resting homes for many fish and wildlife species for which there is high conservation concern as well as essential nursery and refuge habitats for commercially and recreationally important fish and invertebrates [12]. Moreover, coastal ESs contribute to reducing greenhouse gas emissions by sequestering and storing blue carbon [13] with high efficiency: the carbon sequestration rate of mangrove forests is four times higher than that of other tropical forests [14]. The protection and valorization of coastal areas are important pillars of sustainable development, acknowledged by the United Nations as one of its 17 Sustainable Development Goals (SDGs) [15,16], specifically SDG 14, particularly Target 14.2, which focuses on protecting and restoring coastal ecosystems, and Target 14.5, focusing on conserving coastal and marine areas.

Coastal areas are vulnerable to climate change and its related threats (e.g., sea-level rise, storm surges, tsunamis, coastal flooding, coastal erosion, saline water instruction, and so on) [17–21]. According to the Sixth Assessment Report of the IPCC, the global mean sea level increased by 17 cm during the 20th century and is still rising at an increasing pace [22]. The IPCC also projected that once-in-100-years coastal foods might have a devastating impact on 176 to 880 million people by 2100 (based on the IPCC's high-risk climate change scenario, RCP 8.5) [23]. Saltwater intrusion is expected to significantly impact the distribution and abundance of many flora and fauna [20]. For instance, due to the increase in salinity, the density of mangrove forests is declining, and they are increasingly being replaced with salt-tolerant shrubs and herbaceous plants, resulting in reduced carbon storage [14]. Neogi et al. [24] reported that tropical cyclonic storms increased by 26% from 1881 to 2001, damaging coastal biodiversity and its ESs.

Serving to address these challenges effectively, climate change adaptation (CCA) involves adjusting and preparing coastal SESs to prepare and respond to current and expected impacts, aiming to reduce risks, enhance resilience, and confirm coastal communities' long-term sustainability and security, with social–ecological interactions acting as vital components of coastal adaptation [25]. In general, CCA refers to adjustment, moderation, or changes to SESs to avoid or recover from the effects of climate change or take advantage of beneficial opportunities from the adaptation process [22]. Resilience, vulnerability, and adaptive capacity are three key concepts applied to understanding how SESs respond to climate change [26,27]. Resilience here refers to the capacity of a coastal SES to absorb disturbances (due to climate change or associated threats) and reorganize to continue the same functions, structures, identity, and response [28,29]. Vulnerability describes the propensity or predisposition of an SES to be adversely affected, encompassing a variety of concepts and elements including sensitivity or susceptibility to harm and a lack of capacity to cope and adapt [1]. Adaptive capacity is the ability of human actors and communities to respond to change and maintain human well-being over time [30,31]. In coastal SESs, adaptation to climate change and its sustainability requires sufficient information on risks and vulnerabilities in order to find suitable adaptation options (e.g., physical and structural methods, nature-based solutions, and other approaches) to reduce risks.

Over the last two decades, following the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) in 2005 and the Paris Agreement in 2015, there has been a global rise in scientific publications on adaptation to climate change impacts [32,33]. Similarly, there has also been an increase in the number of scientific studies focusing on coastal adaptation [5]. Despite these efforts, progress on successful adaptation remains limited and not explicitly focused on climate adaptation [32], particularly in the climate-prone regions of poor and developing countries [34]. Moreover, the literature on coastal-site-specific (e.g., beach, lagoon, island, mangroves, and other low-lying areas) adaptation strategies is scanty. Systematic reviews provide a significant opportunity to discover and examine broad trends and methodological advancements for adaptation through large datasets over long periods [35,36]. Therefore, our study aims to systematically review scientific publications to identify relevant studies on coastal socio-ecological systems (SESs) in terms of their adaptation to climate change. To achieve this, we have addressed the following specific objectives: (1) we reviewed, summarized, and compared the scientific literature concerning coastal SESs and their adaptation to climate change; (2) we explored the geographical distribution of the empirical literature and different coastal landscapes/ecosystems (e.g., forests, lagoons, estuaries, rural, urban, etc.); (3) we identified and classified the adaptation strategies focusing on different coastal landscapes/ecosystems; and (4) we propose the DPSIR (Driver Pressure State Impact Response) framework for coastal SESs in terms of their adaptation to climate change to elaborate the findings of this review and provide a synoptic view, with an emphasis on causal relationships within the SESs and with exogenous drivers. Through the DPSIR formalization, we allocate the main outcomes of the review to each of five nodes, and we explore how the different response measures proposed so far are expected to act on the other nodes, particularly how they may allow SESs to adapt to climate change impacts. To the best of our knowledge, this is the first attempt at a study with such scope and objectives.

2. Methodology

2.1. Systematic Literature Review

This review included four types of relevant literature on the topic, as mentioned earlier, covering (i) socio-ecological systems (SESs), (ii) vulnerability assessments (VAs), (iii) resilience (RS), and (iv) adaptation approaches (AAs), selected according to the multi-step Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) methodology. PRISMA is used to examine a clearly formulated question using systematic and explicit methods to identify, select, and critically evaluate relevant research and collect and analyze data from the studies included in a review [37]. Therefore, the use of PRISMA confirms the consistency of the research process and the excellence of the results, minimizing bias through a standardized procedure and identifying gaps and future research pathways [38]. In this study, the consistency and standardization of the PRISMA are guaranteed through three main steps: (i) literature identification, (ii) literature screening, and (iii) literature inclusion (Figure 1).

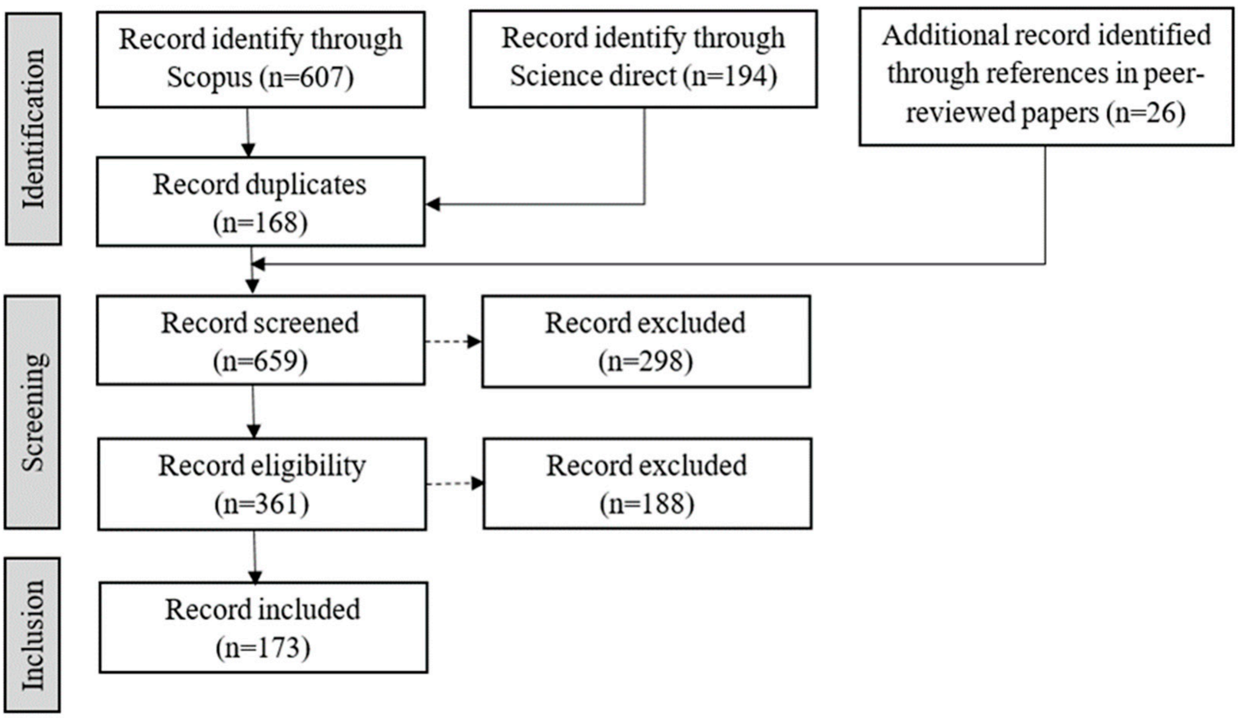

Figure 1. Systematic review process including the number of studies (*n*).

2.1.1. Literature Identification

We used the Scopus and Science Direct databases for the systematic literature search, which covered many peer-reviewed scientific studies. The search string was limited to the title, abstract, and keywords to control for the number of results. The search string was designed to retrieve as much literature that addressed various SES approaches to coastal area adaptation to climate change as possible. Therefore, we used variations of four sets of keywords (Table 1), with one set corresponding to each type of literature (SES, VA, RS, and AA). The search was conducted until April 2024, downloading only English language and peer-reviewed articles. This search identified 801 records in the two databases (607 records on Scopus and 194 on Science Direct). Of this number, 168 were duplicates and thus removed before the screening. Out of these two databases, we identified 26 additional records through references in peer-reviewed articles and considered them for screening (Figure 1).

Table 1. Search description and keywords used in the systematic literature review.

Literature Types	Search Description	Databases and Identified Literature
Socio-Ecological System (SES)	Socio-ecological AND system AND climate AND change AND coastal AND coastal areas	Scopus (607)
Vulnerability Assessment (VA)	Socio-ecological AND system AND climate change AND vulnerability AND coastal AND coastal areas	
Resilience (RS)	Socio-ecological AND system AND climate change AND resilience AND coastal AND coastal areas	Science direct (194)
Adaptation Approaches (AAs)	Socio-ecological AND system AND adaptation AND climate change AND coastal AND coastal areas	Others (26)

2.1.2. Literature Screening

The remaining entries after the identification step were further screened according to three additional eligibility criteria: literature covering coastal areas/ecosystems (e.g., beaches, lagoons, islands, mangroves, etc.), literature focused on SES properties and adaptations, and literature addressing climate change threats. The complete list of the eligibility criteria applied in the identification and screening steps is presented in Table 2. To further screen the selected literature, we examined the full texts using a two-step procedure. First, we checked the titles and abstracts to identify potential literature that met the criteria, resulting in the exclusion of 298 of the 659 records. Second, another 188 pieces of literature were excluded from the full-text screening due to not fulfilling the eligibility criteria or being inappropriate for the stated research objectives of the present study (Figure 1).

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

Criteria	Inclusion Criteria	Exclusion Criteria
Period	Prior to 2024 (April)	Others
Language	English	Not in English
Publication type	Peer-reviewed scientific articles (e.g., research article and review)	Others (e.g., book chapters, conference proceedings, and other grey literature)
Study area	Coastal areas/ecosystems (e.g., beaches, lagoons, islands, mangroves, and other low-lying areas)	Non-coastal areas
Study-focused	Socio-ecological systems (SESs), vulnerability assessment (VA), resilience (RS), and adaptation approach (AA)	Not related to SES properties and adaptations
Environmental issue	Climate change and related threats (e.g., sea level rise, cyclonic storms, salinity, and coastal erosion)	Not related to climate change impacts

2.1.3. Literature Inclusion

Finally, this study included 173 pieces of literature for database preparation and subsequent analysis (Figure 1).

2.2. Database Preparation and Analysis

Creating a comprehensive database is essential to summarizing what was done and what was found through a systematic review, increasing the clarity of analysis and reporting [39]. In this study, the variables of the selected literature were collected and classified through full-text reading that allowed the fulfillment of the stated research objectives. The key variables related to coastal SES properties (e.g., VAs, RS, and AAs), geographical distributions of the literature, coverage of coastal landscapes/ecosystems, adaptation strategies, and so on. Based on the adaptation classification framework of IPCC, the adaptation strategies were categorized into (i) structural/physical, (ii) social, and (iii) institutional [40]. The detailed classification criteria of these variables are shown in Appendices A and B. After the classification step, we prepared a complete database to analyze the variables. The complete database is presented in Appendix C.

3. Results and Discussion

3.1. Summary of the Literature Content

This study analyzed 173 peer-reviewed journal articles published between 2004 and 2024 (April) to explore coastal SESs' adaptation to climate change. Figure 2 shows the number and temporal distribution of coastal SES studies, including literature on vulnerability assessments (VAs), resilience (RS), and adaptation approaches (AAs). The findings of our study reveal that the first study on coastal SESs adapting to climate change was published in 2004, and then the number increased gradually from 2004 to 2024. The reasons might be that the IPCC's Third Assessment in 2001 and Fourth Assessment in 2007 increased the amount of attention paid to adaptation. Similarly, since the Kyoto Protocol's ratification and the UNFCCC's establishment in 2005, there has been a global rise in scientific publications on adaptation to climate change impacts [32,33]. Our results demonstrate that after 2017, there was a rapid increase in the number of studies, with 2023 having the highest number. About 80% of the selected literature was published between 2018 and 2024. This rapid increase might be due to the Paris Agreement of 2015, specifically with respect to Article 7, which secured a prominent platform for climate adaptation as a vital issue for global governance [41]. In addition, the United Nations created 17 SDGs in 2015 and incorporated coastal areas into one of its goals [15]. Specifically, SDG 14 (sections 14.2 and 14.5), which emphasizes the sustainable management and protection of coastal areas and ecosystems [16], could be the reason for the increasing number of scientific studies on coastal SESs in relation to climate change adaptation. In this study, we assessed four types of relevant studies (e.g., SES, VA, RS, and AA), and the first study on coastal SESs was published in 2004, focusing on a VA (Figure 2). Our findings show that the recent publications mainly focused on VAs and AAs. However, most of the literature emphasized a single topic (e.g., VAs or AAs) and hardly focused on combined topics (e.g., VA and AA). Overall, most of the literature emphasized VAs rather than AAs, which indicates poor worldwide case study coverage for adaptation actions. Studies focusing on adaptation in the face of climate change are essential, particularly for the most vulnerable regions, for economic growth and sustainable development; however, there is still limited evidence of adaptation actions in many areas [42,43].

In this systematic review, 86% of the content consisted of research articles (RS), and the remaining 14% consisted of review articles (RW). Most of the research articles used a modelling approach (MO) (36%), followed by analytical (AN) (24%), questionnaire surveys (QSs) (19%), mixed-methods approaches (MX) (4%), and field observation (FO) (3%), respectively. This study found that most of the research literature focused on the local scale (L) (50%), and the rest emphasized the national (N) (30%) and transnational (TN) (20%) scales (Figure 3). Most of the studies focused on modelling approaches in their methodology in order to assess vulnerability and future adaptation strategies for coastal areas by using data from the IPCC's Fifth Assessment Report published in 2014 [44]. Moreover, most models were applied locally to a single landscape/ecosystem to evaluate vulnerabilities and address adaptation approaches.

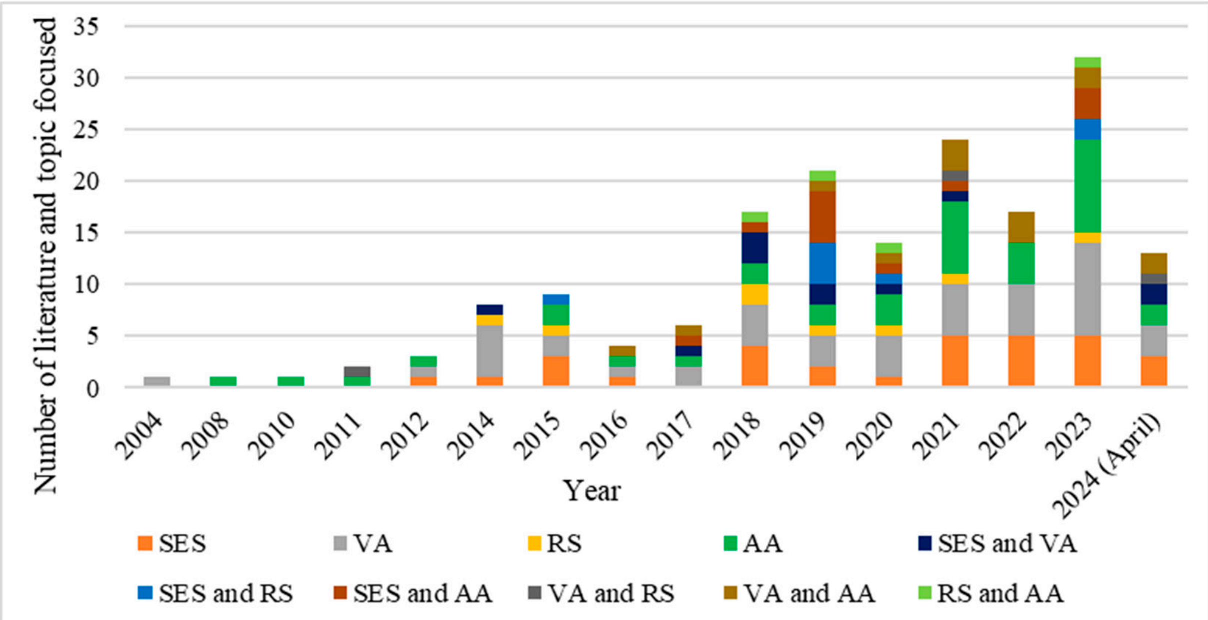

Figure 2. The number of papers and topics over time. SES = socio-ecological system, VA = vulnerability assessment, RS = resilience, and AA = adaptation approach.

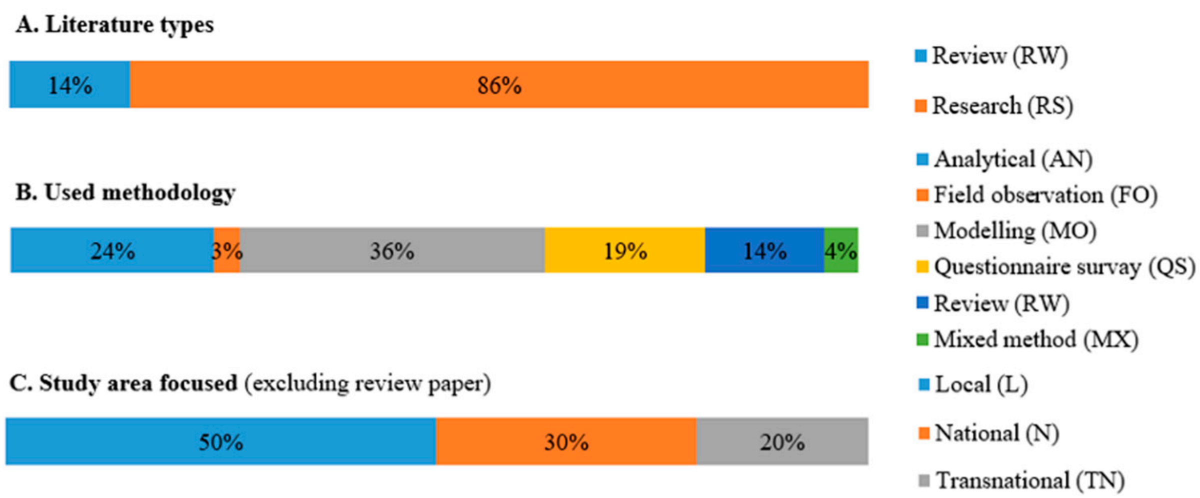

Figure 3. Incidence percentages of key features gathered from the selected literature.

3.2. Geographical Distribution, Landscapes, and Ecosystems

Our study's findings show that the selected literature was distributed over 41 countries across six continents (Figure 4). Bangladesh had the highest number of case studies (20), followed by the USA (15), India (10), Australia (9), and Italy (8). China, Portugal, South Africa, and Brazil had a similar number (5) of case studies. A single case study was found for highly vulnerable, low-lying coastal countries like Indonesia, Japan, Hong Kong, Tanzania, Mozambique, Uruguay, the Solomon Islands, and so on (Figure 4). There are several reasons for the high amounts of literature in Bangladesh. First, climate change, particularly SLR, is considered a severe threat to its coastal areas [45,46], because the relative SLR in the coastal areas of Bangladesh is much higher (3.90 ± 0.46 mm/year) [47] than the rate of global average sea rise (1.8 ± 0.5 mm/year) [48,49]. Second, the world's largest mangrove forest, namely, the Sundarbans (10,000 km^2), spans Bangladesh (62%) and India (38%) [39], providing a wide range of provisioning, regulating, supporting, and cultural ESs of global relevance [50]. According to 2011 census data, approximately 4 million Indians and 3.5 million Bangladeshis rely on these ESs directly or indirectly for their socioeconomic well-being [51–54], and the number of people who depend on the Sundarbans is still rising [55]. Many studies assume that most dry land in the coastal areas, including the Sundarbans, will be flooded by the end of the twenty-first century [56,57]. To protect coastal areas/ecosystems, many international research organizations (e.g., the World Bank, the United Nations Environment Programme, and the Food and Agriculture Organization) are still expanding their funding for climate change adaptation programs. Consequently, increased collaboration among local and international scientists has produced numerous publications supported by these international funding organizations. Third, Bangladesh Sundarbans Delta Vision 2050 and Bangladesh Delta Plan 2100 might draw the attention of scientists for advancing scientific knowledge and publications on climate change adaptation in coastal areas of Bangladesh. The USA has been considered an early investor in adaptation science, with an elevated climate change adaptation policy [58]. In the USA, research on climate change in coastal areas is mainly concentrated in the Southeastern regions (e.g., Florida, Louisiana, and North and South Carolina), which have experienced severe events causing significant damage to ecosystems and the livelihoods of local communities [59,60]. Australia and Italy are developed countries covering different coastal landscapes/ecosystems and vulnerable to the effects of climate change [61,62]. These countries also harbor many prominent scientists who have been working in this area for a long time, which is the reason for the enormous number of publications compared to other developed and developing countries. Our study shows that except for Bangladesh and India, the literature on other Southeast Asian countries was not as abundant. The five most populous countries (e.g., China, India, Bangladesh, Indonesia, and Vietnam) in the world with coastal zones with an elevation of less than 10 m are located in Southeast Asia [63]. These nations are categorized as high-risk disaster regions because they have increased exposure to the risks associated with climate change and its related threats, including SLR, cyclonic storms, tsunamis, and salinity [14,64,65]. Similarly, South American and African coastal communities are vulnerable to the impacts of climate change, including financial, ecological, social, and cultural consequences [66,67]. Despite the existing evidence, the literature on coastal adaptation to climate change is scarce across the South American and African continents. A lack of sufficient funding, research institutions, and collaboration among experts might be the reasons for the dearth of literature on climate change adaptation research in developing and low-income nations.

Most of the studies in developing and low-income countries focused on a local or national scale, while developed nations concentrated their studies on a transnational scale (Figure 4). According to our findings, 25 review papers were distributed across 12 countries. Most were found in relation to Canada (6), followed by the USA and the UK (4), Germany, and Portugal (2). Australia, China, France, Spain, South Africa, Colombia, and Mexico were all found to have a single review paper (Figure 4). The dominance of the review literature in the developed countries (e.g., Canada, USA, UK, and Australia) is due to their earlier and longer-term investments in climate change adaptation science compared to other countries [32].

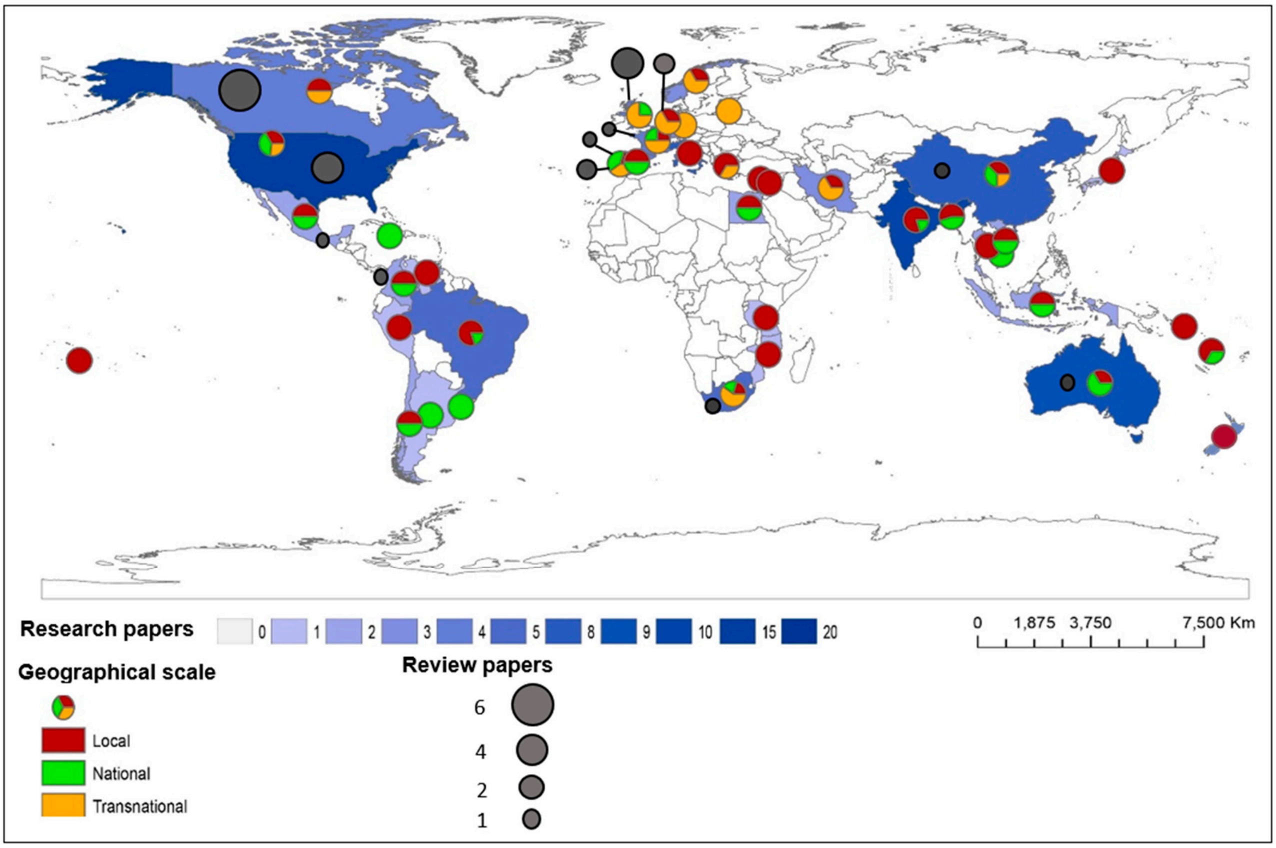

Figure 4. Geographical distribution of the selected literature (*n* = 173). Research papers (*n* = 148) and review papers (*n* = 25) are shown separately based on their numbers in different geographic locations. The research papers are classified based on the study sites mentioned in the literature, and the review papers are classified based on the affiliations of their first authors. The distribution of research papers is shown on different geographical scales (i.e., local, national, and transnational). The detailed classification criteria for the literature are shown in Appendices A and B.

We found 167 coastal landscapes/ecosystems under 12 categories from 148 empirical studies. These include beaches, lagoons, islands, mangroves, estuaries, salt marshes, low-lying rural and urban areas, and so on (Figure 5). This review found the highest number of landscapes/ecosystems for Bangladesh, followed by the USA, India, Italy, Australia, and China. Bangladesh was determined to have the highest number of landscapes/ecosystems compared to other countries due to its highly climate-change-prone regions, and researchers from home and abroad focus their studies on different coastal landscapes under national and international projects. Approximately 70% of the countries included one or two types of landscapes/ecosystems; the USA had the most, followed by India, Italy, Australia, China, and Bangladesh. Most of these countries' studies generally focused on rural landscapes and low-lying regions as their study areas; however, they paid little attention to the specific natural ecosystems (e.g., lagoons, salt marshes, forests, and estuaries). The reason for this limited attention might be that the ESs provided by natural ecosystems are often poorly recognized, and many people are unaware of the relevance of regulating and supporting ESs and their importance for human life [39].

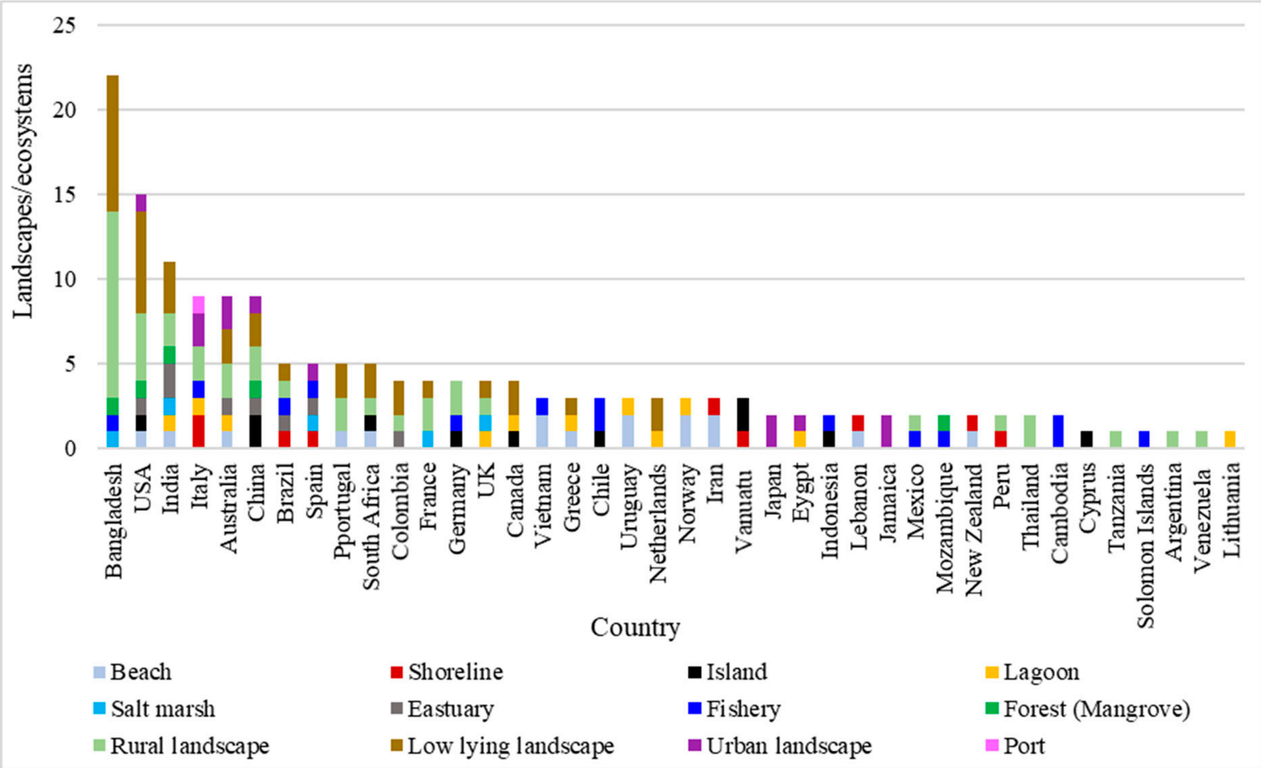

Figure 5. The geographical distribution of the different coastal landscapes/ecosystems focused on in the research papers (n = 148).

3.3. Adaptation Approaches

We found 51 pieces of literature that deal with adaptation strategies. We categorized them into 13 classes (Figure 6). The physical (ecosystem-based) adaptation approach was referenced most frequently (31%), followed by institutional (government policies) (13%), social (informational) (12%), and integrated ones (10%). The rest of the adaptation approaches covered the remaining 44% and ranged between 2 and 6% in terms of each specific approach (Figure 6). The findings of our study reveal that climate change adaptation literature barely considers SESs in coastal adaptation approaches. Notably, the adaptation literature was limited in particular in the high-climate-risk regions of developing and low-income countries. One of the main reasons for this lack of adaptation research is the scarcity and difficulty of accessing data due to economic, institutional, and technical constraints [3,66]. Despite the significant limitations of adaption studies, the number of climate change adaptation studies has recently increased.

Our review demonstrates that most of the literature emphasized the physical (ecosystem-based) adaptation approach to addressing different landscapes and ecosystems (e.g., rural low-lying landscapes, beaches, fisheries, lagoons, salt marshes, forests, etc.), followed by institutional (government policies), social (informational), integrated, and others (Figure 6). The concept of ecosystem-based adaptation has emerged recently in the worldwide climate change arena due to the UNFCCC [67,68]; however, the necessity and importance of ecosystem-based adaptation have not been fully recognized [69,70]. Ecosystem-based adaptation is categorized under the umbrella term "nature-based solutions" [7]. It is a win–win solution for simultaneously achieving social (e.g., human health, water security), economic (e.g., industrial development, GDP), and environmental (e.g., rich biodiversity, carbon sequestration) goals by harnessing and not harming the healing power of nature [71]. Mangrove forests in the tropical regions are the best example of ecosystem-based adaptation. For instance, the Sundarbans in Bangladesh and India are, on average, 150 km long (east to west) and 75 km wide (north to south) and act as a natural green barrier that protects coastal people and their properties from cyclonic storms, tidal surges, and coastal soil erosion without harming the environment [12]. In addition, the Sundarbans provides provisioning ESs (e.g., timber, fish, honey, fuel, fodder, medicine, and other miscellaneous products) for millions of coastal people. Therefore, ecosystem-based adaptation (e.g., afforestation and reforestation, conservation and replanting mangrove forests, green infrastructure, etc.) has a broader scope with respect to protecting, sustainably managing, or restoring natural ecosystems while addressing societal challenges beyond climate change adaptation [72]. However, the ecosystem-based adaptation approach requires institutional and financial support to ensure long-term monitoring and co-benefits.

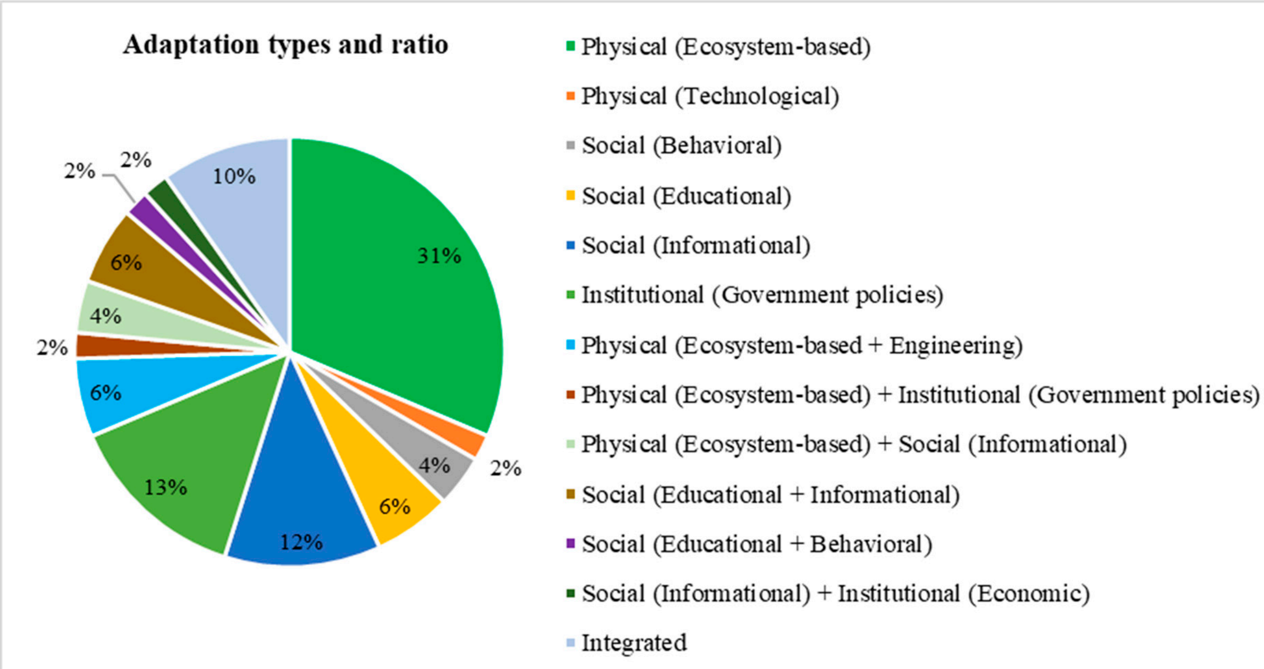

Figure 6. Identification and classification adaptation approaches are focused on in the literature ($n = 51$).

Our study shows that institutional adaptation (government policies) was found for rural landscapes, fisheries, salt marshes, and urban areas (Figure 7). This adaptation approach mainly focuses on local and national adaptation plans. A lack of policy guidance, limited coordination between actors, and insufficient administrative resources are the reasons for the failure of institutional (government policies) adaptation strategies in coastal areas [73]. In our literature review, we identified social (informational) adaptation strategies for urban and rural areas, beaches, lagoons, and estuaries, among other approaches (Figure 7). Social (informational) approaches provide information to make people aware of natural hazards and promote timely responses, including evacuation. Several methods are being employed worldwide, including an emergency alert system, presentations, and seminars [74]. Awareness raising through scenario development and computer modelling is effective for developing future adaptation strategies in coastal areas. Our study revealed that most of the existing social (informational) adaptation approaches are based on a prediction model of sea-level rise and its future effects in coastal areas. However, a lack of education limits learning, and knowledge sharing is the constraint of social (informational) adaptation strategies in coastal regions, especially in developing and low-income countries.

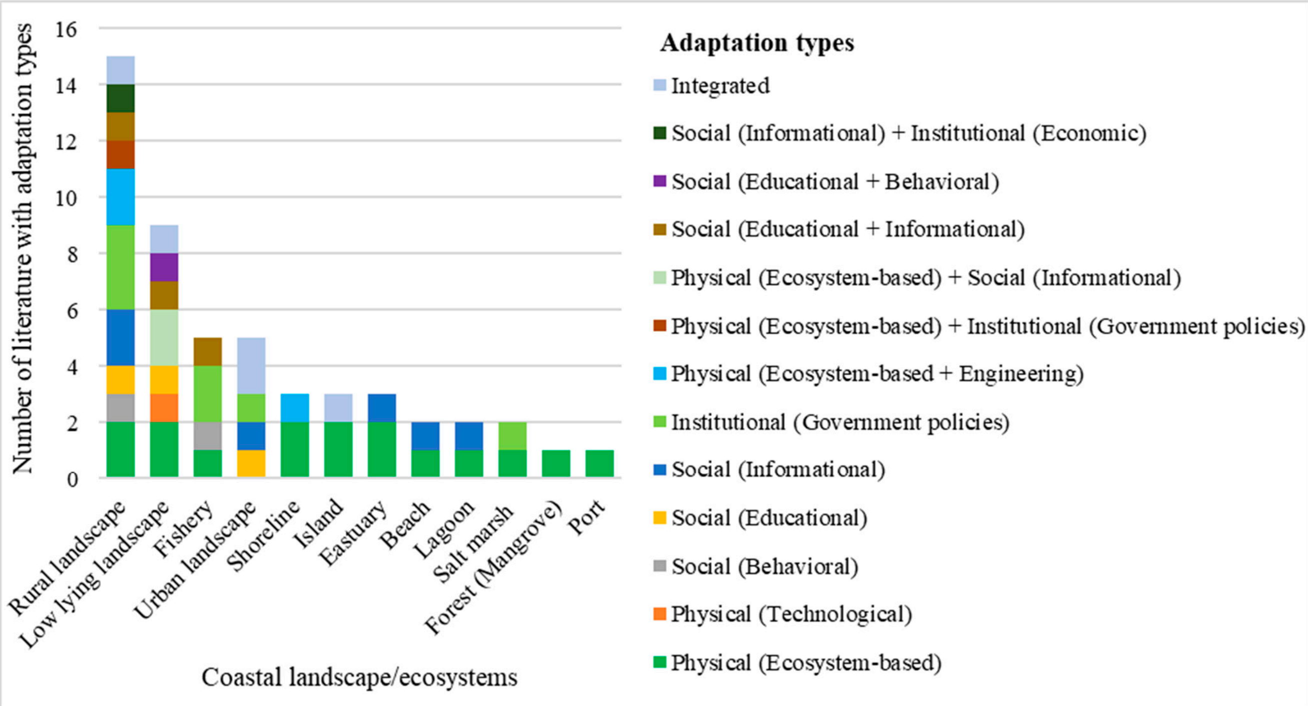

Figure 7. The identification and classification of adaptation types focused on the different coastal landscapes/ecosystems (n = 51).

Research networks and partnerships can help raise awareness and share knowledge about this adaptation approach at all scales, from large institutions to small groups of people. The present study defines integrated adaptation as combining two more adaptation approaches focused on managing coastal areas. We found integrated adaptation approaches primarily for urban areas, including islands and rural low-lying landscapes (Figure 7). Integrated adaptation approaches aim to maintain or restore ecological integrity (i.e., protecting biological diversity and ES productivity) and enhance the quality of life while developing economies in coastal SESs [75]. This adaptation approach involves different actors and sectoral policies; thus, governance remains a significant challenge in implementing integrated adaptation in coastal areas. The coastal SES framework has considerable potential for bridging the gap in the governance system by identifying and prioritizing the policy decisions of the actors.

4. DPSIR Framework for Coastal SESs Adapting to Climate Change

The literature review reported above allowed for the identification of the main issues relating to coastal socio-ecosystems exposed to climate change and the possible avenues for adaptation. Effective adaptation strategies require a deep understanding of the interrelations between social, economic, and ecological dimensions, particularly the causal chains that link climate and anthropogenic drivers to the impacts experienced (either current or expected). A reference framework is needed to provide a functional representation of coastal SESs with their internal interrelations among their main elements and their connections with what is around them. The DPSIR (Driver Pressure State Impact Response) framework has been selected here to present a synoptic view of what we found in the literature concerning the main elements, features, phenomena, and causal links relating to coastal SESs exposed to the impacts of climate change and explore adaptation strategies [76]. The DPSIR framework includes drivers, often defined as global, regional, local, social, and economic factors that act as causal links that exert pressures on the environment. These pressures may result in intentional or unintentional alterations in the state of the environment or, more broadly, the socio-ecosystem, which affects system functionality and quality [77], resulting in positive or negative impacts on the well-being of human communities and natural systems. Responses are actions social groups or individuals take to modify forces or drivers through actor-driven behavioral shifts, prevention, investments, or regulation to avoid, make up for, facilitate, or exploit observed or foreseen changes in the state of the socio-ecosystem and related impacts [77]. In this case, the responses include all the adaptation strategies and measures that emerged from the literature review. The DPSIR framework thus facilitates problem-structuring with reduced complexity while maintaining structure and function to address issues using evidence-based information about coastal SESs [76,78]. Two categories of drivers were defined to identify the causes and consequences of coastal vulnerability to climate change and adaptation opportunities (Figure 8). The first is exogenous to the SES and includes drivers related to climate change phenomena that include natural phenomena such as sea-level rise, cyclonic storms, coastal flooding, and other meteorological events (e.g., heavy and irregular rainfall, higher temperature, and heat waves). They are exogenous to the system since they cannot be directly controlled at the local level, and they are instead affected by mitigation strategies implemented all over the world. The second category includes anthropogenic drivers, such as population growth, land use change, urbanization, industrialization, migration, food, and energy demand related to the social and economic development of the SES. Activities related to these drivers result in pressures on the coastal environment (e.g., deforestation, waste generation, use of chemicals), which in turn give rise to alterations of its state. For instance, agricultural expansion, industrialization, and urbanization reduce the area of coastal forests and wetlands, resulting in changes in the state of coastal ecosystems in terms of loss of biodiversity. Alterations of the State of the environment are assessed to identify related—positive or negative—impacts, such as an alteration in the flow of ecosystems services (e.g., a decline in the provision of food or in the competition for natural resources).

Adaptive responses can prevent future adverse impacts or help people cope with current ones. Formulating an effective response requires a deep understanding of the relationships between the different interacting elements of an SES [79] and the capability to anticipate how they can be environmentally sustainable, economically viable, technologically feasible, socially desirable, and legally acceptable. While only integrated—socioeconomic and ecological—modelling can provide the basis for an ex ante assessment of hypothetical adaptation measures, the DPSIR framework proposed in Figure 8 can facilitate and support these efforts.

In Figure 8, we provide a graphical synthesis of the main outcomes of the literature review processed through the lenses of the DPSIR framework and we show how such a framework could be used to explore a specific case. The figure provides the main elements of a generic SES exposed to climate change and anthropogenic pressure. The items attached to each of the nodes synthesize the elements found in the literature that could be considered in a generic adaptation effort. In the figure, we add an example of a possible use of the framework we propose by extracting one of the proposed measures (sustainable agriculture, in green), which could be considered in response to the impacts of two impacts caused by population growth and the related increase in food demand (the two drivers in red). The cascade of expected causal links is pointed out by arrow connectors, where the P, S, and I elements, for which we can expect beneficial effects according to the measure, are depicted in blue. Accordingly, the framework can provide a very preliminary identification of the expected outcomes of adaptation measures to facilitate discussions with stakeholders and then pave the way for integrated assessment modelling.

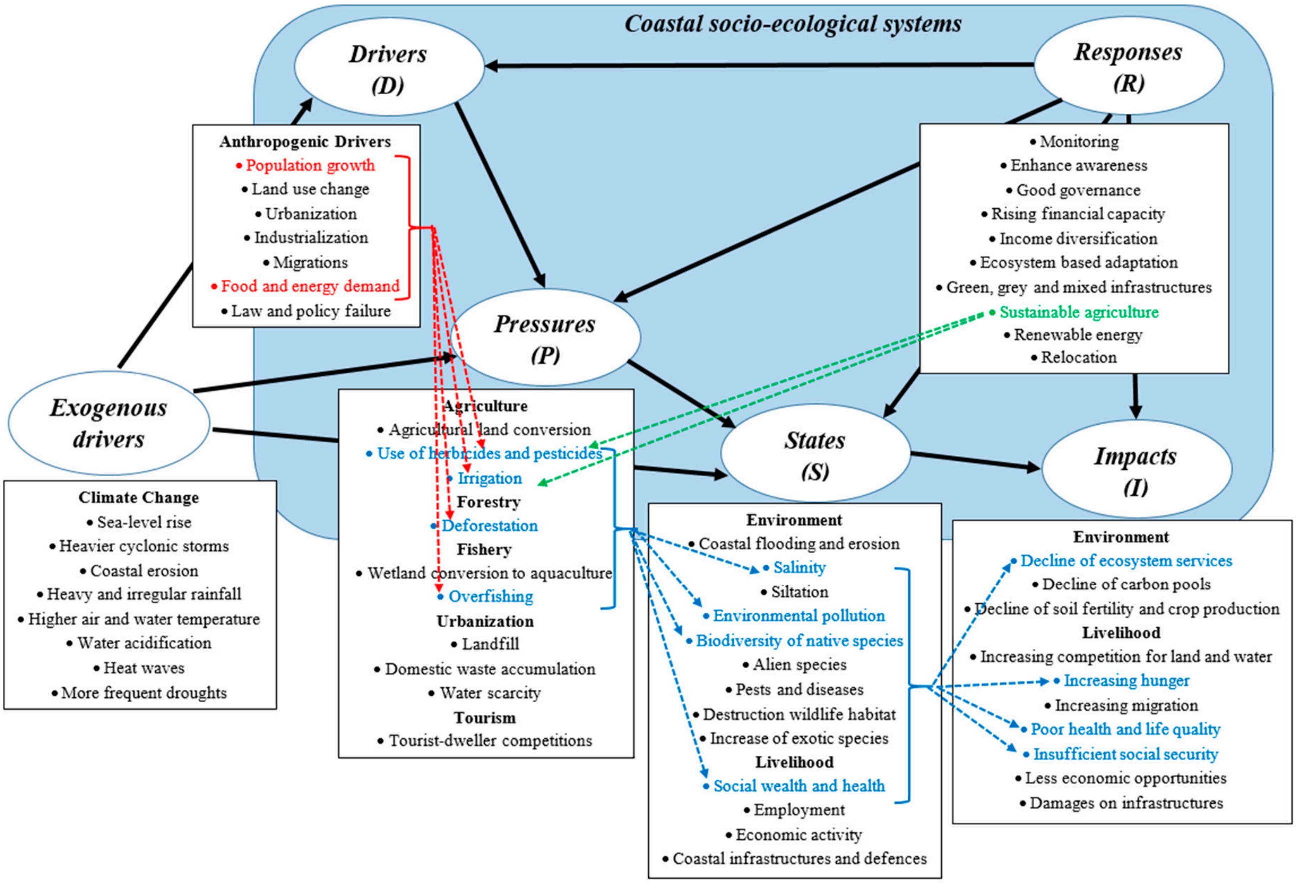

Figure 8. Causal link of the DPSIR framework for exploring the causes and consequences of coastal vulnerability and options for adapting to climate change. The red text and arrows illustrate an example of a particular causal chain of the DPSIR framework caused by two drivers: population growth and a related increase in food demand. Depicted in green is one suitable response, which could be sustainable agriculture, and which is expected to generate a cascade of beneficial effects on a series of connected pressures, states, and impacts (in blue).

5. Conclusions

Coastal ecosystems provide a wide range of provisioning, regulatory, supportive, and cultural ESs to millions of people worldwide, but coastal areas are vulnerable to climate change and human-driven activities and pressure. Therefore, more efforts toward and investments in adaptation are required. Hence, a deeper understanding of social–ecological interactions is essential to overcome the challenges of today and tomorrow.

This systematic review of the scientific literature allowed for identifying gaps and the scientific output needed to support coastal adaptation strategies.

We found a gradual increase in the literature addressing coastal SESs, with 80% of the papers being published after the Paris Agreement of 2015, between 2018 and 2024. The results of the review show that there was an uneven distribution of studies throughout the world. Except for Bangladesh, less research and fewer case studies were found in the highly vulnerable coastal areas, thus pointing out an evident gap in past research efforts. According to our analysis, most of the literature focused on the local perspective rather than the national and transnational scale. Moreover, much of the literature concentrated on low-lying and rural landscapes as their study areas, while there was less consideration of the particular natural ecosystems, such as forests, salt marshes, lagoons, and estuaries. This is another gap that needs to be considered by future research efforts. Moreover, our study demonstrated that most of the literature focused on vulnerability assessment rather than the adaptation processes, indicating another gap to be considered. Several recent studies have emphasized the concept of ecosystem-based adaptation to climate change in coastal areas; however, this approach requires institutional and financial support to ensure long-term monitoring and co-benefits, but these dimensions are rarely integrated in environmental studies.

A concise picture of the results of this work is provided by their organization within the DPSIR framework, which supports problem-structuring to address the open issues and gaps mentioned above. Such a framework represents an initial attempt to distil evidence emerging from the literature and bridge the gaps between science and policy support facilitating communication and public participation for sustainable coastal management and planning, thus contributing to the achievement of the UN SDGs.

The literature review conducted in this study has some limitations. First, our study only included peer-reviewed literature written in the English language. Other documents, such as books and grey literature, were excluded, even though we were aware that these documents might contain important information in this field. Second, we screened the literature through selected topics and keywords, which were carefully selected and refined through a series of iterations, but they might not include the literature that used different terminology and keywords for the same topic. Future research in this area needs to consider these constraints in order to advance.

The main messages emerging from our work, which should be taken into account in future research, are as follows: (i) there must be a more extensive focus on vulnerable regions, beyond iconic areas such as the Sundarbans in Bangladesh; (ii) there should be greater consideration of the multiple scales of the phenomena, thus connecting local studies to national, regional, and global dynamics; (iii) a greater attention to areas of high naturalistic interest is required, but it should be investigated through the broad and integrated lenses provided by socio-ecosystem analysis; and (iv) a much deeper consideration of adaptation strategies and measures within the framework of Agenda 2030 and the SDGs is required in order to provide synergistic (win–win) solutions and control for negative side effects on related areas.

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Data Availability Statement: The original contributions presented in the study are included in the article (Appendix A, Appendix B, and Appendix C); further inquiries can be directed to the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest relating to publishing this paper.

Appendix A. Classification Criteria for the Variables

Research Objectives	Variables	Classification Criteria and Acronyms
1	Document types	A = original research paper, R = review paper
1	Literature types	SES = social–ecological system, VA = vulnerability assessment, RS = resilience, AA = adaptation approaches
1	Methods used	AN = analytical, FO = field observation, MO = modelling, QS = questionnaire survey, RW = review, MX = mixed methods (e.g., integration of one more methods)
2	Study focused	SM = saltmarsh, SL = shoreline, IS = island, FI = fishery, BE = beach, UB = urban landscape, RL = rural, LL = low-lying landscape, FR = forest, ES = estuary, LN = lagoon, PO = port

Research Objectives	Variables	Classification Criteria and Acronyms
2	Study scales	L = local: research that focuses on one study site or ecosystem in a single country N = national: research that focuses on one or more study sites or ecosystems in a single country TN = transnational: research that focuses on one or more study sites or ecosystems in one more country n/a = not applicable (because the review paper did not focus on a particular study site or ecosystem)
3	Adaptation types	(i) structural/physical, (ii) social, and (iii) institutional. The detailed classification criteria are shown in Appendix B.

Appendix B. Classification Criteria for Adaptation Strategies

Category	Sub-Category	Examples
Structural/ physical (S)	Engineered and built environment (E)	Sea walls and coastal protection structures, flood levees and culverts, water storage and pump storage, improved drainage, flood and cyclone shelters, storm and wastewater management, transport and road infrastructure adaptation, floating houses, adjusting power plants and electricity grids.
	Technological (T)	New crop and animal varieties, genetic techniques, traditional technologies and methods, efficient irrigation, water-saving technologies, conservation agriculture, hazard-mapping and -monitoring technology, early-warning systems, building insulation, renewable energy technologies.
	Ecosystem-based (Eb)	Ecological restoration, increasing biological diversity, afforestation and reforestation, conservation and replanting mangrove forests, green infrastructure, fishery co-management, ecological corridors, ex situ conservation and seed banks, community-based natural resource management, adaptive land use management.
	Services (S)	Social safety nets and social protection, food banks and distribution of surplus food, municipal services including water and sanitation, essential public health services, international trade.
Social (S)	Educational (E)	Awareness raising and integration into education, sharing local and traditional knowledge, participatory action research and social learning, community surveys, knowledge-sharing and learning platforms, international conferences and research networks, communication through media.
	Informational (I)	Hazard and vulnerability mapping, early-warning and response systems, systematic monitoring and remote sensing, downscaling climate scenarios, integrating indigenous climate observations, community-based adaptation plans.
	Behavioral (B)	Accommodation, household preparation and evacuation planning, retreat and migration, soil and water conservation, livelihood diversification, changing livestock and aquaculture practices, changing cropping practices.
Institutional (I)	Economic (E)	Financial incentives including taxes and subsidies, insurance, revolving funds, payments for ecosystem services, microfinance, disaster contingency funds.
	Laws and regulations (L)	Land zoning laws, water regulations and agreements, laws supporting disaster risk reduction, laws encouraging insurance purchasing, defining property rights and land tenure security, protected areas.
	Government policies and programs (G)	National and regional adaptation plans, sub-national and local adaptation plans, urban upgrading programs, disaster planning and preparedness, city-level plans, district-level plans, sector plans (e.g., integrated water resource management, landscape and watershed management, integrated coastal zone management, sustainable forest management, fishery management).

Appendix C. Complete Database of the Literature (n = 173) Selected for Subsequent Analysis

Authors	Year	Document Types	Literature Types	Study-Focused	Study Scale	Methods Used	Adaptation Types	Literature Link
Abdrabo et al.	2022	A	VA, AA	UB	N	MO	S-I	Ref
Adams et al.	2021	A	SES	SM	L	MO	(n/a)	Ref
Ankrah et al.	2023	R	SES	SL	(n/a)	R	(n/a)	Ref
Anzidei et al.	2023	A	VA	IS	L	MO	(n/a)	Ref
Aragão et al.	2022	A	VA	FI	N	MO	(n/a)	Ref
Arefipour et al.	2022	A	SES	IS	L	QS	(n/a)	Ref
Armaroli et al.	2012	A	VA	SL	L	MO	(n/a)	Ref
Azcona et al.	2019	R	RS, AA	LL	(n/a)	R	(n/a)	Ref
Baldwin et al.	2016	A	VA, AA	RL	L	AN	S-E,I	Ref
Banos et al.	2016	A	SES	IS	L	MO	(n/a)	Ref
Bayliss et al.	2018	A	SES, VA	LL	L	MO	(n/a)	Ref
Bernzen et al.	2023	A	VA, AA	RL	N	QS	S-B	Ref
Bhattachan et al.	2018	A	SES	LL	L	MO	(n/a)	Ref
Bormann et al.	2012	A	AA	RL	TN	MO	S-I	Ref
Bott et al.	2018	A	AA	RL	L	MO, FO	S-E,I	Ref
Brattland et al.	2019	A	SES, AA	FI	L	AN	I-G	Ref
Bremer et al.	2022	A	SES	BE	N	QS	(n/a)	Ref
Busayo and Kalumba	2021	A	VA, AA	UB	TN	QS	S-E	Ref
Cabana et al.	2023	R	AA	RL	(n/a)	R	(n/a)	Ref
Chales et al.	2023	A	AA	IS	TN	AN	P-Eb	Ref
Chan et al.	2021	R	VA	UB	(n/a)	R	(n/a)	Ref
Chaumillon et al.	2017	R	VA, AA	RL	(n/a)	R	(n/a)	Ref
Coronado et al.	2021	R	SES	RL	(n/a)	R	(n/a)	Ref
Correa and Kintz	2015	R	AA	FR	(n/a)	R	(n/a)	Ref
Costas et al.	2015	A	VA	RL	L	AN	(n/a)	Ref
Culibrk et al.	2021	A	AA	BE	L	MO	S-I	Ref
Dada et al.	2021	A	SES	FR, BE	TN	MO	(n/a)	Ref
Dakey et al.	2023	A	SES, RS	RL	L	QS	(n/a)	Ref
Davila et al.	2014	A	RS	LL	TN	QS	(n/a)	Ref
Deb et al.	2024	A	VA, RS	RL	L	MO	(n/a)	Ref
Dhar and Khirfan	2023	A	RS	UB	N	QS	(n/a)	Ref
Dhénain and Barreteau	2018	A	SES	LL	L	QS	(n/a)	Ref
Ducrotoy	2010	R	AA	ES	(n/a)	R	(n/a)	Ref
Dutra et al.	2015	A	SES	LL	N	QS	(n/a)	Ref
Eger et al.	2021	R	AA	LL	(n/a)	R	(n/a)	Ref
Elliott et al.	2014	R	VA	ES	(n/a)	R	(n/a)	Ref
Fakhruddin et al.	2022	A	VA	RL	L	MO	(n/a)	Ref
Fang et al.	2017	A	VA	LL	N	AN	(n/a)	Ref

Authors	Year	Document Types	Literature Types	Study-Focused	Study Scale	Methods Used	Adaptation Types	Literature Link
Ferro et al.	2022	A	AA	FR	N	QS	I-G	Ref
Fidélis et al.	2019	A	SES	ES	N	MO	(n/a)	Ref
Gallo-Vélez et al.	2023	A	SES	ES	L	FO	(n/a)	Ref
Gammage et al.	2019	A	SES, AA	FI	N	QS	S-B	Ref
Gholami et al.	2021	A	SES, VA	FR	TN	MO	(n/a)	Ref
Ghosh and Mistri	2023	A	VA	RL	L	MO	(n/a)	Ref
Ghoussein et al.	2018	A	VA	BE	L	MO	(n/a)	Ref
Giffin et al.	2021	R	AA	RL	(n/a)	R	(n/a)	Ref
Gijsman et al.	2021	A	AA	LL	TN	AN	P-Eb	Ref
Gilman et al.	2008	R	AA	FR	(n/a)	R	(n/a)	Ref
Giupponi et al.	2024	A	VA	UB	L	MO	(n/a)	Ref
Gonçalves and Pinho	2022	R	SES	LL	(n/a)	R	(n/a)	Ref
Gupta and Shaw	2015	A	RS	FR	L	QS	(n/a)	Ref
Hagenlocher et al.	2018	A	SES, VA	RL	TN	MO	(n/a)	Ref
Hardy et al.	2017	A	AA	LL	N	AN	S-E,B	Ref
Heenan et al.	2015	A	AA	FI	TN	AN	P-Eb	Ref
Henly et al.	2015	A	SES	RL	L	MO	(n/a)	Ref
Hespen et al.	2023	A	AA	LL	TN	AN	P-Eb	Ref
Hoggart et al.	2014	R	VA	RL	(n/a)	R	(n/a)	Ref
Holt et al.	2012	A	SES	FI	N	AN	(n/a)	Ref
Hoque et al.	2019	A	SES, VA	RL	N	MO, QS	(n/a)	Ref
Hoque et al.	2021	A	VA	RL	L	MO	(n/a)	Ref
Horlings and Marschke	2020	A	AA	FI	N	QS	I-G	Ref
Ikhumhen et al.	2023	A	SES	LL	L	MO	(n/a)	Ref
Inácio et al.	2023	A	AA	LN	TN	AN	P-Eb	Ref
Islam et at.	2020	A	AA	RL	N	QS	P-Eb, E	Ref
Jacob et al.	2021	A	SES, AA	LL	TN	AN	S-E	Ref
Jamal et al.	2023	A	VA	FI	N	QS	(n/a)	Ref
Jara et al.	2020	A	VA, AA	FI	L	AN	S-E,I	Ref
Jozaei et al.	2022	A	VA, AA	RL	L	AN, QS	I-G	Ref
Jurjonas and Seekamp	2018	A	RS	RL	L	AN	(n/a)	Ref
Kanan et al.	2023	A	VA	FR	L	MO	(n/a)	Ref
Kar et al.	2020	A	SES	LL	L	AN	(n/a)	Ref
Komugabe et al.	2019	A	RS	IS	L	QS	(n/a)	Ref
Kunte et al.	2014	A	VA	SL	L	MO	(n/a)	Ref
Lawyer et al.	2023	R	SES, AA	RL	(n/a)	R	(n/a)	Ref
Lewsey et al.	2004	A	VA	LL	TN	AN	(n/a)	Ref
Lin et al.	2021	A	VA, AA	UB	L	QS	IT	Ref
Loch and Riechers	2021	R	SES	LL	(n/a)	R	(n/a)	Ref
Losada et al.	2019	A	AA	LL	N	AN	S-I, I-E	Ref

Authors	Year	Document Types	Literature Types	Study-Focused	Study Scale	Methods Used	Adaptation Types	Literature Link
Mafi-Gholami et al.	2019	A	VA	SL	L	MO	(n/a)	Ref
Mahmood et al.	2023	A	AA	SM	L	MO	P-Eb	Ref
Mahmood et al.	2023	A	RS, AA	RL	L	MO	P-Eb, I-G	Ref
Mallick eet al.	2017	A	VA	RL	N	QS	(n/a)	Ref
Mallick et al.	2019	A	SES, RS	RL	N	AN, QS	(n/a)	Ref
Maneas et al.	2019	A	SES	LN	L	MO, FO	(n/a)	Ref
Manes et al.	2023	A	VA, AA	SL	N	MO	P-Eb	Ref
Markphol et al.	2021	A	VA, AA	RL	L	MO	P-Eb,E	Ref
Massuanganhe et al.	2015	A	VA	FR	L	AN	(n/a)	Ref
Maurischa et al.	2023	A	SES, RS	RL	N	QS	(n/a)	Ref
Merino et al.	2024	A	SES	LL	L	MO	(n/a)	Ref
Molinaroli et al.	2019	A	VA, AA	UB	TN	AN	IT	Ref
Mondal et al.	2022	A	VA	RL	L	QS	(n/a)	Ref
Montblanc et al.	2020	A	RS, AA	BE	L	MO	P-Eb	Ref
Montefiore et al.	2023	A	VA	ES	N	MO	(n/a)	Ref
Murphy	2015	R	SES, RS	RL	(n/a)	R	(n/a)	Ref
Nakanishi and Black	2018	A	RS	UB	L	AN	(n/a)	Ref
Natalia et al.	2020	A	SES, AA	UB	TN	AN	I-G	Ref
Navarro et al.	2021	A	VA, RS	RL	N	QS	(n/a)	Ref
Nayak and Armitage	2018	A	SES	LN	TN	QS	(n/a)	Ref
Newton and Weichselgartner	2014	A	VA	LL	TN	AN	(n/a)	Ref
Newton et al.	2014	A	VA	LN	TN	FO	(n/a)	Ref
Nguyen et al.	2020	A	SES, RS	FI	L	QS	(n/a)	Ref
O'Donnell et al.	2022	A	SES	FR, BE, SL	N	QS	(n/a)	Ref
O'Donnell et al.	2024	A	SES, VA	RL	N	MO	(n/a)	Ref
Olivares-Aguilar et al.	2022	A	VA	LL	L	AN	(n/a)	Ref
Oliveira et al.	2022	A	SES	UB	L	MO	(n/a)	Ref
Onetti et al.	2021	A	AA	PO	L	MO	P-Eb	Ref
Orchard et al.	2020	A	VA	SM	L	MO	(n/a)	Ref
Paolisso et al.	2019	A	SES, RS	IS	L	AN	(n/a)	Ref
Pelage et al.	2023	A	SES	FI	L	QS	(n/a)	Ref
Peng et al.	2024	A	VA	RL	N	MO	(n/a)	Ref
Pfaff et al.	2019	R	SES, VA	ES, BE	(n/a)	R	(n/a)	Ref
Phalkey	2020	A	VA	RL	N	QS	(n/a)	Ref
Pham et al.	2023	A	VA	LL	L	MO	(n/a)	Ref
Pike et al.	2022	A	AA	IS	N	QS	I-T	Ref
Pinillos and Ruiz	2024	A	SES	IS	L	AN	(n/a)	Ref
Pinto et al.	2023	A	VA	FI	N	AN	(n/a)	Ref

Authors	Year	Document Types	Literature Types	Study-Focused	Study Scale	Methods Used	Adaptation Types	Literature Link
Poulose et al.	2020	A	VA	LL	N	MO	(n/a)	Ref
Powell et al.	2019	R	AA	SM	(n/a)	R	(n/a)	Ref
Prahalad et al.	2019	A	SES, AA	SM	N	MO	S-I	Ref
Qin et al.	2024	A	AA	ES	L	AN	P-Eb	Ref
Rahman et al.	2019	A	VA	LL	N	MO	(n/a)	Ref
Rahman et al.	2023	R	AA	RL	(n/a)	R	(n/a)	Ref
Ramm et al.	2018	A	RS, AA	LL	L	MO	P-T	Ref
Riera-Spiegelhalder et al.	2023	R	AA	RL	(n/a)	R	(n/a)	Ref
Roebeling et al.	2018	A	AA	SL	TN	MO	P-Eb,E	Ref
Rojas et al.	2014	A	SES	RL	N	AN	(n/a)	Ref
Roy et al.	2023	A	SES	RL	N	AN	(n/a)	Ref
Runting et al.	2018	A	VA	LL	L	MO	(n/a)	Ref
Saddaf et al.	2024	A	VA	RL	L	QS	(n/a)	Ref
Sahana and Sajjad	2018	A	VA	LL	L	MO	(n/a)	Ref
Sajjad et al.	2020	A	VA	LL	N	MO	(n/a)	Ref
Samanta et al.	2023	A	VA	FR	L	MO	(n/a)	Ref
Santhanam et al.	2022	A	AA	LN	L	MO	P-Eb	Ref
Santos et al.	2021	A	SES	FI	TN	FO	(n/a)	Ref
Sarkar et al.	2024	A	VA, AA	RL	L	MO	S-I	Ref
Sauve et al.	2023	R	SES, AA	LL	(n/a)	R	(n/a)	Ref
Sauvé et al.	2023	R	SES, AA	BE	(n/a)	R	(n/a)	Ref
Schernewski et al.	2023	A	AA	RL	TN	MO	I-G	Ref
Schmitz et al.	2018	A	SES	IS	L	MO	(n/a)	Ref
Schwarz et al.	2011	A	VA, RS	RL	L	QS	(n/a)	Ref
Selvaraj et al.	2022	A	VA	FI	N	AN	(n/a)	Ref
Shah and Wang	2024	A	SES, VA	IS	L	MO	(n/a)	Ref
Shalby et al.	2021	A	VA	LN	L	MO	(n/a)	Ref
Shameem et al.	2014	A	SES, VA	RL	L	QS	(n/a)	Ref
Sheaves et al.	2016	A	AA	ES	N	AN	S-I	Ref
Singh et al.	2019	A	SES, AA	RL	L	MO	IT	Ref
Smith et al.	2019	A	SES, RS	RL	N	AN	(n/a)	Ref
Sowman et al.	2018	A	SES, VA	FI	TN	AN	(n/a)	Ref
Spencer et al.	2024	A	SES	LL	TN	AN	(n/a)	Ref
Strain et al.	2022	A	AA	ES	N	FO	P-Eb	Ref
Student et al.	2020	A	SES, VA	RL	L	MO	(n/a)	Ref
Sulis et al.	2024	A	VA, AA	LL	L	MO	P-Eb, S-I	Ref
Thomas et al.	2021	A	VA	LL	TN	MO	(n/a)	Ref
Tonmoy and Zein	2018	A	VA	BE	N	MO	(n/a)	Ref
Touza et al.	2021	A	AA	RL	TN	QS	S-E	Ref

Authors	Year	Document Types	Literature Types	Study-Focused	Study Scale	Methods Used	Adaptation Types	Literature Link
Townend et al.	2021	A	RS	LL	N	MO	(n/a)	Ref
Uddin et al.	2019	A	VA	RL	N	AN	(n/a)	Ref
Unguendoli et al.	2023	A	AA	RL	L	MO	P-Eb	Ref
Van-Dolah et al.	2020	A	RS	LL	N	AN	(n/a)	Ref
Van-Putten et al.	2017	A	SES, VA	RL	N	MO	(n/a)	Ref
Veettil et al.	2021	A	AA	SL	N	AN	P-Eb	Ref
Vögler et al.	2023	A	VA	FI	N	QS	(n/a)	Ref
Warnken and Mosadeghi	2018	A	SES, AA	LL	L	AN	IT	Ref
Whitfield et al.	2019	A	SES, RS	FR, LN	TN	AN	(n/a)	Ref
Whitney and Bann	2019	A	SES, AA	RL	L	QS	I-G	Ref
Whitney et al.	2017	R	SES, AA	RL	(n/a)	R	(n/a)	Ref
Williams et al.	2016	A	VA	LL	TN	AN	(n/a)	Ref
Wongbusarakum et al.	2015	A	SES	RL	TN	AN	(n/a)	Ref
Yasmeen et al.	2024	R	AA	LL	(n/a)	R	(n/a)	Ref
Zamboni et al.	2022	A	VA, AA	RL	L	MO	P-Eb	Ref
Zanchettin et al.	2021	A	VA	UB	L	AN	(n/a)	Ref
Zanuttigh	2011	A	AA	LL	TN	MO	P-Eb, S-I	Ref
Zari et al.	2020	A	AA	IS	L	MO, QS	P-Eb	Ref

References

1. IPCC (Intergovernmental Panel on Climate Change). Annex I: Glossary. In *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Pörtner, H.-O., Roberts, D.C., Masson-Delmotte, V., Zhai, P., Tignor, M., Poloczanska, E., Mintenbeck, K., Alegría, A., Nicolai, M., Okem, A., et al., Eds.; Cambridge University Press: Cambridge, UK, 2019; pp. 677–702. [CrossRef]
2. Hossain, M.S.; Gain, A.K.; Rogers, K.G. Sustainable coastal social-ecological systems: How do we define "coastal"? *Int. J. Sustain. Dev. World Ecol.* **2020**, *27*, 577–582. [CrossRef]
3. Giupponi, C.; Ausseil, A.-G.; Balbi, S.; Cian, F.; Fekete, A.; Gain, A.K.; Essenfelder, A.H.; Martínez-López, J.; Mojtahed, V.; Norf, C.; et al. Integrated modelling of social-ecological systems for climate change adaptation modelling. *Socio-Environ. Syst. Model.* **2022**, *3*, 18161. [CrossRef]
4. Ostrom, E. A general framework for analyzing sustainability of social-ecological systems. *Science* **2009**, *325*, 419–422. [CrossRef] [PubMed]
5. Cabana, D.; Rölfer, L.; Evadzi, P.; Celliers, L. Enabling climate change adaptation in coastal systems: A systematic literature review. *Earth Future* **2023**, *11*, e2023EF003713. [CrossRef]
6. Costanza, R.; Anderson, S.J.; Sutton, P.; Mulder, K.; Mulder, O.; Kubiszewski, I.; Wang, X.; Liu, X.; Pérez-Maqueo, O.; Martinez, M.L.; et al. The global value of coastal wetlands for storm protection. *Glob. Environ. Change* **2021**, *70*, 102328. [CrossRef]
7. Jouffray, J.-B.; Blasiak, R.; Norström, A.V.; Österblom, H.; Nyström, M. The blue acceleration: The trajectory of human expansion into the ocean. *One Earth* **2020**, *2*, 43–54. [CrossRef]
8. UN (United Nations). *World Population Prospects*; Department of Economic and Social Affairs, United Nations: New York, NY, USA, 2017; Available online: https://population.un.org/wpp/Publications/Files/WPP2017_KeyFindings.pdf (accessed on 18 June 2024).
9. Riera-Spiegelhalder, M.; Campos-Rodrigues, L.; Enseñado, E.M.; Dekker-Arlain, J.d.; Papadopoulou, O.; Arampatzis, S.; Vervoort, K. Socio-Economic Assessment of Ecosystem-Based and Other Adaptation Strategies in Coastal Areas: A Systematic Review. *J. Mar. Sci. Eng.* **2023**, *11*, 319. [CrossRef]
10. Loch, T.K.; Riechers, M. Integrating indigenous and local knowledge in management and research on coastal ecosystems in the Global South: A literature review. *Ocean Coast. Manag.* **2021**, *212*, 105821. [CrossRef]
11. Gedan, K.B.; Kirwan, M.L.; Wolanski, E.; Barbier, E.B.; Silliman, B.R. The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. *Clim. Change* **2010**, *106*, 7–29. [CrossRef]
12. MEA (Millennium Ecosystem Assessment). Coastal systems. In *Ecosystems and Human Well-Being: Current State and Trends*; Hassan, R., Scholes, R., Ash, N., Eds.; Island Press: Washington, DC, USA, 2005; pp. 513–549.

13. Donato, D.C.; Kauffman, J.B.; Murdiyarso, D.; Kurnianto, S.; Stidham, M.; Kanninen, M. Mangroves among the most carbon-rich forests in the tropics. *Nat. Geosci.* **2011**, *4*, 293–297. [CrossRef]
14. Kanan, A.H.; Masiero, M.; Pirotti, F. Land cover change across 45 years in the world's largest mangrove forest (Sundarbans): The contribution of remote sensing in forest monitoring. *Eur. J. Remote Sens.* **2022**, 1–17. [CrossRef]
15. Neumann, B.; Ott, K.; Kenchington, R. Strong sustainability in coastal areas: A conceptual interpretation of SDG 14. *Sustain. Sci.* **2017**, *12*, 1019–1035. [CrossRef] [PubMed]
16. UN (United Nations). *The Sustainable Development Goals Report 2017*; Department of Economic and Social Affairs, United Nations: New York, NY, USA, 2017; Available online: https://unstats.un.org/sdgs/files/report/2017/TheSustainableDevelopmentGoalsReport2017.pdf (accessed on 22 June 2024).
17. Merino-Benítez, T.; Bojórquez-Tapia, L.A.; Miquelajauregui, Y.; Batllori-Sampedro, E. Navigating climate change complexity and deep uncertainty: Approach for building socioecological resilience using qualitative dynamic simulation. *Front. Clim.* **2024**, *6*, 1331945. [CrossRef]
18. Mahmood, R.; Zhang, L.; Li, G.; Ranjon-Roy, N.; Rawnaq, N.; Yan, M.; Dong, Y.; Chen, B. Geospatial assessment of intrinsic resilience to the climate change for the central coast of Bangladesh. *Clim. Risk Manag.* **2023**, *40*, 100521. [CrossRef]
19. Olivares-Aguilar, I.C.; Sánchez-Dávila, G.; Wildermann, N.E.; Clark, D.; Floerl, L.; Villamizar, E.; Matteucci, S.D.; Muñoz-Sevilla, N.P.; Nagy, G.J. Methodological approaches to assess climate vulnerability and cumulative impacts on coastal landscapes. *Front. Clim.* **2022**, *4*, 1018182. [CrossRef]
20. Bhattachan, A.; Jurjonas, M.D.; Moody, A.C.; Morris, P.R.; Sanchez, G.M.; Smart, L.S.; Taillie, P.J.; Emanuel, R.E.; Seekamp, E.L. Sea level rise impacts on rural coastal social-ecological systems and the implications for decision making. *Environ. Sci. Policy* **2018**, *90*, 122–134. [CrossRef]
21. Newton, A.; Icely, J.; Cristina, S.; Brito, A.; Cardoso, A.C.; Colijn, F.; Riva, S.D.; Gertz, F.; Hansen, J.W.; Holmer, M.; et al. An overview of ecological status, vulnerability and future perspectives of European large shallow, semi-enclosed coastal systems, lagoons and transitional waters. *Estuar. Coast. Shelf Sci.* **2014**, *140*, 95–122. [CrossRef]
22. IPCC (Intergovernmental Panel on Climate Change). *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, Pörtner, H.-O.,. Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al., Eds.*; Cambridge University Press: Cambridge, UK, 2022; pp. 30–56. [CrossRef]
23. Giupponi, C.; Bidoia, M.; Breil, M.; Corato, L.D.; Gain, A.H.; Leoni, V.; Fard, B.M.; Pesenti, R.; Umgiesser, G. Boon and burden: Economic performance and future perspectives of the Venice flood protection system. *Reg. Environ. Change* **2024**, *24*, 44. [CrossRef]
24. Neogi, S.B.; Dey, M.; Kabir, S.L.; Masum, S.J.H.; Kopprio, G.; Yamasaki, S.; Lara, R. Sundarban mangroves: Diversity, ecosystem services and climate change impacts. *Asian J. Med. Biol. Res.* **2017**, *2*, 488–507. [CrossRef]
25. Barnes, M.; Bodin, R.; Guerrero, A.; Mcallister, R.; Alexander, S.; Robins, G. The social structural foundations of adaptation and transformation in social-ecological systems. *SSRN Electron. J.* **2017**, *22*, 1–20. [CrossRef]
26. Gallopin, G.C. Linkages between vulnerability, resilience, and adaptive capacity. *Glob. Environ. Change* **2006**, *16*, 293–303. [CrossRef]
27. Kaplan-Hallam, M.; Bennett, N.J.; Satterfield, T. Catching sea cucumber fever in coastal communities: Conceptualizing the impacts of shocks versus trends on social-ecological systems. *Glob. Environ. Change* **2017**, *45*, 89–98. [CrossRef]
28. Walker, B.; Holling, C.S.; Carpenter, S.R.; Kinzig, A. Resilience, Adaptability and Transformability in Social—Ecological Systems. *Ecol. Soc.* **2004**, *9*, 5. [CrossRef]
29. Adger, W.N. Vulnerability. *Glob. Environ. Change* **2006**, *16*, 268–281. [CrossRef]
30. Cinner, J.E.; Adger, W.N.; Allison, E.H.; Barnes, M.L.; Brown, K.; Cohen, P.J.; Gelcich, S.; Hicks, C.C.; Hughes, T.P.; Lau, J.; et al. Building adaptive capacity to climate change in tropical coastal communities. *Nat. Clim. Change* **2018**, *8*, 117–123. [CrossRef]
31. Whitney, C.K.; Bennett, N.J.; Ban, N.C.; Allison, E.H.; Armitage, D.; Blythe, J.L.; Burt, J.M.; Cheung, W.; Finkbeiner, E.M.; Kaplan-Hallam, M.; et al. Adaptive capacity: From assessment to action in coastal social-ecological systems. *Ecol. Soc.* **2017**, *22*, 22. Available online: https://www.jstor.org/stable/26270135 (accessed on 14 May 2024). [CrossRef]
32. Nalau, J.; Verrall, B. Mapping the evolution and current trends in climate change adaptation science. *Clim. Risk Manag.* **2021**, *32*, 100290. [CrossRef]
33. Pörtner, H.-O.; Roberts, D.C.; Masson-Delmotte, V.; Zhai, P.; Tignor, M.; Poloczanska, E.; Weyer, N.M. *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*; Cambridge University Press: Cambridge, UK, 2019; p. 775. [CrossRef]
34. UNEP (United Nations Environment Programme). *Adaptation Gap Report 2021: The Gathering Storm—Adapting to Climate Change in a Post-Pandemic World*; UNEP: Nairobi, Kenya, 2021; Available online: https://wedocs.unep.org/bitstream/handle/20.500.11822/37284/AGR21.pdf (accessed on 22 June 2024).
35. Mongeon, P.; Paul-Hus, A. The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics* **2016**, *106*, 213–228. [CrossRef]
36. Mingers, J.; Leydesdorff, L. A review of theory and practice in scientometrics. *Eur. J. Oper. Res.* **2015**, *246*, 1–19. [CrossRef]
37. Sierra-Correa, P.C.; Cantera Kintz, J.R. Ecosystem-based adaptation for improving coastal planning for sea-level rise: A systematic review for mangrove coasts. *Mar. Policy* **2015**, *51*, 385–393. [CrossRef]
38. Bueno, S.; Bañuls, V.A.; Gallego, M.D. Is urban resilience a phenomenon on the rise? A systematic literature review for the years 2019 and 2020 using textometry. *Int. J. Disaster Risk Reduct.* **2021**, *66*, 102588. [CrossRef]

39. Kanan, A.H.; Masiero, M.; Pirotti, F. Estimating Economic and Livelihood Values of the World's Largest Mangrove Forest (Sundarbans): A Meta-Analysis. *Forests* **2024**, *15*, 837. [CrossRef]
40. Noble, I.R.; Huq, S.; Anokhin, Y.A.; Carmin, J.; Goudou, D.; Lansigan, F.P.; Osman-Elasha, B.; Villamizar, A. Adaptation needs and options. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J.D., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK, 2014; pp. 833–868.
41. Parsons, M.; Nalau, J.; Fisher, K.; Brown, C. Disrupting path dependency: Making room for Indigenous knowledge in river management. *Glob. Environ. Change* **2019**, *56*, 95–113. [CrossRef]
42. Salgueiro-Otero, D.; Ojea, E. A better understanding of social-ecological systems is needed for adapting fisheries to climate change. *Mar. Policy* **2020**, *122*, 104123. [CrossRef]
43. Ford, J.D.; Berrang-Ford, L.; Paterson, J. A systematic review of observed climate change adaptation in developed nations. *Clim. Change* **2011**, *106*, 327–336. [CrossRef]
44. Kanan, A.H.; Pirotti, F.; Masiero, M.; Rahman, M.M. Mapping inundation from sea level rise and its interaction with land cover in the Sundarbans mangrove forest. *Clim. Change* **2023**, *176*, 104. [CrossRef]
45. Jabir, A.; Hasan, G.M.J.; Anam, M.M. Correlation between temperature, sea level rise and land loss: An assessment along the Sundarbans coast. *J. King Saud Univ.–Eng. Sci.* **2021**, *in press*. [CrossRef]
46. Islam, M.A.; Mitra, D.; Dewan, A.; Akhter, S.H. Coastal multi-hazard vulnerability assessment along the Ganges deltaic coast of Bangladesh- a geospatial approach. *Ocean Coast. Manag.* **2016**, *127*, 1–5. [CrossRef]
47. Nishat, B.; Rahman, A.J.M.Z.; Mahmud, S. Landscape Narrative of the Sundarban: Towards Collaborative Management by Bangladesh and India. 2019. Available online: http://documents.worldbank.org/curated/en/539771546853079693 (accessed on 10 June 2024).
48. Karim, M.F.; Mimura, N. Impacts of climate change and sea-level rise on cyclonic storm surge foods in Bangladesh. *Glob. Environ. Change* **2008**, *18*, 490–500. [CrossRef]
49. Deb, M.; Ferreira, M. Potential impacts of the Sunderban mangrove degradation on future coastal flooding in Bangladesh. *J. Hydro-Environ. Res.* **2017**, *17*, 30–46. [CrossRef]
50. FAO (Food and Agriculture Organization). *Global Forest Resources Assessment 2010: Main Report*; Forestry Paper; Food and Agriculture Organization of the United Nations: Rome, Italy, 2010; Available online: http://www.fao.org/docrep/013/i1757e/i1757e.pdf (accessed on 7 July 2024).
51. Ortolano, L.; Sánchez-Triana, E.; Paul, T.; Ferdausi, S.A. Managing the Sundarbans region: Opportunities for mutual gain by India and Bangladesh. *Int. J. Environ. Sustain. Dev.* **2016**, *15*, 16–31. [CrossRef]
52. Kibria, A.S.M.G.; Costanza, R.; Gasparatos, A.; Soto, J. A composite human wellbeing index for ecosystem-dependent communities: A case study in the Sundarbans, Bangladesh. *Ecosyst. Serv.* **2022**, *53*, 101389. [CrossRef]
53. Roy, A.K.D.; Alam, K.; Gow, J. Community perceptions of state forest ownership and management: A case study of the Sundarbans Mangrove Forest in Bangladesh. *J. Environ. Manag.* **2013**, *117*, 141–149. [CrossRef] [PubMed]
54. Giri, C.; Pengra, B.; Zhu, Z.; Singh, A.; Tieszen, L.L. Monitoring mangrove forest dynamics of the Sundarbans in Bangladesh and India using multi-temporal satellite data from 1973 to 2000. *Estuar. Coast. Shelf-Sci.* **2007**, *73*, 91–100. [CrossRef]
55. Ghosh, A.; Schmidt, S.; Fickert, T.; Nüsser, M. The Indian Sundarban Mangrove Forests: History, Utilization, Conservation Strategies and Local Perception. *Diversity* **2015**, *7*, 149–169. [CrossRef]
56. WB (World Bank). *Economic of Adaptation to Climate Change: Bangladesh*; Main Report; World Bank: Washington, DC, USA, 2010; Volume 1, Available online: https://openknowledge.worldbank.org/handle/10986/12837 (accessed on 22 June 2024).
57. Payo, A.; Mukhopadhyay, A.; Hazra, S.; Ghosh, T.; Ghosh, S.; Brown, S.; Nicholls, R.J.; Bricheno, L.; Wolf, J.; Kay, S.; et al. Projected changes in area of the Sundarban mangrove forest in Bangladesh due to SLR by 2100. *Clim. Change* **2016**, *139*, 279–291. [CrossRef]
58. Keskitalo, E.C.H.; Preston, B. Introduction: Understanding adaptation in the context of social theory. In Research Handbook on Climate Change Adaptation Policy. Edward Elgar Publishing: Cheltenham, UK, 2019. [CrossRef]
59. Burton, C. A Validation of Metrics for Community Resilience to Natural Hazards and Disasters Using the Recovery from Hurricane Katrina as a Case Study. *Ann. Assoc. Am. Geogr.* **2015**, *105*, 67–86. [CrossRef]
60. Smallegan, S.M.; Irish, J.L.; Den Bieman, J.P. Morphological response of a sandy barrier island with a buried seawall during Hurricane Sandy. *Coast. Eng.* **2016**, *110*, 102–110. [CrossRef]
61. McNamara, K.; Westoby, R.; Smithers, S. Identification of limits and barriers to climate change adaptation: Case study of two islands in Torres Strait, Australia. *Geogr. Res.* **2017**, *55*, 438–455. [CrossRef]
62. Bellafore, D.; Ghezzo, M.; Tagliapietra, D.; Umgiesser, G. Climate change and artificial barrier effects on the Venice Lagoon: Inundation dynamics of salt marshes and implications for halophytes distribution. *Ocean Coast. Manag.* **2014**, *100*, 101–115. [CrossRef]
63. Neumann, B.; Vafeidis, A.T.; Zimmermann, J.; Nicholls, R.J. Future coastal population growth and exposure to sea-level rise and coastal flooding—A global assessment. *PLoS ONE* **2015**, *10*, 34. [CrossRef]
64. Chang, L.F.; Huang, S.L. Assessing urban flooding vulnerability with an emergy approach. *Landsc. Urban Plann.* **2015**, *143*, 11–24. [CrossRef]

65. Goda, K.; De Risi, R. Probabilistic tsunami loss estimation methodology: Stochastic earthquake scenario approach. *Earthq. Spect.* **2017**, *33*, 1301–1323. [CrossRef]
66. Castellanos, E.; Lemos, M.F.; Astigarraga, L.; Chacón, N.; Cuvi, N.; Huggel, C.; Miranda, L.; Moncassim Vale, M.; Ometto, J.P.; Peri, P.L.; et al. Central and South America. 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*; Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., et al., Eds.; Cambridge University Press: Cambridge, UK, 2022; pp. 1689–1816. [CrossRef]
67. Trisos, C.; Adelekan, I.; Totin, E.; Ayanlade, A.; Efitre, J.; Gemeda, A. Chapter 9: Africa. In *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of the WG II to the Sixth Assessment Report of the IPCC*; Cambridge University Press: Cambridge, UK, 2022; pp. 1285–1455. Available online: https://www.ipcc.ch/report/ar6/wg2/chapter/chapter-9/ (accessed on 19 May 2024).
68. Nobi, M.N.; Sarker, A.H.M.R.; Nath, B.; Røskaft, E.; Suza, M.; Kvinta, P. Economic valuation of tourism of the Sundarban Mangroves, Bangladesh. *J. Ecol. Nat. Environ.* **2021**, *13*, 100–109. [CrossRef]
69. Vignola, R.; Locatelli, B.; Martinez, C.; Imbach, P. Ecosystem-based adaptation to climate change: What role for policy-makers, society and scientists? *Mitig. Adapt. Strateg. Glob. Change* **2009**, *14*, 691–696. [CrossRef]
70. Hale, L.Z.; Meliane, I.; Davidson, S.; Sandwith, T.; Bech, M.; Hoekstra, J.; Spalding, M.; Murawski, S.; Cyr, N.; Osgood, K.; et al. Ecosystem-based adaptation in marine and coastal ecosystems. *Renew. Resour. J.* **2009**, *25*, 21–28. Available online: https://www.cabdirect.org/cabdirect/abstract/20093286746 (accessed on 10 June 2024).
71. Raymond, C.M.; Frantzeskaki, N.; Kabisch, N.; Berry, P.; Breile, M.; Nita, M.R.; Geneletti, D.; Calfapietra, C. A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environ. Sci. Policy* **2017**, *77*, 15–24. [CrossRef]
72. Cohen-Shacham, E.; Walters, G.; Janzen, C.; Maginnis, S. *Nature-Based Solutions to Address Global Societal Challenges*; IUCN: Gland, Switzerland, 2016. [CrossRef]
73. Biesbroek, G.R.; Klostermann, J.E.M.; Termeer, C.J.A.M.; Kabat, T. On the nature of barriers to climate change adaptation. *Reg. Environ. Change* **2013**, *13*, 1119–1129. [CrossRef]
74. Van-Aalst, M.K.; Cannon, T.; Burton, I. Community level adaptation to climate change: The potential role of participatory risk assessment. *Glob. Environ. Change* **2008**, *18*, 165–179. [CrossRef]
75. Cicin-Sain, B.; Belfiore, S. Linking marine protected areas to integrated coastal and ocean management: A review of theory and practice. *Ocean Coast. Manag.* **2005**, *48*, 847–868. [CrossRef]
76. Newton, A.; Weichselgartner, J. Hotspots of coastal vulnerability: A DPSIR analysis to find societal pathways and responses. *Estuar. Coast. Shelf Sci.* **2014**, *140*, 123–133. [CrossRef]
77. Baldwin, C.; Lewison, R.L.; Lieske, S.N.; Beger, M.; Hines, E.; Dearden, P.; Rudd, M.A.; Jones, C.; Satumanatpan, S.; Junchompoo, C. Using the DPSIR framework for transdisciplinary training and knowledge elicitation in the Gulf of Thailand. *Ocean Coast. Manag.* **2016**, *134*, 163–172. [CrossRef]
78. Lewison, R.L.; Rudd, M.A.; Al-Hayek, W.; Baldwin, C.; Beger, M.; Lieske, S.N.; Jones, C.; Satumanatpan, S.; Junchompoo, C.; Hines, E. How the DPSIR framework can be used for structuring problems and facilitating empirical research in coastal systems. *Environ. Sci. Policy* **2016**, *56*, 110–119. [CrossRef]
79. Bell, S. DPSIR = A problem structuring method? An exploration from the "Imagine" approach. *Eur. J. Oper. Res.* **2012**, *222*, 350–360. [CrossRef]