Intellectual Output 3

A Framework on Adapting Coastal Built Environment to the Effects of Climate Change during Design, Construction, and Retrofitting

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1 Introduction

Climate change has become a predominant problem that the world is confronted with currently. As IPCC sixth assessment report highlights, anthropogenic Green House Gas (GHGs) emissions have become a key driver of climate change (Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). Coastal regions are experiencing significant impacts due to climate change (Ngo-Duc, 2014; Y. Zhang et al., 2019). Past climate-related disasters such as cyclones, sea-level rise and coastal flooding have elaborated the vulnerabilities of different coastal regions (UNDRR & CRED, 2020). The built environment emits a significant amount of GHGs, so it significantly influences the local climate(Anderson et al., 2015; Holz-Rau & Scheiner, 2019). Also, the built environment significantly impacts the coastal community's environment (Gibbs, 2020; Malalgoda et al., 2014a). In addition, coastal areas are densely populated with urban centres near the coastal belt contributing to the developing country's economy. This exacerbates the abovementioned issues within the coastal built environment associated with climate change(B. Neumann et al., 2015; Zanetti et al., 2016). In this context, Climate Change Adaptation (CCA) of the built environment is a crucial aspect of coping with the present landscape of climate change and its associated impacts (Aguiar et al., 2018; Megahed & Ghoneim, 2020; Stagrum et al., 2020; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021).

Moreover, three landmark global agendas (the Paris Agreement, the Sustainable Development Goals (SDGs), and the Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) were adopted by global leaders aiming to address these issues (Lenzholzer et al., 2020). The key thematic areas addressed by those global agendas (i.e., climate change, sustainable development, and disaster risk reduction) are intrinsically interconnected (Ginige et al., 2013; Malalgoda et al., 2013). Currently, there is a lack of integration of climate change adaptation into the coastal built environment during planning, design, construction, maintenance, and retrofitting (Malalgoda et al., 2014a). Improved integration of the adaptation measures will assist in reducing damages and thereby increasing the economic and environmental benefits (IPCC, 2015b; Oecd & Ocde, 2009). Unless these adaptation measures acknowledge the three global agendas, they become inefficient (Cramer et al., 2018; Sanchez Rodriguez et al., 2018; Smit & Pilifosova, n.d.). However, the three global agendas differ from each other. For instance, the Paris Agreement mainly concerned greenhouse gas emissions regarding the

mitigation of climate change (Bauer & Menrad, 2019; Lenzholzer et al., 2020; Pickering et al., 2017; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). At the same time, SGDs and SFDRR are more concerned with rights and quality of life and, more specifically, with DRR, respectively (COMMIT and CD-LINKS, 2018; UNDRR, 2015, 2019b, 2019a). Hence, identifying tangible CCA measures for the coastal built environment during planning, design, construction, maintenance, and retrofitting aligning with three global agendas is vital for maintaining the functionality of the built environment. This present study is conducted as a part of BEACON (Built Environment leArning for Climate Adaptation), a collaborative research project co-funded by the EU Erasmus+ programme of the European Union. The present study developed a conceptual framework for climate change adaptation measures for the coastal built environment aligning with three global agendas.

The present study initially employed a systematic literature review to identify the climate change adaptation measures for the coastal built environment. Then the identified CCA measures were organised as a conceptual framework. As a final stage of the present study, the developed conceptual framework was validated through the individual county-level case study. This developed framework could be used as a basis to integrate the CCA measures into the coastal built environment to cope with climate change and its impacts.

2 Background

2.1 Summary of Climate Change and its Impacts from Output 01

Disaster and disaster risks are expected to rise as climate change increases the frequency and severity of extreme weather events. The BEACON project output 01 recognised sea-level rise, changing weather conditions and precipitation changes as the primary change evidence in the coastal built environment. The consequent hazards due to the climate change evidence were coastal erosion, inundation, extreme weather events, and flooding.

Climate change-related hazards are significantly affecting the built environment over the past years. The project's output 01 identified four types of climate change impacts concerning the coastal built environment. These include Physical, Economic, Social and Environmental. As the Output 01 report highlights, physical impacts are directly connected to the built environment among four impact categories, while other impact categories are indirectly connected. Damage to coastal infrastructure is one of the most visible physical impacts of

climate change and associated disaster risks in coastal communities. Seaports, residential and commercial buildings, transportation networks, water distribution systems, and stormwater management infrastructure are vital infrastructures within the coastal built environment. The other significant impact due to climate change includes mass movements. As per the Output 01 report, mass movement destabilises hillsides, and sediment runs off, destabilising embankments in most countries. Also, interruptions to emergency facilities, essential services, and critical infrastructure are another physical impact of climate change, especially during climate change-related hazard events. Furthermore, saltwater intrusion and acid rains also have a significant impact on construction materials. Urban overheating caused by global warming induces more energy consumption due to heating and cooling needs in residential and commercial buildings. As a result of damages imposed by hazards, the requirement for physical preventative structures rises. Accordingly, this leads to structural changes in the built environment. These changes include physical actions and engineering-based solutions (i.e., Sea walls, breakwater arms, beach nourishment, sand pumping). Subsequently, these alternations will lead to further physical implications such as governance and institutional changes within the coastal buffer zone or revising land-use plans. Also, these physical implications will demand more environmentally friendly and adaptive solutions to cope with climate change, such as nature-based solutions and Eco-DRR initiatives.

Economic impacts are the other climate change impact category identified through the Output 01 study. The losses attributed to the damages to the coastal infrastructure are captured as the main economic impact due to climate change. The impact of climate change on marine-based sectors such as tourism, fishing, and aquaculture is also a major concern in the coastal built environment. As mentioned before, damages to coastal infrastructure like seaports and transportation systems will indirectly be caused a significant impact on the economy of the nations as these coastal infrastructures are considered vital economic assets. Another major economic attribute of climate change is the loss of coastal income and economic depression. There will be associated costs concerning adaptation and reconstruction due to climate change. This also can be considered as an economic impact.

Output 01 report identified social impacts as another climate change impact category. The threat to human life in terms of casualties and fatalities is one of the most severe impacts of climate change and the accompanying disaster risks. Temperature rise, exposure to UV

radiation due to global warming, air pollution and aeroallergens are some of the climate change incidents that have a significant impact on human health. Furthermore, regarding human health, severe weather conditions have increased the risk of vector and water-borne diseases like Dengue. Lower nutrition level and food security, decreased water quality and availability, decreased availability and increased disruption of health services, and complication in maintaining sanitation and practices during emergencies adds more complications regarding protecting human health. Furthermore, food insecurity will also arise due to climate change as agriculture is more sensitive to temperature and precipitation changes. Also, as an immediate need for a human, water insecurities can be considered another social impact due to climate change. As a result of the life dangers and loss of livelihoods, voluntary and involuntary human migration will occur. This stresses urban infrastructure and the built environment's planning activities. Therefore, the cost of relocation and reconstruction is another social impact due to climate change. In addition, persons who are forced to leave their homes and communities will face psychological and socioeconomic stresses.

The other climate change impact category identified through the Output 01 study is environmental impacts. Damage to coastal eco-systems, salt marshes, mangrove forests, seagrass beds, soft sediments, and coral reefs is identified as the leading environmental impact due to climate change by output 01. Subsequently, damage to the coastal eco-system will affect the biodiversity as well. Another environmental impact of climate change is the alteration of forests' composition and wildlife habitats. Furthermore, impacts on eco-system function affect the quality of the water resources. Especially salinisation, acid rains, and saltwater intrusion caused the reduced freshwater quality. In addition, environmental restoration after a disaster is another environmental impact associated with climate change.

The BEACON project Output 01 outlines four major impact categories corresponding to climate change. These are physical, economic, social and environmental impacts. The physical impacts include,

- Damages to coastal infrastructure
- Access interruption to emergency facilities and critical infrastructures
- Degradation of building materials and structures
- Changes in energy consumption
- Demand more environmentally friendly and adaptive built environment architecture

- Need for physical preventive structure
- Governance and institutional changes in the coastal buffer zone or revising land use plans

The economic impacts include,

- Losses due to damages to the coastal infrastructure
- Loss of coastal income and economic depression
- Loss of employment
- Impact on marine-based industries such as tourism, fisheries, aquaculture
- Impact on planning economic development
- Depletion of resources
- Cost of adaptation and reconstruction

Also, the social impacts include,

- Decreased agriculture/livestock productivity
- Displacement and loss of livelihoods
- Voluntary and involuntary human migration
- Food and freshwater insecurities
- Risk of increased human conflicts resulting in human unrest
- Increased human health risks
- Need for social protection programs
- Threat to human life, causalities, loss of human lives

The impacts on the environment include,

- Damages to coastal eco-systems
- Impact on biodiversity
- Decreased productivity, diversity, and resilience of nearshore marine eco-system
- Environmental pollution
- Impact of surface, ground, and drinking water quality, aquatic, and terrestrial eco-system function
- Environmental restoration after a disaster

2.2 Overview of three global agendas

The Paris Agreement is the main legally binding international agreement on climate change. It was adopted by 196 parties at COP 21 in December 2015 and entered into force in November 2016(UNFCC, 2021b). The Paris Agreement aims to keep global warming below 2 degrees Celsius, preferably 1.5 degrees Celsius, compared to pre-industrial levels(UNFCC, 2021a). This agreement recognises that it would significantly reduce risks related to climate change, increase the ability to adapt to the adverse impacts of climate change and foster climate resilience(United Nations, 2015). It is in place to reflect equity, the notion of shared but varied duties, and distinct competencies in comprehending various country situations(UNFCC, 2021b; United Nations, 2015). The Convention aims to strengthen the global response to the threat of climate change in the context of sustainable development and efforts to eradicate poverty(UNFCC, 2021a).

Built environments account for significant global greenhouse gas emissions, contributing significantly to climate change (Sovacool et al., 2021). They house most of the world's population and economic activity, yet they are increasingly vulnerable to the effects of climate change (Ellena et al., 2020a). As a result, those involved in creating and managing environments must be prepared for climate change (Hürlimann et al., 2022). In addition, the IPCC report highlights that climate change is unprecedented. Also, it is known that climate action cannot be reversed at the moment (Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). Therefore, built environments should be capable of adapting to climate change as they are extremely vulnerable to the effects of climate change (Hürlimann et al., 2022; X. Wang et al., 2020). Hence, as a legally mandated regulatory framework for climate change, Paris Agreement has to play a significant role in adapting built environments to climate change (Mele et al., 2021; Mumtaz, 2021).

The Sendai Framework for Disaster Risk Reduction (SFDRR) is a legally mandated international framework corresponding to disaster risk reduction (Djalante & Lassa, 2019; Maini et al., 2017; UNDRR, 2015). It was adopted in 2015 by global leaders in disaster risk reduction. SFDRR sets out four priorities for action and seven targets. The overall objective of the SFDRR is to substantially reduce disaster risk and losses in lives, livelihoods and health and the economic, physical, social, cultural and environmental assets of persons, businesses of

nations and communities (Djalante & Lassa, 2019; Saja et al., 2020a, 2020b). The four priorities for actions of the SFDRR include the following,

1. Understanding disaster risk
2. Strengthening disaster risk governance to manage disaster risk
3. Investing in disaster risk reduction for resilience
4. Enhancing disaster preparedness for effective response and to "Build Back Better" in recovery, rehabilitation and reconstruction

Furthermore, SFDRR sets out seven global targets to reduce disaster risk substantially. The seven global targets are,

- Target A: Substantially reduce global disaster mortality by 2030
- Target B: Substantially reduce the number of affected people globally by 2030
- Target C: Reduce the disaster economic loss concerning the global gross domestic product
- Target D: Substantially reduce disaster damage to critical infrastructure and disruption of basic services, among them health and educational facilities, including through developing their resilience
- Target E: Substantially increase the number of countries with local and national disaster risk reduction strategies
- Target F: Substantially enhance international cooperation with developing countries through adequate and sustainable support to complement their national actions for implementation of SFDRR by 2030
- Target G: Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk reduction information and assessment to people by 2030

As climate change increases the frequencies and intensities of extreme weather events, SFDRR has implications for reducing the disaster risk posed by climate change (Busayo & Kalumba, 2020; Jetten et al., 2021; Mysiak et al., 2018; Seidler et al., 2018).

The other landmarks global agenda is the Sustainable Development Goals (SDGs). The United Nations approved the SDGs in 2015 as a universal call to action to end poverty, safeguard the environment, and ensure that by 2030, everyone lives in peace and prosperity (Gu et al., 2019; Mio et al., 2020). It has 17 goals and 169 targets to end poverty and the environment. The 17 SDGs are interconnected, recognising that actions in one area have an impact on outcomes in

others and that development must strike a balance between social, economic, and environmental sustainability (Cernev & Fenner, 2020; Government of the Democratic Socialist Republic of Sri Lanka, 2018; Gu et al., 2019; Odey et al., 2021).

Currently, there is a lack of integration of climate change adaptation into the built environment during infrastructure planning, design, construction, maintenance, and retrofitting (Busayo & Kalumba, 2020; Seidler et al., 2018). Improved integration of the adaptation measures will assist in mitigating the aforementioned climate change impacts. Unless these adaptation measures acknowledge the three global agendas, they become inefficient (Busayo & Kalumba, 2020; Jetten et al., 2021; Seidler et al., 2018). However, the three global agendas differ from each other. For instance, the Paris Agreement mainly concerned greenhouse gas emissions regarding climate change mitigation. At the same time, SGDs and SFDRR are more concerned with rights and quality of life and, more specifically, with DRR, respectively. Hence, aligning the climate change adaptation measures with these agendas is crucial.

2.3 Coastal built environment

Output 1 has identified the impacts of climate change under physical, economic, social, and environmental categories. Before identifying the adaptation and migration strategies, it is important to evaluate how the climate change impacts will affect the built environment and the other sectors which are interrelated with the built environment.

The phrase “built environment” refers to man-made environments for human activity, such as buildings, parks, and green spaces, as well as neighbourhoods and cities, which may include supporting infrastructures such as water supply and electricity networks (Joensuu et al., 2020; Rojas-Rueda & Morales-Zamora, 2021; Y. Zhang et al., 2020). Since the project emphasises the importance of incorporating different phases of the life cycle into the analyses, the following components were taken into the study under the phrase ‘physical assets’, and it made the scope of the study more defined. Those are 1. Residential and Commercial buildings 2. Transport infrastructures 3. Water supply-related infrastructures 4. Telecommunication 5. Electricity and Energy sector infrastructures 6. Other infrastructure categories.

However, due to the integrated nature of community infrastructures are actively interacting with other different sectors. Previous authors have considered those sectors in their studies

accordingly. According to Haigh and Amaratunga (2011), the built environment has the ability to contribute to the resilience of the community along with the essential roles of constructing, developing, stimulating, facilitating, protecting, and nurturing. This will strengthen the sector's physical assets, social assets, economic assets, governance assets, environment assets, and social cohesion. Mottaeva (2016) has classified the interactions of construction activities into the sectors of social, environmental, natural, economic, and regulatory. Kaklauskas and Gudauskas (2016) have shown that the life cycle of the built environment can be assessed in different sectors, including economic, social/ cultural, environmental, and policy decisions, etc. due to the interaction with those sectors. Zhang et al. (2022) have highlighted that the benefits of construction land use are directly linked with the social, economic, and eco-environment benefits systems. Also, Liu et al. (2021) have identified that most built environment-related studies focus on sustainable development from a bibliographic study. Therefore, it is essential to consider different sectors interrelating with infrastructures.

The scope and the objective of the previous studies have some deviations from this project scope and objectives. Hence authors have developed a project-specified classification inspired by the previous studies. Here, different sectors have identified which can apply climate change adaptation and mitigation measures to minimise the impacts identified in Output 1. The infrastructures are taken as the key sector since the project emphasises incorporating the different life cycle phases into the study. Economy, Society, and Eco-system are taken as other major sectors since the impacts of Output 1 directly interfere with the above sectors, and the project needs to identify the alignment of the global agendas with the measures. Also, as identified in the previous studies, governance actions can be incorporated to minimise climate change impacts. There are interconnections among the social, environmental and economic assets. However, since the main focus of this study lies on the physical assets, those relations are not considered. Therefore, the following classification of the built environment will be followed in this study.

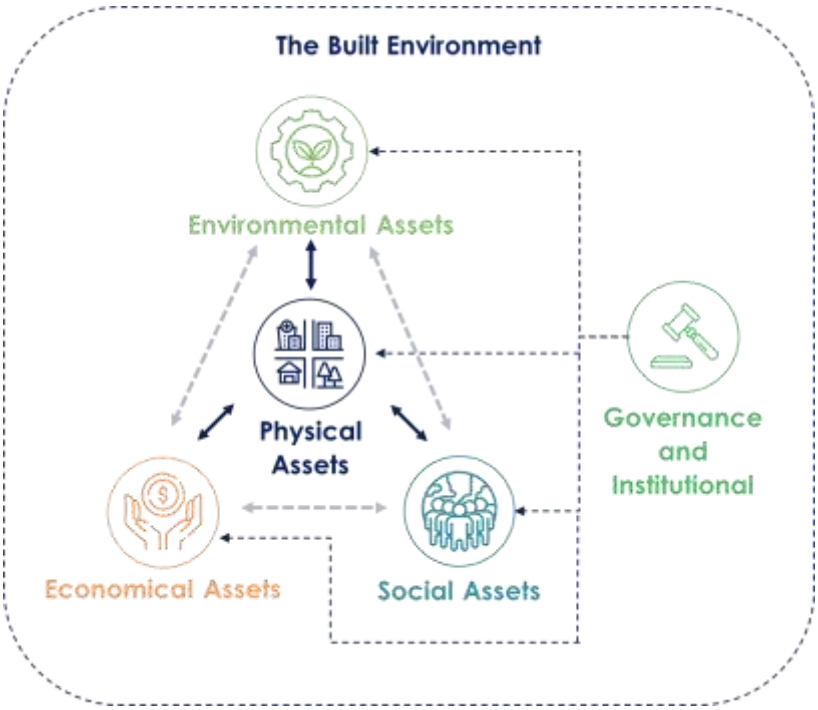


Figure 1- Scope of the built environment for the study

The coastal built environment along the coastline has become vital since they significantly contribute to the economic growth of the countries significantly (Ellena et al., 2020b; Mouratidis et al., 2021; Yıldız et al., 2020). For instance, In Sri Lanka, major transportation infrastructures such as ports, airports and major expressways lie alone in the coastal built environment serving the transportation of goods and people. A significant disruption of these transportation systems affects the Sri Lankan economy significantly.

The built environments are significant victims of disasters. Vulnerability and exposure of the built environment to hazards greatly intensified due to many factors, especially technological advancement and rapid expansion due to service demand (UNDRR, 2019b; UNDRR & CRED, 2020; UNDRR; ISC, 2020). Among these, climate change-related hazards caused greater damage to the built environment (Andrić et al., 2019; Hunt & Watkiss, 2011; Zimmerman & Faris, 2010). As aforementioned, climate change impacts are evident at present. The green land coverage is reduced as a result of urbanisation. The reduction of urban green land coverage pressures urban ecology, including surface temperature, stormwater runoff, carbon accumulation and biodiversity increases (Ciscar & Dowling, 2014; Salimi & Al-Ghamdi, 2020a; Seddon et al., 2020; L. Wang et al., 2018). The threats to the built environment from the disasters such as floods, droughts, and severe weather events tend to increase due to climate action. In addition, sea-level rise caused inundation of the low-lying areas within the coastal

built environment. As concluded from the previous sections, the built environment has become a greater victim of climate change. On the other hand, the built environment has also become the major driver of climate change (Collings & Collings, 2020; Dong et al., 2021; Lampropoulos et al., 2020). Green House Gas (GHGs) emission has caused climate change. The built environment produces a significant portion of the global GHGs. Hence, it contributes to climate change by producing greenhouse gases (Lenzholzer et al., 2020; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). As aforementioned, most of the world's population and economic activity are concentrated inbuilt settings, which are more vulnerable to climate change impacts. As a result, those involved in creating and managing built environments must be prepared for climate change. Many nations have devoted significant attention to climate change adaptation in the context of the built environment to cope with the challenges posed by climate change (Busayo & Kalumba, 2020; Jetten et al., 2021; Lenzholzer et al., 2020; Seidler et al., 2018).

2.4 Climate change adaptation

Even if significant steps to reduce GHG emissions are implemented, some further degree of climate change will be unavoidable, with severe economic, social, and environmental consequences for communities (Cramer et al., 2018; Pickering et al., 2017; Sanchez Rodriguez et al., 2018). Nations must adapt to mitigate the negative effects of climate change and take advantage of its tremendous opportunities (Seidler et al., 2018; Working Group| Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2021). The IPCC defines adaptation as an "adjustment in the natural or human system to a novel or shifting environment or in response to actual or expected stimuli or their effects, which moderates harm or utilises beneficial opportunities" (IPCC, 2015a). It encompasses efforts to reduce vulnerability and augment capacity through system modifications and adjustments (Hosseini et al., 2016; Owen, 2020; Singh et al., 2021). It entails an understanding of how systems may respond appropriately to changes in their environment by coping, adjusting, and altering (Becker et al., 2018; Fedele et al., 2019; IPCC, 2015b; UNDRR, 2019b; UNDRR; ISC, 2020). Adaptation focuses on mitigating negative effects while also building resilience and reaping any benefits that may arise. It is all about preventing disasters, dealing with existing hazards or planning for a future threat that is not (yet) recognised as imminent (Owen, 2020; Singh et al., 2021; UNDRR, 2019b). Adaptation can be reactive, occurring in response to impacts, or proactive, occurring before the impacts of climate change become apparent. Most often, proactive adaptations will be less expensive in the long run and more effective than reactionary

adaptations (R. Gupta & Gregg, 2012; V. Gupta, 2021). Many nations have devoted significant attention to climate change adaptation and mitigation. Mitigation (efforts to minimise emissions and future climatic changes) is more important than adaptation in dealing with climate change causes. Mitigation aims to address the underlying causes of climate change and provides long-term benefits by minimising damages and consequent adaptation costs (Bolan et al., 2021; B. V. Gupta, n.d.; R. Gupta & Gregg, 2012; Lenzholzer et al., 2020; Ross, 2017). Adaptation actions include large-scale infrastructure changes, like building coastal defences, heat insulation, revised standards, improved drainage or behavioural shifts like individuals using less water. Furthermore, in the context of the built (R. Gupta & Gregg, 2012; V. Gupta, 2021)environment, climate change adaptation can take several forms and can serve various functions, as presented in Table 1.

Table 1 Bases for characterising and differentiating adaptation to climate change (Adopted form: (Smit & Pilifosova, 2018))

General differentiating concept or attribute	Examples of terms used
Purposefulness	Autonomous- Planned Spontaneous- Purposeful Automatic- Intentional Natural- Policy Passive- Active
Timing	Anticipatory- Responsive Proactive- Reactive Ex ante- Ex-post
Temporal Scope	Short-term – Long term Tactical – Strategic Instantaneous- Cumulative Contingency Routine
Spatial Scope	Localised- Widespread
Function/Effects	Retreat, Accommodate, Protect Prevent, Tolerate, Spread, Change, Restore

Form	Structural, Legal, Institutional, Regulatory, Financial, Technological
Performance	Cost, Effectiveness, Efficiency, Implement ability, Equity

Last but not least, climate change adaptation is crucial for the contemporary world. Climate change is generally acknowledged, and policymakers have considered mitigation and adaptation options at national and international levels (Bolan et al., 2021; Lenzholzer et al., 2020; Lin et al., 2021). On the other hand, climate change adaptation has emerged as a crucial strategy for reducing the negative effects of climate change that can no longer be prevented, as well as maximising good socioeconomic prospects, given that no amount of mitigation will be able to avert climate change impacts in future (Hussain et al., 2019; IPCC, 2015a; Salehi et al., 2019). Furthermore, it is crucial to consider the alignment of the adaptation measures with current global initiatives as aforementioned. As mentioned above, the built environment is the greater victim and a driver of climate change. Thus, it is crucial to integrate climate change adaptation measures that agree with global agendas into the planning, design, construction, maintenance and retrofitting stage of the built environment. Currently, there is a lack of a framework for climate change adaptation in the context of the coastal built environment (Ghbn, 2016; Hussain et al., 2019; Salehi et al., 2019).

2.5 Life cycle phases of the built environment

Built environment development involves many stages. In the context of development activities of the built environment, various stages can be identified through literature. Also, various terminologies are used to identify different stages of the infrastructure life cycle. Many established frameworks for the life cycle phases of the built environment can be found in the literature. RIBA Plan of Work 2013, BIM digital Plan of Work 2013, BS 6079-1:2010, ISO 21500:2012 and OGC gateways (Amaratunga et al., 2018; CIOB, 2014). The RIBA Plan of Work 2013 has been used as the best UK model for the building development process. This framework divides the process of briefing, designing, constructing, managing, running, and using construction projects into eight stages. The stages of the building property cycle, according to the RIBA Plan of Work, include strategic definition, preparation and brief, concept design, developed design, technical design, construction, Handover and closeout, and in use (*RIBA Plan of Work*, n.d.). The main objectives of these eight stages are outlined in Table 2.

Table 2 Different stages of built environment(Amaratunga et al., 2018)

Stage	Objectives
Strategic definition	Determine the client's business case and strategic brief, as well as the other fundamental requirements of the project.
Preparation and brief	Conduct feasibility studies and a site inspection; develop project objectives, including quality objectives and project results, sustainability aspirations, project budget, and other criteria or limits, as well as an initial project brief.
Concept design	Prepare concept designs per the design program, including outline suggestions for structural design, building services systems, outline specifications, preliminary cost information, and appropriate project strategies. Agree on any changes to the brief and send out the final project brief.
Developed design	Prepare a developed design in accordance with the design program, comprising coordinated and updated proposals for structural design, building services systems, outline specifications, cost information, and project strategies.
Technical design	Prepare technical design in line with the design responsibility matrix and project strategies, considering all architectural, structural, and building services information, as well as specialised subcontractor design and requirements, in compliance with the design schedule.
Construction	Offsite fabrication and onsite construction in compliance with the construction schedule, as well as onsite resolution of design questions as they emerge.
Handover and closeout	Building handover and completion of the construction contract
In use	Utilise services in accordance with the scheduled schedule.

In the scope of the project management, there can be identified four main stages in the RIBA framework: planning, design, construction and operational stages (Willar et al., 2017). "Strategic definition", "Preparation and brief", and "concept design" stages of the RIBA framework can be categorised under the planning stage (Pilanawithana & Sandanayake, 2017; Tucker & Masuri, 2018). When it comes to the design stage includes the "developed design"

and “technical design stages” of the RIBA framework (Galiano Garrigós & Kouider, 2016; Othman & Abdelwahab, 2018; Papa Yaw Attobrah et al., 2021). When it comes to the construction stage includes the “construction” and “handover stages” of the RIBA framework (Othman & Abdelwahab, 2018; Pilanawithana & Sandanayake, 2017). The operational stages include the “in use” stage of the RIBA framework. Design and construction stages of the modern infrastructure development project are implemented simultaneously most often (Papa Yaw Attobrah et al., 2021; Shou et al., 2014; Tucker & Masuri, 2018). This study aims to create a conceptual framework for CCA measures for the coastal built environment during planning, design, construction, maintenance and retrofitting phases that align with the three global agendas. Therefore, this study considers the three lifecycle phases of the built environment as planning, design and construction, and maintenance and retrofitting.

3 The overall methodology of the Output 03

The present study was planned to be carried out under two-level. A Systematic Literature Review (SLR) was employed as an initial step to identify the adaptation measures for mitigating the climate change impacts. SLR has led to the development of a conceptual framework for climate change adaptation measures of the coastal built environment. Then the structured interview questionnaire was developed to collect the data to validate the developed framework. The target interviewees include urban planners and policymakers, built environment construction professionals, and decision-makers in disaster risk reduction and management. The questionnaires were arranged to validate the found CCA measures and link them with the climate change impacts identified in Output 01. Finally, the alignment of the CCA measures with the global agendas was assessed.

3.1 Aims of the study

This study seeks to develop a conceptual framework for CCA measures for the coastal built environment during planning, design, construction, maintenance and retrofitting phases that align with the three global agendas (i.e., SFDRR, Paris Agreement, SDGs). As aforementioned, the present study framed the research questions as follows,

1. What are possible CCA measures for Critical Infrastructures?
2. What are possible CCA measures for residential and commercial buildings?
3. What are possible CCA measures for mitigating climate change impacts on society?

4. What are possible CCA measures for mitigating climate change impacts on the economy?

. 5.What are the possible governance and institutional measures to facilitate CCA?

Consequently, the above research questions directed the study to a global-level SLR. Then the CCA measures for the built environment were identified through the analysis. The identified CCA measures and developed conceptual framework are presented in the subsequent sections of this report.

3.2 Systematic Literature Review

SLR is a research methodology that addresses specific research questions by collecting, appraising, and summarising all empirical evidence that fits pre-specified eligibility criteria (Baird, 2018). The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guideline was used in performing the SLR in this study. The PRISMA guidelines contain four steps: identification, screening, eligibility, and inclusion (Vicente & Soledad, 2018), as presented in Figure 2.

The literature was gathered from four scientific databases, Scopus, Web of Science, Science Direct and Emerald Insight, to identify the CCA measures for the coastal built environment. These databases were selected due to the availability of a broader range of peer-reviewed journal articles from international publishers. The search query was developed to initiate the search process as follows,

1. (“Critical Infrastructures” OR “Electricity” OR “Energy” OR “Water” OR “Transportation” OR “Coastal Built Environment” OR “Telecommunication” OR ((“Commercial” OR” Residential”) AND” building*”))) AND (“Climate Change” OR “adaptation” OR “measures”) AND (“Design” OR “Construction” OR “Retrofitting” OR “Refurbishment”, “Rehabilitation” OR “Renovation” OR “Restoration” OR “Maintenance”)
2. (”Soci*” OR ”Governance” OR ”Econom*”) AND (“Climate Change” OR “adaptation” OR “measures”) AND (“Coastal” AND” Built Environment”)

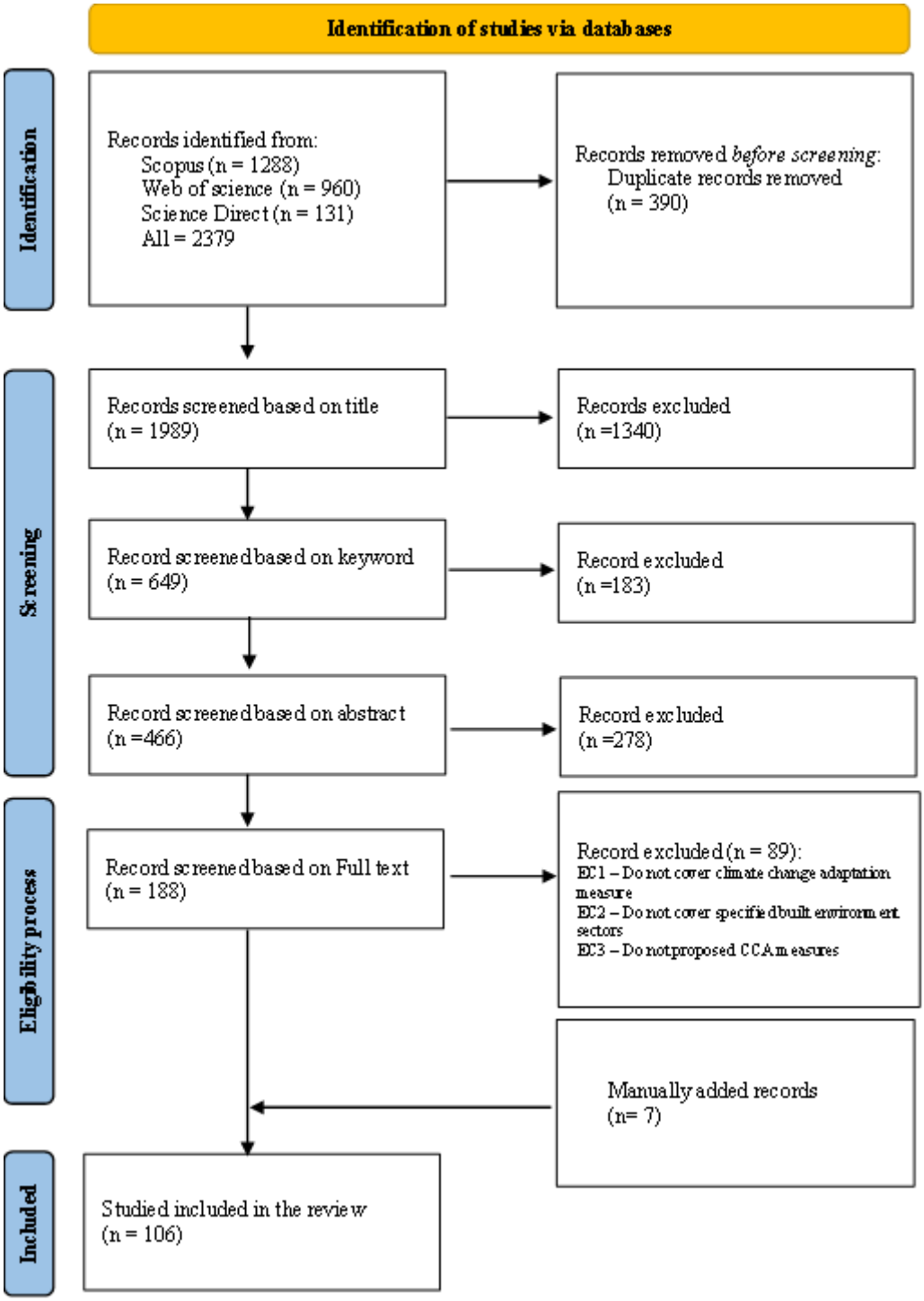


Figure 2 - Screening process of the literature

The key terms in the title, keywords, and abstracts were used as inclusion criteria. Due to the higher reliability of the results, the journal articles were chosen from the search criteria. The articles that mostly incorporated a coastal perspective were then chosen at the initial screening to comply with the scope of the study. Moreover, non-English articles and duplicates in the databases were ruled out during the initial screening step.

4 Climate change adaptation measures for the built environment

This section discusses identified adaptation measures for the built environment. As presented above, this study considered the built environment under a few categories. The identified CCA measures were summarised under each category.

4.1 Adaptation measures for physical assets

This section presents the identified adaptation measures for the physical assets of the built environment. As mentioned above, it includes Residential and commercial buildings, transport infrastructures, water infrastructures, telecommunication infrastructures, electricity and energy sector infrastructures and other infrastructure categories. Figure 3 illustrates the general overview of the focused sectors within the literature. As it depicts, scholars have devoted significant attention to climate change adaptation in the context of transportation infrastructures, water infrastructures, and residential and commercial buildings. A few studies have focused on other major infrastructure categories, such as the electricity and energy and telecommunication sectors.

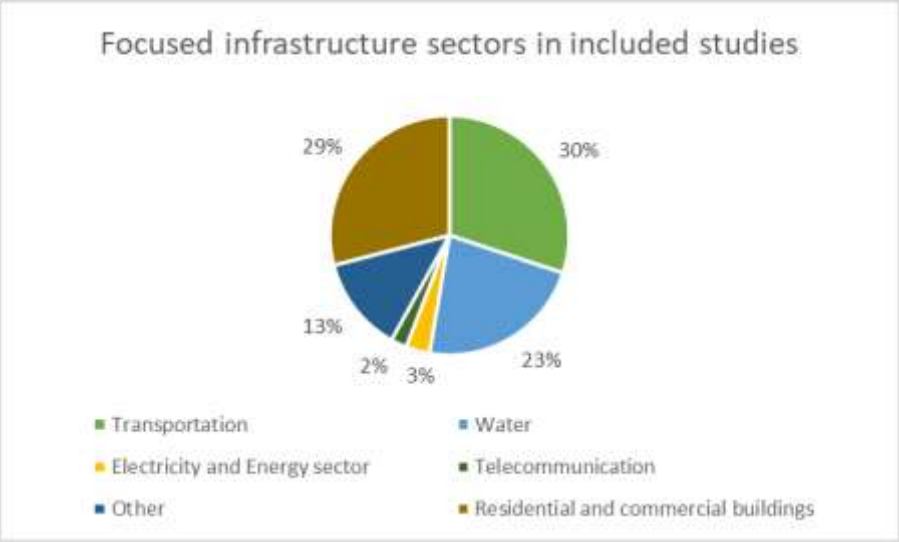


Figure 3 - Infrastructure sectors consider in the past studies

Considering the alignment of adaptation measures with the different life cycle phases is crucial for effectively functioning physical assets with challenges posed by climate change. This study considers the three main lifecycle phases of the built environment project: design and planning, construction, and maintenance and retrofitting. The design and planning stage is an important step of project development. It involves a systematic approach to the installation, operation and

management of the physical assets. Under this stage, built environment professionals consider the material, structural and architectural layouts, energy performance and structural performance to deliver the best performance for the asset. Within this stage, climate change adaptation can be integrated into several steps. Especially, it can be identified several climate change adaptation measures under the material selection, plans, and energy performance steps. Under the construction stage, following the optimised designs and plans are crucial. Also, during this stage, following effective and efficient construction methods, recycling or reusing material, if possible, any other applications of CCA are possible. The maintenance and retrofitting stage involves any activity performed to maintain the functionality of the infrastructures. After delivering the project, assets are subjected to maintenance and retrofitting work. Since the physical assets deal with different climate change scenarios over their lifetime, the frequency of maintenance and retrofitting work of infrastructure increases significantly, affecting the life cycle cost of infrastructures unless they acknowledge the climate change adaptation. Hence the identified adaptation measures were categorised into the design and planning, construction and maintenance and retrofitting stages, which give more understanding of the applicable CCA measures at each phase for different sectors.

Table 3 summarises the identified CCA measures for transportation infrastructures. It includes measures related to the design modifications to the structures and materials, considering anticipated loads in the designs, additional protection measures and monitoring and maintenance measures.

Table 3: CCA measures for transportation infrastructure

Adaptation measure	**Applicable phase**			**References**
	Design and planning	**Construction**	**Maintenance and retrofitting**	
Rising the road level to combat the flooding	●			(Batouli & Mostafavi, 2016; Cervigni et al.,
Proper asphalt mix design suits regional climatic conditions	●			

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Alternative mix design for the pavement treatment (e.g., Warm mixes, rubberised asphalt, and pervious concrete)	●			2015; Charlesworth et al., 2016; Cheng et al., 2017; V. Gupta, 2021; Major et al., 2018; Manocha & Babovic, 2017; Markolf et al., 2019; Mauree et al., 2019; Mohebbi et al., 2020; Moura et al., 2016; J. E. Neumann et al., 2015; M. B. Neumann et al., 2015; Oswald Beiler et al., 2016; Picketts et al., 2015; Qiao et al., 2020; Salerno et al., 2018; Scussolini et al., 2017; Seah
Comprehensive snow and ice control program that includes pre-wetting surfaces to combat ice on roads and using only coarse gravel on roads to minimise air quality and aquatic impacts	●			
Consideration of traffic loads on pavements/load restrictions and Traffic demand prediction and pavement design (With the sea level rise, people move inland, increasing traffic demand)	●			
Improved data (Weather events and crashes, collision data, data sharing)			●	
A method to predict the maintenance of the road in combination with the climate change simulation model (e.g., winter severity index (WSI))	●			
Improved drainage system incorporating the Sustainable drainage system (SUDS) principles in the design	●			
Use of highly reflective coating against the urban heat island		●		
Hydrological and drainage design considering anticipated increment of the precipitation, water levels	●			
Planning for/providing alternative routes in the event of a road/railway closure	●			

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Construct roadway over embankments to accept the passage of floodwaters at defined locations (ensuring safe failure)		●		et al., 2021; Simons et al., 2022; Strauch et al., 2015; van de Ven et al., 2016; World Bank, 2015)
Proper sizing of the culverts/ Allow undersized culverts to be overtopped by designing for such failures ensuring safety	●			
Use appropriate embankment materials-rock fill at bridge approach, granular materials		●		
Increase longitudinal drains capacities- Ensure Road drainage is routinely shaped by the grader, protect verges and channel side slopes with appropriate vegetation cover, and ensure effective longitudinal drainage capacity in cutting to remove flood water		●		
Provide cutting slope drainage -adequate and effective drainage cut-off drains installed to the top of cutting slopes berms.		●		
Harden river defences using retaining walls. Gabion baskets, earth dikes, random rubble		●		
Protection of the structural materials against salinity		●		
Robust pavement structures-erosion resistant surfacing	●			
Use of design guidelines for asset design	●			
Adopting tools for evaluating risk, vulnerability, and exposure of the transportation infrastructure	●		●	
Prevent build-up of debris against intermediate supports or under deck soffit through upstream river and development management			●	
Maintainable back-of-wall drainage			●	

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Scour protection around bridge abutment, wing wall, piers, minor culvert, and headwall/toe wall		●		
Deepen foundation, Pilled foundation, Cut-off sheet piling at the foundation	●			
Increase the Vertical clearance of the soffit	●			
Design a bridge to accommodate the permanent raising of the bridge deck	●			
Design the bridge as a floating bridge	●			
Improving material quality with mechanical or chemical material stabilisation		●		

Table 4 summarises the identified CCA measures for residential and commercial buildings. The measures include design modifications aiming at different hazards, change of building usage patterns, adopting new materials, and methods for constructions.

Table 4: CCA measures for residential and commercial buildings

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Elevated building construction in flood-prone areas	●			(Abeysinghe et al., 2020; Ahmad & Afzal, 2020; Al-Faesly et al., 2015; Ardekani & Hosseini, 2012; Bernier et
Building construction on strong pillars and posts	●			
Design for the impact of the tsunami wave and debris flow	●			
Construction of seawalls	●			
Proper detailing of joints to withstand the hydraulic loads	●			

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Anchoring the building to the foundation to increase the stability	●			al., 2015; de Ruig et al., 2020; Esteban et al., 2013; R. Gupta & Gregg, 2012; Haddad et al., 2020; Han & Mozumder, 2021; Hinkel et al., 2011; Huang & Hwang, 2016; Hudson, 2020; Hwang et al., 2009; Morin et al., 2008; Mycoo, 2014; Nofal et al., 2020; O'Malley et al., 2014; Porritt et al., 2012; Ross, 2017; Sari, 2021; Shimoda, 2010; Solecki et al., 2011; Storbjörk & Hedrén, 2011; Wu et al., 2019;
Increase the weight of the building to increase the stability	●			
Openings on the ground floor in flood and tsunami-prone areas	●			
Wet and dry proofing of building in flood-prone areas		●		
Amphibious buildings in flood-prone areas	●			
Use of flood-proof materials		●		
Post-flood drainage system	●			
Better insulation of walls, lofts and floors for better energy performance		●		
Rainwater harvesting			●	
Solar thermal water heating to reduce energy use			●	
Low energy lighting and more natural lighting			●	
Reused or recycled material		●		
Vegetation cover around the building	●			
Use of material with high albedo rating (cool envelope materials)		●		
Shadings for windows to reduce energy use		●		
Night Ventilation and ventilative cooling			●	
Window rules for reducing energy use			●	
Green roofs, roof pond, and green facades	●			
Optimising building orientation and placement of openings for better energy performances	●			

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
				Zhang et al., 2021)

Table 5 summarises the CCA measures for water-related infrastructures, including dams and tank water pipelines. The measures suggest different approaches, such as design modifications to withstand different effects of climate change and innovative monitoring and maintenance practices.

Table 5: CCA measures for water infrastructures

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Safety assessment, reinforcement of discharge facilities in spillways	●			(Cheng et al., 2017; Choi et al., 2017; Emilsson & Ode Sang, 2017; Ghbn, 2016; Hatvani-Kovacs et al., 2018; Herath et al., 2018; Hurlimann & Wilson, 2018; Job et al., 2020; Kohlitz et al., 2020; Lin et al., 2021; Manocha & Babovic, 2017; McPhillips et al.,
Raising dam level	●			
Adopting dam rehabilitation evaluation techniques			●	
Proper design approaches for drinking water sources (for the local community, Ex: coverage, construction methods to overcome ingress of water)	●			
Increasing storage and pumping capacities/Resilient tank system	●			
Physical barriers such as sea walls to minimise impacts of tidal events and rising elevations of the infrastructure	●			
Design and build floatable critical properties	●			
Relocating vulnerable critical facilities			●	

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Adopting green infrastructure	●			2020; Mikovits et al., 2017; Moura et al., 2016; M. B. Neumann et al., 2015; Radhakrishnan et al., 2019; Salerno et al., 2018; Salimi & Al-Ghamdi, 2020; Seah et al., 2021; Senosiain, 2020; Shanmugasundaram et al., 2017; Sharifi et al., 2021; Trogrlić et al., 2018; Van Engelenburg et al., 2019; Yerri et al., 2018)
Mapping vulnerable areas and critical facilities	●		●	
Collecting critical data for monitoring purposes			●	
Forecasting model to risk-informed decision making	●		●	
Revision of the codes/policies based on forecasting			●	
Reducing impervious surfaces in land use-Stop the water pollution	●			
Heating systems for water systems hydraulic fracturing at drill sites to prevent frost	●			

Table 6 summarises the CCA measures for energy and electricity infrastructures. The measures include design modification, revision of design threshold values based on climate change predictions, optimising the maintenance and monitoring cycle etc.

Table 6: CCA measures for energy and electricity infrastructures

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Review design thresholds and guidelines of structures considering climate change	●		●	(V. Gupta, 2021; Katopodis & Sfetsos, 2019; Varianou Mikellidou et al., 2018)
Upgrading oil platforms, the rigs and the number of anchors to make it more resilient to hurricanes	●	●		
Offshore drilling companies should invest in lighting protection for offshore drilling	●			
Raising the elevation of infrastructures	●			
Plan and train for the evacuation of personnel			●	
Review of the design of installations located on the coastline.			●	
Relocation of critical facilities and securing of equipment (e.g. Anchoring storage tanks, restraining gas cylinders			●	
Early warning systems	●			
Increasing storage capacities for vital equipment and supplies	●			
Investing and managing drainage systems within critical facilities	●			
Implement a method for risk assessment	●			

Table 7 includes the identified measures for telecommunication infrastructures.

Table 7: CCA measures for telecommunication infrastructures

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Replacing copper wire network with waterproof fiberoptic cables		●	●	(Balcell et al., 2014; V. Gupta, 2021)
Using portable or provisional base stations to provide network continuity and backup power sources	●		●	
Tailoring continuity of service plans based on the needs of localities	●			
Employing network management techniques for addressing congestion			●	

Table 8 summarises identified CCA measures which can be applied generally for any infrastructure sector. Measures suggest considering future effects of climate change, incorporating greener concepts etc.

Table 8: CCA measures for other and general infrastructure sectors

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
Planning for future inland movement due to sea level rise	●			(Clark et al., 2018; Gedikli, 2018; Hatvani-Kovacs et al., 2018; Herath et al., 2018; Manocha & Babovic, 2017;
Land use incorporating green concepts	●			
Regulating minimum green space ratio	●			
Adopting nature-based solution	●	●		
Networks of parks, urban greenery, and open spaces	●			

Adaptation measure	Applicable phase			References
	Design and planning	Construction	Maintenance and retrofitting	
				Salerno et al., 2018; Scussolini et al., 2017; Shanmugasundaram et al., 2017; Sharifi, 2020; Sharifi et al., 2021; Wang et al., 2019)

Considering the complexity of continuing with the high number of infrastructure types and adaptation measures, all the identified measures were compressed into the following set of adaptation measures.

- Consideration of anticipated loads in the designing of infrastructure
- Revision of the building codes, rule and regulations
- Proper planning of evacuation routes
- Adopting tool for evaluating risk, vulnerability, exposure of infrastructure
- Risk informed infrastructure development
- Creating maps of infrastructure assets, facilities
- Better land use planning with greener/nature-based solutions
- Proper material design and integrating greener materials
- Proper storm water management techniques/Drainage system designs
- Considering safe engineering designs
- Using protective measures (e.g., Flood protection barriers)
- Infrastructure design to accommodate future modifications
- Raising elevation of infrastructure
- Implementation of method/techniques to predict the maintenance of the infrastructure
- Increasing and maintenance of longitudinal drains capacities

- Implementation of proper monitoring of routine maintenance service
- Performing retrofitting, repair activities in deteriorated infrastructure
- Conducting risk assessment for infrastructure facilities and revising vulnerability and exposure maps

4.2 Climate Change Adaptation measures for social assets

Climate change has caused significant disturbances to the community. Food and freshwater insecurity are the major social impact of climate change. Food security is one of the most critical areas that need special attention in climate adaptation among nations. The agriculture sector is the most climate-sensitive sector. Climate-related hazards have significantly affected agricultural production and farm assets recently (Aryal et al., 2021; Karimi et al., 2018). Hence, the high climate sensitivity and livelihood dependency of a large population make food security a highly vulnerable sector to climate change impact that needs special attention for climate change adaptation (Aryal et al., 2021). Also, displacement and loss of livelihoods are other major impact of climate change on society (Kaluarachchi, 2018; Nikuze et al., 2019; Přívara & Přívarová, 2019). Another area where climate change can have a substantial impact is health. Changes in climatic patterns have been linked to increased health risks in studies worldwide. As a result, making major efforts to adapt to potential health risks related to climate change is a top concern (Chersich & Wright, 2019; Sharifi et al., 2021; Travert et al., 2019). The other social impact of climate change includes the requirement of social protection plans, migration, a threat to human life, causalities, loss of human lives and risk of conflicts among people. In order to mitigate these impacts on society, different nations have taken several adaptation measures. The present study has identified the following climate change adaptation measures for protecting the community from the literature review (Aryal et al., 2021; Aslany & Brincat, 2021; Kaluarachchi, 2018; Karimi et al., 2018; Nikuze et al., 2019; WHO, 2019).

- Preparation in advance for food and medications, availability of safe water, and assurance of accessible public health service during a post-disaster situation
- Increase the accessibility to MHEWs facilities
- Conducting safety drills and evacuation plans
- Implementing proper signboards
- Adopting new agricultural technologies to increase the productivity of the agriculture
- Launch awareness programs on climate change for the public

- Promote climate-resilient building designs and revise building approval systems to increase the climate resilience

4.3 Climate Change Adaptation measures for economic assets

This section presents the identified adaptation measures for mitigating the adverse impacts of climate change on the economy. As the economic impacts, losses due to infrastructure damages were highlighted as a major impact. As aforementioned, climate change has caused a significant impact on coastal infrastructures. The cost of retrofitting and repairing the damaged infrastructure needs capital. In addition, disruption of infrastructure service will affect the nation's economy as these infrastructures assist in the economic gain of most countries. As aforementioned, coastal built environments are major economic hotspots in most countries. Therefore, any damage to the coastal built environment causes economic depression. On the other hand, most marine-based industries, such as tourism, fisheries, and aquaculture, will be affected due to climate change (Becker et al., 2018; Mouratidis et al., 2021; Stappers et al., 2018). One of the major incomes of countries is the marine-based industries. It is evident that climate change has a significant impact on marine-based industries (Johnson et al., 2020; Tegar & Gurning, 2018). Hence, the impact of marine-based industries directly affects the economy of the nations. The other identified economic impacts include the cost of adaptation and reconstruction, loss of employment, depletion of resources, and impact on planning economic development. In order to mitigate these impacts on the economy, different nations have taken several adaptation measures. The present study has identified the following climate change adaptation measures for protecting economies of the coastal built environment (Busayo & Kalumba, 2020; Ellena et al., 2020; Joensuu et al., 2020; Mouratidis et al., 2021; Singh et al., 2021).

- Introduce innovative risk transfer instruments
- Promote climate-proof infrastructure design practices
- Develop guidelines for economic activities in vulnerable areas
- Identify adaptation actions suitable for respective industries
- Increase the awareness of industrial operators on climate change and its impacts
- Increasing infrastructure protection measures

4.4 Climate Change Adaptation measures for environmental assets

Environmental assets related to the built environment can identify as natural forests, parks, wetlands, and mangroves. These assets play a pivotal role in climate change mitigation, absorbing CO_2 (Faivre et al., 2018; Fedele et al., 2019; Lau et al., 2019; van de Ven et al., 2016). Also, they provide shelter for living beings. The identified adaptation measures for protecting the environmental assets include the followings (Anjali et al., 2020; Climate Change Secretariat, 2016; Collings, 2020; Faivre et al., 2018; Fedele et al., 2019; Grima et al., 2020; Singh et al., 2021).

- Conduct research studies on climate change impact on ecosystems and biodiversity
- Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity
- Prepare and implement adaptive management programs for climate-sensitive ecosystems
- Prepare and implement recovery plans for highly threatened ecosystems and species
- Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity
- Improve land use planning with nature-based solutions

4.5 Governance and institutional measures to facilitate climate change adaptation

Governance is the broader term (Chinyere et al., 2020; da Cruz et al., 2018). Generally, in the context of the built environment, it refers to the processes of decision-making involved in the control and management aspect of the built environment (Amaratunga et al., 2019; Malalgoda et al., 2013; UNDRR, 2019). The governance of the infrastructure has a direct impact on other components of the built environment, as presented in Figure 1. Therefore, strengthening governance is crucial for building climate resilience (Amaratunga et al., 2019; Dias et al., 2019; Wedawatta et al., 2016). The following governance and institutional measures were identified through the present study to facilitate climate change (Amaratunga et al., 2019; Dias et al., 2019; Hürlimann et al., 2022; IPCC, 2014; Malalgoda et al., 2014).

- Strengthen the mechanisms for sharing information and data among stakeholders
- Defining clear responsibilities and roles for stakeholders
- Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities

- Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects
- Conduct training programs for government officers and private sector employees on climate change adaptation
- Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation
- Establish a national network of research agencies and universities that are carrying out research on climate adaptation to promote coordinated research and information dissemination

5 Development and validation of the framework

The intended framework is developed to suggest the applicable adaptation measures for identified climate change impacts. The framework development process includes three major steps which are 1. Filtering the suitable CCA measures from the identified measures under each category. 2. Identify the applicable CCA measure which can be used against climate change impacts in Output 01. 3. Assess the alignment of the selected adaptation measures with the global agendas.

Task 1 and Task 2 were done based on the expert opinion. A structured questionnaire was distributed among the identified experts. It consisted of five interviews to gather data to validate the conceptual framework. Each questionnaire focuses on a specific aspect of the built environment. The questionnaires were distributed to the designated professionals in the table.

Table 9: Selected professionals for the data collection

Area	Target professionals
Physical assets	Architects
	Urban planners
	Engineers of different disciplines
	Academics
Social	Social scientists, NGOs and volunteers who are working with the

	community, social activists, Academics, Demographers, Agroclimatologists, Geographers
Economy	Economists, Academics, Lawyers
Environment	Environmentalists, Academics, Lawyers, Climate specialists, Agroclimatologists, Geologists, Lawyers
Institutions and governance	Policy makers, Government officials, Climate specialists

In order to identify appropriate professionals, the following criteria were adhered.

Table 10: Criteria for selecting built environment professionals.

Built environment professionals	Criteria
Architects, Urban planners, Engineers of different disciplines, social scientists, NGOs and volunteers who are working with the community, social activists, Demographers, Agroclimatologists, Economists, Environmentalists, Climate specialists, Geologists, Lawyers	• Experience in the field (At least ten years of experience) • Involvement in coastal built environment-related works • Any awards related to their contributions to the built environment (if any)
Built environment Academics and researchers	• Research interest in the built environment, building resilience, coastal management, disaster risk reduction, sociology, relocation, biodiversity conservation, climate change and adaptation, and any related area • Publications • Citations (Mentioned the number)

Policy makers, Government officials, administrative officers	• Select the highest profile of the affiliated institutions, organisations, or governing body. • If not, select the recommended person by the highest profile.

Forty-nine responses were collected from professionals from Sri Lanka and Malta. The following chart summaries the number of contributed professionals under each category.

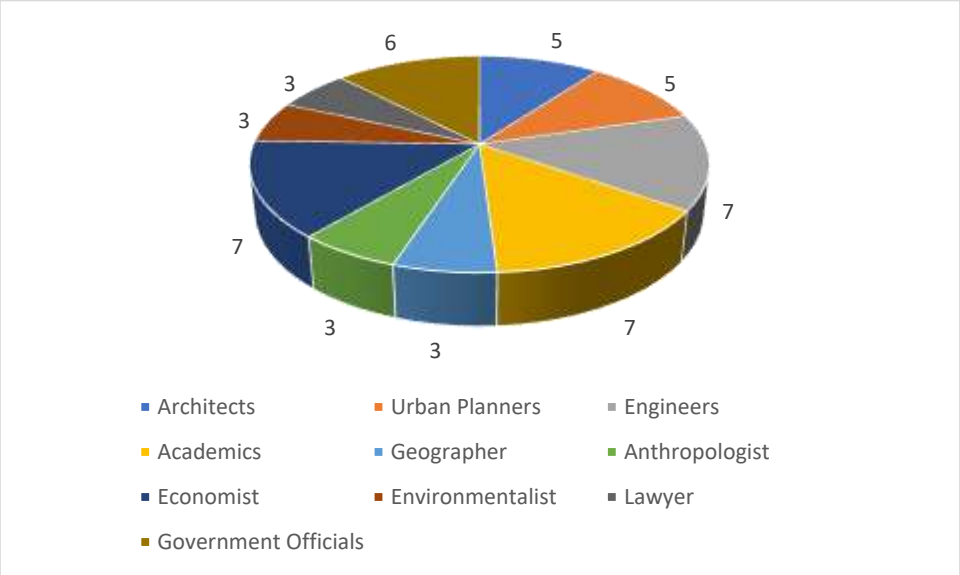


Figure 4 - Number of respondents

5.1 Selection of the applicable CCA measures

The applicability of various adaptation measures was evaluated in selected areas using the questionnaire administered to the selected professionals. Here, the adaptation measures were evaluated using a weighting system. All areas except the physical assets were assessed as either not applicable, less applicable, neutral, applicable, or highly applicable, with corresponding values of 1, 2, 3, 4, and 5, respectively. The evaluation of whether these adaptation measures were applicable or not was based on the average responses.

For the physical assets, selected adaptation measures were evaluated according to the lifecycle phases, such as design and planning, construction, maintenance, or retrofitting. Adaptation

measures were considered applicable if the average rating value exceeded the value of 3. The following tables present the average value received for each adaptation measure.

5.1.1 Adaptation measures for physical assets

Adaptation measure	**Design and Planning**	**Construction**	**Maintenance or Retrofitting**	**Not an adaptation measure**
Consideration of anticipated loads in the designing of infrastructure	3	1	1	0
Revision of the building codes, rule and regulations	4	1	0	1
Proper planning of evacuation routes	4	0	0	0
Adopting tool for evaluating risk, vulnerability, exposure of infrastructure	3	1	1	1
Risk informed infrastructure development	4	0	1	1
Creating maps of infrastructure assets, facilities	4	0	1	0
Better land use planning with greener/nature-based solutions	4	1	0	0
Proper material design and integrating greener materials	0	4	0	1
Proper storm water management techniques/Drainage system designs	3	2	0	0
Considering safe engineering designs	1	4	0	0
Using protective measures (e.g., Flood protection barriers)	1	4	0	0

Infrastructure design to accommodate future modifications	0	4	0	0
Raising elevation of infrastructure	0	3	1	1
Implementation of method/techniques to predict the maintenance of the infrastructure	1	1	4	0
Increasing and maintenance of longitudinal drains capacities	0	1	4	1
Implementation of proper monitoring of routine maintenance service	0	2	3	0
Performing retrofitting, repair activities in deteriorated infrastructure	0	1	3	1
Conducting risk assessment for infrastructure facilities and revising vulnerability and exposure maps	0	1	4	0

5.1.2 Adaptation measures for social assets

Adaptation measure	**Average response**
Preparation in advance for food and medications, availability of safe water, assurance of accessible public health service during a post-disaster situation	5
Increase the accessibility to MHEWs facilities	5
Conducting safety drills and evacuation plans	5
Implementing proper signboards	4.8
Adopting new agricultural technologies to increase the productivity of the agriculture	4.4
Launch awareness programs on climate change for the public	4.8
Promote climate-resilient building designs and revise building approval systems to increase the climate resilience	5

5.1.3 Adaptation measures for economic assets

Adaptation measure	**Average response**
Introduce innovative risk transfer instruments	4.1
Promote climate-proof infrastructure design practices	3.7
Develop guidelines for economic activities in vulnerable areas	4.0
Identify adaptation actions suitable for respective industries	4.1
Increase the awareness of industrial operators on climate change and its impacts	3.7
Increasing infrastructure protection measures	3.6

5.1.4 Adaptation measures for environmental assets

Adaptation measure	**Average response**
Conduct research studies on climate change impact on ecosystems and biodiversity	4.9
Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity	4.9
Prepare and implement adaptive management programs for climate-sensitive ecosystems	4.9
Prepare and implement recovery plans for highly threatened ecosystems and species	5
Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity	4.4
Improve land use planning with nature-based solutions	4

5.1.5 Governance and institutional measures for facilitate CCA

Adaptation measure	**Average response**
Strengthen the mechanisms for sharing information and data among stakeholders	3.7

Defining clear responsibilities and roles for stakeholders	3.7
Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	3.8
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	3.8
Conduct training programs for government officers and private sector employees on climate change adaptation	4.2
Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation	3.7
Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination	3.5

5.2 Identification of the applicable CCA measure which can be used against climate change impacts

The validated CCA measures were then directed to assess the applicable climate change impacts, which can be mitigated using the CCA measures. As discussed earlier, the climate change impacts were identified under four categories. Identifying adaptation measures for each category was evaluated in this step. Apart from that, as identified, the applicability of governance measures was also assessed to mitigate the impacts of each category. Respondents were asked to assess each CCA measure upon each impact under a 1-5 scale representing the applicability. The following tables summarise the average scores obtained . If the average score exceeds 3, it is considered an applicable CCA measure to mitigate the respective impact.

5.2.1 CCA measure for physical impacts of climate change

Adaptation measure	Damages to Infrastructure, buildings, or properties	Access interruption emergency facilities and CIs	Degradation of building materials and structures	Changes in energy consumption	Demand more environmentally friendly and adaptive built environment architecture	Physical preventive structures	Governance and institutional changes coastal buffer zone or revising land use plans
CCA Measures for physical assets							
Consideration of anticipated loads in the designing of infrastructure	5	2.2	3.2	3.6	2.5	4	2.8
Revision of the building codes, rule and regulations	4.6	3.2	2.8	3.4	3.6	2.8	4
Proper planning of evacuation routes	0	5	0	0	2.8	2.2	3.2
Adopting tool for evaluating risk, vulnerability, exposure of infrastructure	5	4.2	4	4.2	3	3.8	3

Risk informed infrastructure development	5	3.2	3.8	3	3.2	3.8	2.4
Creating maps of infrastructure assets, facilities	1	5	0	0	3	1.4	4
Better land use planning with greener/nature-based solutions	3.8	2.4	4	5	4	3.2	5
Proper storm water management techniques/Drainage system designs	3.6	2	2.6	2.8	3.5	3	2.8
Alternative infrastructure designs (eg: floating infrastructure)	5	3.8	4	3	4	5	3.2
Proper material design and integrating greener materials	4.2	2.6	4.8	5	5	3.6	3
Considering safe engineering designs	5	3.2	3.6	3.8	4	4.6	3.2
Using protective measures (e.g., Flood protection barriers)	5	4.2	3.8	2.4	3	3.2	3

Infrastructure design to accommodate future modifications	5	4.6	4.2	4	4	3.8	3
Raising elevation of infrastructure	4	5	5	2	3	4	3
Implementation of method/techniques to predict the maintenance of the infrastructure	4	3.6	4	4.8	4	4	3
Increasing and maintenance of longitudinal drains capacities	3.2	3.8	4	2.4	3.2	4.2	2
Implementation of proper monitoring of routine maintenance service	5	4.2	4	4	5	4.6	2
Performing retrofitting, repair activities in deteriorated infrastructure	5	3.8	5	3.6	4	4	2
Conducting risk assessment for infrastructure facilities and revising vulnerability and exposure maps	5	5	3	3	4.2	4	3

Governance and Institutional measures							
Strengthen the mechanisms for sharing information and data among stakeholders	3.2	3.3	3.0	3.0	2.8	3.0	3.4
Defining clear responsibilities and roles for stakeholders	3.7	3.3	3.2	3.6	3.5	3.7	3.6
Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	3.0	3.2	3.2	3.6	3.5	3.3	3.6
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	3.1	3.2	2.8	3.4	3.3	3.3	3.6
Conduct training programs for government officers and	2.8	3.2	2.8	3.4	3.3	3.5	3.6

private sector employees on climate change adaptation							
Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation	3.2	3.2	2.7	3.4	2.7	2.8	3.2
Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination	2.8	2.8	3.0	2.8	3.0	3.0	3.0

5.2.2 CCA measure for social impacts of climate change

Adaptation measure	Displacement and loss of livelihoods	Food and freshwater Insecurities	Need of social protection programs	Voluntary and involuntary human migration	Risk of increased human conflicts resulting in human unrest	Threat to human life, causalities, loss of human life
CCA Measures for Social Assets						
Preparation in advance for food and medications, availability of safe water, assurance of accessible public health service during a post-disaster situation	4.8	4.8	4.4	4	3.6	5
Increase the accessibility to MHEWs facilities	4.8	3.2	4.6	3.2	4.4	4.8
Conducting safety drills and evacuation plans	4.4	2.4	4.6	3.2	4.4	4.5
Implementing proper signboards	4.4	2	4.5	2.4	3.2	4
Adopting new agricultural technologies to increase the productivity of the agriculture	2.8	4.8	3.2	2.8	2.4	3.6
Launch awareness programs on climate change for the public	4.8	4.4	4.4	4.4	4.4	4.4
Promote climate-resilient building designs and revise building	4.8	3.6	4	4.4	3.2	4

approval systems to increase the climate resilience						
Governance and Institutional Measures						
Strengthen the mechanisms for sharing information and data among stakeholders	3.2	3.3	3.0	3.0	3.3	3.0
Defining clear responsibilities and roles for stakeholders	3.7	3.3	3.2	3.6	3.5	3.7
Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	3.0	3.2	3.2	3.6	3.5	3.3
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	3.1	3.2	2.8	3.4	3.3	3.3
Conduct training programs for government officers and private sector employees on climate change adaptation	2.8	3.2	2.8	2.8	3.0	3.5
Develop an inventory of international climate donors, funding schemes, training	3.2	3.2	2.7	2.8	2.7	2.8

providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation						
Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination	2.8	2.8	3.0	2.8	3.0	3.0

5.2.3 CCA measure for economic impacts of climate change

Adaptation measure	**Losses due to damages in the coastal infrastructure**	**Loss of employment**	**Impact on planning economic development**	**Cost of adaptation and reconstruction**	**Loss of coastal income and economic depression**	**Impact on marine based industries such as tourism, fisheries, agriculture**	**Depletion of resources**
CCA Measures for economic assets							
Introduce innovative risk transfer instruments	3.9	3.4	3.6	3.9	3.3	3.7	3.6

Promote climate-proof infrastructure design practices	4.0	3.8	3.3	3.3	3.9	3.9	3.4
Develop guidelines for economic activities in vulnerable areas	3.6	3.6	4.0	3.6	4.1	4.0	3.6
Identify adaptation actions suitable for respective industries	3.9	3.7	3.9	3.6	3.4	3.9	4.0
Increase the awareness of industrial operators on climate change and its impacts	3.4	3.4	3.3	3.6	3.6	3.1	3.9
Increasing infrastructure protection measures	4.0	4.0	3.4	4.0	4.3	4.0	4.0
Governance and Institutional Measures							
Strengthen the mechanisms for sharing information and data among stakeholders	3.0	3.7	3.7	3.8	4.0	3.5	4.0
Defining clear responsibilities and roles for stakeholders	4.2	3.3	3.8	4.4	4.3	3.7	3.6
Undertake a review of relevant macro and	3.3	3.8	3.3	4.4	4.2	3.3	3.6

sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities							
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	3.6	4.0	3.8	4.2	3.3	3.7	3.6
Conduct training programs for government officers and private sector employees on climate change adaptation	3.8	3.7	3.3	4.2	3.3	4.0	3.6
Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/	4.0	3.8	3.7	4.2	3.3	3.8	4.0

consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation							
Establish a national network of research agencies and universities that are carrying out research on climate adaptation for promoting coordinated research and information dissemination	3.7	3.7	3.7	4.2	4.0	4.0	3.4

5.2.4 CCA measure for environmental impacts of climate change

Adaptation measure	**Damage to ecosystems, salt marshes, mangrove forests. Seagrass beds etc.**	**Decreased productivity, diversity, and resilience of nearshore marine ecosystem**	**Impact on water quality**	**Impact on biodiversity**	**Environmental pollution**	**Environmental restoration after a disaster**
CCA Measures for environmental assets						

Conduct research studies on climate change impact on ecosystems and biodiversity	4.4	4.3	4	4.9	3.5	4.4
Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity	4.7	4.6	4.5	5	4	4.3
Prepare and implement adaptive management programs for climate-sensitive ecosystems	4.6	4.7	4	4.6	4	4.4
Prepare and implement recovery plans for highly threatened ecosystems and species	5	5	5	5	4.5	5
Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity	4.2	4.3	4	4.4	3	4
Improve land use planning with nature-based solutions	3.6	4	4.2	4.4	4.8	4.6
Governance and Institutional Measures						
Strengthen the mechanisms for sharing information and data among stakeholders	2.8	3.5	4.0	4.0	4.0	3.7
Defining clear responsibilities and roles for stakeholders	3.8	4.0	3.8	4.4	4.0	3.7

Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	3.7	3.7	3.2	4.2	3.5	3.8
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	3.6	3.8	3.2	4.2	3.3	3.8
Conduct training programs for government officers and private sector employees on climate change adaptation	2.6	3.7	2.8	3.2	3.3	3.7
Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation	3.2	3.7	3.3	3.2	2.8	3.8
Establish a national network of research agencies and universities	3.8	4.0	3.0	3.2	3.0	4.0

5.3 Assess the alignment of the adaptation measures with the global agendas

The alignment with the global agendas of the selected adaptation measures was assessed considering the key aspects, targets and goals of the considered global agendas. The following attributes were considered from each framework. The following tables present the different attributes satisfied by each adaptation measure identified.

Key aspects of the Paris Agreement

PA1: Long-term temperature goal (Art. 2) – The Paris Agreement, in seeking to strengthen the global response to climate change, reaffirms the goal of limiting global temperature increase to well below 2 degrees Celsius, while pursuing efforts to limit the increase to 1.5 degrees.

PA2: Global peaking and 'climate neutrality' (Art. 4) –To achieve this temperature goal, Parties aim to reach global peaking of greenhouse gas emissions (GHGs) as soon as possible, recognising peaking will take longer for developing country Parties, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of GHGs in the second half of the century.

PA3: Mitigation (Art. 4) – The Paris Agreement establishes binding commitments by all Parties to prepare, communicate and maintain a nationally determined contribution (NDC) and to pursue domestic measures to achieve them. It also prescribes that Parties shall communicate their NDCs every 5 years and provide information necessary for clarity and transparency. To set a firm foundation for higher ambition, each successive NDC will represent a progression beyond the previous one and reflect the highest possible ambition. Developed countries should continue to take the lead by undertaking absolute economy-wide reduction targets, while developing countries should continue enhancing their mitigation efforts, and are encouraged to move toward economy-wide targets over time in the light of different national circumstances.

PA4: Sinks and reservoirs (Art.5) –The Paris Agreement also encourages Parties to conserve and enhance, as appropriate, sinks and reservoirs of GHGs as referred to in Article 4, paragraph 1(d) of the Convention, including forests.

PA5: Voluntary cooperation/Market- and non-market-based approaches (Art. 6) – The Paris Agreement recognises the possibility of voluntary cooperation among Parties to allow for higher ambition and sets out principles – including environmental integrity, transparency and robust accounting – for any cooperation that involves internationally transferal of mitigation outcomes. It establishes a mechanism to contribute to the mitigation of GHG emissions and

support sustainable development, and defines a framework for non-market approaches to sustainable development.

PA6: Adaptation (Art. 7) – The Paris Agreement establishes a global goal on adaptation – of enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change in the context of the temperature goal of the Agreement. It aims to significantly strengthen national adaptation efforts, including through support and international cooperation. It recognises that adaptation is a global challenge faced by all. All Parties should engage in adaptation, including by formulating and implementing National Adaptation Plans, and should submit and periodically update an adaptation communication describing their priorities, needs, plans and actions. The adaptation efforts of developing countries should be recognised

PA7: Loss and damage (Art. 8) – The Paris Agreement recognises the importance of averting, minimising and addressing loss and damage associated with the adverse effects of climate change, including extreme weather events and slow onset events, and the role of sustainable development in reducing the risk of loss and damage. Parties are to enhance understanding, action and support, including through the Warsaw International Mechanism, on a cooperative and facilitative basis with respect to loss and damage associated with the adverse effects of climate change.

PA8: Finance, technology and capacity-building support (Art. 9, 10 and 11) – The Paris Agreement reaffirms the obligations of developed countries to support the efforts of developing country Parties to build clean, climate-resilient futures, while for the first time encouraging voluntary contributions by other Parties. Provision of resources should also aim to achieve a balance between adaptation and mitigation. In addition to reporting on finance already provided, developed country Parties commit to submit indicative information on future support every two years, including projected levels of public finance. The agreement also provides that the Financial Mechanism of the Convention, including the Green Climate Fund (GCF), shall serve the Agreement. International cooperation on climate-safe technology development and transfer and building capacity in the developing world are also strengthened: a technology framework is established under the Agreement and capacity-building activities will be strengthened through, inter alia, enhanced support for capacity building actions in developing country Parties and appropriate institutional arrangements. Climate change education, training as well as public awareness, participation and access to information (Art 12) is also to be enhanced under the Agreement.

PA9: Climate change education, training, public awareness, public participation and public access to information (Art 12) - is also to be enhanced under the Agreement.

PA10: Transparency (Art. 13), implementation and compliance (Art. 15) – The Paris Agreement relies on a robust transparency and accounting system to provide clarity on action and support by Parties, with flexibility for their differing capabilities of Parties. In addition to reporting information on mitigation, adaptation and support, the Agreement requires that the information submitted by each Party undergoes international technical expert review. The Agreement also includes a mechanism that will facilitate implementation and promote compliance in a non-adversarial and non-punitive manner and will report annually to the CMA.

PA11: Global Stock take (Art. 14) – A "global stock take", to take place in 2023 and every 5 years thereafter, will assess collective progress toward achieving the purpose of the Agreement in a comprehensive and facilitative manner. It will be based on the best available science and its long-term global goal. Its outcome will inform Parties in updating and enhancing their actions and support and enhancing international cooperation on climate action.

Priorities of Sendai framework

SF1: Understanding disaster risk: This priority emphasises the need to assess and understand the risks associated with various hazards. It involves collecting and analysing data, conducting risk assessments, and sharing knowledge to improve understanding of the causes, patterns, and impacts of disasters. By understanding risk factors, governments and organisations can develop effective policies and strategies to mitigate and manage these risks.

SF2: Strengthening disaster risk governance: This priority focuses on enhancing governance structures and institutions to promote effective disaster risk reduction. It involves developing and implementing policies, legislation, and plans that prioritise disaster risk reduction. This priority also emphasises the importance of multi-sectoral collaboration and coordination among government agencies, civil society organisations, and other stakeholders to ensure effective decision-making and implementation of risk reduction measures.

SF3: Investing in disaster risk reduction for resilience: This priority highlights the need for increased investments in disaster risk reduction measures. It emphasises that investing in prevention, preparedness, and resilience-building measures is more cost-effective than responding to and recovering from disasters. It calls for integrating risk reduction considerations into development planning, infrastructure development, and financial

mechanisms to build resilience at all levels, from local communities to national and regional levels.

SF4: Enhancing disaster preparedness for effective response and recovery: This priority underscores the importance of preparedness, response, and recovery capacities to manage disasters effectively. It involves developing early warning systems, emergency response plans, and mechanisms for rapid and effective coordination during emergencies. Additionally, it emphasises the importance of building the capacity of communities and institutions to recover and rebuild after disasters, promoting livelihoods, and restoring essential services.

Sustainable Development Goals

SDG1: No Poverty: End poverty in all its forms and dimensions, ensuring social protection systems and access to basic services for all.

SDG2: Zero Hunger: Achieve food security, improve nutrition, and promote sustainable agriculture to eliminate hunger and malnutrition.

SDG3: Good Health and Well-being: Ensure healthy lives and promote well-being for all at all ages, focusing on issues such as maternal and child health, infectious diseases, and access to healthcare services.

SDG4: Quality Education: Ensure inclusive and equitable quality education for all, promoting lifelong learning opportunities and improving literacy rates.

SDG5: Gender Equality: Achieve gender equality and empower all women and girls, eliminating discrimination and violence against women and girls.

SDG6: Clean Water and Sanitation: Ensure availability and sustainable management of water and sanitation for all, promoting access to safe drinking water and adequate sanitation facilities.

SDG7: Affordable and Clean Energy: Ensure access to affordable, reliable, sustainable, and modern energy for all, promoting the use of renewable energy sources and energy efficiency.

SDG8: Decent Work and Economic Growth: Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.

SDG9: Industry, Innovation, and Infrastructure: Build resilient infrastructure, promote inclusive and sustainable industrialisation, and foster innovation to support economic development.

SDG10: Reduced Inequalities: Reduce inequality within and among countries, ensuring equal opportunities for all and promoting social, economic, and political inclusion.

SDG11: Sustainable Cities and Communities: Make cities and human settlements inclusive, safe, resilient, and sustainable, promoting sustainable urbanisation and efficient resource management.

SDG12: Responsible Consumption and Production: Ensure sustainable consumption and production patterns, promoting resource efficiency, and reducing waste and pollution.

SDG13: Climate Action: Take urgent action to combat climate change and its impacts, including by mitigating greenhouse gas emissions and promoting adaptation measures.

SDG14: Life Below Water: Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.

SDG15: Life on Land: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt biodiversity loss, and promote ecosystem conservation.

SDG16: Peace, Justice, and Strong Institutions: Promote peaceful and inclusive societies, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels.

SDG17: Partnerships for the Goals: Strengthen the means of implementation and revitalise the global partnership for sustainable development through enhanced cooperation and collaboration among governments, organisations, and stakeholders.

5.3.1 Adaptation measures for physical assets

CCA Measure	**Alignment with PA**	**Alignment with SFDRR**	**Alignment with SDGs**
Consideration of anticipated loads in the designing of infrastructure	PA6	SF3	SDG11, SDG13,
Revision of the building codes, rule and regulations	PA6	SF2	SDG11, SDG13
Proper planning of evacuation routes	PA6	SF2	SDG11
Adopting tool for evaluating risk, vulnerability, exposure of infrastructure	PA6	SF1	SDG11

Risk informed infrastructure development	PA6	SF2	SDG9, SDG11
Creating maps of infrastructure assets, facilities	PA6	SF1	SDG11, SDG13, SDG17
Better land use planning with greener/nature-based solutions	PA4, PA6	SF2	SDG11, SDG13
Proper material design and integrating greener materials	PA3, PA6, PA8, PA11	SF3, SF4	SDG7, SDG9. SDG11
Proper storm water management techniques/Drainage system designs	PA6	SF1, SF2, SF3, SF4	SDG6, SDG11, SDG13
Considering safe engineering designs	PA6	SF2	SDG11
Using protective measures (e.g., Flood protection barriers)	PA6	SF4	SDG11
Infrastructure design to accommodate future modifications	PA1, PA6	SF2, SF3	SDG11, SDG13
Raising elevation of infrastructure	PA6	SF4	SDG11,
Implementation of method/techniques to predict the maintenance of the infrastructure	PA6	SF1	SDG9
Increasing and maintenance of longitudinal drains capacities	PA6	SF2	SDG6, SDG11
Implementation of proper monitoring of routine maintenance service	PA6, PA10	SF2	SDG9
Performing retrofitting, repair activities in deteriorated infrastructure	PA6	SF2	SDG9
Conducting risk assessment for infrastructure facilities and revising vulnerability and exposure maps	PA6	SF1	SDG11

5.3.2 Adaptation measures for social assets

CCA Measure	**Alignment with PA**	**Alignment with SFDRR**	**Alignment with SDGs**
Preparation in advance for food and medications, availability of safe water, assurance of accessible public health service during a post-disaster situation	PA6	SF1, SF3	SDG2, SDG3, SDG6
Increase the accessibility to MHEWs facilities	PA6	SF3	SDG17
Conducting safety drills and evacuation plans	PA6	SF4	
Implementing proper signboards	PA6	SF1	
Adopting new agricultural technologies to increase the productivity of the agriculture	PA3, PA6	SF1, SF3	SDG2, SDG12
Launch awareness programs on climate change for the public	PA6	SF1	SDG13
Promote climate-resilient building designs and revise building approval systems to increase the climate resilience	PA9	SF3	SDG13

5.3.3 Adaptation measures for economic assets

CCA Measure	**Alignment with PA**	**Alignment with SFDRR**	**Alignment with SDGs**
Introduce innovative risk transfer instruments	PA6	SF3	SDG1, SDG8, SDG13
Promote climate-proof infrastructure design practices	PA6, PA8	SF2, SF3	SDG 11, SDG13
Develop guidelines for economic activities in vulnerable areas	PA6	SF1, SF2, SF3, SF4	SDG11, SDG13

Identify adaptation actions suitable for respective industries	PA6	SF2	SDG11, SDG13
Increase the awareness of industrial operators on climate change and its impacts	PA6		SDG13
Increasing infrastructure protection measures	PA6	SF3	SDG11

5.3.4 Adaptation measures for environmental assets

CCA Measure	**Alignment with PA**	**Alignment with SFDRR**	**Alignment with SDGs**
Conduct research studies on climate change impact on ecosystems and biodiversity	PA6		SDG15
Establish a comprehensive program to monitor climate change impacts on key natural ecosystems and biodiversity	PA6	SF1	SDG13, SDG15
Prepare and implement adaptive management programs for climate-sensitive ecosystems	PA6	SF1	SDG13
Prepare and implement recovery plans for highly threatened ecosystems and species	PA4, PA6	SF1, SF3	SDG14, SDG15
Develop research institutes' capacity for conducting research on climate change impacts on ecosystems and biodiversity	PA6	SF1	SDG13, SDG15
Improve land use planning with nature-based solutions	PA1, PA4, PA6	SF1, SF3, SF4	SDG11, SDG13, SDG15

5.3.5 Governance and institutional measures for facilitate CCA

CCA Measure	**Alignment with PA**	**Alignment with SFDRR**	**Alignment with SDGs**
Strengthen the mechanisms for sharing information and data among stakeholders	PA6	SF1	SDG11, SDG17
Defining clear responsibilities and roles for stakeholders	PA10	SF2	SDG16
Improve information and data sharing among stakeholders	PA3, PA6, PA10	SF1, SF2, SF3, SF4	SDG4, SDG9, SDG11, SDG17
Undertake a review of relevant macro and sectoral policies, ordinances, acts, statutes and procedures to identify options for mainstreaming climate change adaptation activities	PA6	SF2	SDG13
Develop policy recommendations necessary for addressing vulnerability to impacts of climate change in all development /management projects	PA6	SF2	SDG13
Conduct training programs for government officers and private sector employees on climate change adaptation	PA6	SF2	SDG4, SDG13
Develop an inventory of international climate donors, funding schemes, training providers, training programs, research agencies/consortiums and events (conferences, seminars) for the benefit of local stakeholders of adaptation	PA8	SF2	SDG17
Establish a national network of research agencies and universities that are	PA6	SF1, SF2	SDG11, SDG17

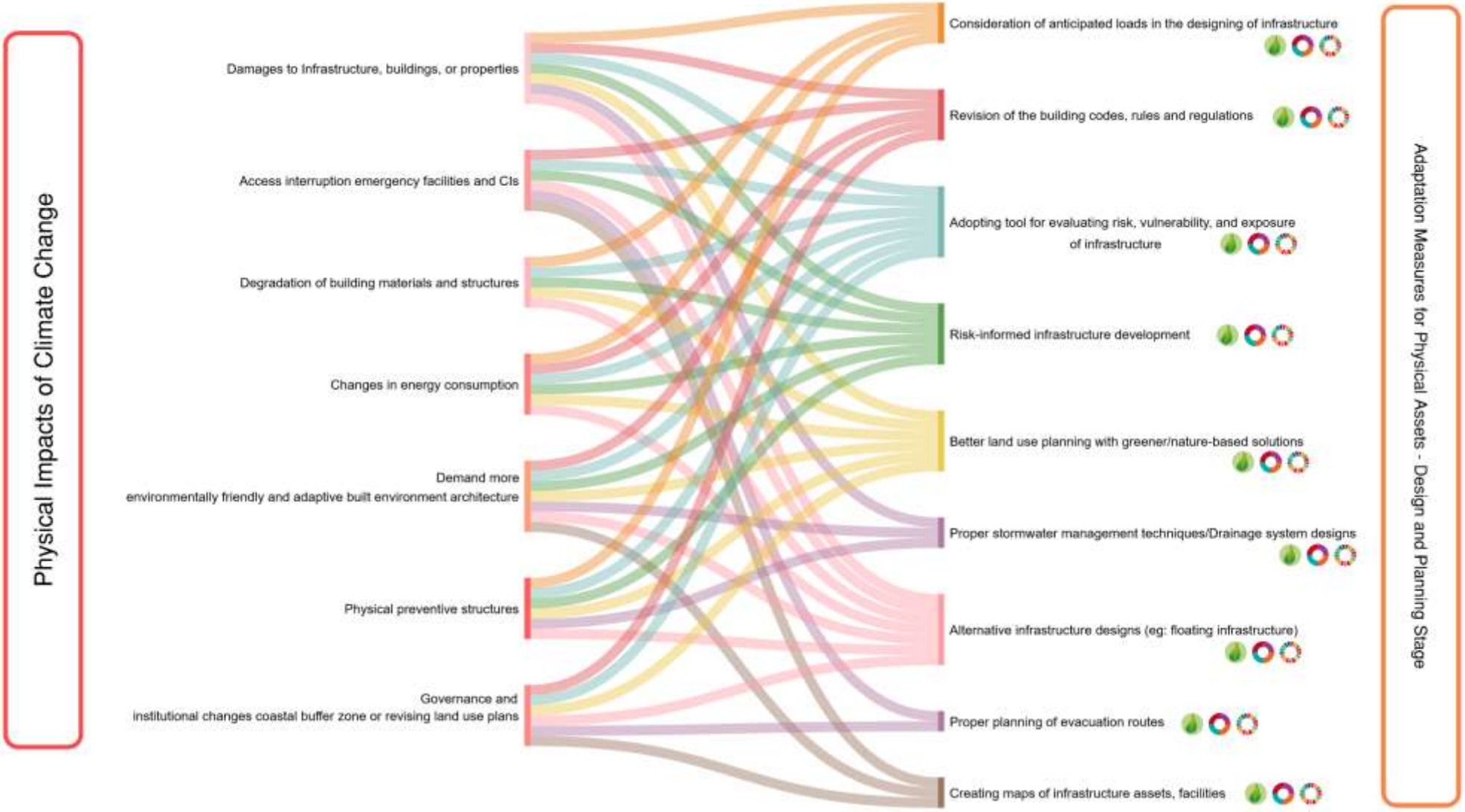
carrying out research on climate adaptation for promoting coordinated research and information dissemination			

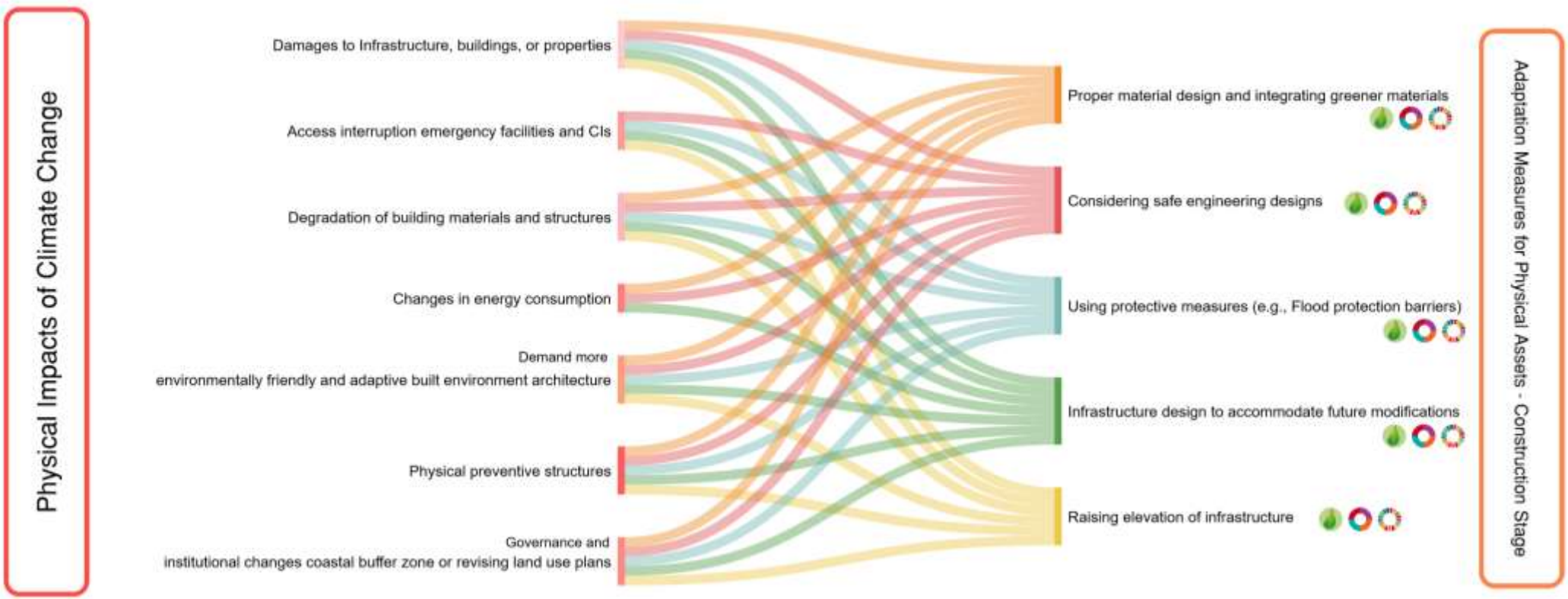
6 Finalised framework on adapting coastal built environment to the impacts of climate change

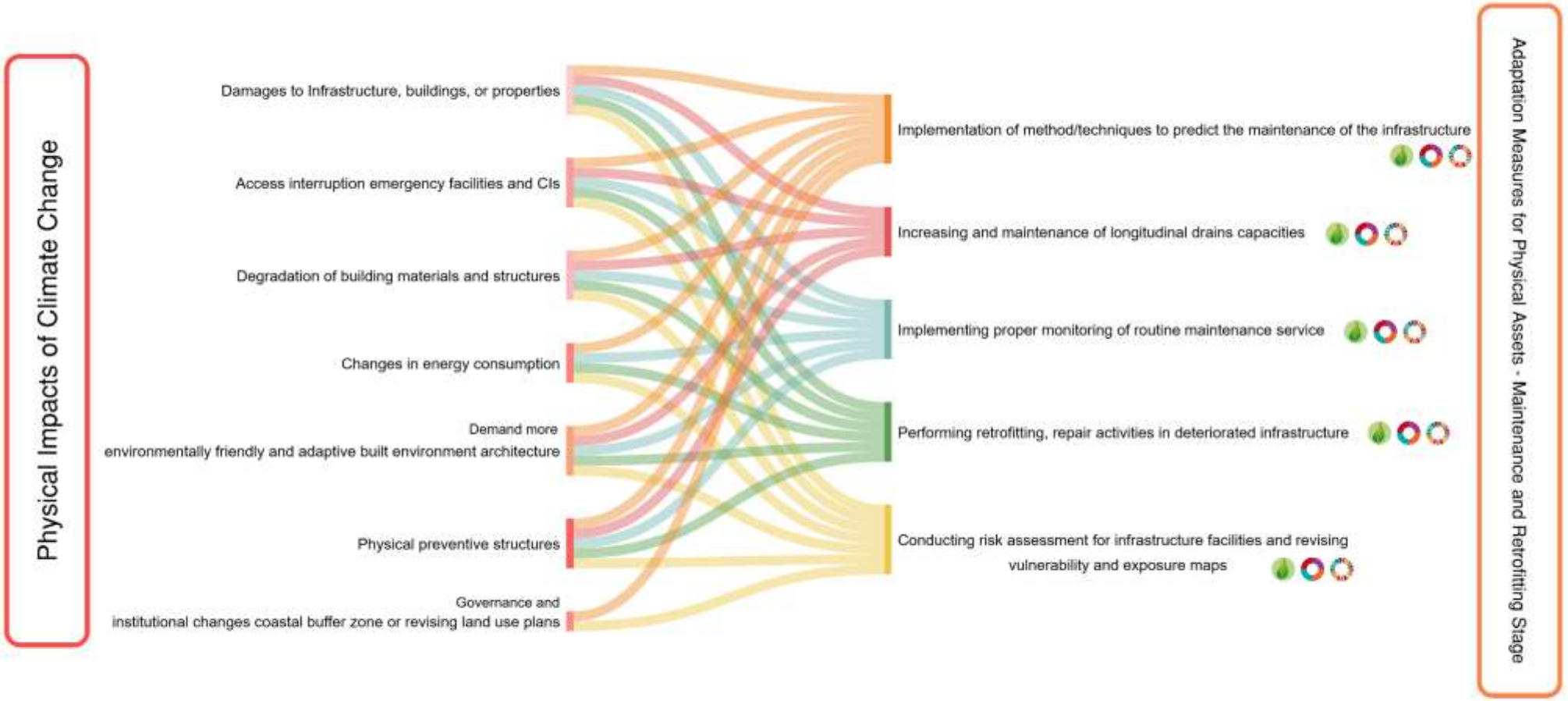
As developed and verified, the finalised framework is arranged in matter to show the applicable CCA measures for each category of climate change impacts identified in Output 01. For the physical impacts of climate change, the identified adaptation measures were divided based on the life cycle phase where the adaptation measures are applicable. The applicable adaptation measures for each category are linked with the climate change impacts. Also, the alignment of the adaptation measures was indicated with appropriate icons. The meaning of the icons is described below.

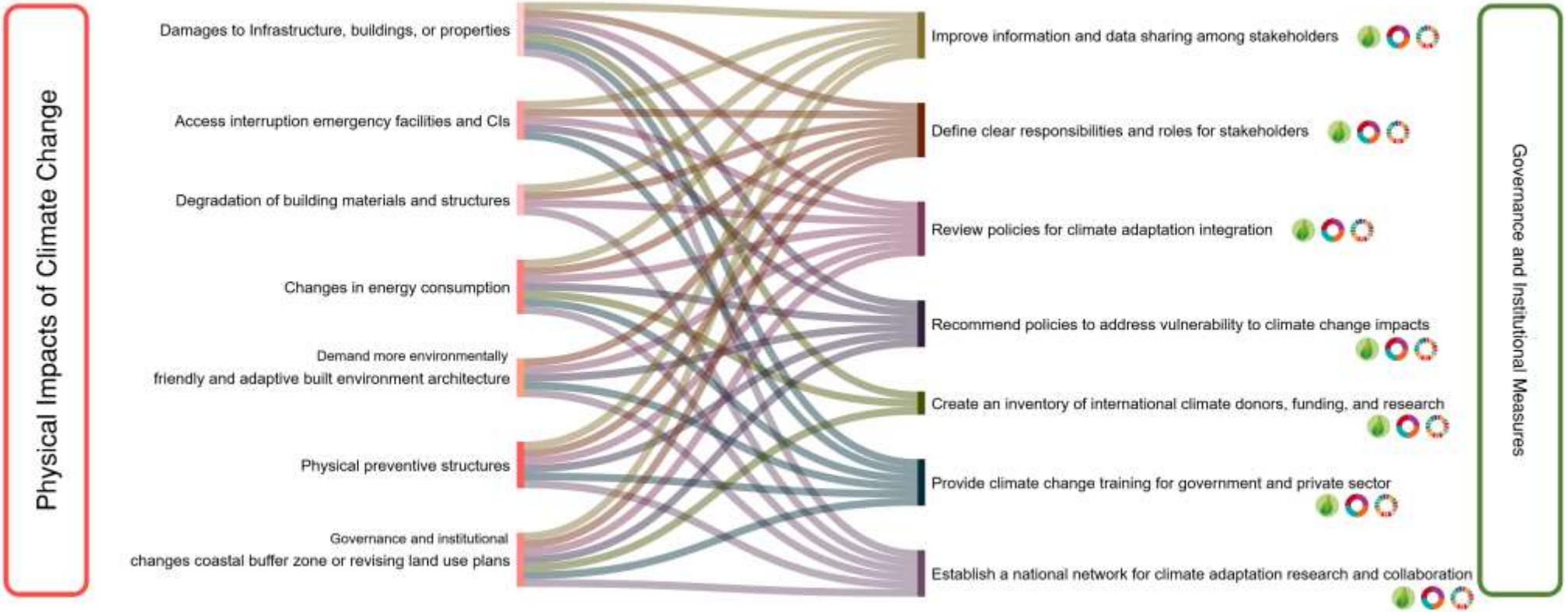
- Measure aligning with the Paris Agreement
- Measure aligning with the Sendai Framework for DRR
- Measure aligning with the Sustainable Development Goals

6.1 Applicable CCA measure for physical impacts of climate change and the alignment with the global agendas

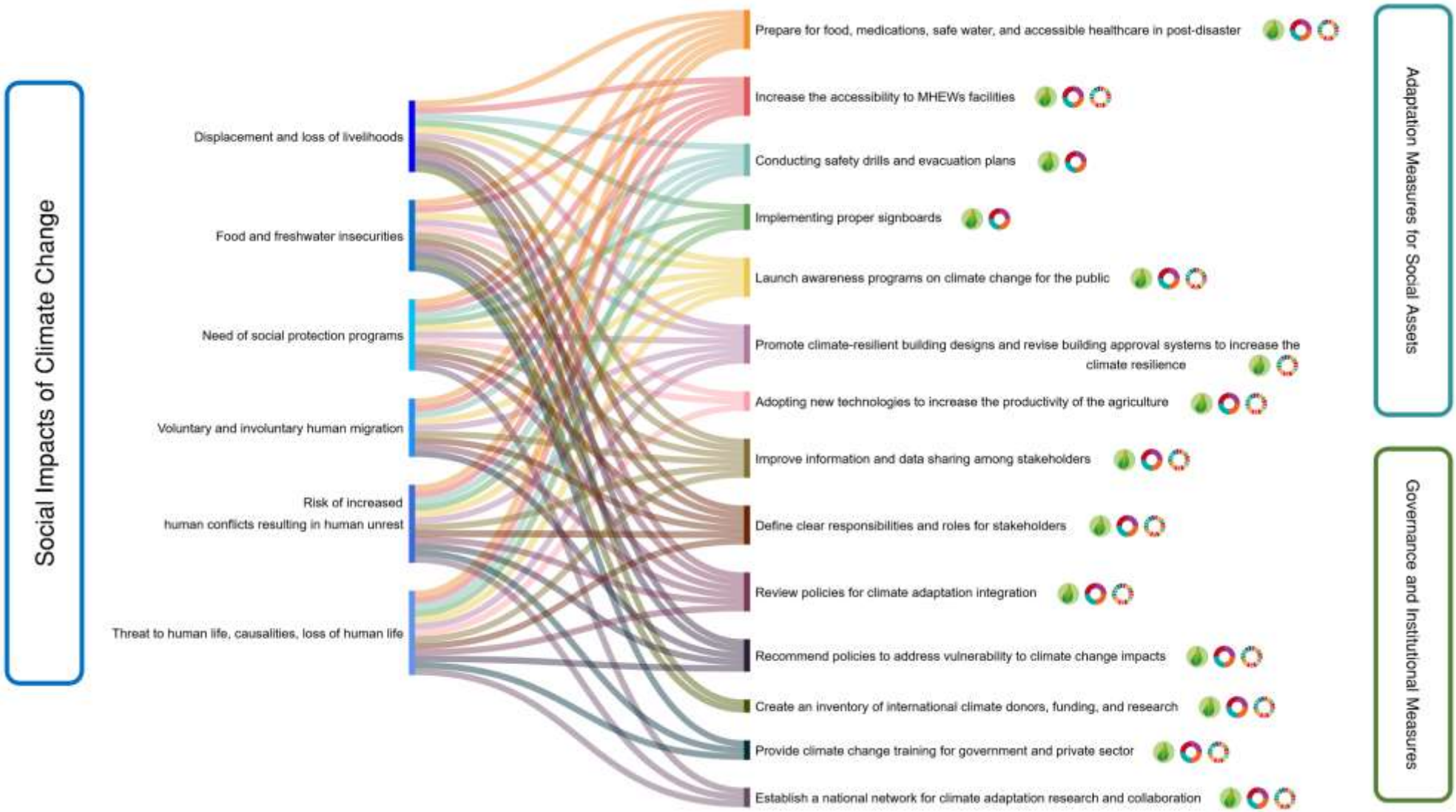



Physical Impacts of Climate Change
Damages to Infrastructure, buildings, or properties
Access interruption emergency facilities and CIs
Degradation of building materials and structures
Changes in energy consumption
Demand more
environmentally friendly and adaptive built environment architecture
Physical preventive structures
Governance and
institutional changes coastal buffer zone or revising land use plans
Proper material design and integrating greener materials
Considering safe engineering designs
Using protective measures (e.g., Flood protection barriers)
Infrastructure design to accommodate future modifications
Raising elevation of infrastructure
Adaptation Measures for Physical Assets - Construction Stage

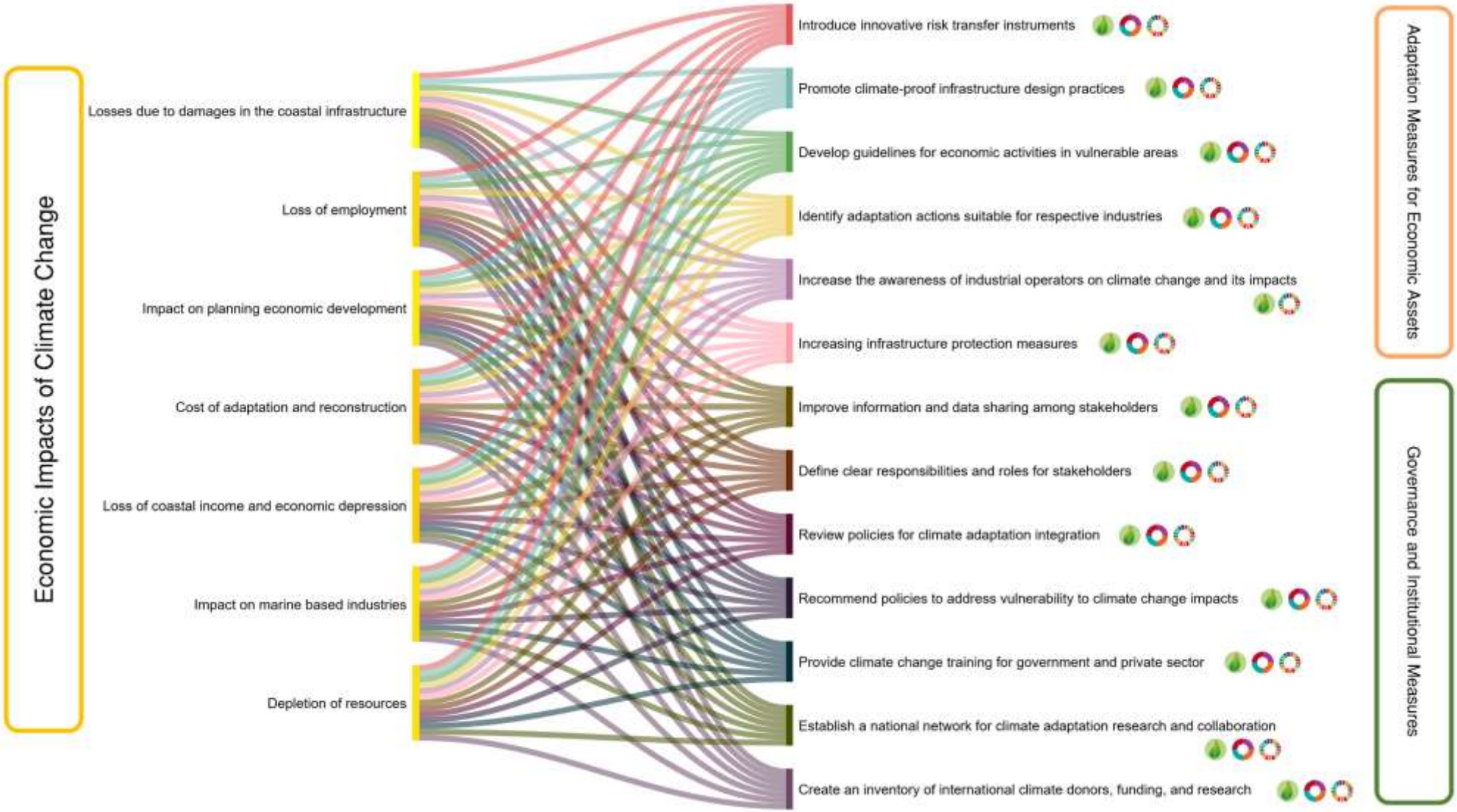

Physical Impacts of Climate Change
Damages to Infrastructure, buildings, or properties
Access interruption emergency facilities and CIs
Degradation of building materials and structures
Changes in energy consumption
Demand more environmentally friendly and adaptive built environment architecture
Physical preventive structures
Governance and institutional changes coastal buffer zone or revising land use plans
Implementation of method/techniques to predict the maintenance of the infrastructure
Increasing and maintenance of longitudinal drains capacities
Implementing proper monitoring of routine maintenance service
Performing retrofitting, repair activities in deteriorated infrastructure
Conducting risk assessment for infrastructure facilities and revising vulnerability and exposure maps
Adaptation Measures for Physical Assets - Maintenance and Retrofitting Stage


Physical Impacts of Climate Change
Damages to Infrastructure, buildings, or properties
Access interruption emergency facilities and CIs
Degradation of building materials and structures
Changes in energy consumption
Demand more environmentally friendly and adaptive built environment architecture
Physical preventive structures
Governance and institutional changes coastal buffer zone or revising land use plans
Improve information and data sharing among stakeholders
Define clear responsibilities and roles for stakeholders
Review policies for climate adaptation integration
Recommend policies to address vulnerability to climate change impacts
Create an inventory of international climate donors, funding, and research
Provide climate change training for government and private sector
Establish a national network for climate adaptation research and collaboration
Governance and Institutional Measures

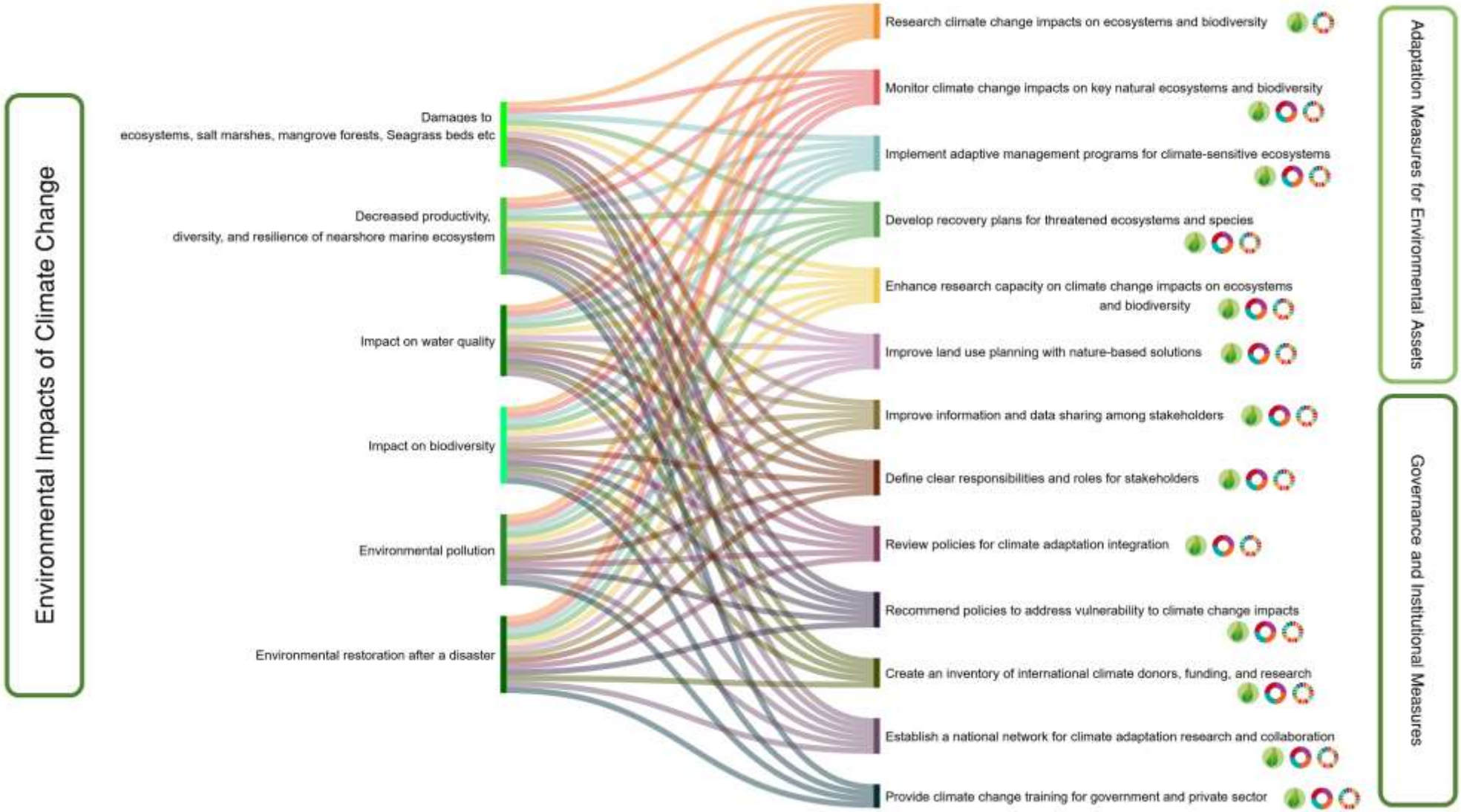
6.2 Applicable CCA measure for social impacts of climate change and the alignment with the global agendas



6.3 Applicable CCA measure for economic impacts of climate change and the alignment with the global agendas



6.4 Applicable CCA measures for environmental impacts of climate change and the alignment with the global agendas



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