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Review

Creating a Novel Multi-Layered Integrative Climate Change Adaptation Planning Approach Using a Systematic Literature Review

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Abstract: Climate change adaptation planning requires the integration of disciplines, stakeholders, different modelling approaches, treatment options, and scales of analysis. An integrated stepwise planning approach is a critical requirement for effective climate change adaptation in the context of small island developing states and coastal communities. To address this need, this paper reports on a systematic review of 116 research papers from an initial set of around 650 academic peer-reviewed papers. These papers were assessed and categorised based on their planning framework or the approach utilised, measured climate change impacts, employed methods and tools, and recommended adaptation strategies or options. This study identified three important dimensions of a fully integrated climate change adaptation planning process, namely, integration in assessment, integration in modelling, and integration in adaptive responses. Moreover, it resulted in the formulation of a novel multi-layered integrative climate change adaptation planning approach. Adopting this holistic and integrative approach is more likely to yield better climate change adaptation in planning outcomes over the long term.

Keywords: climate change adaptation; integrated modelling approach; small island developing states; adaptation planning; ecosystem-based adaptation

1. Introduction

Climate change adaptation considering local to global scales as defined by the Intergovernmental Panel on Climate change (IPCC) Fifth Assessment Report (AR5) refers to activities that are aimed at adjusting to actual or expected climate and its effects [1]. Moderating the adverse effects of specific climate change impacts can be achieved through a wide range of actions to protect, accommodate, or retreat from the hazards associated with a rapidly changing climate [2]. Meanwhile, some projected climate change impacts may provide opportunities that can be harnessed to generate positive outcomes through the employment of appropriate adaptation strategies [3]. A well-designed climate change adaptation planning process and plan, combined with its successful implementation, will enhance local community wellbeing under a changing climate condition [4].

Generally, an assessment of the quality of a plan is complex and difficult which requires the consideration of some general and case-specific criteria [5,6]. Specifically, the degree of success of a climate change adaptation plan requires an assessment criteria approach incorporating multiple factors, such as legitimacy, equity, and efficiency, as well as the unified capacity to adapt [7]. Yet, capability of addressing different needs according to the various characteristics of a region-specific (geographical, ecological, environmental, and socio-economic), as well as other common adaptation considerations is an essential component of a high-quality adaptation plan [8]. While plan assessment frameworks have traditionally had some criteria that are focused on the planning process, the complexity of long-term climate change adaptation planning requires more evaluation emphasis on the design of the planning process, since plan performance can often not be evaluated until many decades after implementation [9].

Furthermore, to move beyond a technical exercise and to achieve an effective adaptation plan, the identification of region-specific characteristics, opportunities, and limitations requires the elicitation of local and stakeholders' knowledge, using appropriate participatory tools and methods alongside other required assessments and modelling outcomes [1,10–13]. The assessment of the causes and impacts of climate change are beyond a single component, sector, field, or discipline [14,15]. The processes of mitigating and managing the concerns that are raised by climate change, particularly for coastal communities and small island developing states (SIDS), have to be considered as a whole system with the inclusion of its wide range of components across social, environmental, organisational, and conceptual boundaries [16]. Integrated approaches in the process of climate change adaptation planning promote incorporating and considering a spectrum of concerns as well as region-specific aspects, and fulfilling all requirements of planning [17,18]. By the same token, AR5 emphasises the importance of an integrated approach, specifically in the process of climate change adaptation planning and implementation. Relevant AR5 chapters included those titled: the integrated resources management, integrated coastal zone management [19]; integration in assessment with a range of planning practices and approaches [20]; integration of planning, including policy design and decision-making; and, integration of community knowledge in adaptation planning [1]. Sections 2 and 3 detail the persuasion for adopting an integrative approach in the process of adaptation planning.

Other recent works highlight the need for both an integrated and holistic approach to climate change adaptation planning [21,22]. To date, adaptation strategies and actions are not generally developed through an integrated and holistic approach, and are unable to fully satisfy adaptation and sustainable development goals, often having unintended negative impacts on other plans, strategies, processes, or other systems [23]. A holistic approach for adaptation transcends technological solutions and encourages the employment of social, organisational, technical, and infrastructural opportunities that respect uncertainties [22,24]. Preston, Westaway [25] evaluated adaptation plans from a number of developed countries and contended that the majority of them were largely under-developed, had insufficient assessments of impacting factors, or lacked consideration for the nation's adaptive capacity [25]. A growing body of work argues for both greater integration and holistic approaches for adaptation planning to yield better climate change adaptation planning outcomes over the long term [26–29].

SIDS are highly vulnerable to the impacts of climate change [1,30]. Although the contribution of SIDS to the world's total greenhouse gas (GHG) emissions is less than one percent, they are acknowledged as being significantly vulnerable to the impacts of climate change [31]. In particular, SIDS are often characterised by rapidly growing populations, fragile environments, poor economic growth, and high exposure to natural hazards [32]. 57 SIDS have been globally recognised as being particularly vulnerable to global climate change [33]. Twenty-three of SIDS are located in the Caribbean region (such as Haiti, Puerto Rico, Saint Lucia, etc.), twenty in the Pacific region (such as Vanuatu, Cooks Island, Fiji, etc.), and the rest in the African region, Indian Ocean, Mediterranean, and the South China Sea. Despite their specific cultural and geographical differences, they have similar sustainable development challenges, including: remoteness; limited available funds for adaptation works; institutional barriers; limited public awareness; international aid dependence; and, exposure to identical natural disasters and extreme events [34,35]. SIDS often have no choice but to urgently prepare for climate change impacts by integrating adaptation into their policies and strategic plans in order to reduce their vulnerability and enhance resilience.

In light of the above discussion, the overarching goal of this research was to conduct a comprehensive systematic literature review of the following aspects in the context of SIDS: (1) climate change impacts; (2) adaptation planning framework and analysis approaches; (3) adaptation policies and strategies; and, (4) modelling tools and methodologies that were used in the process of adaptation planning. A multilayered integrative approach was formulated that was founded on the findings of the following literature-mining research procedure: (1) Specifying and describing the process of climate change adaptation and discussing the primary drivers for exploitation of an integrative planning approach; (2) Systematically identifying recent research literature covering various aspects of climate change adaptation planning for SIDS and other coastal communities with similar challenges; (3) Investigating and critique of different planning procedures advocated in the reviewed papers; and, (4) Grouping and defining different aspects of climate change adaptation planning for SIDS and coastal communities.

2. The Process of Adaptation Planning

The process of adaptation can be divided into four core stages. The first stage involves the scoping and designing of an adaptation project and includes the identification of project boundaries, establishment of project teams and resources, sourcing and synthesising available data, and designing the initial adaptation policy framework [36]. The second stage is focused on project planning that can follow the process set out in the UK Climate Impacts Programme (UKCIP) technical report [37]. The third and the fourth stages are focused on project implementation, monitoring, and evaluation [38]. Therefore, the whole process of climate change adaptation can be conceptualised as a continuous planning cycle to deal with the uncertainties inherent to future projections, the interdependencies within and between sectors and level, and complex interactions between system components, including feedbacks.

Fussel and Klein [39] argued that adaptation strategies must answer the two key question of 'what to adapt to?' and 'how to adapt?', Sahin and Mohamed [40] suggested the addition of a temporal dimension by adding a third question, namely, 'when to adapt?'. Based on these perspectives, the development of adaptation plans comprises two major sequential planning phases. The first step is a vulnerability assessment (VA) that seeks to answer the question of what to adapt to. The second step involves the decision-making process that answers the remaining two questions of how and when to adapt. Despite the differences in approaches and methodologies that constitute the details of the planning procedure, these two common phases are recognised in numerous related technical reports and reviewed papers [1,39,41–46]. Figure 1 illustrates both of these phases with their specific components and sub-systems.

First, vulnerability is commonly assessed through (1) assessing the climate change impacts on the components of the scoped system (i.e., impact assessment) and (2) the evaluation of the target population, community, or organisation's capacity to adapt (i.e., adaptive capacity evaluation). Impact assessment is specifically defined as a function of exposure and sensitivity to specific hazards arising from climate change-related stressors or impacts. Applying the outcomes of the vulnerability assessment, the process of decision making requires the inclusion of different steps comprising adaptive options and opportunities identification, adaptation options assessment and analysis, and adaptation performance analysis. As the first step, all potential adaptive opportunities and options are to be identified, followed by the selection of the most applicable and realistic options. This identification and selection process was achieved through the utilisation of different evaluation approaches and must include the involvement of a range of stakeholders to ensure that the objectives are suitably defined and met. All nominated actions have to be prioritised and embedded in a final action plan.

The framework and steps outlined in Figure 1 still follow a rationale planning approach. A missing element to this approach is the emphasis on the integration of disciplines, stakeholders, planning and modelling approaches, treatment options, and scales of analysis. The complexity of climate change adaptation planning necessitates a further emphasis on integration, particularly related to assessment, modelling, and adaptive responses. The drivers for an integrative approach are argued below, which provided the context for the systematic literature review research design conducted in this study.

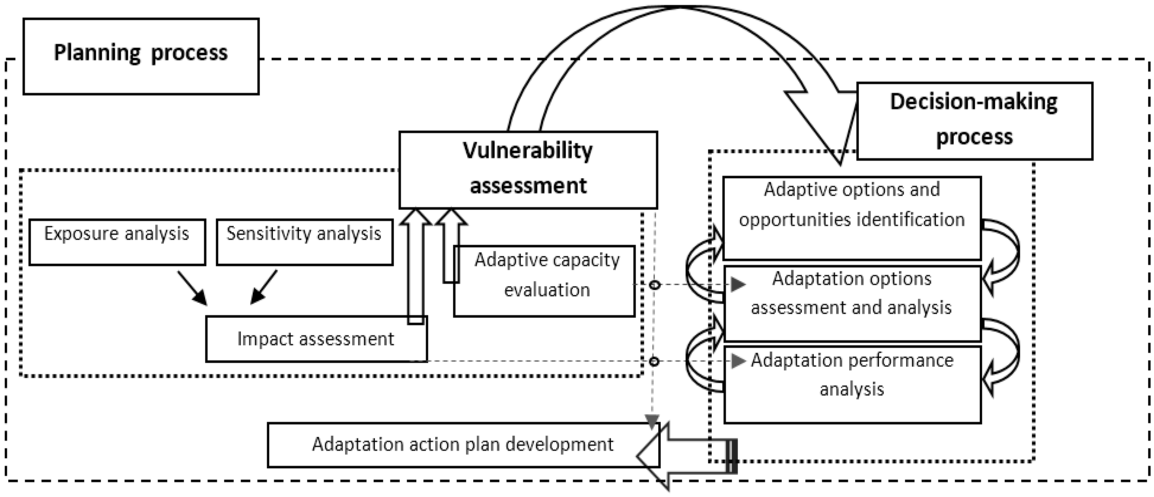

Figure 1. Conceptual framework for the process of adaptation planning. (Adapted from Sahin and Mohamed (2014) [47] and Nguyen et al., (2016) [46]).

3. Drivers for Integrative Approach

The term 'integration' or 'integrated modelling or assessment' has been defined and addressed differently in academic and scientific reports. Nguyen et al. (2016) [46] and Wiek and Walter (2009) [48] suggest that a fully integrated planning approach for complex systems with transdisciplinary challenges includes a spectrum of related assessments, analysis, modelling, and methods of strategy derivation that are framed in a multi-methodological sequential plan. Accordingly, the quality of climate change adaptation plans can be enhanced by an effective integration of stakeholders' knowledge with all the various modelling, technical, and management assessments in the planning stage, in which different tools, methodologies, and expertise from different disciplines are exploited as a whole [7,8,12]. Specifically, Nicholls et al. (2008) [14] are also proponents of the integration of multidisciplinary engineering, natural, and social science evaluations for any coastal vulnerability assessments. Similarly, Kelly et al. (2013) [18] have addressed integration in environmental assessment and management as a process rather than an outcome that can be referred to in terms of five main considerations: treatment of issues, stakeholders, disciplines, process, and scales of the planning. Similarly, Hamilton et al. (2015) [49] have identified ten dimensions of integration in assessment and modelling of such a planning procedure that relate to the key drivers, methodological, and systems requirements of integration.

The review identified 15 key dimensions of climate change adaptation planning. These dimensions have been categorised into four main categories, consisting of the main factors or drivers for developing a high-quality climate change adaptation plan (Figure 2). As illustrated in Figure 2, these four categories are: (i) System characteristics; (ii) Fundamental requirements of adaptation planning; (iii) Technical and methodological considerations; and, (iv) Adaptation planning specific considerations.

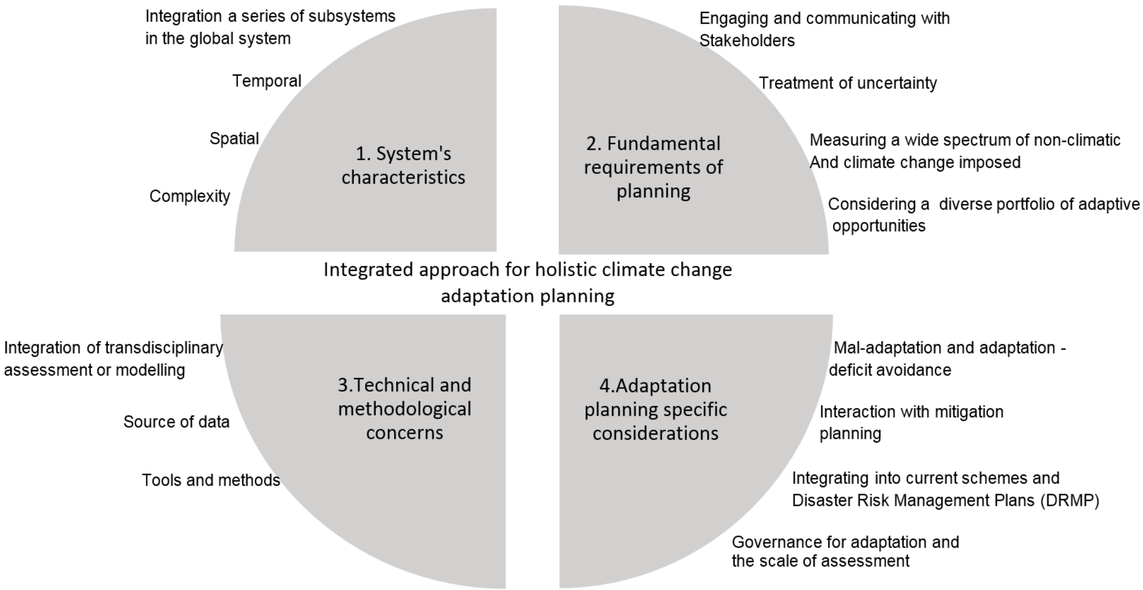

Figure 2. Drivers for an integrative approach for holistic adaptation planning.

3.1. System Characteristics

System characteristics need to be understood comprehensively as a necessary precursor for the development of appropriate planning for environmental and other related systems and associated policy adoption [18]. SIDS and coastal areas, in general as socio-ecological systems, are complex and dynamic systems with dependencies and multiple interactions, as well as feedbacks between systems and sectors within a diverse range of economic, biophysical, social, and natural aspects [40]. Furthermore, the global system comprises a series of interconnected economic, environmental, and social sub-systems that are under constant pressure from climatic impacts [16]. Moreover, the spatial scales that are needed for adaptation planning can vary from the local community to national levels, and may also be influenced by other factors. The process of selecting appropriate spatial scale requires keeping a balance between the stakeholders' scale of interest, data availability and limitations, different scales of system components, and the scale in which the planning is likely to be impacted [18,50]. Furthermore, heterogeneity and complexity were highlighted in AR5 as the main neglected aspects of small islands in the past literature [51], although more considerations have been given to these aspects since this criticism. Modelling temporal changes of all system's components and their impact on each other, in both vulnerability assessment and decision-making analysis phases is requisite. Assessing the modelling and assessment concerns that are raised by a system's characteristics (including complexity, temporal, and spatial aspects) will determine the chosen methods and modelling tools.

3.2. Fundamental Requirements of Planning

Approaches supporting the participation of stakeholders in all stages of the adaptation process, from planning to monitoring and implementation, can increase the likelihood of its success, specifically in developing societies [12,26,52–55]. In the planning process, communication between stakeholders, modellers, and researchers from different fields is crucial due to the multidisciplinary nature of adaptation. In recent times, stakeholder engagement, taking many forms, such as collaboration, participation, and shared learning, has become a necessity in the process of environmental assessments or modelling [56]. Chapter 15 of the AR5 recommended the participation of a broad range of stakeholders as a critical component in any adaptation planning in order to avoid mal-adaptation and promote the linkage between different levels of government [19]. An example of the significance of stakeholder engagement in planning processes is demonstrated by its ability to enhance equity, flexibility, legitimacy, and governance capacity through the linking of different governance levels [53].

A second fundamental requirement is the utilisation of probabilistic or scenario-based modelling tools in the process of adaptation planning in order to treat embedded uncertainties. Suitable treatment of uncertainty can be achieved through the careful description and quantification of uncertainty in both the modelling and assessment phases and by the exploitation of applicable tools and methodologies [57].

A third consideration is that individual climate change impacts and appropriate treatments must not be considered in isolation [49]. Adaptation action plans are more effective when they consider an optimal combination of different strategies, such as protection, accommodate, and retreat [58]. Accordingly, the integrated utilisation of adaptation options significantly promotes the effectiveness of adaptation plans by employing all adaptive capacities of environmental and social systems of a particular region. Assessment of interactions between adaptation options in an action plan is also significant in conjunction with independent assessments of single options.

3.3. Technical and Methodological Considerations

Coastal and SIDS systems comprise of environmental, geophysical, biological and socio-economic subsystems that need to be studied within a multidisciplinary lens [8,59,60]. Integrating the different modelling and assessment outcomes of the various disciplines involved in adaptation planning is a challenging but essential requirement if the goal of a holistic approach is to be achieved. When a multidisciplinary holistic approach is taken, each field of study has its specific conceptual frameworks and tools that are selected and employed in the adaptation planning process and which can address important features of the system's dynamics. All tools and methods have their own range of applications with their characteristic, limitations, complications, and caveats. Best practice suggests that all applicable methods and tools be drawn upon and coupled using an integration strategy in the process of modelling and assessment. For this purpose, there are two main approaches for fulfilling the need for integration in the process of planning recognised by Nicholls et al. (2008) [17]: different modelling tools within an integrative methodology (assemblage approach); and, one comprehensive modelling methodology covering the whole system's requirements (integral approach). Therefore, choosing appropriate tools through an appropriate integration strategy is a crucial decision point in the adaptation planning process.

Accordingly, to achieve an effective integration of multidisciplinary studies that are involved in the planning process, a series of meetings with multidisciplinary experts should be conducted in order to accomplish the following objectives: to provide team members with initial information and data; to share outputs; to discuss and understand how output data from one assessment feeds in as input data to another; and finally, to integrate all output in a single platform and finalise the outcomes of their research [61]. In another study, Serrao-Neumann et al. (2015) [62] have suggested an integrated multidisciplinary approach to climate change adaptation research that supports the design of a stakeholder engagement process to increase the role of the stakeholders' participation in the decision-making process.

Additionally, the selection of tools and approaches is often dictated by the reliability and types of available data. To consider some specific instances, exploratory tools are needed for additional statistical analysis and pattern recognition in order to provide researchers and modelers with sufficient data on key system variables [63]; scenario-based, participatory, or probabilistic tools may be required when there is high uncertainty around available data [57]; and process-based approaches can be exploited for knowledge and data integrating and encoding [16].

3.4. Adaptation Planning Specific Considerations

An adaptation plan is developed in conjunction with other policies and plans, including future and in-progress ones (e.g., development plan, mitigation plan, disaster risk management plans (DRMP), coastal management plan). Disregarding the integration of current ongoing policies and DRMP into the planning process may result in parallel actions, duplicated resources, potential conflicts of actions, increased vulnerability at other locations, and inefficiency of action plans [19].

Additional determinative elements of adaptation planning are governance, institutional arrangements, and resource mobilisation [58]. While a detailed analysis of these elements is beyond the scope of this paper, two aspects that warrant some comment here are governance and scope of planning and the direction of implementation. Regarding the former, the boundaries of land (or sea) at risk from climate change-related impact threats may not conveniently lay within recognised geographical, political institutional, or organisational borders. Furthermore, the targeted levels of actions may require coordinated responses across sectors (private, government, civil society), levels of government (national, provincial, local), and internationally. Regarding the direction of implementation, both top-down and bottom-up approaches are accepted and are also needed in the process of planning [16].

3.5. Summary

A strategic and planned integrative approach for climate change adaptation planning, capable of transcending technocratic boundaries through stakeholder engagement and the integration of public knowledge, as well as being capable of fulfilling the requirements of adaptation planning, is the key to delivering an effective and holistic adaptation action plan. However, current frameworks do not sufficiently integrate the above-mentioned planning dimensions and requirements. Accordingly, a systematic review of recently published climate change adaptation literature has been undertaken, which led to the creation of an integrated approach and its associated layers and components in the context of SIDS and coastal communities.

4. Systematic Review Methodology

The concept of a systematic literature review originated in the early 1970's for the purpose of a social science study [64,65]. In recent years, it is becoming more commonly used in the environmental and engineering sciences [64,66–72]. Generally, a systematic review is used to address specific questions, through a carefully designed and systematic process for categorising and synthesising literature [73]. Berrang-Ford et al. (2015) [64] explain a systematic review of climate change adaptation research and advocate following a stepwise process in a systematic review of environmental-related studies generally and climate change adaptation research in particular. Systematic literature review steps include scope definition and research questions, defining the selection criteria, critically assessing selected documents while using a systematic pathway, qualitatively and/or quantitatively synthesising and analysing paper contents, and finally presenting assessments in a chosen system to adequately respond to the designed study questions. Other authors propose a similar stepwise approach [66–68].

An important preliminary stage of this study was to identify and review leading internationally recognised literature reports and documents, including Chapters 14 to 17, 19, and 29 of AR5, UK Climate Impacts Programme (UKCIP) technical report of adaptation [37], and the United Nations Development Programme Adaptation Policy Framework (APF) [36]. This was completed in order to formulate robust research questions as well as practical and tangible literature selection criteria (i.e., inclusions and exclusions). Specifically, in accordance with the objectives of the research, this systematic review aimed to address the following questions in the context of SIDS and coastal communities:

(1) What climate change impacts and adaptation policies have been reported in the reviewed literature? (Section 5.2)
(2) Which modelling methods and tools are being adopted in the process of climate change adaptation? (Section 5.3)
(3) What adaptation planning framework and analysis approaches have been adopted? (Section 5.4)
(4) What adaptation strategies have been considered, recommended, or implemented? (Section 5.5)

These four research questions helped to frame the systematic review exclusion and inclusion criteria. The reviewing process has been accomplished by searching through respectable peer-reviewed papers only. For conducting the systematic literature review methodically, a stepwise procedure with four main steps was designed for this comprehensive collection of papers (Figure 3). In the first and second steps, the authors agreed on the design of the systematic review process and searching criteria, and as a result, an initial database was established using the *Scopus* and the *ISI Web of Knowledge (WoK)* search engines and the terms "*planning*", "*climate change*", " *adaptation*", and "*coastal*" or "*Small Island*", then the terms "*model**" or "*assess**" in the topic field of literature; a total of 650 papers were identified from this search. A number of papers were excluded gradually in step 3.1, step 3.2, and step 3.3, and by completion of the third step, the number of papers was decreased to 132 based on the inclusion and exclusion criteria. Conducting a thorough review and comprehensive assessment in step 4, another 16 papers were excluded, and finally, 116 papers were selected for more in-depth content synthesis. The literature selection inclusion criteria included: (a) peer-reviewed papers; (b) papers that are directly relevant to the research scope; (c) papers that are focused on SIDS and coastal zones; (d) published between 2003 and 2016; and, (e) papers that have employed original evaluation, assessment or modelling methods in the climate change adaptation planning process that is focused on a specific region(s). The last inclusion criterion was set to ensure that the included papers recommended an adaptation solution that was supported by both literature and some form of scientific methodology. These methods and tools were classified in different groups as described in Section 5.3. In addition, apart from the exclusion criteria, shown in step 3 in Figure 3, papers that cannot be considered in support of any steps in the process of climate change adaptation planning were also excluded.

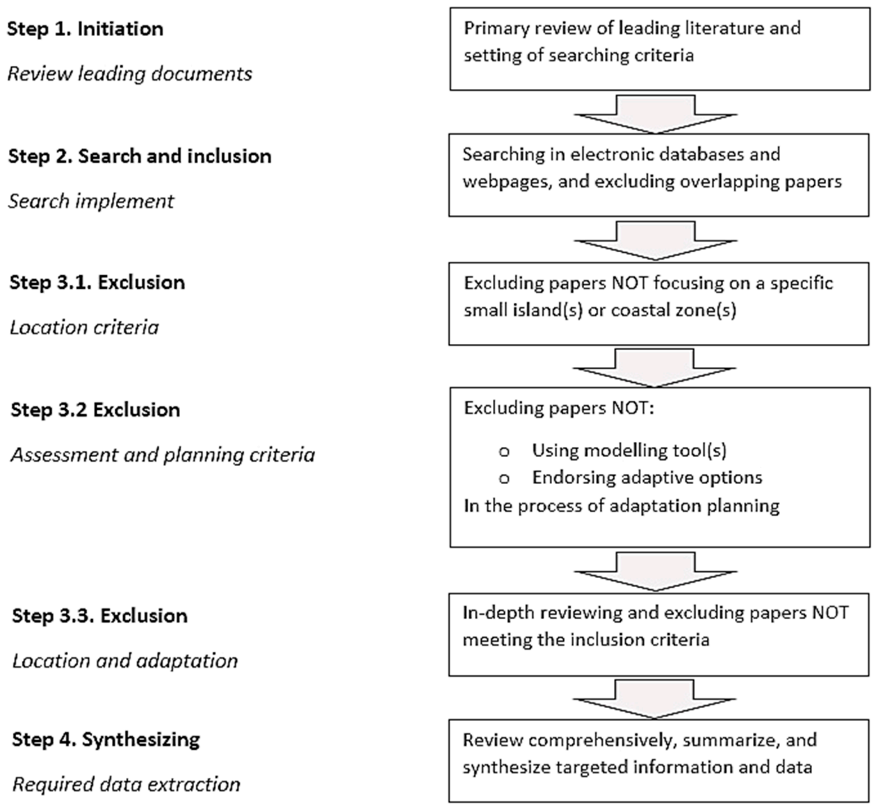

Figure 3. Systematic review stepwise procedure.

Following the identification of 116 relevant papers through this stepwise process, these papers were assessed carefully and organised by applying a set of specific criteria. These criteria were mainly designed in accordance with the primary research questions in order to address the bibliography, location of study, methodological or modelling approach, climate change risk assessment approach, recommended adaptation option(s) categories, framework and analysis approach, and other non-typical elements of each paper.

Each categories grouping description was based on well-established literature or a procedure developed for the purpose of this study, as described below:

(a) Climate change-induced impacts on SIDS and coastal communities (Section 5.2) were grouped according to the mentioned impacts on small islands provided in Chapter 29.5 of AR5.
(b) The classification of commonly used climate change adaptation tools and methods (Section 5.3) were initially developed according to the main drivers for an integrative approach for holistic adaptation planning, as discussed in Section 3. This initial grouping was progressively refined throughout the systematic review process.
(c) Adaptation planning framework and analysis (Section 5.4) were classified into groups that are based on the general adaptation planning procedure, as discussed in Section 2, which was founded on the guidelines and discussions in UKCIP [37] as well as Chapters 14 and 15 of AR5.
(d) The categorisation of adaptation options and opportunities (Section 5.5) was based on general adaptation planning requirements stemming from climate risks and vulnerabilities, as described in Chapter 14.3 of AR5.

The outcomes of this systematic analytical review and assessment are detailed in the next section.

5. Results

5.1. Geographical and Chronological Distribution of Reviewed Paper

A total of 116 peer-reviewed papers were finally selected to be analytically reviewed and scrutinised. These selected papers are published in different types of journals based on their main subject area, focus, and scope according to Web of science-InCites categorization: (a) 87 papers in Environmental Sciences and Studies; (b) 21 papers in Management and Social Sciences; (c) 52 papers with a spectrum of categories, including agriculture, Meteorology and atmospheric sciences, geoscience, water sciences, urban planning, marine and freshwater biology, ecology, and computer sciences and software engineering; (d) 45 papers in different types of interdisciplinary subjects; and finally, (e) only 31 papers in journals specifically designated to the climate change related issues. It should be mentioned that journals could be categorised under multiple types according to Web of science-InCites categorization. Figure 4 demonstrates the chronological distribution of reviewed papers based on their year of publication. There is an increasing trend of published papers over the 14 year period examined, particularly in recent years with years 2014–2016, accounting for approximately 58% of all reviewed publications, in which 11 have specifically focused on SIDS. This increasing tendency towards adaptation in the coastal zone, of small islands in particular, may possibly stem from the AR5 call for adaptation planning future scenario development, in-depth vulnerability assessment.

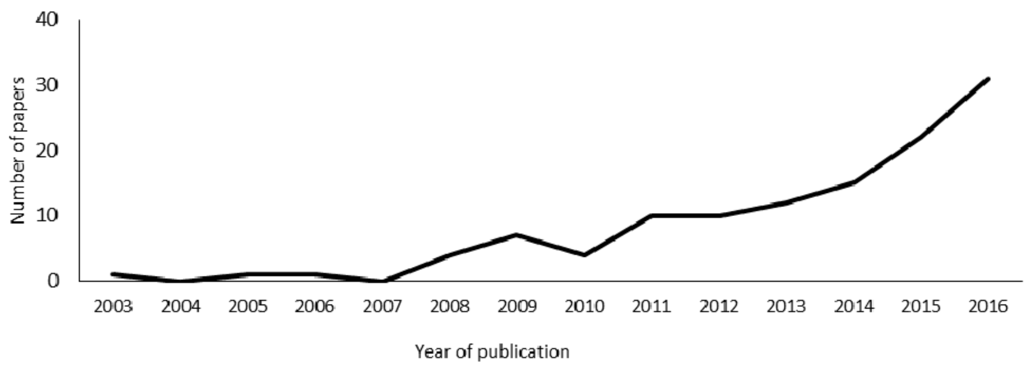

Figure 4. The chronological distribution and trend of reviewed papers over the 14 years (2003–2016).

Figure 5 shows the geographical distribution and coverage of the reviewed papers. A total number of 29 papers have focused on coastal zones and SIDS in the Middle East and Asia, 26 papers on Oceania and Pacific region, 20 papers on European coastal zones, and the rest on the American and African case studies. Meanwhile, only a total number of 25 papers have specifically been dedicated to SIDS across the globe, 65% of which are located in Oceania and Pacific region.

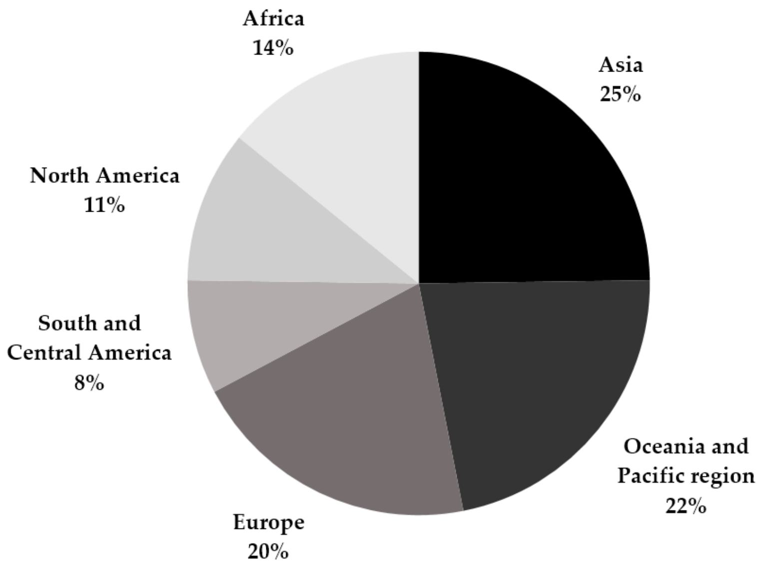

Figure 5. The geographical distribution of the reviewed papers' case studies.

5.2. Climate Change Impacts

The induced risks of climate change to coastal zones and small islands are not limited to these primary threats, with a number of interrelated secondary threats that need to be holistically considered. Our systematic review process categorised these primary and secondary impacts into four main groups, as shown in Table 1. It is to be noted that this grouping is adopted from AR5 (i.e., Chapter 29.5 of AR5) [51].

The four main groupings of climate change impacts do not mean that particular impacts cannot be evaluated across multiple groups and are not interrelated. For instance, an assessment of the causes of risks to both the ecosystem and agriculture could possibly be approached with similar methodologies. However, they should be organised in different groups of climate change induced risks due to their dissimilar range of socioeconomic and biophysical impacts. As another example, inundation threats located in group three may be one of the causal factors leading to the salinization of water supply systems, which falls into group two.

Specifically, twelve specific climate change threats contained with these four groups (Figure 6) have been emphasised in the reviewed literature: (1) damage as a result of extreme events including cyclones, coastal flooding and storm surges; (2) inundation caused by sea-level rise; (3) agriculture and fishery hazards due to diverse causes; (4) damage to the environment and ecosystem; (5) direct damages from changing rainfall intensity and patterns; (6) coastal erosion; (7) potable water accessibility; (8) impacts to the tourism industry; (9) migration between countries or displacement within a country due to localised climate change impacts; (10) food security; (11) bushfire; and, (12) heat waves. This grouping shows that threats from sea-level rise to human settlement and infrastructure are the centre of researchers' attention for climate change adaptation planning. Besides, because the identified climate change impacts and threats that are categorized within a group are likely to have interrelated characteristics, considering all of these four groups of impacts in the process of adaptation planning can pave the way to achieve a holistic plan. To illustrate that there is a trend to conduct multiple combined impact assessments in recent literature, the top bar in Figure 6 identifies the number of papers considering two or more group of climate change impacts.

Damage to urban infrastructure and other properties caused by coastal flooding and storm surge events have been the most studied climate change impact, followed by inundation and then coastal erosion impacts. As a systems approach to climate change adaptation planning begins to take hold, it is expected that the majority of future peer-reviewed documents will report on integrative climate change assessments addressing multiple impacts and remedy portfolios, rather than the single dimensional assessments that are predominately reported in the current literature.

Table 1. Grouped categories of climate change-induced impacts on SIDS and coastal communities.

No.	Group Title	Group Description
G1	Impacts on morphology and ecosystem	Coastal and/or island erosion, impacts on coastal ecosystems and natural resources, deltas, rivers, estuaries, mangroves, coral reefs, soil salinity etc.
G2	Hazards to coastal/island livelihood and tourism	Any climate change induced risks which are related to the quality of living, including direct damage from changing rainfall intensity and patterns, clean water accessibility, impacts on tourism attractions, food security, bushfire, and heat waves. This also relates to studies of social impacts leading to migration due to climate change impacts
G3	Threats from sea-level rise to human settlement and infrastructure	Damage as a direct result of extreme events including storm surges or resulted coastal flooding and intense precipitation, inundation due to sea-level rise, etc.
G4	Impacts on agriculture and fisheries	Impacts on coastal agriculture and fishery industries including indigenous to large-scale

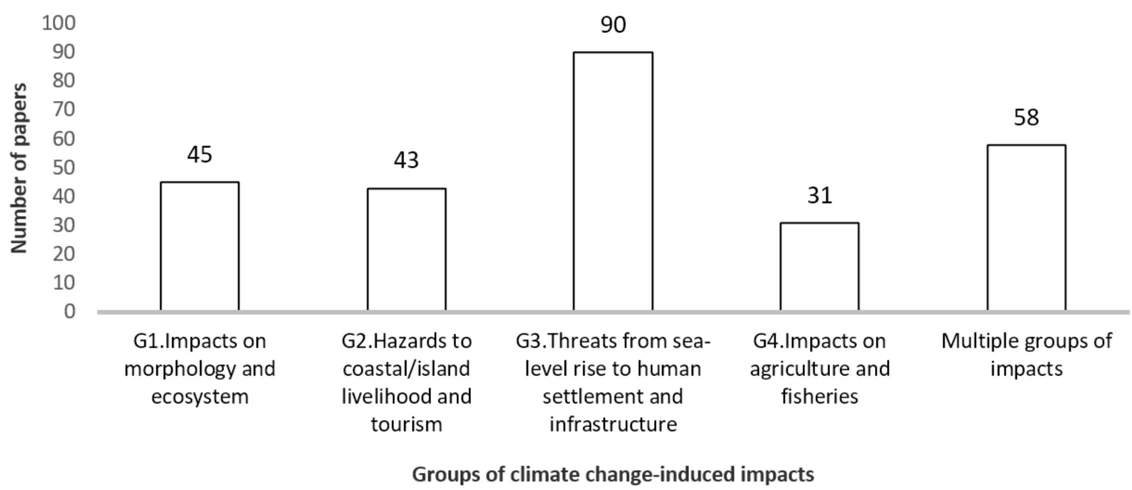

Figure 6. The domain of identified climate change-induced impacts in the reviewed literature.

5.3. Adaptation Planning Methods and Tools

Various different approaches, employing a wide range of modelling tools and methods, have been applied to the climate change adaptation planning process. The most commonly used formal modelling methods and tools used in planning procedures, based on their specific features and capabilities in fulfilling adaptation planning requirements, can be classified into six main groups, as shown in Table 2.

Given the complexity of climate change adaptation planning, a number of the methods and tools that are described in Table 2 would need to be deployed in order to fulfil the objectives of a holistic planning process, so as to include coverage of: (1) temporal and spatial dimensions; (2) stakeholder engagement; (3) engineering computations; (4) inherent uncertainty; and, (5) prioritisation criteria, among other things.

The number of reviewed papers using different methods/tools across the entire climate change adaptation planning procedure is shown in Figure 7. Spatial and participation-based methods were identified as being the most commonly employed. This is a promising trend, which demonstrates that a considerable number of papers have considered a form of stakeholder engagement in their planning procedure. However, this mandate still requires more attention due to the key role of stakeholder engagement in the success of any adaptation plan. Moreover, almost 65% of the reviewed papers have exploited a partially integrated approach by using two or more groups of tools in their planning process, which is encouraging.

Table 2. Classification of commonly used climate change adaptation tools and methods.

No.	Group Title	Group Description
1	Temporal	Approaches or tools that are able to capture the complexity or dynamic changes over time and complex interactions between system components, such as system dynamics, Cellular automata, Agent-based modelling. Note that scenario-based approaches are not included in this category
2	Participation-based	Approaches or tools that are based on the participation of different stakeholders and/or are capable of integrating the stakeholder's knowledge in the process of planning, including Bayesian belief networks, fuzzy mapping, Delphi survey, interviews, workshops, cross-sectional survey, expert-derived modelling, analytical hierarchy process (AHP)
3	Spatial	Approaches or tools that are capable of considering spatial or topographical features of the study zone including satellite imaging, GIS-based analysis (e.g., DEM or raster-based modelling)
4	Multi-criteria analysis (MCA)	Approaches or tools in different stages of climate change adaptation planning in which options are evaluated through multiple conflicting criteria
5	Process simulation models	Approaches or tools that rely mainly upon empirical, mathematical or engineering equations or rules and computations such as general circulation model (GCM), impact downscaling methods, hydrologic or flooding models (e.g., using MIKE software), storm surge simulations
6	Indexing and prioritisation	Approaches or tools that do not fall into the other groups and are capable of assessing and prioritising alternatives that may include coastal vulnerability indexing (CVI), social vulnerability index (CSoVi), or other indices methods, decision-making indicators, cost-effectiveness, cost-benefit analysis, matrix-based analysis, etc.

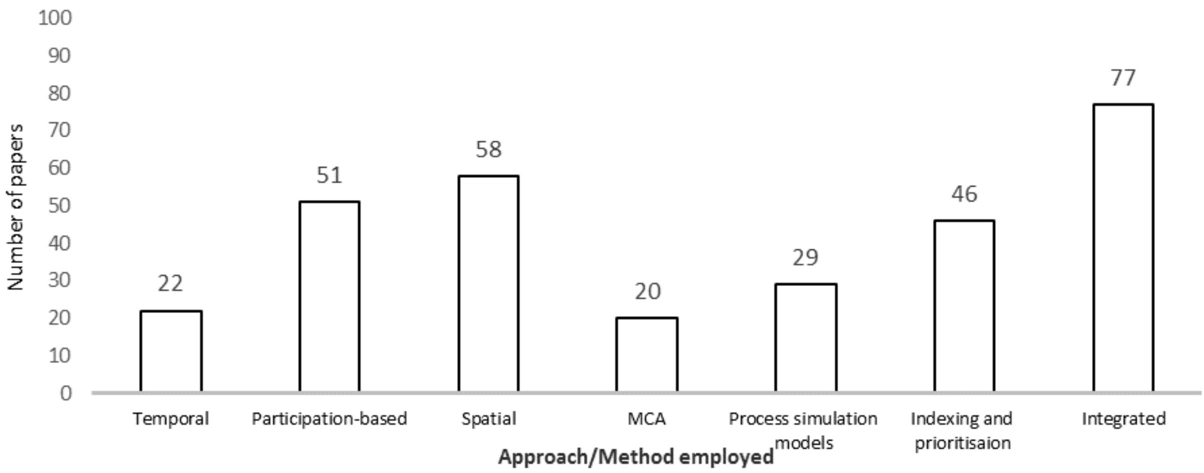

Figure 7. The number for each category of method and tools found in the reviewed literature to have been used in climate change adaptation planning.

5.4. Adaptation Planning Framework and Analysis Approach

Recommendations of effective adaptive responses to adverse impacts of climate change are best analysed and developed through the two major steps and their subsets of adaptation planning: vulnerability assessment and decision-making process, as demonstrated in Figure 1 and discussed in Section 2. However, different strategies were employed to support adaptive solutions and opportunities by researchers. When considering the reviewed papers, climate change adaptation planning framework and analysis approaches or strategies were classified into four categories: (1) stand-alone vulnerability assessment-led planning approach; (2) integrated vulnerability assessment-led planning approach; (3) decision-making process-led planning approach; and, (4) integrated vulnerability assessment/decision-making-led planning approach.

Figure 8 shows the number of papers that used these different approaches in their planning framework and analysis. One-third of papers have adopted a framework that included both vulnerability assessment and decision-making processes. Only a few papers (5%) have undertaken vulnerability assessment through a single element, either being exposure, sensitivity, or adaptive capacity analysis. More than half of reviewed papers have followed an integrated approach applying vulnerability assessment only. This widely-used approach for vulnerability assessment integration is acknowledged as a hybrid vulnerability assessment in which two or all three components of vulnerability, as described previously, are addressed in the process of planning [74].

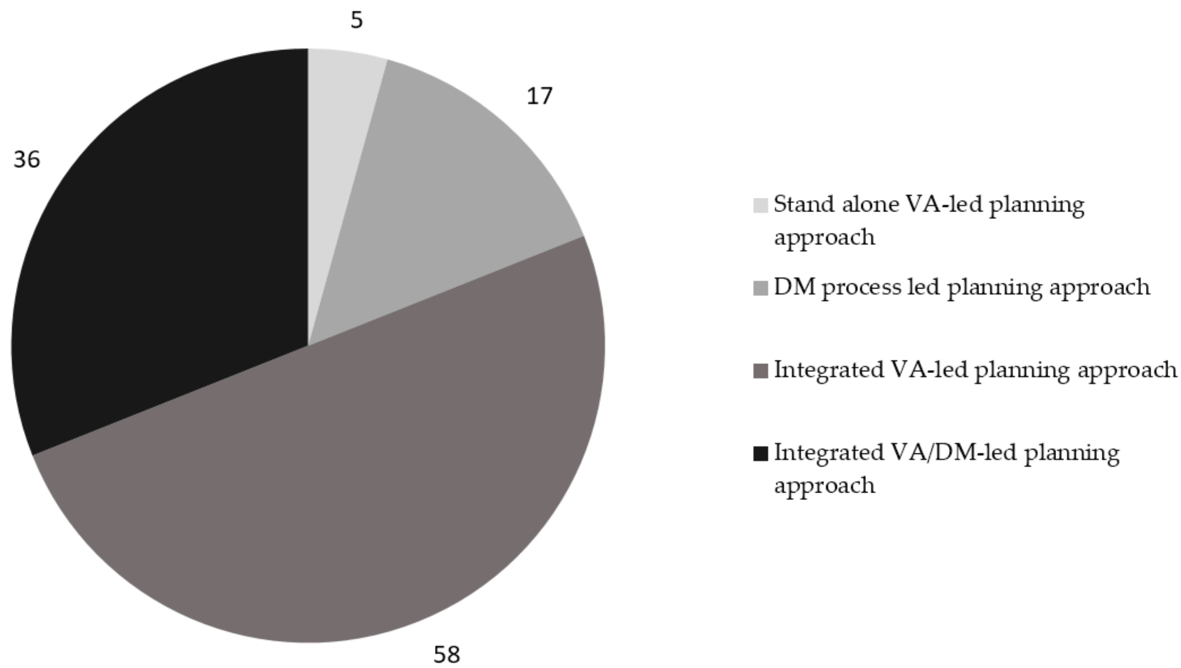

Figure 8. The number of papers using four categories of Adaptation planning framework and analysis approaches used in reviewed papers. (VA: vulnerability assessment; DM: decision-making).

5.5. Adaptation Strategies

It is unlikely that a single strategy will address all of the diverse climate change impacts in SIDS and coastal communities. According to the IPCC (2014) [1] categorization, adaptation plans can include a wide range of adaptive responses, such as exploitation of social capital or ecological assets, infrastructure development, technological process optimization, integrated natural resources management, regulatory changes, educational and behavioural change or reinforcement, information systems to support early warning, and proactive plans. All of these choices can be categorised into different broad groupings according to different issues, such as their spatial scale of action, resources for implementation of adaptation strategies (e.g., natural, human, or capital resources), and the timescale of execution and completion. The following four broad categories were adopted for this study: (i) structural; (ii) social; (iii) regulatory; and, (iv) ecosystem-based.

Structural options imply physical actions and engineering-based solutions such as building seawalls and breakwater arms, water recycling systems, water waste treatment plant development, and beach nourishment sand pumping. Examples of the Regulatory/institutional category include improvement and reinforcement of management plans and restrictions in decision-making, such as the creation of a coastal buffer zone or the revision of land use plans. Social adaptive options employ social capital for educational and behavioural reforms or change [75]. Ecosystem-based adaptation (EbA) interventions aim to maintain or restore ecosystem condition and services while ensuring that community resilience is enhanced by accessing ecosystem services [76]. Ecosystem-based adaptation offers a strategy to increase resilience to both climatic and non-climatic pressures.

Ecosystem-based adaptation offers an integrated adaptation approach that can be applied to all types of ecosystems at different geographical scales. Ecosystem-based adaptation has been shown to enable communities to adapt to the adverse impacts of global climate change through the integrated management of biodiversity and ecosystem [77]. However, the benefits of the ecosystem-based adaptation approach have yet to be reflected sufficiently in the reviewed papers, despite its increasing popularity in recent years. As shown in Figure 9, only 16 papers included ecosystem-based interventions (e.g., planting mangrove belts for coastal protection from flooding and erosion).

Figure 9 shows the number of papers that recommended the four categories of adaptation strategies. In the context of SIDS and coastal communities, regulatory strategies were the most recommended, followed by structural and then social strategies, with ecosystem-based adaptation being the least referenced strategy. Almost 60% of the reviewed papers considered a portfolio of strategies that were covered within two or three of the suggested broad categories, which is labelled as integration of more than one category in Figure 9.

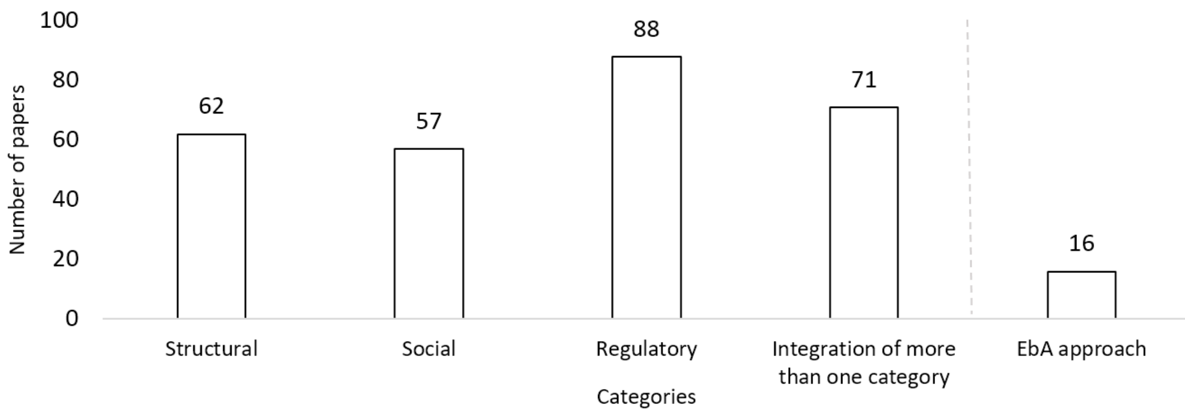

Figure 9. Categories of adaptation strategies and number of papers focusing on each category. (Structural options include physical actions and engineering-based solutions; Social category include employment of social capital for educational and behavioural reforms; Regulatory category include improvement and reinforcement of management plans and restrictions in decision-making).

Table 3. Systematic literature review categorisation summary.

No.	Groups of Concerns Raised by Climate Change [1]				Tools and Methods [2]						Adaptive Options [3]				Analysis Approach [4]	Authors	Ref
	Group. 1	Group. 2	Group. 3	Group. 4	Tem.	Par.	Spt.	MCA	PSM	IP	Str.	Soc.	Reg.	EbA			
1	*	*	*	*			*	*			*	*	*		HI-DM-VA	Torresan et al. (2016)	[45]
2		*	*			*						*	*		VA	Richards et al. (2016)	[78]
3		*	*	*						*		*	*		DM	Rosegrant et al. (2016)	[79]
4				*		*		*			*		*		DM	Michailidou et al. (2016)	[3]
5		*					*			*	*	*	*		IVA	Hoque et al. (2016)	[80]
6			*				*		*	*	*		*		IVA	Yan et al. (2016)	[81]
7				*			*		*			*	*		HI-DM-VA	Maina et al. (2016)	[82]
8			*			*	*			*	*	*	*		IVA	Margles Weis et al. (2016)	[83]
9		*		*					*	*	*		*		HI-DM-VA	Elshennawy et al. (2016)	[84]
10			*							*			*		DM	Withey et al. (2016)	[85]
11			*			*	*		*		*		*		IVA	Nardini and Miguez, (2016)	[86]
12		*	*			*				*		*			DM	Ung et al. (2016)	[87]
13			*		*				*	*	*			*	IVA	Marzloff et al. (2016)	[88]
14				*					*	*	*	*	*		IVA	Dey et al. (2016)	[89]
15			*				*	*		*			*		HI-DM-VA	Rizzi et al. (2016)	[90]
16			*					*	*		*			*	IVA	Stark et al. (2016)	[91]
17		*	*			*	*		*	*	*	*	*		IVA	Sperotto et al. (2016)	[92]
18			*						*	*	*				HI-DM-VA	Hoshino et al. (2016)	[93]
19	*	*	*							*			*		IVA	Zanetti et al. (2016)	[94]
20			*			*	*			*		*			HI-DM-VA	Codjoe and Issah, (2016)	[95]
21			*				*				*	*	*		DM	Butler et al. (2016)	[96]
22		*			*					*		*	*		IVA	Bin Kashem et al. (2016)	[97]
23	*		*		*		*	*		*		*	*		HI-DM-VA	Spirandelli et al. (2016)	[98]
24	*	*	*	*			*			*		*	*	*	HI-DM-VA	Turner et al. (2016)	[11]
25	*	*	*				*			*		*			HI-DM-VA	Bennett et al. (2016)	[99]
26		*		*					*	*	*	*	*		IVA	Salinas et al. (2016)	[100]
27			*						*	*			*	*	IVA	Vogiatzakis et al. (2016)	[101]
28				*			*	*		*	*		*		HI-DM-VA	Freire et al. (2016)	[102]
29			*									*	*		DM	Ojomo and Bartram, (2016)	[103]
30			*		*				*	*	*	*	*		IVA	Mellor et al. (2016)	[104]
31	*		*				*	*		*			*		IVA	Satta et al. (2016)	[105]
32			*			*	*					*			HI-DM-VA	Leon et al. (2015)	[106]
33			*				*		*				*		DM	Knight et al. (2015)	[107]
34			*				*			*	*	*	*		HI-DM-VA	Sano et al. (2015)	[44]
35			*				*		*	*	*	*	*		HI-DM-VA	Genovese and Green, (2015)	[108]
36				*	*	*							*		HI-DM-VA	Joffre et al. (2015)	[109]
37		*				*			*	*			*		HI-DM-VA	Bujosa et al. (2015)	[110]
38		*				*						*			DM	Henly-Shepard et al. (2015)	[111]
39			*		*		*						*		IVA	Sekovski et al. (2015)	[112]
40			*				*		*		*		*		IVA	Muis et al. (2015)	[113]
41		*	*			*		*		*		*	*		DM	Broto et al. (2015)	[114]
42		*	*			*					*		*		DM	Batisha, (2015)	[115]
43	*	*	*			*				*	*		*		DM	Mostofi Camare and Lane, (2015)	[116]

Table 3. *Cont.*

No.	Groups of Concerns Raised by Climate Change [1]				Tools and Methods [2]						Adaptive Options [3]				Analysis Approach [4]	Authors	Ref
	Group. 1	Group. 2	Group. 3	Group. 4	Tem.	Par.	Spt.	MCA	PSM	IP	Str.	Soc.	Reg.	EbA			
44	*					*				*	*		*	*	HI-DM-VA	Khan and Amelie, (2015)	[117]
45	*	*	*	*		*						*	*		IVA	Salik et al. (2015)	[118]
46	*					*		*		*			*		IVA	Okey et al. (2015)	[43]
47	*		*			*	*			*	*				IVA	Kane et al. (2015)	[119]
48	*						*				*		*	*	IVA	Geselbracht et al. (2015)	[120]
49		*	*			*				*		*	*		IVA	Ajibade et al. (2015)	[121]
50	*	*	*			*					*				IVA	Thomas et al. (2015)	[122]
51			*		*		*		*		*				IVA	Hauer et al. (2015)	[123]
52	*	*	*	*		*				*	*				DM	Armah et al. (2015)	[124]
53		*			*		*					*	*		IVA	Lin and Chi, (2014)	[125]
54		*			*							*	*	*	HI-DM-VA	Lee and Lin, (2014)	[126]
55				*	*	*						*	*	*	DM	Metcalf et al. (2014)	[127]
56			*				*						*		IVA	Hansen and Fuglsang, (2014)	[128]
57	*		*			*						*			IVA	Gray et al. (2014)	[42]
58			*						*	*	*		*		HI-DM-VA	Koks et al. (2014)	[129]
59			*			*	*			*	*		*		HI-DM-VA	Lasage et al. (2014)	[130]
60	*	*	*			*				*	*		*	*	IVA	Langridge et al. (2014)	[131]
61			*			*	*					*	*		DM	Stokke, (2014)	[132]
62	*	*	*			*						*	*		IVA	Hiwasaki et al. (2014)	[133]
63			*	*	*	*					*	*	*		IVA	Birk, (2014)	[134]
64	*	*	*			*	*				*	*	*		VA	Grasso et al. (2014)	[135]
65		*	*						*				*		DM	Rogers et al. (2014)	[23]
66			*				*				*				VA	Lacerda et al. (2014)	[136]
67			*	*			*	*	*		*	*	*		HI-DM-VA	Lamon et al. (2014)	[137]
68				*	*			*		*		*	*		HI-DM-VA	Hardy et al. (2013)	[138]
69	*	*	*	*		*					*	*	*		HI-DM-VA	Jopp et al. (2013)	[139]
70	*			*	*	*	*				*		*	*	HI-DM-VA	Forsius et al. (2013)	[140]
71	*		*		*	*	*	*			*	*	*		HI-DM-VA	Sahin and Mohamed, (2013)	[40]
72	*		*			*	*		*		*		*	*	HI-DM-VA	Schmitt et al. (2013)	[10]
73	*		*			*					*		*		HI-DM-VA	Santoro et al. (2013)	[141]
74	*		*			*		*					*		IVA	Le Cozannet et al. (2013)	[142]
75	*	*	*			*	*	*			*	*	*	*	IVA	Lan et al. (2013)	[143]
76	*		*				*					*			IVA	Albert et al. (2013)	[31]
77			*				*		*		*				IVA	Suroso et al. (2013)	[144]
78				*					*	*	*		*		IVA	Ruane et al. (2013)	[145]
79	*	*		*		*					*		*	*	DM	Catenacci and Giupponi, (2013)	[60]
80	*		*			*	*				*	*	*		HI-DM-VA	Sano et al. (2012)	[146]
81	*				*			*			*		*		HI-DM-VA	Ko and Chang, (2012)	[147]
82		*	*	*			*				*		*		HI-DM-VA	Boateng, (2012)	[148]
83		*	*			*			*	*	*				HI-DM-VA	Bormann et al. (2012)	[149]
84	*		*			*		*			*		*		IVA	Torresan et al. (2012)	[150]
85	*	*	*			*							*	*	IVA	Reyes and Blanco, (2012)	[151]
86	*		*			*						*			IVA	Richmond and Sovacool, (2012)	[152]

Table 3. *Cont.*

No.	Groups of Concerns Raised by Climate Change [1]				Tools and Methods [2]						Adaptive Options [3]				Analysis Approach [4]	Authors	Ref
	Group. 1	Group. 2	Group. 3	Group. 4	Tem.	Par.	Spt.	MCA	PSM	IP	Str.	Soc.	Reg.	EbA			
87			*				*	*			*				IVA	Friedrich and Kretzinger, (2012)	[153]
88	*		*	*			*					*	*	*	IVA	Khan et al. (2012)	[58]
89	*		*			*						*			IVA	Smith et al. (2011b)	[154]
90		*	*			*	*	*			*	*	*		IVA	Yoo et al. (2011)	[155]
91	*					*	*	*					*		IVA	Omo-Irabor et al. (2011)	[156]
92			*							*		*	*		IVA	Sano et al. (2011)	[157]
93		*	*	*			*			*	*				IVA	Hallegatte et al. (2011)	[158]
94			*							*	*				HI-DM-VA	Bjarnadottir et al. (2011)	[159]
95			*	*		*	*				*				IVA	Ward et al. (2011)	[160]
96		*	*	*			*			*		*	*		IVA	Kumar et al. (2011)	[161]
97			*			*	*		*	*	*		*		HI-DM-VA	Smith et al. (2011a)	[162]
98			*				*				*				IVA	Addo et al. (2011)	[163]
99			*		*			*					*		HI-DM-VA	Hansen, (2010)	[164]
100	*	*		*		*						*	*		DM	Dumaru, (2010)	[165]
101	*	*	*	*		*					*	*	*		IVA	Bunce et al. (2010)	[166]
102		*	*	*			*		*	*	*	*	*		IVA	Niang et al. (2010)	[167]
103	*		*		*		*				*	*	*		IVA	Sahin and Mohamed, (2009)	[41]
104		*	*	*	*		*				*	*	*		IVA	Angus et al. (2009)	[168]
105			*				*					*	*		IVA	Rodríguez et al. (2009)	[169]
106		*				*				*		*			HI-DM-VA	Kuruppu, (2009)	[170]
107	*	*	*			*						*	*		IVA	Ozyurt and Ergin, (2009)	[171]
108			*		*		*						*		VA	Henriques and Tenedorio, (2009)	[172]
109	*		*				*				*				IVA	Snoussi et al. (2009)	[173]
110	*				*								*	*	HI-DM-VA	Chang et al. (2008)	[174]
111			*						*		*		*		IVA	Purvis et al. (2008)	[175]
112	*	*	*	*			*				*	*	*		VA	Al-Jeneid et al. (2008)	[176]
113	*		*				*						*		IVA	Cooper et al. (2008)	[177]
114	*	*	*	*	*							*	*		HI-DM-VA	Leal Neto et al. (2006)	[178]
115			*		*		*		*	*	*		*		IVA	Warrick et al. (2005)	[179]
116	*		*				*		*		*				IVA	Kont et al. (2003)	[180]

[1] Groups of climate change induced impacts (Table 1). [2] Groups of methods/tools: Tem. = Temporal; Par. = Participatory; Spt. = Spatial; MCA = Multi-Criteria Analysis PSM = Process Simulation Models; IP = Indexing and Prioritisation methods (Table 2). [3] Three categories of adaptation strategies: Str. = structural; Soc. = Social; Reg. = Regulatory; EbA = Ecosystem-based approach. [4] Climate Change adaptation framework and analysis approach: DM: Decision Making; VA: Vulnerability Assessment; IVA: Integrated Vulnerability Assessment; and HI-DM-VA: Hybrid Integrated DM and VA assessment.

6. Discussion

6.1. The Need for Multi-Layered Adaptation Planning

In this study, recently published papers were systematically selected and then studied in order to identify key trends and approaches that were taken for the assessment, modelling, and analysis stages of climate change adaptation planning. Table 3 summarises the results of this systematic review, based on the previously discussed categorization of approaches that were used in the reviewed papers. There is a welcomed trend in the literature towards climate change planning involving a more holistic approach reflecting three major elements:

1. Identification, quantification and assessment of *all key system components, their interactions including feedbacks, and relevant climate change-related concerns and risks*.
2. Employment of tools and methodologies capable of addressing *all of the relevant temporal aspects, spatial dimensions, stakeholder participation requirements, simulation of adaptation interventions, assessment of associated risks, and prioritisation and decision support concerns in the planning process*.
3. Enhancement of resilience and adaptive capacity, and mitigation of vulnerability through the evaluation of the *all potential efficacy of a range of potential and feasible adaptation options*.

A number of effective practices can be recommended to help promote a more holistic approach to adaptation planning. First, planning for coastal systems and associated socio-economic and environmental systems requires assessments that are inclusive of all climatic and as well as non-climatic factors. Specifically, adaptation planning for SIDS and coastal communities needs the integrated assessment of climate change impacts on coastal processes, risks to coastal ecosystem condition and services, impacts on human settlements, and implications for activities, such as coastal agriculture and fisheries. According to the interrelationships of climate change imposed impacts and also their feedbacks on themselves and each other, inclusive assessment of all these issues could be an appropriate guide to check whether planning is undertaken in a holistic manner. In addition, climate change may impose dissimilar socioeconomic and environmental impacts on different locations and territories that result in different region-based elements of impact and risk categories that should be defined and studied specifically through an integrated approach. As an empirical illustration, Torresan, Critto [45] have developed a GIS-based risk assessment framework so-called DESYCO to assess a wide range of climatic and non-climatic impacts. This platform can be exploited to operationalize a comprehensive adaptation planning procedure inclusive of all of the essential steps of adaptation planning framework from vulnerability assessment to the decision-making process [45].

Second, ensuring that the employed tools and methodologies are capable of addressing all the required elements, processes assessment will greatly facilitate the development of a holistic adaptation action plan. In our review, six categories of methods and tools were identified to be relevant to adaptation planning for SIDS and coastal communities. In other words, a holistic adaptation planning process should employ all six categories of methods and tools identified in this study, starting with a vulnerability assessment, including all of its critical components (i.e., exposure, sensitivity, and impact assessments, as well as adaptive capacity evaluation) and finishing with a well-informed decision-making process. To mention a practical example, Sahin and Mohamed [40] have proposed a spatial-temporal decision framework for climate change adaptation focusing on the sea level rise. This framework employs the system dynamics modelling approach as a platform to integrate process simulations results, GIS analysis, and stakeholders' views to better predict and understand the temporal and spatial impacts of climate change [40]. Accordingly to Sahin and Mohamed [47], the results of scenario analyses of system dynamics modelling are to be assessed using the MCA technique to conclude with the best available options for planning.

Third, adaptation solutions should be proposed based on the outcomes of identifying, modelling, and assessing climate change-related impacts inclusive of their interactions with other pressures risks. Adaptation interventions are more effective and successful when the full suite of potential and feasible strategies are evaluated and integrated into the planning process. The multiple benefits of eco-system based approaches offer the potential to integrate adaptation priorities with development processes tackling many issues threatening the most vulnerable countries and communities [77]. It is important to identify all the potential opportunities and to consider them integratively when deciding on the optimal portfolio of adaptation strategies. For instance, Stark, Plancke [91] have conducted a process simulation-based analysis (i.e., hydrodynamic model) for coastal flood and inundation modelling using different climate change scenarios to predict the future conditions and potential adaptation options for a case study location in the Netherlands. As a result, a combination of coastal structures (i.e., structural category), retreating strategies (i.e., regulatory category), and ecosystem-based solutions are found as the best combination to adapt to the adverse impact of climate change [91]. Therefore, applying an integrative approach to the assessment and modelling of adaptive strategies will increase the likelihood that adaptation plans will be successfully implemented.

Our review identified three important dimensions of the climate change adaptation planning process requiring integration, namely: (1) assessment, (2) modelling, and (3) adaptive responses that can be visualised as a three-sided pyramid, with the pyramid base representing the integrated policy (Figure 10). In other words, multi-layered integration is an urgent necessity for development and implementation of an effective and successful adaptation to climate change in which; all climatic concerns are addressed/acknowledged (integration in assessment); all requirements and aspects of a socio-environmental system are appropriately addressed (integration in modelling); and, all potential adaptive solution and strategies including structural, social, regulatory, and ecosystem-based are considered (integration in adaptive responses).

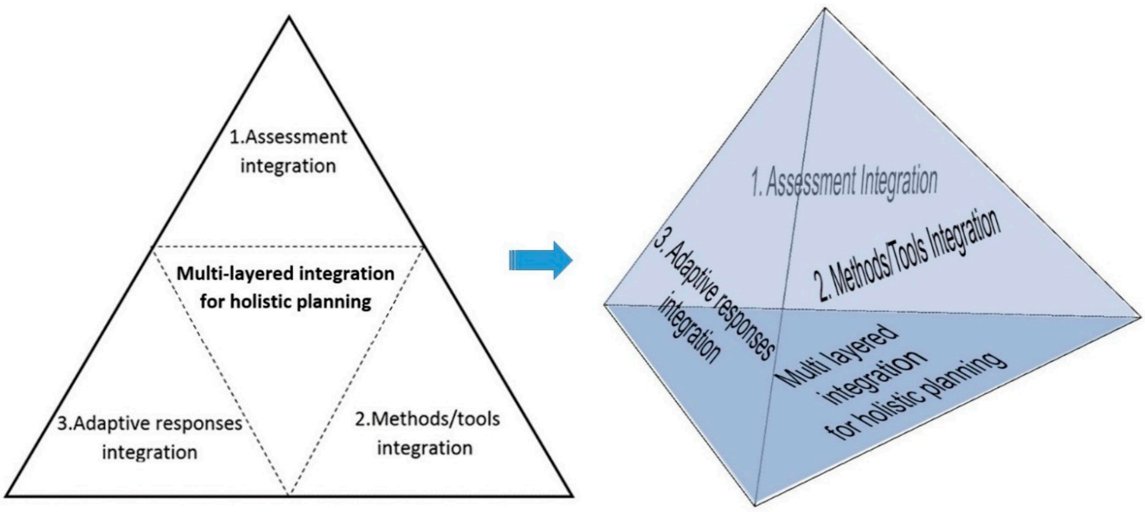

Figure 10. Dimensions of the multi-layered integration approach for climate change adaptation planning.

6.2. Managing the Integration Process

A manageable degree of multi-layered integration is necessary for holistic climate change adaptation planning, as suggested in this paper. On the other hand, an uncontrolled extension of an integrated approach may lead to unintended over-complexity of the whole process [17]. An explicit definition of the necessary dimensions of integration for planning is essential to keep the complexity of the process under control, as is the determination of the minimum requirements for the integrative approach. Therefore, an integrative adaptation planning procedure is needed, in which all necessary aspects are addressed satisfactorily as well as any further complexity or unintended malfunctions are prevented. For this purpose, an optimum point is defined based on the necessary requirements for adaptation planning for exploitation of the integration approach: the nearer the level of integration to this optimum point, the higher confidence in the development of a holistic action plan. On the other hand, going beyond this point does not necessarily imply the development of a more realistic and feasible action plan. Figure 11 constitutes a three-dimensional graph expressing the concept of multi-layered integration, making explicit this optimum point. As illustrated in Figure 11, this plan should seek to identify the optimal point of integration where all essential planning objectives and requirements are achieved, but without creating excessive complexity that impedes action plan' feasibility. Commonly, this point is to be defined specifically based on each system's socioeconomic and environmental factors. For SIDS and coastal communities in particular, the outcomes of the systematic review in this study can be used in identifying the minimum requirements for planning, establishing a planning framework, and defining an optimal point accordingly, as discussed. For instance, to ensure that an appropriate level of assessment integration is being achieved (axis Z in Figure 11), the four identified groupings of climate change impacts (Section 5.2.) have to be addressed in the process of both the vulnerability and risk assessment stages of adaptation planning for SIDS.

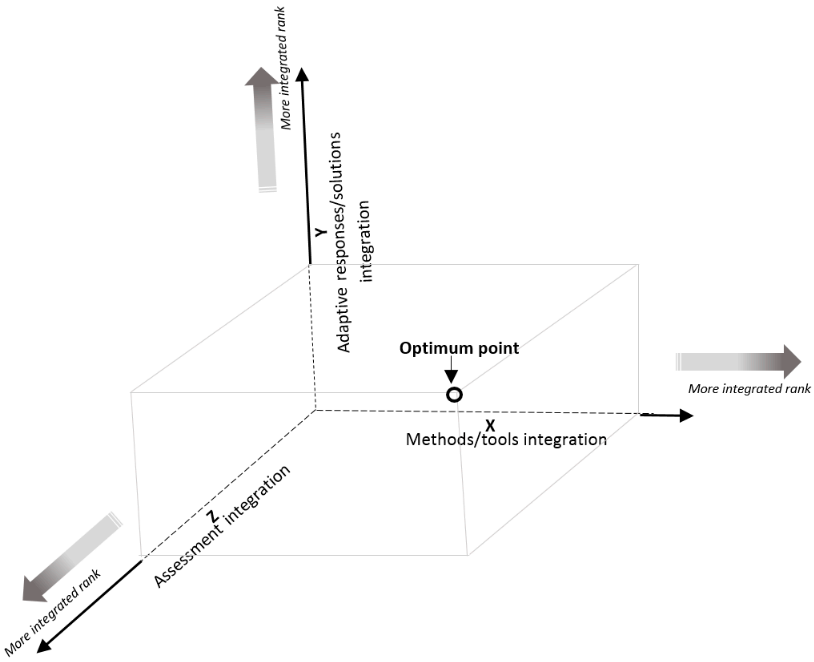

Figure 11. The three-dimensional graph for multi-layered integration.

6.3. Practical Implications

The concept of the multi-layered integrative approach in the process of planning for climate change adaptation has significant implications for practitioners. Planners and specialist consultants are at the centre of this approach, which can pave the way for framing a holistic adaptation planning procedure, inclusive of all required components, to enhance the successfulness of the planned adaptation. The three main layers of integration that are explained above should be addressed appropriately, specifically in the design of the intended adaptation planning framework. This consideration can facilitate the development of a holistic planning procedure likely to address all requirements of planning. In other words, the employment of the multi-layered integration approach can support developing a holistic adaptation planning framework; this framework should include a process to ensure all assessments and modelling requirements, as well as potential adaptive responses and opportunities, are measured appropriately. This paper reports on an extensive systematic review of papers that make adaptation recommendations for SIDS and other coastal communities sharing similar risks and opportunities. Thus, this paper can provide practitioners with useful categorized information on a range of important topics, including: (a) a list of climate change impacts on SIDS communities that are categorized in four different groups (Section 5.2); (b) a list of all required adaptation planning methods and tools categorized in six different groups (Section 5.3); (c) classification of the various adaptation planning framework and analysis approaches into four main groupings (Section 5.4); and, (d) four main categories of potential adaptive responses (Section 5.5). Planning teams initiating a climate change adaptation planning process with SIDS can employ this synthesis of information. Firstly, the categorization and comprehensive listing of climate change impacts will ensure that the planning team considers all relevant impacts on SIDS. Secondly, a team planning a climate change adaptation plan for a SIDS may have a predetermined familiar set of methods and tools for undertaking their analysis; this study will hopefully broaden their perspective through providing a comprehensive suite of methods and tools available and facilitate them adopting multiple approaches in their planning process. Thirdly, planning teams may not have previously had a great awareness of the broader framework category they have adopted; the herein categorization of planning framework may influence them to combine VA and DM-led approaches more often. Lastly, most planners would be aware of the categories of adaptive responses that are available but the herein categorization exercise and repository of demonstration papers will hopefully emphasize the importance of integrating structural, regulatory, and social responses together in one integrated response strategy, and to also consider ecosystem-based approaches that are often overlooked.

This paper explains the importance of a holistic and integrated adaptation planning process for SIDS. For instance, an integrated assessment of climate change induced risks including impacts on morphology and ecosystem, threats from sea-level rise to human settlement and infrastructure, impacts on agriculture and fisheries, and also hazards to coastal livelihood and tourism, are all required to be able to address different aspects of socio-economic and environmental issues. For another example of the importance of integrating different tools and methods in the adaptation process, the integrated employment of participation-based and process simulation models binds the integration of public participation and local knowledge with scientific assessment and modelling. Specifically, this latter example shows how integration in employing tools and methods, can improve the degree of success of adaptation planning through stakeholder engagement and securing future support, as noted previously in AR5 as being a crucial factor of any effective adaptation plan.

7. Conclusions

While this systematic review shows an increasing trend towards climate change adaptation planning for vulnerable SIDS and coastal communities, most of the reviewed papers lack a thorough multi-layered integrative procedure to satisfy the requirements of a holistic adaptation plan. The use of a holistic, multi-layered integration approach ensures that major induced risks and interrelated variables and mechanisms of the studied system are not ignored unintentionally, all of a systems' characteristics and methodological considerations are adequately addressed, and that all relevant and feasible adaptation opportunities are considered.

According to the reviewed papers in the process of adaptation planning for SIDS and coastal communities, the impacts on coastal processes, hazards to coastal/island livelihoods and tourism, infrastructure and human settlement threats from sea-level rise, and impacts on agriculture and fisheries, are identified as major climate change-related risks that must be addressed explicitly. Moreover, the modelling tools and methodologies used should be capable of capturing temporal, spatial and other specific dimensions of the target system and sub-systems, the range of adaptation strategies, and enable the participation of key stakeholders. Furthermore, achieving public support for data collection requirements as well as effective integration of multidisciplinary models and assessments is challenging; nonetheless, this challenge highlights the importance of a communication and stakeholder engagement plan in the procedure of planning for climate change adaptation.

To conclude with an effective and holistic adaptation plan, it is also of paramount importance to identify, assess, and prioritise all potential adaptive responses, including engineering, social, and regulatory, through an integrated vulnerability assessment and decision-making process with all of their subsets. While the benefits of the ecosystem-based approach need to be studied further and greater consideration given to how they can be employed to help improve community resilience and promote sustainable development for SIDS and coastal communities.

In conclusion, a climate change adaptation plan must encompass an array of climate change-related risks and consider multiple factors in ways that extend beyond the reach of a single discipline [15]. Adaptation plans need to provide an integration of different assessments and modelling outcomes across a holistic approach that spans engineering, ecological and social discipline, among many others. Therefore, the inclusion of multidisciplinary teams in the process of planning for climate change adaptation is essential. Specifically for SIDS and coastal communities, these multidisciplinary teams should include experts on: (i) regional ocean and coastal processes; (ii) engineering; (iii) ecological and ecosystems dynamics; (iv) climate impact analysis; (v) economic valuation; (vi) the social sciences; and, importantly (vii) integrative system modelling, scenario analysis, and decision support. A well-considered organisation of transdisciplinary teams and sub-projects based on the herein explained multi-layered integration dimensions can significantly enhance the efficiency and effectiveness of the climate change adaptation planning procedure.

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