GLOBAL CENTER ON ADAPTATION

WORKING PAPER: STOCKTAKE OF CLIMATE-RESILIENT INFRASTRUCTURE STANDARDS

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EXECUTIVE SUMMARY

Consistent standards, codes, guidance documents and rating systems (collectively "standards") underpin efforts to ensure that infrastructure is resilient to climate change.

There is now a critical window of opportunity for mainstreaming climate resilience into standards, building on the progress that has already been made. Achieving significant integration will require the collaboration of a broad range of stakeholders, from international and national organizations to citizens, from public and private financial institutions to academia.

This report for discussion is intended to catalyse mainstreaming by providing a stock take of the ways in which existing standards consider climate risks, resilience and adaptation. Five recommendations (Figure 1) to strengthen the enabling environment for climate-resilient infrastructure are the outcome of this analysis.

GENERAL Recommendation 1

Establish a common approach to the infrastructure lifecycle and typology of standards, accelerating the uptake of climate-resilient infrastructure.

PLANNING Recommendation 2

Develop guidance to increase the understanding of physical climate risks, enabling the planning of infrastructure systems that consider the uncertainty of current and future scenarios.

PLANNING Recommendation 3

Promote the use of systems approaches to infrastructure planning upstream into decision-making to help develop a pipeline of climate-resilient projects.

DELIVERY Recommendation 4

Promote adaptation and resilience measures for infrastructure in the procurement of assets and services.

MANAGEMENT Recommendation 5

Quantitatively track the results achieved by infrastructure in enhancing climate resilience to make the business case for investment and showcase good practices.

Figure 1 – Recommendations to make climate-resilient infrastructure the norm.

PLANNING	DELIVERY	MANAGEMENT
Recommendation 2: Develop guidance to increase the understanding of physical climate risks, enabling the planning of infrastructure systems that consider the uncertainty of current and future scenarios. **Recommendation 3:** Promote the use of systems approaches to infrastructure planning upstream into decision-making to help develop a pipeline of climate-resilient projects.	**Recommendation 4:** Promote adaptation and resilience measures for infrastructure in the procurement of assets and services.	**Recommendation 5**: Quantitatively track the results achieved by infrastructure in enhancing climate resilience to make the business case for investment and showcase good practices.

Recommendation 1: Establish a common approach to the infrastructure lifecycle and typology of standards, accelerating the uptake of climate-resilient infrastructure.

INTRODUCTION

Infrastructure systems urgently need to be made more resilient to the physical impacts of climate change. By considering resilience at the outset, there is an opportunity to strengthen people's resilience to climate impacts through infrastructure, rather than risking locking in vulnerability for decades to come.

Climate-resilient infrastructure is defined in this report as being infrastructure that is "(…) planned, designed, built and operated in a way that anticipates, prepares for, and adapts to changing climate conditions. It can also withstand, respond to, and recover rapidly from disruptions caused by these climate conditions" (OECD, 2018, p.4).

In order to accelerate action in climate change adaptation, the Global Center on Adaptation is taking forward the work of the Global Commission on Adaptation. In the Climate Change Summit in September 2019, the Commission released a flagship report ('Adapt now: a global call for leadership on climate resilience') calling for action on adaptation in eight Action Tracks.

The Infrastructure Action Track is led by Cora van Nieuwenhuizen (Minister of Infrastructure and Water Management of the Netherlands), and Shemara Wikramanayake (CEO of Macquarie).

The three objectives of the Infrastructure Action Track are to:

- Raise standards for climate-resilient investment, initially through a stocktaking of approaches, metrics and processes;
- Strengthen the resilience of infrastructure systems, by encouraging systems-based approaches and stress tests to understand and manage the impacts of climate change on infrastructure;
- Mobilize finance for climate-resilient infrastructure projects, particularly through demonstrating the benefits of incorporating resilience into investments and developing a knowledge module in Public-Private Partnerships (PPPs).

Standards have an essential role in underpinning progress towards strengthening the resilience of infrastructure systems and mobilizing finance. They can provide the necessary criteria and guidance to evaluate a project in terms of resilience, adaptation and climate risks throughout the lifecycle of the infrastructure. By integrating with the needs of the different stakeholders – as users and developers of standards – there is the potential to achieve greater coherence over time.

This study takes a broad definition of standards, including codes, guidance documents and rating systems, both voluntary and mandatory. It explores the metrics that can be applied to one or more phases of the infrastructure lifecycle and that are used by different stakeholders. Section 1 defines climate-resilient infrastructure, the main physical risks and the infrastructure lifecycle. Section 2 presents how different stakeholders relate to the use of standards. Section 3 analyses existing standards, codes, guidance documents and rating systems to identify how they incorporate climate risks, resilience and adaptation. Lastly, Section 4 concludes with an overview of the gaps of analysis and window of opportunity to ensure new and existing infrastructure is climate-resilient.

This report is a contribution of the GCA to the Global Commission on Adaptation's Infrastructure Action Track to make climate-resilient infrastructure the norm rather than an exceptional best practice. It has been produced to stimulate discussion, having been discussed and reviewed in consultation with practitioners and experts in the lead-up to the Climate Adaptation Summit on 25 January 2021.

1. DEFINING CLIMATE-RESILIENT INFRASTRUCTURE

Infrastructure systems are heavily affected by the physical impacts of climate change, and these impacts are becoming increasingly severe. To minimize direct and indirect losses caused by disruption in those networks, it is essential to ensure that infrastructure is resilient to climate impacts (OECD, 2018). This requires taking action – in terms of the location, design and management of infrastructure – to achieve an acceptable level of risks. This encompasses society, the environment and asset owners over the infrastructure's lifecycle.

The acceptable level of risk is inherently context specific: it depends on factors including the degree of exposure and sensitivity to climate hazards, the impacts of failure, the costs of risk reduction and the ability to adapt. It also requires making decisions in the face of uncertainty, given that our knowledge on climate models and scenarios is constantly evolving.

Standards can assist this process in various ways: they can outline a systematic process for identifying and managing risks on a case-by-case basis. Alternatively, they set technical and/or management norms that achieve a good outcome in most circumstances – such as ensuring an additional operating margin or safety of construction.

However, this will only happen if standards have been informed by the concepts of climate risks, resilience and adaptation to climate change. These include uncertainty about current and future climatic conditions, the ability of infrastructure systems to withstand shocks and stresses, and their capacity to adjust to new conditions and reduce the vulnerability to natural hazards.

There is strong urgency to achieve this given the pace and scale of infrastructure investments. USD 80 trillion will be needed for infrastructure projects by 2030 (Bhattacharya et al., 2016). The investments will determine our future path: tackling climate risks to sustainably grow and prosper or locking in development and wasting resources on inadequate infrastructure (Rydge, Jacobs and Granoff, 2015).

For the purpose of this report, infrastructure is understood through a systems approach, considering the interconnections between systems, assets and equipment in all sectors (e.g., water, transport, energy, etc.). In addition, given the sectoral specificity of existing standards and the need for a common, broad approach, the infrastructure lifecycle prescribed is composed by three stages: planning, delivery and management.

This section explores the normative question of what it means for infrastructure to be resilient to climate change, the implications of not developing appropriate standards for climate resilience and it argues the need to incorporate climate risks, resilience and adaptation into the infrastructure lifecycle.

1.1. Impact of physical risks on infrastructure

The climate is changing at unprecedented rate: sea level rise, floods, droughts, heat waves, earthquakes, landslides and many other climate-related events have been increasing in frequency and intensity. The "near-term impacts of climate change add up to a planetary emergency that will include loss of life, social and geopolitical tensions and negative economic impacts" (WEF, 2020).

According to the Global Risk Report 2020, Climate Change is one of the biggest risks in terms of likelihood of occurrence and severity. Anthropogenic actions are expected to raise temperature by 1.5°C between 2030 and 2052, increasing the risks to health, livelihoods, food security, water supply, human, security, and economy growth (IPCC, 2018).

Climate change will increase meteorological, hydrological and climatological risks to infrastructure. Meteorological risks result from short-term extreme weather or atmospheric conditions at the micro- or meso-scale, such as extreme heat events and storms. Hydrological risks result from the movement, distribution and occurrence of (sub)surface fresh or saltwater, which can be floods, landslides and tsunamis.

Climatological hazards result from long-term atmospheric processes, at meso- to macro-scale, that can be intra-seasonal or multi-year climate variation, like drought and wildfires.

Those risks are experienced throughout the world, but regions differ widely in their capacity to invest and recover from them. For example, a report of the major natural catastrophes in 2017 (Munich RE, 2018) showed that the overall losses accounted for $340 billion – the majority from meteorological events – and that Africa, South America and Asia have the largest insurance gaps (**Figure 2**).

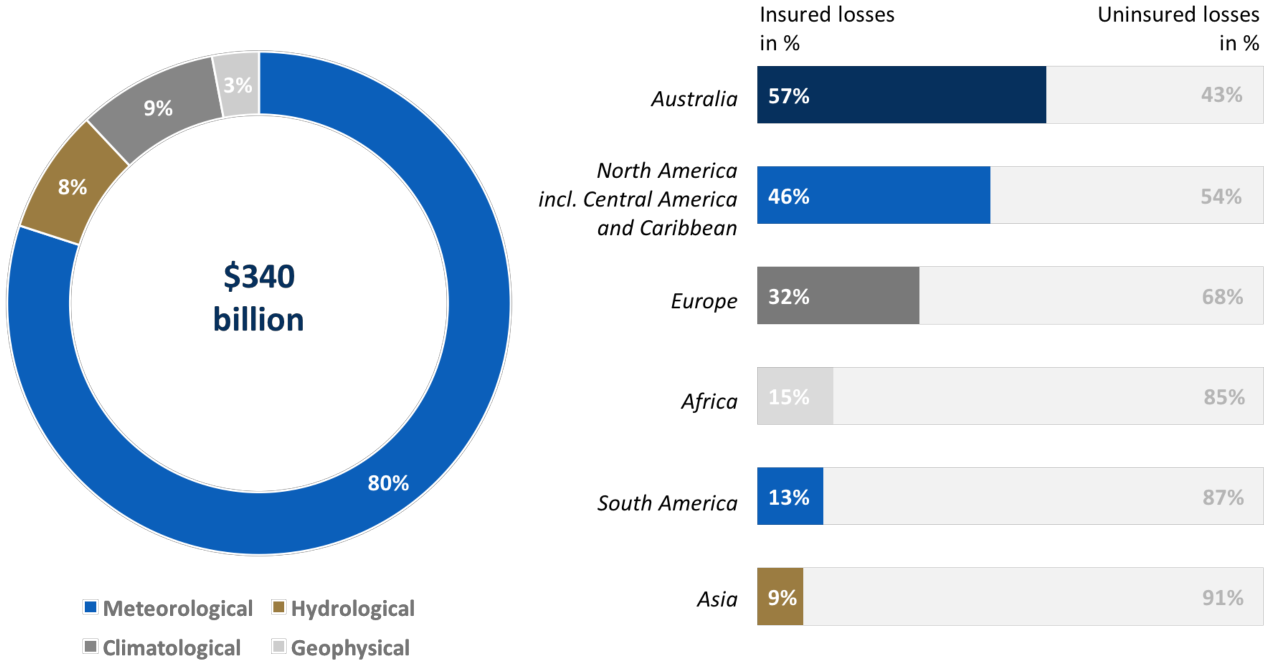
For infrastructure, ageing assets, increasing demand, gap of investment and development of 'shovel-ready' projects exacerbate the physical risks of climate change. **Table 1** illustrates how those impacts can translate into risks for infrastructure systems.

To achieve and maintain sustainable development, infrastructure systems need to be prepared for and withstand climate change impacts (Mogelgaard et al., 2019). Yet, in order to do so it is necessary to have a better comprehension of the magnitude and probability of occurrence of those risks. This is a challenging task because of data gaps, and uncertainties in projecting future impacts – particularly when looking at high spatial resolutions.

Figure 2 – Summary of losses and insurance gaps of natural catastrophes in 2017.

(a) Percentage of losses per natural hazard

(b) (Un)insured losses in percentage.



Source: adapted from Munich RE (2018).

Table 1 – Overview of climate change impacts to infrastructure sectors

Sector	Potential impacts per type of natural hazard		
	Meteorological (e.g., extreme heat and storms)	Hydrological (e.g., floods, landslides and tsunamis)	Climatological (e.g., droughts and wildfires)
Water	• Need for more water treatment; • Higher evaporation loss, mainly on reservoirs; • Physical damages to assets (e.g., treatment plants).	• More risk of overtopping river embankments; • Overwhelming drainage systems.	• Need for higher storage capacity; • Disruptions to the supply due to water scarcity.
Transport	• Buckle of railway lines; • Physical damages to assets (e.g., bridges); • Disruption of port and airport services.	• Inundation events of coastal infrastructure (e.g., ports, roads and railways); • Disruptions due to floods or higher water levels in water ways.	• Disruptions due to lower levels in water ways.
Energy	• Power outages or reduced output from power plants; • Physical damages to assets (e.g., wind farms and distribution networks).	• Inundation events of coastal infrastructure (e.g., generation, transmission and distribution); • Disruptions in the supply of energy.	• Lack of cooling water (e.g., thermal plants).
ICT	• Higher demand for cooling (e.g., datacenters); • Physical damages to above ground transmission (e.g., radio masts).	• Inundation events of coastal infrastructure (e.g., telephone exchanges).	• Damages due to subsidence of infrastructure.

Source: adapted from OECD (2018).

1.2. Resilience to climate change

Resilience is an essential factor to ensure the functionality of (critical) infrastructure systems. As a starting point, the components of the system (e.g., individual assets, such as a road or a bridge) need to be robust. The resilience of those individual components is usually understood to represent the ability of an infrastructure to restore its function following an external disturbance. However, the system as a whole has to be sufficiently resilient to continue functioning and operate at – or close to – normal conditions in the face of shocks and stresses (Gallego-Lopez and Essex, 2016).

Although not explicitly stated in the definition of climate-resilient infrastructure adopted (see Introduction), the perspective on resilience has to be long term and it has to account for uncertainty about the future. Infrastructure consists of long-lived assets, which need to be able to perform well across a range of different climate scenarios.

Standards are an essential for incorporating climate resilience into infrastructure projects, but they have generally not been developed with that purpose. Climatic and weather conditions (e.g., temperature, precipitation, and wind) and extreme events (e.g., floods and freeze-thaw cycles) may be included in standards, yet they are not necessarily established under the assumption of uncertain and changing climate scenarios (SCC, 2019).

Historic data is often used to set standards but these will provide an increasingly unreliable guide to the future as climate change becomes more severe. Events that used to occur every 1 in 100 years may become 1 in 10 year events due to climate change. To effectively address climate resilience, relevant standards should consider scenarios of climate risks that might be experienced over the entire lifecycle of the infrastructure – for example, including longer return periods and quality thresholds to increase the safety margins of the technical requirements of a project.

1.3. Infrastructure lifecycle

The definition of climate-resilient infrastructure emphasizes the importance of considering the entire asset lifecycle. Infrastructure projects can have a lifespan of 70+ years, in some cases. Consequently, considerations made at early stages of the project development will be felt mainly after the asset is built and operating. This makes the case for ensuring new infrastructure, including individual components and systems, will not lock-in vulnerability but rather incorporate adaptation measures, climate change impacts, and resilience throughout. It can also mean retrofitting existing infrastructure to incorporate wider climate-resilient measures.

As proposed by the Capacity Assessment Tool for Infrastructure (CAT-I) developed by the United Nations Office for Project Services (UNOPS), the infrastructure lifecycle can be divided into three macro stages: planning, delivery, and management (UNOPS, 2018). Linking those stages to the development of a project in the context of Public-Private Partnerships (PPPs), based in the PPP Knowledge Lab Platform from the Public-Private Infrastructure Advisory Facility of the World Bank Group (PPIAF), the phases of the infrastructure development can be described as:

- Planning: this phase is composed by the strategies, plans, policies that will guide infrastructure planning in alignment with international, national and local development goals, including the climate agenda. The strategies, plans, policies and other instruments can be understood as the enabling environment for infrastructure planning at the upstream level. It also encompasses the development of investment pipelines that will enable the implementation of infrastructure through public and private capital to attend the current and future needs.

- Delivery: includes the process of design, planning, procurement, and construction of the infrastructure project. The design involves an initial conceptualization of outputs required for construction; procurement refers to type of investment made (e.g., traditional public procurement or through Public-Private Partnerships), the process of contracting a party to deliver the infrastructure and other resources that are going to be used; construction involves building the asset and installing the necessary equipment for the operations stage.

- Management: climate change needs to be considered throughout the operation, maintenance and decommissioning phases of infrastructure assets. 'Operation' refers to the use of the services provided by that asset, 'maintenance' to the adequate operating levels and conditions of the assets and equipment, and the 'decommissioning' and hand-back strategy the closure of function of the asset at the end of its lifetime. Throughout this process, contract management is a key underlying activity that ensures compliance of the parties involved and the achievement of the output specifications.

This approach addresses the need for an overview of how standards can be applied across the infrastructure lifecycle. Standards are characterized by variability across projects and/or sectors and such an approach provides a common basis of understanding for different stakeholders and the role they play (further detailed in Section 2.1). The purpose was not having granularity in terms of existing standards in each sub-stage of the lifecycle, but rather to identify overall knowledge gaps and relate to the main practical challenges faced by stakeholders, developing a paper that talks to this broad audience to show the benefits of climate-resilient infrastructure standards. More detailed analysis could be explored in further publications.

The division in those three main stages – planning, delivery and management – is going to guide the analysis, understanding the role of stakeholders and use of standards for climate-resilient infrastructure.

2. IDENTIFYING KEY STAKEHOLDERS FOR INFRASTRUCTURE PROJECTS

Increased collaboration is needed between government, investors, developers and users to achieve resilient infrastructure systems (Gallego-Lopez and Essex, 2016). Bringing all relevant stakeholders together can help to achieve cost reduction over the asset lifetime, optimize the interlinkages between infrastructure systems, and adaptation co-benefits to a changing climate. Collaboration can also promote innovative approaches for financing resilient projects, identify synergies in the development of different systems, and recognize the vulnerability to natural hazards – to not forget addressing the responsibilities and interests of each player in this agenda.

This section explores the role of different stakeholders in determining and using standards, how they are applied in the project lifecycle, what are the levels or boundaries of analysis of an infrastructure system and which sectors are prioritized.

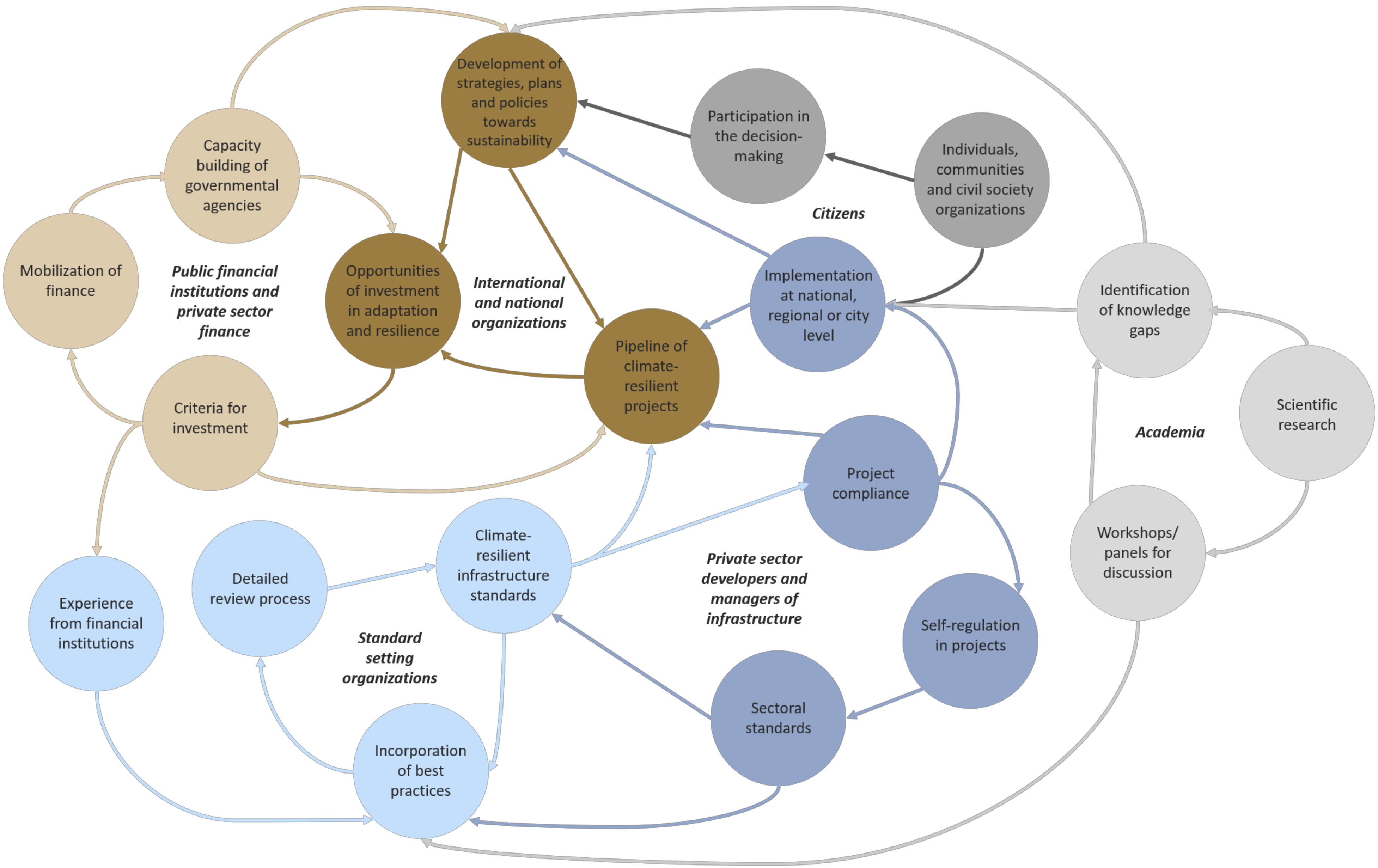
2.1. Main stakeholders and roles

A broad range of stakeholders are involved in the planning, delivery and management of infrastructure. Each has a different role to play in adopting or developing standards related to climate-resilient infrastructure.

The following groups of stakeholders are considered in this report: international and national organizations, public financial institutions, standard setting organizations, private sector organizations, academia, and citizens – the latter also seen as users of the infrastructure. It has to be recognized that this is a broad clustering, as the groups themselves are not homogeneous – for example, private sector can range from small companies to large multinationals, and from utilities to financial institutions. Nonetheless, this division enables a general perspective of how different actors interact with each other in developing and implementing climate-resilient infrastructure. **Figure 3** illustrates the main interlinkages between those various players. The connections (arrows) represent the direction of influence between two elements (circles), and a group of interconnected elements constitutes a loop.

It is possible to visualize that some elements in the systems map have a higher number of connections than others. Particularly, the 'Development of strategies, plans and policies towards sustainability', 'Pipeline of climate-resilient projects', and 'Implementation at the national, regional or city level' are the ones with the highest number of connections. This means that they are points where the system is concentrated, and which have a direct or indirect influence from the majority of stakeholders mapped – it also indicates they can be seen as leverage points, with the biggest possibility of impact in the system.

Figure 3 - Summary of relationships among stakeholders in developing climate-resilient infrastructure.



Source: authors.

Overall, the agenda on climate-resilient infrastructure standards would be supported if collaborative actions are taken by stakeholders in each loop. This would allow better designed standards and more effective implementation from the outset in infrastructure planning. A positive improvement in one element can promote co-benefits in another, thus promoting co-benefits that will positively reinforce all the loops in the system.

As previously mentioned, the different groups of stakeholders can play distinct roles in the development or application of standards – in all its types (standards, codes, guidance documents and rating systems). Those roles also relate to the stages of infrastructure lifecycle, as one actor might be involved in more than one process.

There are six main functions the different stakeholders can assume during the infrastructure lifecycle: financiers, owners, developers, managers, regulators, and users. They are described in more detail as follows, noting types of organizations included in each constituency, how they can contribute to the climate-resilient infrastructure agenda, and also examples of good practices and/or involvement in this context.

- Financiers

This group includes governmental bodies (e.g., Ministries of Environment, Planning and Finance), public and private financial institutions (e.g., International Finance Institutions (IFIs), Multilateral Development Banks (MDBs), insurance companies and asset managements), and international and national organizations (e.g., philanthropic institutions).

They are fundamental in providing capital, developing project pipelines, financing greenfield projects and assuming the risk of infrastructure investment (OECD, 2018). In this context, standards can be used by this group in the screening and selection of projects, to better understand their exposure to physical climate risks. Ultimately, standards could encourage capital flows for more resilience investments.

Financial institutions' objectives vary: profit maximization is a key objective in the private sector, while public institutions may pursue a broader range of objectives. Based on countries' development, public financial institutions can provide the necessary guidance and build capacity of officials to develop projects that account for climate risks under uncertain scenarios, and improving the conditions for loans and grants that will determine the selected projects (Barlett, 2019)

Financiers have been particularly influential in the development of more socially and/or environmentally conscious investment approaches. By enhancing resilience through their business operations, a contribution is made to broader policy objectives of sustainable development. However, it is important to consider that different institutions set different return periods for their investments which, for infrastructure projects, can mean that traditional investments do not correspond to the asset lifetime.

Examples of improved guidance for investments include the 'Principles for Climate Resilience Metrics' (IDB, 2019). This was developed in a joint effort between several MDBs and the International Development Finance Club (IDFC) in 2019. It is characterized as a logical model and results chain, which proposes a set of metrics to analyze investments considering the quality of project design (diagnosis, inputs and activities) and the project results (outputs, outcomes and impacts).

- Owners and Managers

This group includes mainly governmental bodies (e.g., Ministries of Environment, Planning and Finance), public and private financial institutions (e.g., national banks and MDBs) and private sector owners (e.g., asset managers, utilities).

As owners or managers of the infrastructure assets and networks, including the legal ownership of the land, the objective is generally to ensure that their assets can meet the regulatory requirements and provide the needed services, while minimizing costs (for public owners) or maximizing profits (for private owners). Throughout the contract term the infrastructure should ensure the provision of services under normal circumstances and under shocks and stresses. Furthermore, owners and managers of infrastructure, mainly governmental bodies, play an important role in determining the enabling environment for infrastructure planning. In this context, standards can be used to ensure the technical quality of the project, as well as to incorporate climate risks, resilience and adaptation measure in the planning, delivery and management of the infrastructure if requested.

Given that those actors can also perform the functions of financiers, developers or regulators, it was chosen to not present the best practices here.

- Developers

This group includes stakeholders with direct and indirect influence in the development of infrastructure. The private sector (e.g., asset managements and constructions companies) has a direct influence, while professional associations (e.g., Engineering Associations), academic institutions (e.g., universities and research institutions), and civil society (e.g., individuals or non-governmental organizations (NGOs)) usually have an indirect influence.

As developers who have a direct influence in infrastructure, their objective is to ensure project compliance during its implementation. That can be related to technical and managerial standards required by legislations and regulations, as well as criteria from financiers when applicable, to ensure the financial feasibility and profit maximization of the project. It is also observed if the asset fulfils the output specifications of the contract, ensuring the agreed quality and performance levels within the contract period.

Those actors can proactively choose to account for climate change impacts to safeguard the project if hazard events are likely to provoke disruptions in the asset or service. Sustainability, resilience and adaptation measures are thus incorporated into the project to enhance economic, environmental and social benefits.

Stakeholders with an indirect influence can also support the integration of climate-resilience. Professional associations and peer-to-peer supporting organizations can share their expertise to promote sectoral standards to be used by developers and managers. Although voluntary, there may be a significant influence to adopt such measures by sectoral associations themselves. For example, the Leadership in Energy and Environmental Design (LEED) Certification developed by the United States Green Building Council (USGBC), is a rating system for green buildings (e.g., hospitals, schools, and data centers) that can be applied to new and existing facilities (USGBC, 2020).

Two significant initiatives are SuRe® (GIB, 2017) and Envision (ISI, 2015), rating systems that aim to integrate sustainability and resilience metrics throughout the lifecycle of infrastructure projects. The first was developed by Global Infrastructure Basel (GIB), a Swiss foundation. It consists of three dimensions (environment, governance, and society), divided in 14 themes and 61 criteria, some of them being defined as 'Safeguarding Red Criteria' and obligatory to be achieved. The second was developed by the Zofnass Program for Sustainable Infrastructure at Harvard University, an academic institution, and the Institute for Sustainable Infrastructure (ISI), a non-profit professional organization. It includes 60 indicators that are divided in five categories (quality of life, leadership, resource allocation, natural world, and climate risk), with requirements from the definition and achievement of outcomes.

Lastly, the development and management of infrastructure systems can be enhanced by engaging with NGOs, citizens and taking into account the impacts on the most vulnerable groups. Gallego-Lopez and Essex (2016) explain that, especially in the cases where sub-national budget is allocated to improve infrastructure, the involvement of communities in the consultation processes ensured the consideration of critical local needs and thus optimized the investment made to also improve their livelihoods.

- Regulators

Similar to the previous group, stakeholders can have a direct or indirect influence as regulators. This group includes governmental bodies and agents (e.g., Ministries and politicians) and international and national organizations (e.g., intergovernmental organizations) that have a direct influence in determining the enabling environment of infrastructure projects. Beyond this, an indirect influence is exercised by professional associations (e.g., Engineering Associations), academic institutions (e.g., universities and research institutions), and civil society (e.g., individuals or NGOs).

Legislation, regulations and guidance principles are established to guide infrastructure upstream and downstream. If aligned to international policies and agreements, national plans, and local strategies, these can provide an opportunity to explore synergies and draw attention to climate-resilient infrastructure. However, for this to be achieved, it is necessary that the enabling environment facilitates the identification and assessment of climate risks, build resilience, and promote adaptation measures to changing and uncertain climate conditions.

Relevant instruments include National Adaptation Plans (NAPs) and Nationally Determined Contributions (NDCs) and the G20's 'Principles for Quality Infrastructure Investment'. Meanwhile, the Sustainable Development Goals provide an overarching framework for this work.

More specifically, SDG 9 and SDG 11 proposed targets directly related to climate-resilient infrastructure – promoting sustainable and resilient infrastructure across borders, sustainable transport, green and public spaces, and reducing the impact of disasters, to name a few (UN, 2016).

Among international and national organizations, regulatory and legislative institutions, standards setting organizations and professional bodies have a significant role in determining standards for climate-resilient infrastructure. They can foster the inclusion of climate risks and adaptation through appraisal of infrastructure systems (such as Strategic and Environmental Impacts Assessments) and developing standards for the reliability of services and quality of resources. In the last case, when regulated by law, standards are known as technical codes – such as the Eurocodes (EC, 2007) and the International Building Code (ICC, 2018).

Other typologies include guidance documents and standards. From the first example, the European Committee for Standardization (CEN) and for Electrotechnical Standardization (CENELEC) developed the Guide 32 to address climate adaptation in standards. From the second, the International Standard Organization (ISO) developed and is developing several standards that include adaptation to climate change risks and resilience, such as the ISO 37123:2019 and the ISO/DIS 14091.

Academia is also playing a leading role in supporting regulation, for instance, in the assessment of infrastructure systems. That is the case of the National Infrastructure System Model (NISMOD) developed by the UK Infrastructure Transitions Consortium (ITRC), University of Oxford Environmental Change Institute (ECI) and other academic partners (ITRC, n.d.). This approach was applied in 2018 for the UK's first National Infrastructure Assessment (NIA) that planned for 10-30 years of actions in infrastructure systems (NIC, 2018).

- Users

This group include governmental bodies (e.g., Ministries of Health and Education), academic institutions (e.g., schools and universities), and civil society (e.g., individuals and NGOs).

As users of an infrastructure and its assets, the main concern is having access to good quality, reliable and cost-effective infrastructure services. Nonetheless, especially for civil society, the project should also improve the livelihood of individuals in the area affected, protect the natural environment, and reduce existing vulnerabilities – it is not just about providing an infrastructure to certain location.

Recently, the rise of social movements pushing for adaptation and climate resilience from the local to national levels is gaining relevance. Individuals, communities and civic organizations are not only concerned about how the services provided by infrastructure will improve their socioeconomic conditions, but rather if they are aligned with a broader goal of sustainable development.

However, civil society and NGOs are often involved only when projects are already at approval stages, and not in investment and design stages. This may result in disagreements or stronger opposition to the development of infrastructure projects. Also, because they are not involved at early stages in the process, it leaves room only for measures that if incorporated will minimize and reduce impacts, whereas if they collaboratively build a project plan, more substantial risks could be avoided (Barlett, 2019). Local communities may have a better understanding of their reliance in ecosystems, and the characteristics of their local context. This information could substantially Inform and improve decision-making and also the elaboration of standards, guidance documents, codes, and ranting systems. **Table 2** summarizes the main roles of stakeholders throughout the infrastructure lifecycle, presenting examples of how they can use standards.

Table 2 – Roles of stakeholders throughout the infrastructure lifecycle.

Role of stakeholders	Planning	Delivery	Management
Financiers	Establishment of investment pipelines for infrastructure projects. *UoS: Criteria for the selection of bankable projects*	Provision of finance, advisory and capacity-building *UoS: Financial structuring, allocation and accounting of (climate) risks, project preparation, incorporate climate change into Value for Money.*	Enabling return on investment *UoS: Management of financial risks*
Owners and Managers	Development of the enabling environment and prioritization of infrastructure projects *UoS: Criteria for the prioritization of projects, in alignment with policies, plans and strategies.*	Development of a project that will meet its financial feasibility expectations *UoS: Compliance with legal and regulatory norms and/or requirements*	Monitoring and evaluation of risks and the compliance with regulatory requirements and service levels. *UoS: Performance and availability of infrastructure and risk management*
Developers	N/A	Project planning, design, procurement and construction *UoS: Reducing the use of resources, maximizing efficiencies and promoting co-benefits with other projects*	Monitoring and evaluation of risks and the compliance with output specifications of the project. *UoS: Performance and availability of infrastructure, use of resources, and risk management*
Regulators	Development of the enabling environment and standards for climate-resilient infrastructure *UoS: Policies, plans and strategies, as well as identification of climate risks, socioeconomic and environmental conditions, and future scenarios*	Definition of technical specifications to deliver a project *UoS: Social and environmental impact assessment, climate scenarios, lifecycle costing, accounting for resilience benefits, and sustainable procurement*	Management of the project and achievement of broader development goals *UoS: Risk management*
Users	Public participation in the development of policies, plans and strategies, and election of representatives *UoS: Sustainable development, protection of nature, and conservation of biodiversity*	Consultation of the project plan and design *UoS: Reducing vulnerabilities, improving livelihoods, and environmental quality*	Use of the services provided by infrastructure assets *UoS: Affordability, quality and availability of service*

Legend: “UoS” – examples of interest in the use of standards, N/A – not applicable.
Source: authors.

2.2. Infrastructure sectors and systems

Infrastructure systems can be analyzed according to different boundaries. At a wider perspective, it can be considered the interconnections between infrastructure systems of different sectors (e.g., water and energy) to identify the linkages among different assets and networks in a 'systems of systems' approach. For example, the UK National Infrastructure Assessment (NIC, 2018) considered all types of economic infrastructure to propose a long-term strategy on how to address the needs in transport, energy, water and wastewater, flood resilience, digital connectivity, and solid waste. This was done in consultation with experts, independent organizations and public participation, to set out recommendations until 2050.

The interdependency of infrastructure systems is not restricted to administrative boundaries of countries, regions or cities. Although in urban areas this connection is more visible given the spatial density of assets, it is not common for infrastructure projects to span administrative boundaries and therefore require the involvement of an even wider range of stakeholders – which adds up to the complexity of addressing future climate risks and enhancing resilience.

Even if the analysis considers only a specific sector, the multitude of intricacies of an infrastructure cannot be avoided. Sectoral plans also are usually aligned with Municipalities' Strategic Master Plans and National Infrastructure Plans, therefore maintaining the complexity of scale and actors. In this case, the only nuance is that policies, plans and strategies are specified for one particular type of infrastructure (e.g., transport).

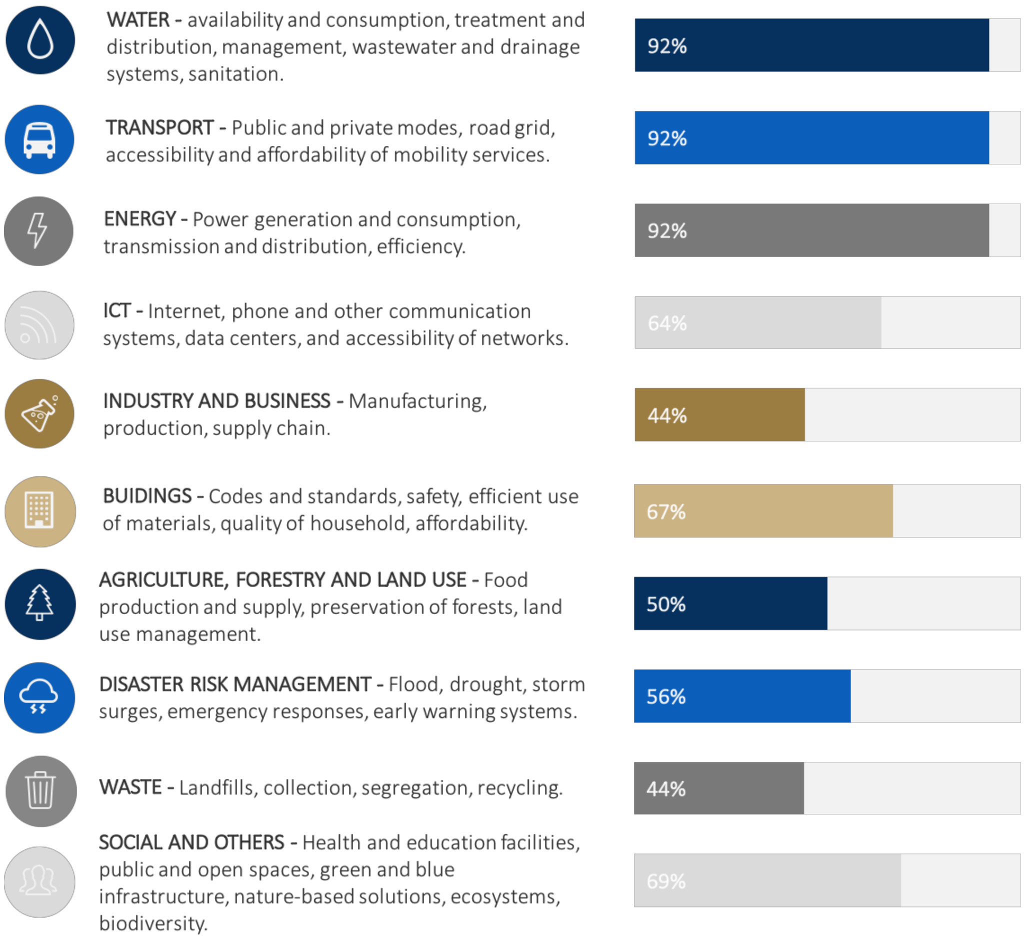
Figure 4 presents a description of infrastructure sectors and shows an overview of how the different sectors are included in existing policies, plans, investment priorities, and other documents, of different organizations in each stakeholder group considered in the report (see Section 2.1), to identify which sectors were prioritized. Appendix 1 presents the full list of organizations that were considered and how the results presented in **4** were calculated.

From all types of infrastructure, this analysis illustrates that water, transport, energy, information and communication technology (ICT), buildings, and social sectors are the ones most addressed – those are also often classified as critical systems. That is understandable given that critical infrastructure can be understood as a set of systems, with corresponding assets and elements, that should be highly reliable and secure to withstand both external and internal threats.

However, given interdependencies between systems, and the diversity of climate impacts, this report takes a broad view of infrastructure, instead of limiting the view to traditional economic infrastructure or critical systems. In addition to economic infrastructure, it also includes sectors that can affect infrastructure resilience, such as disaster risk management, agriculture, forestry and land use, waste and industry and business. Ultimately all types of infrastructure must be planned, designed, constructed, operated, maintained and managed to cope with uncertain scenarios and promote climate resilience.

Infrastructure in all sectors can aim to avoid stranded assets by considering emissions, energy use and criteria for social and environmental safeguards, which is considered to be sufficient to assess if a project is sustainable and resilient to climate risks (Barlett, 2019). Only with a duly analysis of each context of climate hazards, geophysical characteristics, conditions of existing infrastructure systems, needs of most vulnerable groups, among other criteria, it will be possible to determine which are the most critical assets and the ones who ought to be prioritized.

Figure 4 - Infrastructure sectors and priorities of stakeholders.



Source: authors.

3. STANDARDS FOR CLIMATE RESILIENCE

Standards are crucial to ensuring infrastructure is prepared to withstand present and future climate scenarios. They can assist stakeholders to incorporate climate risks, resilience and adaptation measures in the planning, delivery and management of infrastructure.

However, there is the need for a consistent approach across standards, codes, guidance documents, and rating systems. Many stakeholders are developing those four typologies but with different objectives and without adopting a common set of stages from the upstream until the project level. It is thus important to understand the needs of all the stakeholders and the role they play in the process of developing and implementing standards in all typologies and across the infrastructure lifecycle.

The previous chapter showed that standards at each stage of the infrastructure lifecycle are used differently by different stakeholders. When involved in the development of standards, stakeholders are more likely to incorporate adaptation and climate resilience into infrastructure. When they just apply standards due to regulations or to fulfill contractual requirements – either from the project or investors – additional criteria to enhance social, economic and environmental benefits tend to not to be incorporated since they are not obligatory.

In this report, the following typology of standards in the context of infrastructure is considered:

- Standards, which are technical and/or managerial definitions, procedures, and frameworks to promote consistent use of certain topic in one or more stages of the infrastructure lifecycle;
- Codes, which are standards that were consolidated by a legislation or regulation at any jurisdictional level and are usually related to minimum technical requirements to ensure the safety of the delivery of infrastructure;
- Guidance documents, which are usually recommendations or research to inform the development of standards and can include good practices on the implementation of infrastructure;
- Rating systems, which are frameworks that can encompass metrics from standards, codes and guidance documents for the evaluation of an infrastructure project according to a level of performance from planning to management.

Standards, guidance documents and rating systems are voluntary, whereas codes are regulated by law and thus compulsory. For the types that depend on voluntary adhesion, their (positive) impact on promoting climate-resilient infrastructure might not be effectively leveraged. OECD (2018, p.21) highlights that an "underlying challenge in achieving this [use of standards] is the tension between two goals: establishing standards that are straightforward and can be applied consistently, while also taking into account the uncertain and context-specific nature of climate risks".

In this report, climate resilience is viewed as a subset of sustainability: more generally, all sustainable projects should be resilient to climate change. However, sustainability considers a far broader range of factors than are covered by climate resilience.

This section explores how standards within the typology defined are approached by different stakeholders, particularly to what extent they incorporate the need to consider climate risks, build resilience and adapt to climate change. This analysis is necessary to be able to address the gaps of knowledge, leverage existing best practices and identify opportunities for improvement in the use of standards throughout the infrastructure lifecycle (which is further described in Section 4).

3.1. Existing approaches to resilience and climate change

The approaches to climate-resilient infrastructure systems can be divided in two categories. First, a direct application of metrics in rating systems to evaluate the sustainability and resilience of infrastructure projects – including CEEQUAL, Envision, IS Rating Tool and SuRe®. Second, an indirect application of concepts related to climate-resilient infrastructure in standards, codes, and guidance documents. These concepts can refer to: indicators for resilience at the city level, in the ISO 37123:2019 and the Disaster Resilience Scorecard for Cities; methodologies to assess adaptation to climate change, in the ISO 14080:2018 and CEN-CENELEC Guide 32; use of climate data, in the guidance document from Roy, Fournier and Huard (2017); green investment criteria, in the ISO/DIS 14097; and structural safety codes of buildings and constructions, in the Eurocodes.

Table 3 shows a summary of approaches across the four types of standards and how they could be applied in the stages of the infrastructure lifecycle. Appendix 2 presents a table with the complete list of almost 40 standards analyzed.

Table 3 – Summary of approaches to climate change resilience in the typologies of standards.

Type	Examples	Approach to climate risks, resilience and adaptation	Application in the infrastructure lifecycle		
			Planning	Delivery	Management
Standards	ISO 37123:2018, ISO 14080:2018, ISO/DIS 14091, and ISO/DIS 14097.	Climate risks, resilience and adaptation are usually considered for specific infrastructure sectors or broadly without directly approaching infrastructure. Nonetheless, it considers exposure, sensitivity and vulnerability to climate risks, recovery and adaptation to shocks and stresses, and dependency in the natural environment.	• Guidance and policies, plans and strategies, as well as broader national commitments; • Economic valuation of the environmental impacts to better inform decision-making; • Definition of a pipeline of investments of climate-resilient projects.	• Project specifications for efficiency in the use of materials and consumption of energy and sustainability aspects; • Use of lifecycle costing and economic, environmental and social impact assessments; • Incorporation of adaptation and mitigation measures, including for retrofit; • Evaluation of physical risks to infrastructure and development flood-proof designs	• Assessment of environmental and resilience performance; • Monitor and evaluation of implemented climate actions and the occurrence (or not) of climate risks; • Tracking the flow of finance and effectiveness of investments in climate-resilient projects.
Codes	Eurocodes, International Building Code 2018 (USA), and National Model Construction Codes 2015 (Canada).	Resilience is mostly considered in terms of structural safety and only addresses climate change in terms of risks to natural disasters, such as floods, hurricanes, and earthquakes. Adaptation measures and sustainability are overall not considered.	• Application of a transnational set of standards for construction works.	• Project specifications to consider the structural safety of buildings, energy efficiency, use of materials, and risks to natural hazards.	• Monitoring and evaluation of project specifications.
Guidance documents	CEN-CENELEC Guide 32:2016, Roy, Fournier and Huard (2017), Disaster Resilience Scorecard for Cities (UNDRR, 2017), and the Sustainable Framework from IDB (2018).	It considers how to incorporate adaptation to climate change in standards, integrate (disaster) resilience in terms of preparedness for disruptions and disturbances in operations, and promote sustainable development of infrastructure.	• Incorporation of climate risks, resilience and adaptation aspects in standards to guide policies, plans and strategies; • Identification and understanding of risks, through the use of climate data, to ensure coordinated responses, and establishment of contingency funds.	• Better use of climate data to inform project design; • Characteristics of building components that include sustainability and resilience; • Alignment to building codes, protection of natural ecosystems, use of green and blue infrastructure, among others. • Methodologies for risk assessment and inclusion of adaptation measures to climate change.	• Monitor the occurrence (or not) of climate risks and long-term liabilities; • Assessment of resilience performance and maintenance of critical assets; • Reporting of environmental impacts.

(Table 3 continued)

Type	Examples	Approach to climate risks, resilience and adaptation	Application in the infrastructure lifecycle		
			Planning	Delivery	Management
Rating systems	SuRe ®, Envision, IS Rating Tool, LEED, CEEQUAL, GRESB	Resilience and adaptation to climate risks are extensively considered throughout the infrastructure lifecycle in an integrated approach. It includes aspects related to siting, energy and resource consumption, use of adaptation and mitigation measures, economic and social impact, evaluation of the vulnerability to natural hazards, impacts on natural ecosystems and biodiversity, and future climate scenarios, among others.	• Integration with policies, plans and strategies, to ensure that projects are bankable for investors and aligned with development goals; • Promoting leadership to mainstream climate resilience into infrastructure projects.	• Specification of several economic, environmental and social criteria for all stages of the infrastructure to incorporate concepts of resilience, sustainability, adaptation, climate change, among others; • Consideration of vulnerable communities and the need for stakeholder engagement.	• Monitoring and evaluation of project specifications to ensure the measures considered contribute to achieving climate-resilient and sustainable infrastructure; • Consultation of the performance of infrastructure systems to ensure they are adequate to the service needs of users; • Measurement of (in)direct health and safety benefits.

Source: authors.

Rating systems have the most comprehensive approach in considering climate risks, resilience and adaptation measures, among other concepts, throughout the lifecycle of infrastructure. In contrast, codes tend to have most impact during the delivery phase.

Whenever appropriate, those metrics should be applied in the development of policies, plans, strategies and projects across government levels, sectors and actors. Nonetheless, three main considerations can be drawn from the results in Table 3:

- In the Planning Phase, standards ought to establish a clear link with policies, plans and strategies from national to local levels. This would allow to determine an adequate guidance to develop a pipeline of climate-resilient projects that are bankable and feasible, integrate different climate scenarios, and explore synergies with other infrastructure systems. Currently, some of these topics are considered, but there remains a need for deeper mainstreaming.

- In the Delivery Phase, standards could focus on mainstreaming the concepts of resilience, climate change and adaptation – as well as other economic and social criteria – to the planning and design of infrastructure systems. The main concern is to ensure the any works relative to existing and new projects address the vulnerabilities to climate change and consider a long-term perspective of adaptation. Further specifications in project conditions, operating margins and quality thresholds at the project-level, as well as outputs specifications and bid requirements in the procurement process, could incorporate those topics more effectively.

- In the Management Phase, it could be considered how the previous metrics are going to be monitored and evaluated during operations and maintenance, as well as in the decommissioning of the asset. The goal is to understand if climate risks occurred and what was the response of the infrastructure to feedback into the Planning and Delivery Phases. Although important, the focus on this stage currently is on contract management (ensuring the project achieves the output specifications within the expected time and budget), but not on the impact of adaptation measures implemented or the resilience benefits they brought to the project.

Standards currently focus on the Delivery Phase and could have a higher emphasis on criteria for climate-resilient infrastructure. Most of the metrics do not address the relation with upstream decision-making (Planning Phase) or how they will be followed-up over time (Management Phase) and feedback into the planning process.

Table 3 and the complete list in Appendix 2 do not represent an exhaustive list as not all references were analyzed. Several other standards are being developed or updated to include resilience, climate change and adaptation aspects, but their information is not yet available. One in particular that can be mentioned is the Eurocodes, which are being updated to include relevant impacts of climate change under different scenarios, since now it only relies on historical weather information.

3.2. Addressing the needs of different stakeholders

The use of standards depends on the extent to which they are requested or required by financiers, owners, managers, developers, regulators and users of infrastructure – standard bodies themselves cannot enforce the use of those standards. As Dora (2018) further explains, although standards can be used as examples of good practice in court judgements, they are not an essential requirement of projects, unless required by existing legislations and regulations, or as part of the contract agreement.

The use of climate data and hazard risk assessments are key factors providing the necessary information to plan for uncertain future scenarios. Although climate models cannot precisely predict the future, they provide valuable information – with significant confidence – on which impacts are expected to occur and with which order of magnitude. Risk assessments can, therefore, help to identify and select projects that will enhance the resilience to climate change and address the main vulnerabilities of a location.

During the Delivery Phase, infrastructure must consider a long-term perspective to adequately incorporate those concepts. However, because the typical investment in infrastructure is often based on a return-on-investment period that is short in comparison to the asset's life time, the financial analysis and technical design solutions usually do not adequately take into account future risks, including the ones from climate change (Gallego-Lopez and Essex, 2016). This highlights the importance of a whole lifecycle approach to infrastructure, so that impacts and benefits can be rightfully costed during the asset's or network's life time.

Linking to the enabling environment and procurement processes, project specifications also have to take into account climate risks to make resilience the norm. In particular, a collaborative discussion of the definition of 'force majeure' events, how to account for the uncertainty of future climate risks and resilience benefits that may be achieved, and which requirements could be incorporated in the tender and contract stages of procurement to help ensure an appropriate risk share to between the public and private party, besides clearer estimative of risks that could be insured by lenders – which would certainly facilitate the financial feasibility.

During this stage, the private sector is more interested in maintenance of the asset and managing the risks. This relates to developers attending the output specification of the project standards and complying with the contractual obligations. At the same time, owners and managers have to consider that the more users access the asset – optimizing its benefits – the more wear and tear will increase, which should be planned for in renewal and refurbishment costs.

Academia also provides valuable inputs to the planning, delivery and management of climate-resilient infrastructure projects. Its efforts range from policy analysis and national infrastructure assessments, to case studies of specific projects and the proposition of infrastructure standards.

Civil society is interested on the performance of the assets in providing or improving a service they need and the benefits promised at earlier stages of project development. It pays particular attention to the affordability, improvement of livelihoods and protection of the natural environment.

3.3. Guiding frameworks for climate-resilient infrastructure

To different extents and purposes, the standards' typology – standards, codes, guidance documents, and rating systems – propose metrics to evaluate the resilience of infrastructure systems to climate change. Although rating systems provide a more integrated evaluation throughout the infrastructure lifecycle in comparison to the other types, they could be complemented by knowledge from existing standards, codes and guidance documents, as well as by the expertise of the different stakeholders – which tend to be case-specific, applied to a particular sector or project – particularly in Planning Stage.

It is thus necessary to understand what the gaps of knowledge in the development of climate-resilient infrastructure standards are, and how the different types and stakeholders could work together help bridge that gap. Additionally, if they are to promote climate-resilient infrastructure, it would be valuable to understand to what extent their criteria incorporate the concepts of climate risk, resilience and adaptation.

The rating systems proposed by Envision (ISI, 2015) and SuRe ® Standard (GIB, 2017), were chosen to be analyzed as the most comprehensive of their kind. In addition, IDB's Sustainable Framework (IDB, 2018), was also selected from the guidance documents because it incorporates other rating systems and standards on its elaboration. Each of those three sources have proposed around 60 standards and criteria, in topics that range from labor rights to alignment with national policies, from siting the project to preparing a climate change action plan to deal with current and future risks.

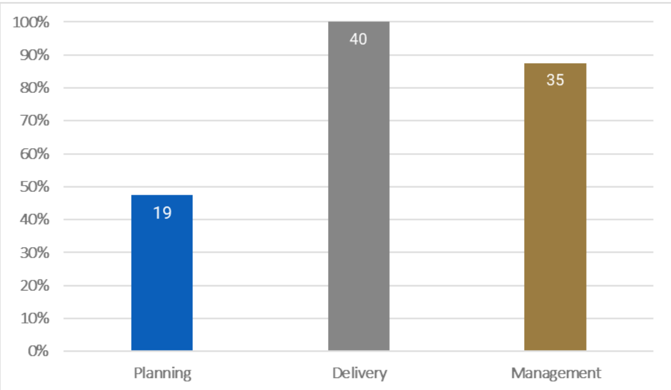
Given that many of the criteria proposed addresses similar topics and could be applied to different phases of the infrastructure lifecycle, it was necessary to determine a method to analyze those rating systems. Therefore, a four-stage process was applied, which is described as follows.

First, the definition of each of those standards was analyzed to determine to which phase of the lifecycle they were related to. Secondly, given that there were several similar parameters, the criteria were simplified where appropriate to avoid redundancies – for example, the groups of 'management' and 'management and oversight' were clustered. Thirdly, the summarized list was classified in three broader dimensions: built environment, for items related to the development of infrastructure (design, construction, financing, operation, and maintenance); enabling environment, for items related to policies, plans and strategies, employment and capacity building; and natural environment, for items related to environmental conditions and resources used throughout the infrastructure lifespan. This division intended to observe to what extent standards focus on upstream (Planning) or downstream (Delivery and Management) processes, as well as preserve and protect the natural capital. Lastly, the final list with the main climate-resilient standards was analyzed to see how the concepts of climate risk, resilience and adaptation were incorporated.

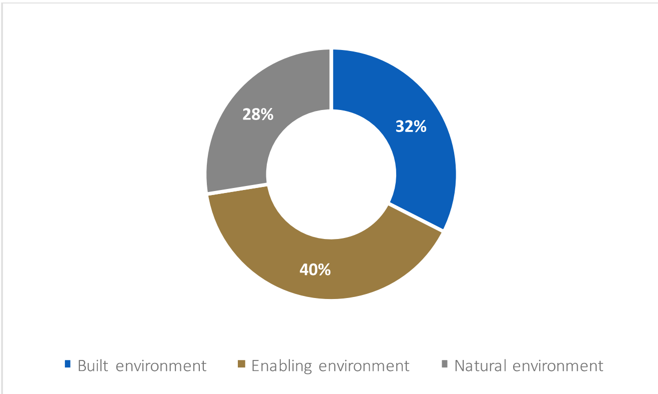
Even though can be applied throughout the infrastructure lifecycle, **Graph 1a** shows that the documents analyzed address mainly the Delivery and Management Phases of the lifecycle. Yet, **Graph 1b** shows that the majority of standards proposed are related to the enabling environment, which links to the Planning Phase of the lifecycle. In other words, the metrics analyzed that are related to the enabling environment also focus on the last two stages of the lifecycle and put less emphasis on planning needs. At the same time, the analysis also indicates that the natural environment is the least prioritized among the standards since it was the group with the minority percentage of total standards.

Graph 1 - Comparison of standards and criteria examined per stage of the lifecycle and per dimension to the total of standards.

(a) Percentage of standards and criteria per stage of the lifecycle



(b) Percentage of standards and criteria per dimension



Source: authors.

In addition to comparing the relative percentage of indicators per stage or dimension, it is important to analyze to what extent they incorporate climate resilience aspects. Looking across the dimensions (built, enabling and natural environments) and focusing on understanding to what extent climate risks, resilience and adaptation are incorporated, it is possible to observe that:

- Climate risks are considered in terms of vulnerabilities to natural hazards and climate-related events, which are aggravated by the uncertainties of current and future scenarios.
  It is acknowledged that climate risks may affect infrastructure, communities and natural ecosystems. However, besides the

criteria proposed to the elaboration of recovery and adaptation plans and the provision of buffer and protected zones, it does not necessarily emphasize the importance of understanding the local context (socioeconomic, geographic and political aspects) to determine the magnitude of risks, exposure and the most vulnerable areas. The standards ISO37123:2019, ISO/DIS 14091, and ISO/ST 14092, and the guidance documents by Roy, Fournier and Huard (2017) and UNDRR (2017) partially incorporate those aspects.

- Resilience is considered in terms of interlinkages of infrastructure systems, quality and reliability of service, preparedness for emergencies, and the ability to withstand and reduce exposure to shocks and stresses. Durability, flexibility and safety (of assets, citizens and ecosystems), as characteristics related to resilience, are also proposed for the delivery and management of infrastructure. In addition, it is suggested the improvement of quality of life, green and public spaces, ecosystem services, and the natural environment.
  Despite the fact that this concept is quite comprehensively incorporated, two elements are not apparent. The first is explicitly adopting a 'systems of systems' approach to fully understand the interlinkages of infrastructure systems across its three dimensions (built, enabling and natural environments). One example of such approach is the NISMOD methodology developed by University of Oxford's ECI and other institutions (ITRC, n.d.).
  The second gap is about setting the boundaries of analysis, which means establishing a limit to guide adoption of performance-based targets that will quantitatively measure the achievement (or not) of resilience in an infrastructure project. Examining the boundaries would also be useful for plans, policies and strategies to promote an agreement of the concepts of resilience and how to achieve it – depending on the boundaries and objectives set, the outcome will be substantially different.

- Adaptation is considered through the understanding of interdependencies with natural capital, promoting the co-benefits of nature-based solutions and green-blue infrastructure, and protection of biodiversity – which should be aligned with sociocultural values and policies, plans and strategies towards sustainable development.
  Besides alternative solutions to 'hard-engineered' assets, it also promotes the use of technology and innovation, as well as incorporates lifecycle thinking, sustainable procurement for an efficient use of resources, and the accounting of socioeconomic and environmental impacts. This concept is also comprehensively approached but could be benefited by more extensive knowledge and investments to scale up those measures. In particular, capacity building could share existing local knowledge (e.g., from local and indigenous communities) and promote a better understanding of how natural capital and ecosystem services provided can help tackle climate change. Some of these considerations, mainly related to determining adaptation measures in a broad perspective but without focusing on local capacity and natural ecosystems, can be found in the standards ISO 14007:2019 and the guidance document CEN-CENELEC Guide 32:2016.
  Furthermore, it is necessary to direct more investments to adaptation, instead of the majority that goes to mitigation measures, to bridge the gap of funding sustainable and resilience infrastructure. In particular, also addressing financial support to resilient projects, the standards of ISO/DIS 14030-1 and ISO/DIS 14097, which are still not published, and other practices previously mentioned – such as the 'Principles for Climate Resilience Metrics' (IDB, 2019) and the Climate Resilience

Bond (EBRD,2019) – could ensure a need investment in climate-resilient infrastructure to adapt to climate change.

The analysis of these three topics illustrates the need to improve the standards, in all its types, to foster climate-resilient infrastructure upstream in the Planning Phase. Both the built and natural environments are better equipped with standards to incorporate climate risks, while the enabling environment and its institutions are falling behind. However, it was also shown that significant effort of multiple stakeholders is necessary in developing better standards for the Delivery and Management Phases. This resonates with the findings of the system map in Figure 2, which presented that the 'Development of strategies, plans and policies towards sustainability', 'Pipeline of climate-resilient projects', and 'Implementation at the national, regional or city level' are relevant leverage points to promote change in the development of climate-resilient infrastructure standards.

Incorporating climate risks, resilience and adaptation are key entry-points for the standards agenda. There is a need to better understand and account for climate risks relative to the local context of exposure and vulnerability, under the current and future climate scenarios, with the support of scenario planning techniques. A systematic approach to analyze the interdependencies among infrastructure systems, institutions and the environmental conditions would help to enhance resilience overtime. The knowledge about the local context also needs to be shared with all stakeholders to build capacity and harness the potential of natural capital and its ecosystem services, besides ensuring that investments are made to implement adaptation measures.

Table 4 presents a summary of the results, segregating the final list of indicators by the dimensions and phases of the infrastructure lifecycle. Appendix 3 provides a complete description for all standards.

Table 4 – List of standards and criteria for climate-resilient infrastructure per stage of the lifecycle.

Dimension	Standard	Planning	Delivery	Management	Climate risks	Resilience	Adaptation
Built environment	Integration of infrastructure systems	x	x	x	• Evaluation and management of impacts (climate change, natural disasters, among others), risks and vulnerabilities to infrastructure systems; • Avoid development in areas exposed to natural hazards; • Prepare and monitor recovery and adaptation plans; • Consider current and future scenarios.	• Enhance interlinkages between different infrastructure systems and better integrate the provision of services; • Ensure infrastructure is climate-resilient and prepared to withstand shocks, reducing the exposure to natural hazards; • Design, operational and maintenance standards that promote durability, flexibility and resilience; • Achievement of performance, quality and reliability of service; • Promote gender equality in all stages of the lifecycle and gender responsive infrastructure; • Demonstrate technical, financial and social feasibility; • Safety of infrastructure and assets, ecosystems provided, and emergency preparedness.	• Incorporate lifecycle thinking; • Allow easier expansions and reconfigurations, besides using project features to minimize impact; • Integrate with technology and innovations; • Efficient use of resources and effective delivery of services; • Consider green infrastructure and potential for nature-based solutions; • Reduce the use of greenfield and conserve undeveloped land; • Align with social and cultural values and historical heritage; • Foster the use of unmotorized modes of transportation; • Measure (in)direct impacts to ensure benefits to health and safety.
	Achievement of performance		x	x			
	Disaster risk management and climate change adaptation	x	x	x			
	Increased lifecyle use		x	x			
	Optimal infrastructure use		x	x			
	Adequate siting		x				
	Land development		x				
	Preservation of cultural, historical and local characteristics	x	x	x			
	Resettlement of communities		x	x			
	Accessibility and affordability of services		x	x			
	Building climate resilience	x	x	x			
	Management of public health and safety risks		x	x			
	Gender equality and women empowerment		x	x			

(Table 4 continued)

Dimension	Standard	Planning	Delivery	Management	Climate risks	Resilience	Adaptation
Enabling environment	Alignment with international and national institutional framework	x	x	x	• Improve understanding of sustainable infrastructure for disaster risk management; • Develop a financial structure to cover project risks and costs; • Development of data collection and M&E to ensure effectiveness and sustainability of the project; • Not increase the risks of community and provide compensation of affected communities; • Consider changing environmental conditions and different pathways.	• Capacity development and employment of local workers; • Development of emergency plans and trainings, drills for response; • Incorporate needs of the community to improve quality of life; • Identify health and safety hazards in the workplace, implementing preventive and protective measures.	• Foster interlinkages with existing policies, plans, strategies and national/international commitments; • Adopt sustainable procurement policies to the efficient and sustainable use of resources, accounting for environmental, social and economic impact; • Promote long-term sustainable investment and development; • Identification and dependencies on natural capital, exploring environmental and social co-benefits; • Commitment and leadership, with clear definition of roles and responsibilities, to mainstream sustainability into policies, including design and construction of infrastructure.
	Transparency of information and anti-corruption mechanisms	x	x	x			
	Financial sustainability	x	x	x			
	Employment and qualification		x	x			
	Governance structure	x	x	x			
	Environmental and social management systems	x	x	x			
	Addressing liabilities		x	x			
	Preparedness for emergency response		x	x			
	Sustainable procurement mechanisms	x	x	x			
	Stakeholder engagement and community consultation		x	x			
	Effective leadership and commitment	x	x				
	Capacity building	x	x	x			
	Improvement of quality of life	x	x	x			
	Promoting sustainable growth and development		x	x			
	Mobilization of finance	x	x				
	Labor and human rights and working conditions		x	x			

(Table 4 continued)

Dimension	Standard	Planning	Delivery	Management	Climate risks	Resilience	Adaptation
Natural environment	Waste management and materials		x	x	• Reduce heat accumulation and microclimatic changes; • Provision of buffer zones and protected zones to reduce risk of natural hazards; • Adoption of low-carbon pathways and reduction of GHGs emissions; • Perform a lifecycle assessment to reduce impacts to climate change and try to achieve net-zero impacts; • Monitor air quality and emissions, including emissions management plan if it exceeds regulatory thresholds.	• Access and promote the quality of public spaces, green infrastructure and natural areas; • Maintaining ecosystem connectivity and their services to reduce impact on natural environment; • Capacity management and storage of runoff stormwater.	• Reduce, reuse and recycle materials; • Use efficient materials in accordance with sustainability standards and monitor their performance; • Promote the protection of biodiversity and natural capital, supported by policies and governmental agencies; • Reduce the use of hazardous chemical products, avoid and minimize pollution (air, water, soil); • Provide an efficient and sustainable use of natural resources, ensuring the availability in quantity and quality.
	Management of biodiversity	x	x	x			
	Public spaces	x	x	x			
	Control of invasive species		x	x			
	Management of ecosystems and their services	x	x	x			
	Soil management		x	x			
	Protection of natural capital		x				
	Emissions and climate change mitigation	x	x	x			
	Reduction of pollutants	x	x	x			
	Water management		x	x			
	Reduction of energy		x	x			

Source: authors, adapted from Envision (ISI, 2015), SuRe® (GIB, 2017), and IDB (2018)

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4. GAPS AND OPPORTUNITIES

Infrastructure systems are experiencing and will experience the impacts of climate change. To achieve an acceptable level of risk over the infrastructure lifecycle it is necessary to consider the exposure and vulnerability to climate hazards, consequences of failure and costs of risk reduction. Among the hazards, climatological, meteorological and hydrological events affect the most infrastructure, and they are influenced by abrupt and slow on-set climate-related impacts.

Therefore, all infrastructure projects should plan for uncertain climatic conditions, to withstand shocks and stresses and avoid disruptions in the services they provide. Projects should also enhance the interlinkages with other infrastructure assets and systems and be part of a robust set of policies, plans and strategies. However, this requires coordination across a wide range of stakeholders as financiers, owners, developers, managers, regulators and users –each of them with different needs and interests throughout the infrastructure lifecycle.

Standards, codes, guidance documents and rating systems are a key part in this process of ensuring infrastructure is climate-resilient. They are fundamental in providing the necessary metrics and evaluation tools to assist in this process. However, those types of standards currently focus on the Delivery Phase and could have a higher emphasis on criteria for climate-resilient infrastructure. Most of the metrics do not address the relation with upstream decision-making (Planning Phase) or how they will be followed-up over time (Management Phase) and feedback into the planning process.

The analysis of all types of standards across the infrastructure lifecycle indicated the need to: in the Planning Phase, consider different climate scenarios and mainstream a systems approach to infrastructure to incorporate climate resilience from the outset; in the Delivery Phase, have a long-term perspective and include specifications in project conditions to procure infrastructure that accounts for climate risks and promotes resilience; and, in the Management Phase, ensure the metrics to measure the achievement of climate-resilient projects are followed to showcase the benefits achieved.

The analysis of how climate risks, resilience and adaptation are incorporated in those existing types of standards also showed gaps of knowledge. Particularly, it is necessary to emphasize the risks and exposure of the most vulnerable areas, set boundaries of analysis to measure the resilience benefits achieved by an infrastructure project, and scale up investments in adaptation measures that work with the natural environment, among others.

To ensure greater coherence overtime and make climate-resilient infrastructure the norm, five recommendations are proposed to address the gaps identified in this paper (Figure 5).

Figure 5 – Recommendations to make climate-resilient infrastructure the norm.

PLANNING	DELIVERY	MANAGEMENT
Recommendation 2: Develop guidance to increase the understanding of physical climate risks, enabling the planning of infrastructure systems that consider the uncertainty of current and future scenarios. **Recommendation 3:** Promote the use of systems approaches to infrastructure planning upstream into decision-making to help develop a pipeline of climate-resilient projects.	**Recommendation 4:** Promote adaptation and resilience measures for infrastructure in the procurement of assets and services.	**Recommendation 5**: Quantitatively track the results achieved by infrastructure in enhancing climate resilience to make the business case for investment and showcase good practices.

Recommendation 1: Establish a common approach to the infrastructure lifecycle and typology of standards, accelerating the uptake of climate-resilient infrastructure.

Source: authors.

GENERAL Recommendation 1

Establish a common approach to the infrastructure lifecycle and typology of standards, accelerating the uptake of climate-resilient infrastructure.

The current implementation of standards tends to operate in silos, hindering the achievement of greater coherence over time. There are many standards, codes, guidance documents and rating systems being developed by different stakeholders, each of them with its own objectives. Many of them are relevant for climate resilience but this knowledge is not always widely accessible. Furthermore, those types of standards tend to be specific to one or more stages of the infrastructure lifecycle, with different levels of granularity depending on the application, which makes it hard to compare existing approaches for a comprehensive overview (ICSI, 2020).

Standards deriving from upstream and downstream applications differ in terms of scope. Policies, plans and strategies tend to propose more general principles regarding the characteristics of climate-resilient infrastructure. At the project level, the different types of standards can be focused to a specific sector or topic instead of an integrated approach. In both cases, input and collaboration across stakeholders and sectors could be greatly beneficial towards a common interpretation of how to incorporate climate risks, resilience and adaptation into infrastructure. The lack of concrete examples of assessments that effectively integrated climate change adaptation to large-scale infrastructure projects emphasizes a remaining knowledge gap that is essential to inform decision-making and investment (Barlett, 2019).

Facilitating dialogue is essential to ensure a common understanding of climate-resilient infrastructure and to identify the existing gaps of knowledge and good practices. Stakeholder engagement is essential to accelerate the uptake of climate resilient infrastructure as a norm rather than exceptional best practice. To coordinate those efforts, a conducive environment needs to be established to stimulate discussions on how to deal with uncertainty of climate risks, innovative adaptation measures among other topics. Whether via financial analysis or technical design solutions, those concepts can ensure the development of bankable projects that account for climate change impacts.

PLANNING Recommendation 2

Develop guidance to increase the understanding of physical climate risks, allowing to plan infrastructure systems that consider the uncertainty of current and future scenarios.

Standards are essential to ensure greater coherence overtime and that climate risks, resilience and adaptation are going to be the norm from the outset of the project. As stated by (Kapos et al., 2019, p.46) "the regulatory environment and standards of good practice have roles to play in broadening uptake, enhancing effectiveness, and avoiding perverse outcomes and maladaptation". In that context, assessing the variety of future scenarios has become increasingly important to address the uncertainty of climate change.

Despite improvements in data availability and modelling, it remains technically challenging to integrate climate risks in the development of infrastructure plans, policies and strategies. If those uncertainties are explicitly addressed, they can reduce disincentives (to invest in projects, to incorporate climate-resilient standards, etc.) and find evidence to fill the current knowledge gaps (Kapos et al., 2019). In addition, the visualization of different future scenarios is an important tool helping to raise awareness on how climatic conditions might change and affect infrastructure. Some techniques that can be used in that regard are decision-making under deep uncertainty, scenario-based planning, forecasting and back-casting (Barlett, 2019).

To effectively incorporate climate risks, it is also necessary to understand the local context. Instead of adopting a top-down approach that downscales from emissions to impacts of climate change, it is necessary to adopt a bottom-up approach that considers the hazards and vulnerabilities from where the project is located – especially from the most exposed areas. Climate-sensitive informed decision-making can take into account uncertain conditions by better identifying and evaluating the occurrence (or not) of climate risks throughout the infrastructure lifecycle.

For that, it is important to apply the work being done by regulators, financiers, owners and developers to into practice. Academic institutions have produced extensive research on future scenario analysis and climate risks that could be leveraged. Likewise, there are examples of financiers, owners and developers that are making an extra effort to implement those techniques into their business. In that context, a guidance document able to summarize the best practices to both government officials and practitioners would greatly benefit an increased understanding of physical climate risks to infrastructure. Furthermore, good practices and main considerations that should be taken into account to deal with uncertain climate risk scenarios would be widely available to the various stakeholders.

PLANNING Recommendation 3

Promote the use of systems approaches to infrastructure planning upstream into decision-making to help develop a pipeline of climate-resilient projects.

The most relevant opportunity to achieve a transformational change is to promote climate resilience from the early stages of the infrastructure lifecycle. Infrastructure exists as highly interdependent and interconnected system of systems, assets and equipment in all sectors (e.g., water, transport and energy, etc.).

Actions taken upstream to promote standards in policies, plans and strategies and a pipeline of investment for climate-resilient infrastructure have the highest potential of improvement (see Section 2.1, Figure 2). However, in practice countries face challenges in developing a pipeline of sustainable projects given the long-term lifespan, interconnections and externalities; and second, the difficulty of mobilizing finance that accounts for the risks during the lifecycle of the project at a reasonable cost (IDB, 2018).

Policy and planning can also be treated independently, with different ministries and development objectives, usually without interacting with each other. Although international and national organizations provide guidance for sustainable development and how to address climate change impacts, "too often infrastructure and climate policies exist in separate silos" (Rydge, Jacobs and Granoff, 2015, p.3). Standards, codes, guidance documents and rating systems can help bridge those silos, positively influencing the development of a pipeline of climate resilient-infrastructure projects if integrated into plans, policies and strategies.

A systems approach aims to bridge these divisions and enable a collaborative work among institutions. It allows to consider climate risks to infrastructure systems and assets, besides analyzing the interlinkages with the enabling, built and natural environments. For example, there are several cases of regulators – from academia, governments and private institutions –developing and applying stress testing methods of infrastructure from urban to national levels.

Co-developing these studies with ministries and agencies, academia and citizens will result in a prioritization of areas for investment that are aligned with development priorities. For example, a systems approach can help achieve up to 72% of the Sustainable Development Goals' targets (Thacker et al., 2018). This approach will also allow to create a list of adaptation measures to tackle changing climatic conditions with the highest possibility of generating pipeline of bankable climate-resilient projects to provide the infrastructure and services needed.

DELIVERY Recommendation 4

Promote adaptation and resilience measures for infrastructure in the procurement of assets and services.

When an infrastructure project is on the table, it is necessary to have a long-term perspective that considers how the asset and/or service will perform under shocks and stress. However, many projects are developed based on historic climate data, choosing the shortest-path and/or least-cost options, which are not compatible to reality of a changing climate. Furthermore, many standards do not consider either the uncertainties of climate change or future scenarios, and they might not be applicable even in the short-term (Gallego-Lopez and Essex, 2016).

The procurement of assets and services have thus an important role in ensuring climate-resilient infrastructure is delivered. Following either a traditional procurement or through Public-Private Partnerships (PPPs), it is necessary to go beyond economic and social criteria and the current appraisal tools. The procurement has to require the design of a project with appropriate operating conditions and quality thresholds. In addition, there are (recurrent) climate-related events that should not be considered as *force majeure* events and, ultimately, climate risks and resilience benefits should be accounted for in the project financial structuring.

By outlining tender requirements, incorporating specific clauses in the contract and setting output specifications for the bidders, it will be more likely for projects to incorporate climate risks, resilience and adaptation. These requirements should ensure that the design of a project with appropriate operating conditions and quality thresholds, as well as enable the use of innovative approaches that integrate green infrastructure., for example by giving additional points for innovation during the award of a project. That is because incorporating nature-based solutions provides an alternative to traditional grey infrastructure for enhanced resilience and are highly cost-effective.

Co-benefits of investment in climate-resilient infrastructure are out there and they need to be showcased to highlight the potential for transformation in the procurement process. For example, the IDB developed a toolkit with the Rebel Group and the Development Bank of Jamaica, that proposes a set of recommendations of how to include climate resilience into PPPs (Frisari et al., 2020).

Settling the ground for better pipeline of investments, providing financial guarantees and innovative technical solutions, among others, can also allow – mainly developing countries - to leapfrog towards a more integrated and comprehensive approach, one that is aligned to the need to build resilient and promote adaptation to uncertain climatic scenarios.

MANAGEMENT Recommendation 5

Quantitatively track the results achieved by infrastructure in enhancing climate resilience to make the business case for investment and showcase good practices.

Adaptation solutions are expected to work differently depending on the impacts of climate change (Kapos et al., 2019). The efficiency, effectiveness and co-benefits of implementing climate adaptation and resilience measures to infrastructure are still underestimated and sparsely visible since it is difficult to evaluate the benefits and costs these measures will bring. However, this information would help in making the case for climate-resilient infrastructure projects that consider the natural environment, how it will respond to different future climate scenarios and what are the most feasible approaches that could be implemented.

Setting a clear boundary of analysis for the project will provide additional guidance for performance-based targets to fulfill those goals. If climate models and data are limited or uncertain for the context and scale necessary for the implementation of a project, the evaluation will be harder. Nonetheless, clearly defining the concept of resilience and its metrics to adequate to the context will also determine whether the objective was achieved.

Monitoring and evaluation of the results achieved by climate-resilient infrastructure can shed light into its potential. The comparison with the business-as-usual case, existing standards and case studies can reinforce the benefits of such practice, helping to mobilize investments into projects that account for climate risks and foster resilience. The Global Commission on Adaptation (2019) estimated that for every $1 invested in making new and existing infrastructure climate-resilient can yield as much as $4 in co-benefits.

It is important to highlight that those measures for the Management Phase should be defined, if not before, in accordance with the Planning and Delivery Phases. These metrics for monitoring and evaluation should be reflected with tangible outcomes that highlight the impacts of the provision of infrastructure to the community,. such as the number of people protected, loss/cost avoided, etc. This will ensure that infrastructure is not only operated and maintained as the output specifications determined but is able to show the adaptation and resilience benefits achieved, which support sharing knowledge on good practices and making the business case for investment in climate resilience.

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APPENDICES

An excel file will follow with the following appendices:

Appendix 1 – List of stakeholders and infrastructure sectors

Source: authors.

Appendix 2 – Existing infrastructure standards analyzed

Legend: ST – standard, G – guidance document, RS – rating system, C – codes, N/A – non-applicable.

Source: authors.

Appendix 3 – Standards per stage of the lifecycle

Source: authors, adapted from Envision (ISI, 2015), SuRe® (GIB, 2017), and IDB (2018).