Adapting Urban Transport to Climate Change

Module 5f

Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities

2nd Edition

On behalf of

Federal Ministry for Economic Cooperation and Development

Implemented by

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

SUTP. Sustainable Urban Transport Project

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OVERVIEW OF THE SOURCEBOOK

Sustainable Transport: A Sourcebook for Policy-Makers in Developing Cities

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of 35 modules. It is also complemented by a series of training documents and other material available from http://www.sutp.org.

Who is it for?

The *Sourcebook* is intended for policy-makers in developing cities and their advisors. This target audience is reflected in the content, which provides policy tools appropriate for application in a range of developing cities. The academic sector (*e.g.* universities) has also benefited from this material.

What are some of the key features?

The key features of the *Sourcebook* include:

- A practical orientation, focusing on best practices in planning and regulation and, where possible, successful experiences in developing cities.
- Contributors are leading experts in their fields.
- An attractive and easy-to-read, colour layout.
- Non-technical language (to the extent possible), with technical terms explained.

How do I get a copy?

Electronic versions (pdf) of the modules are available at http://www.sutp.org.

Comments or feedback?

We would welcome any of your comments or suggestions, on any aspect of the *Sourcebook*, by e-mail to sutp@sutp.org and transport@giz.de, or by surface mail to:

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About the authors

This document has been developed by the authors based on the 1st edition of this module by Urda Eichhorst.

About this edition

The second edition of this Sourcebook module was developed in cooperation with the Islamic Development Bank. It has been restructured to better reflect the adaptation planning cycle; includes updated data and case studies; and introduces new concepts that have emerged since its first edition.

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Acknowledgements

We would like to thank Niklas Baumert, Clarissa Klees, Daouda Ben Ndiaye, Linus Platzer, Armin Wagner and Olatunji Yusuf for having contributed to the development of this Sourcebook module with multiple contributions and/or reviewing the document. Ahmed Al Qabany and Mohammed Al Sayed provided strategic guidance and advice.

Status

October 2021

Adapting Urban Transport to Climate Change
Module 5f

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1 Introduction

Extreme weather events- such as droughts, heatwaves, flooding and storm surges repeatedly wreak havoc on cities and their transport networks. Climate change is expected to further increase the frequency and intensity of these events, with impacts highest in low lying coastal and delta cities and disproportionately affecting the poor and most vulnerable groups. Disruptions to the transport network impairs access to education, jobs, markets, services and products with hard-hitting ramifications on the broader economy and society for extended periods of time.

In the first few months of 2021 alone, a record-breaking heatwave in North America and Southern Europe has forced people into their cars pumping air conditioning, and in British Columbia, Canada the heatwave has resulted in inundated roads which have submerged some vehicles from melting snow off the nearby mountaintops. The California, Australian, Turkey and Greek wildfires have soared onto freeways and feeder routes trapping people in their homes and blocking rescue vehicles. Fierce storms hit London, causing flash flooding disrupting large parts of the capital's public transport routes and roads.

In Belgium and Western Germany, hundreds died as swollen rivers surged through cities, homes and roads. Mozambique, Malawi and Zambia are being battered by storms while still grappling to repair their infrastructure after Hurricane Ida (2009) caused nearly a 1 billion USD of devastation, a large fraction of those damages associated with transport infrastructure. Similarly, flash flooding in Freetown, Sierra Leone is compounding existing damage to its limited transport infrastructure from the devastating mudslides of 2017.

Pudding Mill lane DLR Station London, 2021; Source: @R0bday/Twitter


Flooding, China; Source: @jeanbeller/Unsplash


Source: Saikiran Kesari/Unsplash

Transport authorities and planners around the world are waking up to the threat of climate change and are implementing ambitious actions to reduce emissions from the sector (mitigation) and increase the climate resilience of transport systems and infrastructure (adaptation) from current and future climatic events. For instance, Singapore under there Walk2Ride programme has constructed shaded access routes - to promote comfort from the extreme heat and protection from torrential rainfall - to increase public transport ridership by enhancing the connectivity between transport nodes. There are over 200km of shaded walkways between MRT stations to surrounding residential, commercial and public facilities. In Rotterdam, the city is greening its tramways to reduce heat stress from the cooling effect of vegetation and enable rainwater to infiltrate the soil which provides a higher buffer capacity for heavy rainfall.

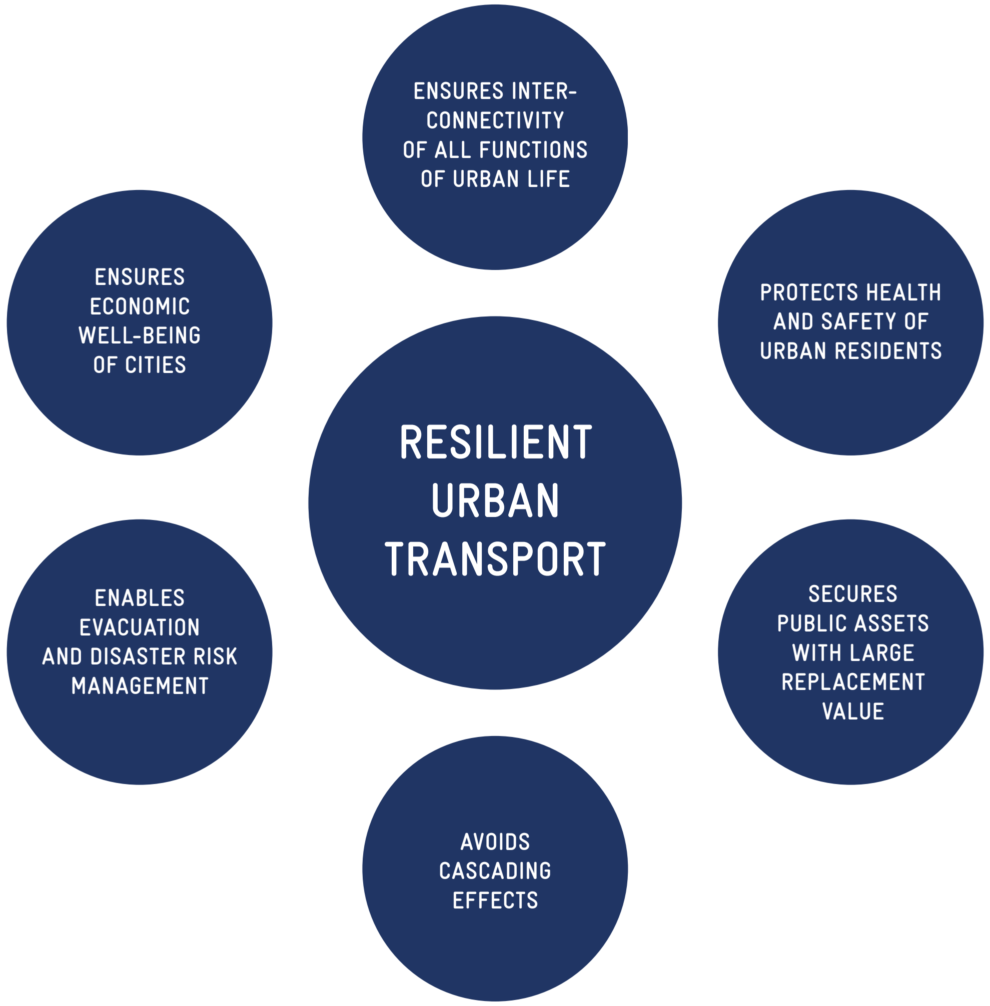
The climate is changing. People are becoming increasingly aware of the potential threats that this is bringing. From floods and droughts to storms and heatwaves, it is evident that our historical weather patterns are already being disrupted, ice caps are melting, and sea-levels are rising. The conditions we have been used to and have historically designed most of our urban developments around, are rapidly becoming a thing of the past. Urban development and design must be able to cope with a changing climate to strive in the future. A climate resilient transport system is the backbone of a sustainable urban life and economy (see figure 1). Our towns and cities must urgently become climate change resilient and adaptive. Working out how best to do this is a challenge.

This sourcebook module is designed to introduce climate adaptation to urban leaders, city departments and other organisations with responsibility for urban transport, along with their engineers, planners, as well as infrastructure and transport service operators. It includes descriptions of climate adaptation approaches, good practices, guidelines and tools for implementing them.

This sourcebook module aims to guide urban transport professionals on how to incorporate climate change considerations into their decisions and how and when to ensure climatic changes are being appropriately factored into transport policy, design and implementation. This includes commissioning external climate services, as well as developing and delivering internal programmes of work.

It is crucial that there is cross-sectoral cooperation between the transport sector and other sectors such as energy and flood management as the interdependencies of modern infrastructure systems means that disruptions can cause major ripple effects across a city. Only cross-sectoral cooperation can achieve long-term climate resilience.

FIGURE 1: WHY ADAPT URBAN TRANSPORT TO CLIMATE CHANGE?



The sourcebook module provides readers with:

Background: A general background on the need to adapt to climate change, an introduction to specific terminology and the role of cities and urban transport policy-makers.

Part I: An overview of what to consider when preparing for adaptation planning and collecting relevant data in urban transport systems.

Part II: An understanding of how to integrate climate risk management steps into transport planning (see figure 2). This includes, how to assess the risks and to respond appropriately using both hard options (e.g. adapting physical infrastructure) and soft options (e.g. adapting planning and risk assessment procedures or nature-based solutions). Part II also provides a suite of good practice examples and available tools.

Information on standard adaptation options for different climate hazards and different modes of transport are provided in the annexes.

This sourcebook module draws on experience from around the world, providing users with pragmatic, informative and effective insights into good practices. It is generally applicable to all modes of transport.

Box 1

KEY CLIMATE RISK MANAGEMENT STEPS

After ISO14090 "Adaptation to climate change — Principles, requirements and guidelines"

Step 1
Pre-planning (assessing needs for starting climate riskmanagement)

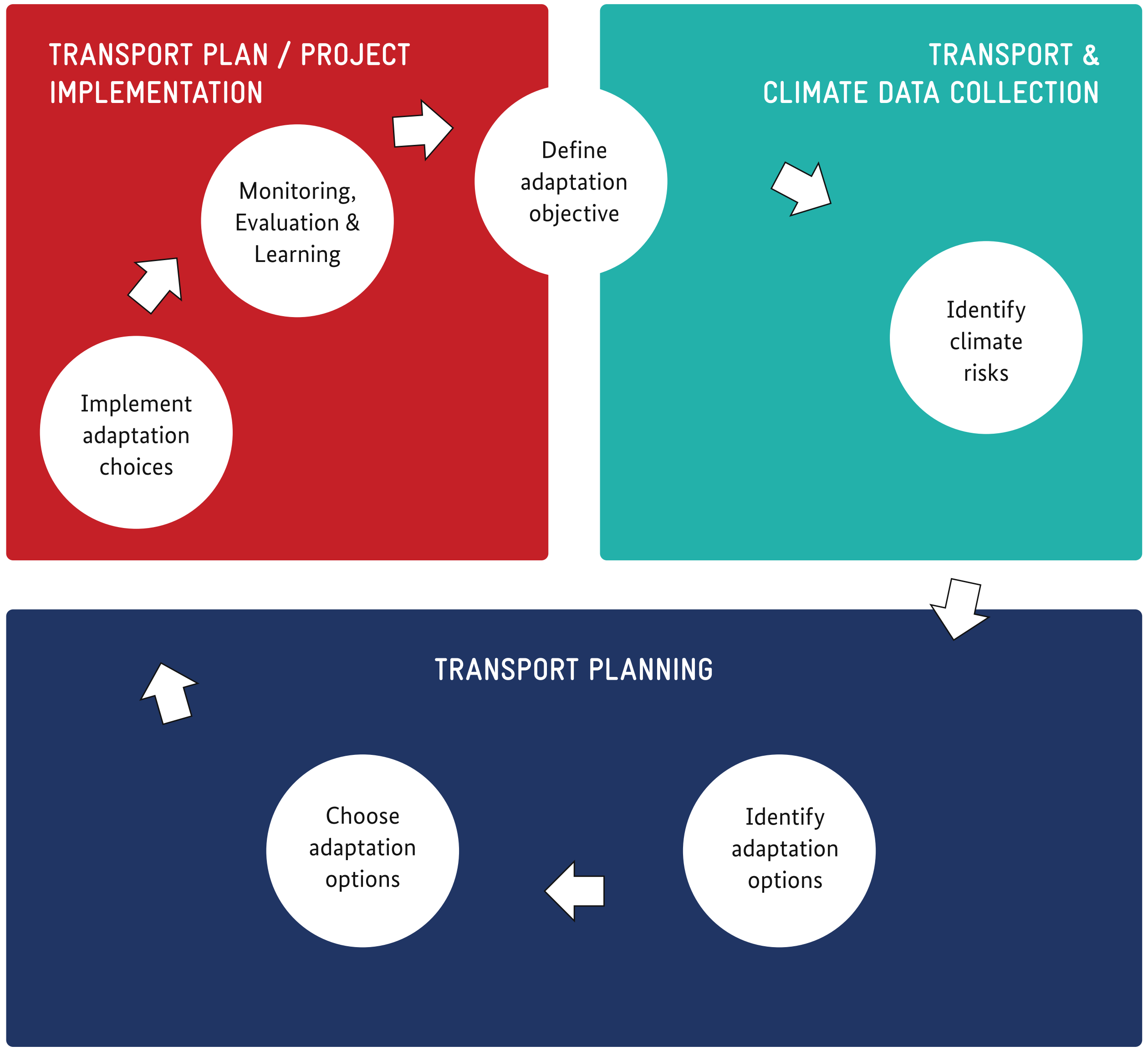
Step 2
Assessing Climate Change Risk

Step 3
Adaptation Planning

Step 4
Adaptation Implementation

Step 5
Monitoring, Evaluation and Learning

FIGURE 2: CLIMATE RISK MANAGEMENT STEPS IN THE TRANSPORT PLANNING CYCLE



2 Background: Adaptation for a changing climate

The speed of human-made climate change is unprecedented. The 2015 Paris Agreement on climate change committed the world's governments to limiting global warming to well below 2°C and pursuing a limit of 1.5 C. The UN Environment Programme in 2019 assessed that "if we rely only on the current climate commitments of the Paris Agreement, temperatures can be expected to rise to 3.2°C this century. Temperatures have already increased 1.1°C, leaving families, homes and communities devastated" (UNEP, 2019). There is currently a clear gap between (planned) actions and targets.

The transport sector needs to rapidly decarbonise from its current 8 GtCO2 globally (IEA, 2021) to become carbon neutral by mid-century in order to achieve the Paris Agreement targets (see for instance ***Enhancing Climate Ambition in Transport*** for action recommendations on how to align transport with the Paris Agreement and the Sustainable Development Agenda).

The consequences of global warming are multifaceted. Sea level rise of 0.2m has already occurred over the last century. The Intergovernmental Panel on Climate Change (IPCC) has issued guidance for an average of 1.1m by 2100 (IPCC 2019), with some governments independently recommending plans for up to 2m (e.g. UKCP18, 2018). The hydrological system is also prone to severe changes induced by global warming. Depending on the region, this can lead to changed annual and/or seasonal water availability, in turn leading to more droughts and/or floods.

More droughts can worsen desertification and increase air-borne dust and sand. The melting of glaciers affects freshwater availability in springs, and more extreme rainfall events (more concentrated rainfalls) will further heighten flood risk. Temperature extremes, i.e. heat waves or cold spells, are expected to occur more and tropical storms are likely to increase in intensity and frequency, posing the risk of storm surges and damages (IPCC, 2019).

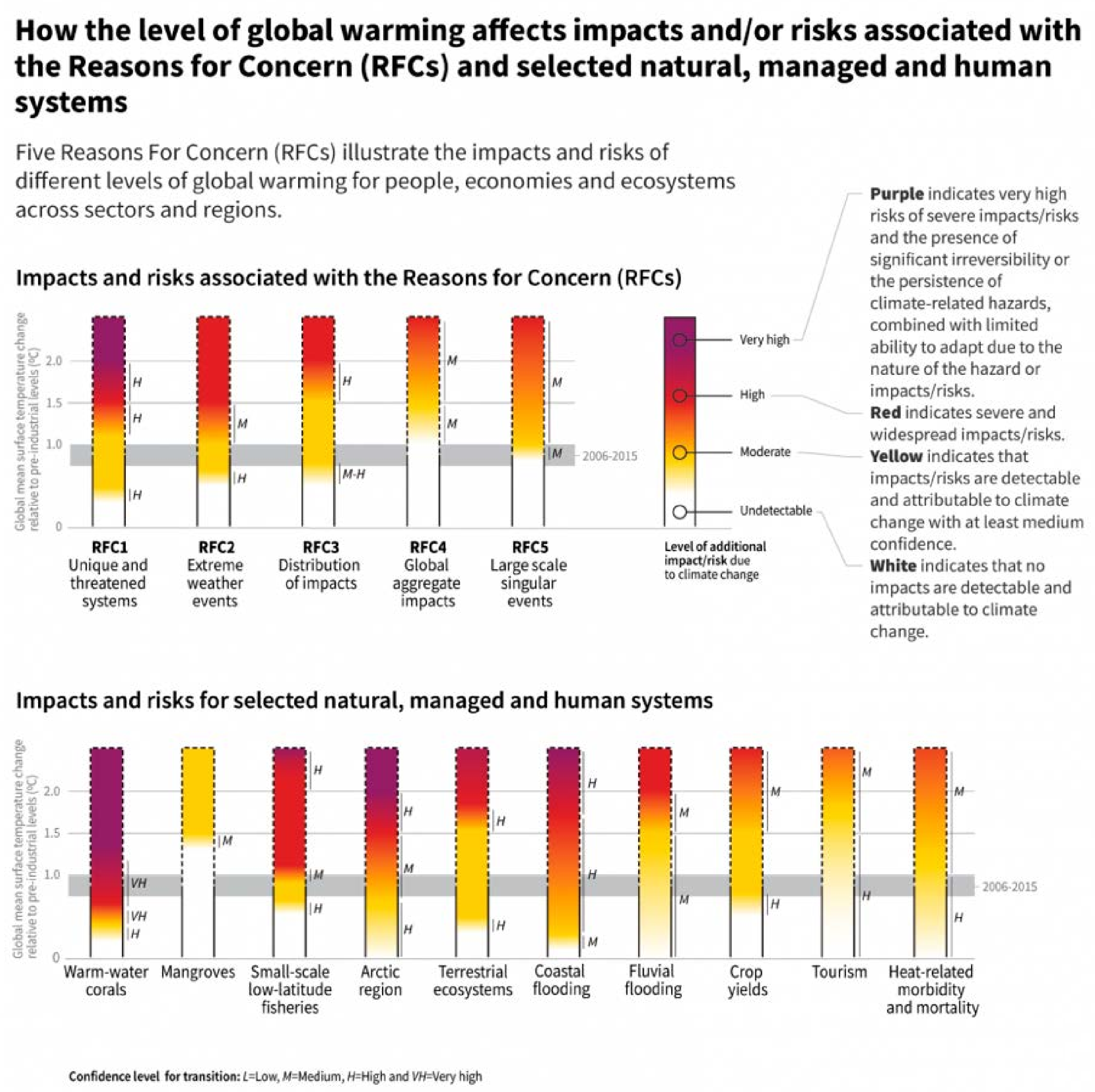
The effects of these natural processes on human activities will vary in extent with the rate of global warming (see figure 3), adaptive capacities and the regional socioeconomic context in general (see section 2.1). Although the impact of regional climate change can be observed on all continents, the countries and cities of the developing world are particularly affected by changes in the physical environment. The ***World Bank Climate Change Knowledge Portal*** provides summaries of expected climate change. Impacts are based on different models and presented on a country-level for the entire world. The data is freely accessible online.[2]

Box 2

SUMMARY OF CLIMATE IMPACTS

- higher temperatures
- more heat waves
- more droughts
- more cold spells
- more extreme rain
- more flooding and extreme floods
- more intense and frequent storms
- sea-level rise
- changed water availability
- melting of glaciers and permafrost

FIGURE 3: REASONS FOR CONCERN (RFC) ABOUT CLIMATE CHANGE



Source: IPCC (2019)

Despite enormous progress in climate predictions, there remains a lack of definitive information about climate change impacts and vulnerability at the local level. Hence, a degree of uncertainty will always remain in planning for adaptation.

The good news is that there are ways of effectively managing this uncertainty and adapting to climate change. There is greater experience in producing planning approaches which enable us to be increasingly climate smart, making better decisions at more appropriate times and reducing the associated cost of acting too early or too late (see Part II for more details).

The benefits of adapting effectively have become much clearer in recent years. The World Bank calculates that in low- and middle-income countries for each USD 1 spent on climate change resilient infrastructure it generates USD 4 of benefits, saving USD 42 trillion (Hallegatte et al., 2019).

Transport planners and engineers are making decisions now which project the impacts of climate change on transport systems, if they are to meet their objectives over their useful life. Otherwise impacts will carry enormous social and economic consequences. The World Bank estimates the costs of direct damage to power generation and transport infrastructure by natural disasters at around t USD 18 billion a year in low- and middle-income countries, which does not include knock-on effects through disrupted infrastructure services (Hallegatte et al., 2019).

Box 3

CASE STUDY – IMPACTS OF CLIMATE CHANGE ON ROAD INFRASTRUCTURE IN VIETNAM

Vietnam's infrastructure is growing rapidly but is expected to be exposed to more extreme precipitation, temperature and flooding in the next decade. Therefore, the additional costs for maintenance could amount to several billion USD (Chinowsky et al. 2015). As a result, Vietnam's adaptation strategy includes the modernisation of meteorological data, integration of climate change into national and provincial policies and plans, as part of the adaptive capacity development to deliver more resilient infrastructure management (Pham et al. 2019). The GIZ project CSI (Enhancing Climate Services for Infrastructure Investments) has been supporting the developments in Vietnam.

Box 4

GENERAL DEFINITIONS

Adaptation
Process of adjustment to actual or expected climate and its effects. Adaptation seeks to moderate or avoid harm or exploit beneficial opportunities.

Hazard
A hazard is a potential source of harm, where harm can be in terms of loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems and environmental resources. Climate hazards comprise slow-onset developments (e.g. rising temperatures over the long term) as well as rapidly developing climatic extremes (e.g. a heatwave or tropical storm) or increased variability.

Exposure
Presence of people, livelihoods, species or ecosystems, environmental functions, services, resources, infrastructure, or economic, social or cultural assets in places and settings that could be affected.

Vulnerability
Vulnerability describes the propensity or predisposition to be adversely affected, depending on the sensitivity of the system and its ability to cope with a hazard. Strengthening adaptive capacity can reduce vulnerability.

Adaptive capacity
Ability of systems, institutions, humans, and other organisms to adjust to (and thereby limit or avoid) potential damage, to take advantage of opportunities, or to respond to consequences.

Resilience
Ability of an organisation or a system to resist being affected by disruptions, in this case by climate hazards.

Source: Based on ISO 14091

2.1 What affects the level and severity of climate impacts?

The risk that climate change poses to urban transport infrastructure or service is the combined effect of three things[3]:

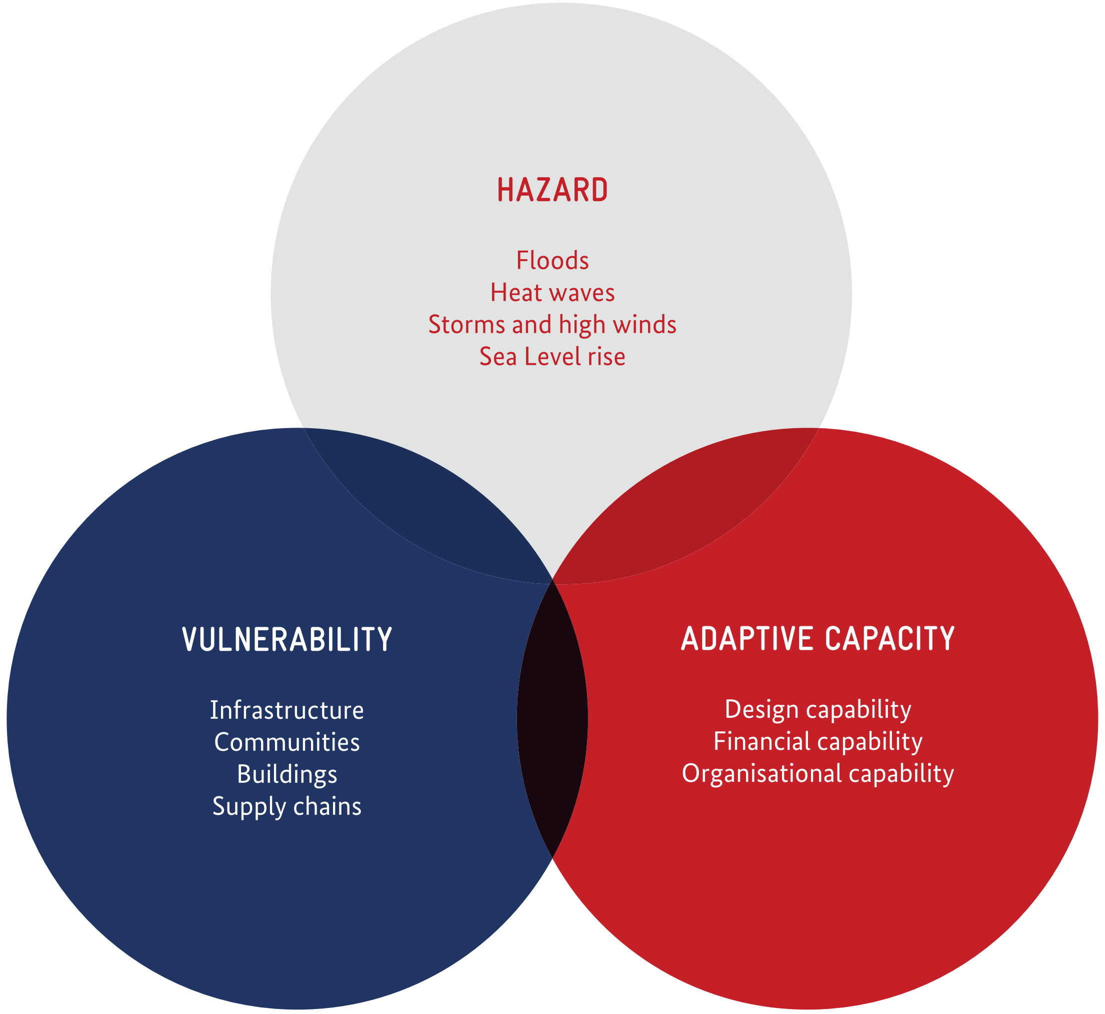
1. Hazard: the climate changes that are the drivers of climate risk, e.g. increased flooding disrupting traffic; extreme temperatures requiring slower rail speeds and sea level rise requiring relocation and so making transport infrastructure redundant.

2. Vulnerability: the degree to which the transport system will be affected by the hazard(s), e.g. the same flooding event may cause severe disruption in some places but not others, depending on the sensitivity of the system and its ability to cope with the hazard (see box 5).

3. Adaptive capacity: the ability of the transport planning and governance systems to reduce disruption to the transport system over its useful life and possibly take opportunities presented by the changing climate, e.g. a low adaptive capacity organisation will expose themselves to higher climate risk than a high capacity organisation with the same hazards.

[3] Climate risk can be defined in a number of ways. The driver of risk in all cases is the changing climate "Hazard" e.g. more frequent and extreme hot days, intense rainfall, different seasonal patterns or sea level rise. Vulnerability in this definition of climate risk equates to "Potential Impact" in the IPCC's definition. The IPCC's components of Potential Impact are the exposure to the hazard and sensitivity to that hazard (see Box 5). What the actual impact is depends on the Adaptive Capacity of the organisation(s) whose decisions affect the outcomes of a climate change event. The higher the adaptive capacity, the lower the actual impact because they are more able to reduce the vulnerability/potential impact.

FIGURE 4: COMPONENTS OF CLIMATE RISK



Source: ISO 14091

Box 5

UNDERSTANDING TERMINOLOGY – EXAMPLE OF A METRO SYSTEM

The **vulnerability** of an underground railway system to the hazard of increasing flooding depends on:

- The **exposure** of the system to flooding, e.g. once every 5 years or several times a year;
- The **sensitivity** of the system to flooding, e.g. how quickly in a flood event does the system experience delays or total disruption of services when flood water reaches a certain level and how quickly can the system recover. In a changing climate, how does the sensitivity change at different levels and frequency of flooding; and
- The **adaptive capacity** of local service providers and their physical infrastructure to cope with the floods as exposure increases with climate change e.g. through an early warning and an adequate pumping system until that is no longer enough and being able to stop and implement additional measures to keep the system running as exposure increases.

A climate resilient transport system indicates the capacity of the system to maintain its core functions in the face of a hazard, i.e. ensuring serviceability and avoiding damage or loss of infrastructure assets. In the urban transport context, climate resilience is a product of city authorities, enterprises, groups in society and individuals with a strong adaptive capacity, i.e. to anticipate climate impacts and to plan for and implement adaptation options.

How to apply the framework for assessing climate risk will be elaborated in more detail in Part II.

2.2 The role of cities and urban transport policy-makers

In 2020, 56% of the world's population was living in urban areas (Statista, 2021). With high population and infrastructure densities as well as concentrated economic activity, cities are particularly exposed to the impacts of climate change. Moreover, urban growth is concentrated in the present mega-cities, many of which are in coastal and delta areas, especially in Asia. Coastal cities are especially vulnerable to sea-level rise and increasing storm activity, intensifying the need to adapt.

As the proportion of the world's population living in urban areas grows to nearly 70% by 2040 (Oxford Economics, 2014), and investments are made to expand transport systems and make transport greener, annual spending on transport infrastructure is likely to exceed USD 900 billion (PwC, 2015). How well adapted these investments are to climate change over their useful life will have a significant impact on how well urban communities are served by their transport systems over that time.

This leads to important considerations and consequences for those who run transport systems and services in a city. In many territories, mayors and directors of public authorities have a 'duty of care and due diligence'. Climate change is now seen as a risk that is both capable of causing harm and in legal terms is deemed 'reasonably foreseeable' (i.e. there is an obligation to act). Senior management must consider the impact on their operations as failure to do so can potentially bring liability for future losses (Hutley and Hartford-Davis, 2016).

In addition, maladaptation, i.e. developments that increase the vulnerability of cities by ignoring climate change implications, such as allowing new developments on flood plains or reducing provisions for non-motorised transport, must be avoided.

Adaptation cannot be viewed in isolation

In order to create sustainable transport systems and address climate change, urban policy- and decision-makers are tasked to plan and design their systems to cater for the mobility demands of all urban transport users, including the poor and vulnerable, under changing climatic conditions. At the same time, urban transport systems must be redesigned to become carbon-neutral by mid-century.

Adaptation measures go hand in hand with mitigation measures. Adaptation measures are required to ensure transport infrastructure and its use remain sustainable

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and functional to the changing climate. Long-term mitigation actions (e.g. the design and location of an electric rail route) need to ensure they can remain climate change resilient over their full lifecycle.

This is particularly relevant since many developing cities are still undergoing (rapid) growth, providing a unique opportunity to put in place climate-proof urban systems that are both resilient and as low-carbon as possible. The need to address both the adaptation and mitigation agendas simultaneously is remarkably evident in urban transport decisions. Reducing emissions by increasing access and use of low-carbon modes of transport (e.g. electric trams, improved cycling and walking routes, electric buses, etc.), for example, needs to be supported by a transport infrastructure that remains resilient to a changing climate. Significant synergies exist e.g. in transport and urban planning that reduces the need for the number of trips and the length of trips – reducing emissions and exposure at the same time.

Nonetheless, adaptation responses are often significantly different from mitigation actions, and so while this sourcebook at times refers to both agendas, it does so from the perspective of adaptation/resilience.

Box 6

WHY IS URBAN TRANSPORT VULNERABLE TO CLIMATE CHANGE

Urban transport is vulnerable to climate change because it entails key decisions and developments that are expensive, and / or difficult to reverse, with lifespans of 10 years or more and which therefore need to manage the impact of a changing climate e.g. heat, precipitation or flood.

The rate of climate change makes it probable that over the life of these decisions, climate risk will go beyond the tolerance of systems designed for the current climate. The risk of unacceptable disruption to transport and / or costly retrofitting works then become significant. In extreme cases, the transport system may become unviable.

We know that the climate is changing. These disruptions are unnecessary. Effective climate adaptation makes them unlikely.

To be considered as climate change resilient, the transport system must:

1. Be operated by organisations which are themselves adaptive and embed the capacity for adaptation in all their functions, not just asset management.

2. Understand the range of current and future weather conditions which will affect it and have operational and management strategies in place which enable it to respond both in the present and over time to climate challenges.

3. Account for how climate change may affect its range of operating conditions over time and be evolving its operating and management strategies before it can be harmed by the climate.

4. Remain adaptive to climate change as part of business-as-usual so as to work towards the cost of adaptation having only marginal impact on financial performance.

A resilient urban transport system therefore has the capacity to do three things which together enable it to continue to deliver its service objectives; 1) anticipate its climate risks, 2) adapt what is changeable and 3) withstand inevitable impacts.

To maximise resilience, adaptation activities should be integrated with other sectors, especially with urban planning. **Transport decision-makers and city planners are in the driver's seat of stimulating a climate proof, inclusive and sustainable urban transport development.**

Box 7

SOURCES OF INFORMATION ON EFFECTIVE CLIMATE ADAPTATION

The World Road Association (PIARC) has gathered ***examples of good climate adaptation practice*** in the roads sector and an approach for delivering the overarching lessons into a document "Adaptation methodologies and strategies to increase the resilience of roads to climate change"

The World Association for Waterborne Transport Infrastructure (PIANC) has gathered ***examples of good climate adaptation practice in the ports*** and inland waterways sector and an approach for delivering the overarching lessons into a document "Climate Change Adaptation Planning for Ports and Inland Waterways".

The International Union Of Railways (UIC) has studied climate adaptation challenges and effective responses for the worldwide rail sector. It has presented it's findings in the report: "***Rail Adapt: Adapting the railway for the future***".

The European aviation sector body Eurocontrol has gathered examples of good climate adaptation practice in the aviation sector: "***Adapting aviation to a changing climate***".

Impacts and adaptation needs differ between countries and regions and hence scenarios will have to be developed for particular cities on an individual basis. To be able to do so, specific climate information on a regional or local level is needed. Where and how to access such information is explained in GIZ's ***Practitioner's Manual Climate Change Information for Effective Adaptation (2008)***. The manual, which is still valid today, also provides a more detailed background of basic climate change science and is a good entry point for an overview of how to gather and interpret relevant climate data.

For a more detailed source of methodology for infrastructure climate risk assessment, a report by GIZ's "***Enhancing Climate Services for Infrastructure Investments***" (CSI) explains how to use the flexible PIEVC protocol developed by Engineers Canada for climate risk assessments of infrastructures, including procedures, quantities, and costs.

Several more relevant publications of the CSI project can be found at the "***product landscape***" page, including training manuals and country-specific experiences from Costa Rica, Vietnam, and Brazil.

The UK's Rail Safety and Standards Board (RSSB) has produced a ***Risk Analysis and the Safety Risk Model*** on the biggest climate hazards to rail systems (looking at all types of hazards).

The United Nations Conference on Trade and Development (UNCTAD) has an Ad Hoc Expert Meeting on Climate Change Adaptation for International Transport: Preparing for the Future which provides numerous ***presentations and resources*** on transport resilience across all modes of transport.

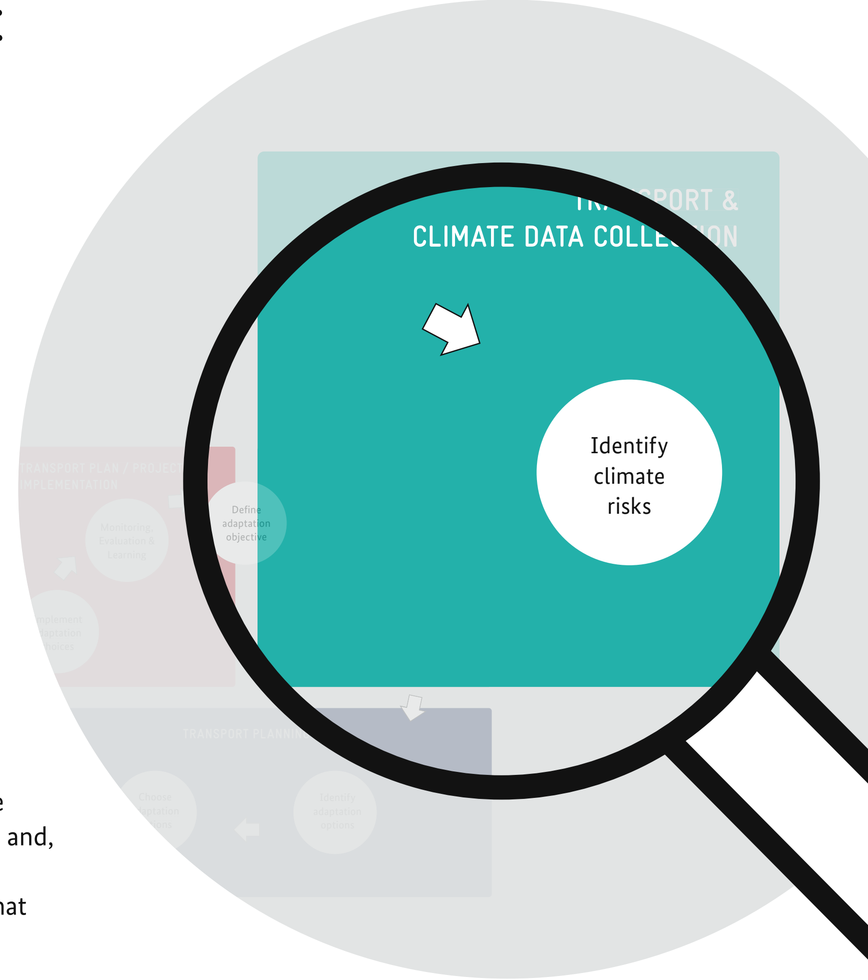
IsDB Climate Change Knowledge Hub (CCKH) is a dynamic, curated, online repository of national level climate action information for IsDB's 57 Member Countries. The portal collects and connects dispersed sources of information from multiple partners in a map-based, interactive interface. It is suitable to Member Country practitioners as well as development partners to access information on NDC and SDG implementation, climate finance and relevant national policies, strategies and development plans. The platform also contains a repository of free, e-learning resources on climate related issues: ***https://cckh.weadapt.org/placemarks/isdb-maps.***

3 Part I: Preparing for adaptation planning in transport

3.1 Making climate resilience a reality in transport planning

Action to respond to a changing climate cannot be guaranteed unless multiple factors are developed in combination. Contrary to popular belief, the production of data, information and new technologies does not necessarily lead to raised awareness, nor does raised awareness necessarily lead to meaningful action. Actions on climate change are a combination of:

- data;
- information;
- technological solutions;
- awareness about the risks faced and the availability of opportunities to respond; and,
- the governance and social behaviours that stimulate and support action.



Developing the ability to do new things, as well as identifying what new things to do, is key (see box 8 for a case study from Costa Rica).

Box 8

CASE STUDY - CLIMATE RISK ASSESSMENT OF THE RÍO TEMPISQUE BRIDGE IN COSTA RICA

In 2020, the multidisciplinary team of the GIZ project "Enhancing climate services for infrastructure investment (CSI)" conducted an extensive climate risk assessment of the Río Tempisque bridge in Gauncacaste, Costa, Rica using the PIEVC Protocol. The PIEVC Protocol has been developed by Engineers Canada as a flexible tool to evaluate climate risks in different circumstances. A detailed overview of the methodology and information on procedures, quantities and costs are provided in GIZ (2019). The report provides decision-makers with useful information on making bridges climate-resilient.

The Río Tempisque Bridge. Source: GIZ

To identify the most suitable infrastructural development for the study, different criteria were used: (1) availability of climatological information, (2) construction characteristics, and (3) socio-economic, political and geographic criteria. For instance, the authors reviewed several databases, weather bulletins, and even social media. Moreover, extreme weather events and heir resulting precipitation, wind strengths and temperatures were analysed. To determine risk factors, assessment criteria were developed, ranging from 0 (no effect) to 7 (catastrophic). In the end, the research proved that the bridge in question is of high standard and has withstood many extreme events. Yet potential users may be cut off during flooding. Another outcome of the risk assessment was the successful capacity building regarding climate-relevant thinking among personnel of public institutions involved, which will be useful in future assessments.

Key recommendations for climate risk assessment of bridges include:

1. Reviewing infrastructure operation and maintenance policies and their potential costs;
2. Improving monitoring and evaluation by developing certain maintenance tools;
3. Identifying wind or storm hazards such as trees;
4. Improving access to climate information and services to collect useful data;
5. Conducting hydrological-hydraulic studies of close waters to assess potential flood risks;
6. Coordinating with all stakeholders;
7. Reviewing and adapting drainage systems to heavy rainfall;
8. Raising awareness among responsible entities of climate-friendly land-use; and
9. Adapting risk assessment protocols to local circumstances.

Sources and further reading:
GIZ (2020). Evaluación de riesgo de la infraestructura ante el cambio climático.

3.2 The challenges and opportunities of creating a climate resilient transport sector: considerations when pre-planning and assessing climate change impacts

Before embarking on climate adaptation planning for a resilient transport system, it is important to consider that the approach to climate impact management requires new behaviour and processes compared to the current status quo of transport planning.

3.2.1 Managing changes in extreme weather - weather data is no longer sufficient

There are two broad categories of climate hazard:

1. Long term trends such as sea level rise and changing average temperatures

2. Extreme events such as floods, storms, heatwaves, landslides and droughts

Transport planners and operators are used to considering the impact of extreme weather events, such as heavy rains. Transport infrastructure is constructed under design standards that consider very specific temperature and precipitation ranges and return intervals for extreme events, such as floods and extreme heat. While this may be true for a certain time period, it is now becoming far less likely over the useful life of an infrastructure investment (especially with long lifespans investments such as bridges, routes, design and location of ports, etc.). Useful lives can be, and often are, far longer than design lives. In climate adaptation full asset lifecycles therefore need to be considered.

The ability to anticipate the emergence or greater frequency of hazards that are not already present requires new ways of thinking and new types of information.

If urban transport planners continue to abide by "business-as-usual" approaches, they will be negatively impacted by climate change risks. For example, recent work in Europe has highlighted that many current standardized approaches for factoring extreme weather parameters into transport infrastructure design are still applying historical weather data that is already out of date. The climate has already changed so much in the past two decades that historical weather data no longer reflects current climate risk, let alone the way climate risks will change over the useful life of a transport system.

It is crucial that scenarios of climate change and their implications for average and extreme temperatures and precipitation, as well as the likely frequency of extreme events in the future need to be accounted for and implemented in all stages of design and implementation.

Infrastructure construction and management standards need to be revised to add future proofing transport systems against climate change impacts. In the EU this revision has already begun e.g. with the revision of EU asset management standards (CEN 2020). These revised standards consider resilience to both long onset climate changes and increasing frequency and intensity of extreme events.

Box 9

CASE STUDY – HEAVY RAINFALL DESTROYING INFRASTRUCTURE IN ST LUCIA (UNCTAD, 2017)

The island state St Lucia is not only exposed to the hazard of rising sea levels but also extreme weather events. In 2010, Hurricane Tomas severely hit St Lucia, causing flooding and landslides. Fixing the damages to bridges and road infrastructure were estimated to cost over USD 52 million. Moreover, the resulted landslides were responsible for the most of the seven deaths which occurred in relation to the event. As the intensity of hurricanes is projected to further increase as well as the occurrence of heavy rainfall, improved sturdiness and persistence of the road transport network are required.

Source: Colin Lloyd / Unsplash

3.2.2 Turning information into action

We have known for many years that the impacts which climate change brings will grow in frequency, scale and magnitude for decades to come. There is a wealth of data available which is being updated all the time.

The majority of public transport operators, port operators, road authorities and railway companies have not yet developed the awarness and/or capacity to make sense of climate data. They are also yet to develop the capacity to respond effectively if they are able to interpret the data.

The good news is that there are already numerous examples of best practice that can be scaled up. For instance, ISO14090 "Adaptation to climate change — Principles, requirements and guidelines" (ISO 2019) has consolidated internationally agreed best practices to guide effective adaptation.

Box 10

CASE STUDY – ELEVATION OF CAUSEWAY AT TERMINAL MARITIMO MUELLES EL BOSQUE (MEB) IN COLOMBIA

An extensive study conducted by Stenek et al. (2011) provided information on costs related to adaptation. Whilst there were gaps in the information available, it demonstrated that the cost of raising the causeway by 20cm is relatively low (USD 380,000) compared to the potential costs of flooding by 2030 (USD 2,040,000). This approach may be applied to other cases while keeping geographical differences in mind.

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For those developing a climate adaptation plan, the required planning process in ISO 14090 is made more effective if it considers the following in a pre-planning considerations:

- Expertise and knowledge
- Strategic decisions
- Leadership and broader governance
- Roles & responsibilities
- Human resources
- Financial resources
- Interested parties/stakeholders

Expertise and knowledge: How an organisation views its climate vulnerability is a product of its available knowledge and expertise. It is important therefore to understand what climate change knowledge and expertise your organisation has access to (either internally with staff, or externally with partners and contractors).

Strategic decisions: Not all decisions need to consider adaptation to climate change. Identifying which decisions are vulnerable to a changing climate is therefore important. These are often the decisions whose outcomes are difficult or very expensive to reverse and have the longer lifespans (e.g. a bridge, a new transport route, or location of transport hub).

Leadership and broader governance: The extent of adaptation possible in an organisation is directly affected by leadership behaviours and governance processes. It is essential therefore to ensure that leadership and governance creates the best working environment for employees to identify and take advantage of opportunities and to address risks. This means that leaders need to be seen as strong advocates of the agenda and stay close to innovation and delivery.

Roles & responsibilities: If nobody has responsibility for adapting to climate change, action will be limited. A useful pre-planning activity is to understand how the roles and responsibilities in an organisation would allow climate adaptation policy to be effectively turned into operations.

Human resources: Delivery of meaningful actions requires sufficient human resources, which includes the the correct training and skills available to address the organisation's climate challenges. This includes ensuring adequate allocation of time.

Financial resources: The financial resources made available need to meet the level of challenge being addressed. It is not possible to do everything, and so it is important to understand where change will have optimum impact. Cost-benefit type analysis are useful here. Pre-planning can identify what financial resources are available to address climate risks and opportunities, and prioritisation processes can be used to determine which to proceed with.

Interested parties/stakeholders: It is important to understand which stakeholders influence the organisation's adaptation, and what capacity you have to support and influence them. This ensures that decisions enable effective adaptation.

These pre-planning measures help establish a baseline understanding of the current capacity of the organisation to address its climate risks. With that understanding, planners can effectively move through the following steps in this sourcebook to understand; what capacity the organisations needs, the strengths and opportunities it already has to adapt, and how to efficiently move towards developing all the capacities it needs.

Adaptation actions tend to be most effective and efficient when climate change is integrated early on in the decision-making process. It is harder and usually far more expensive to respond to climate change information if it is an afterthought. Making these pre-planning assessments in an early decision-making process will help gain the opportunities for effective and efficient adaptation. Early adaptation also makes it easier to spot and take opportunities that climate change can offer.

Box 11

CASE STUDY – LOCAL MATERIALS TO ADAPT LOW VOLUME ROADS IN TANZANIA

The gravel roads of Bagomoyo District in Tanzania are damaged by flooding and heavy rainfall. The District invested in a new paving system. The material is not suited for a high number of heavy vehicles but the District's roads are not heavily used. The materials are waterresistant, locally sourced, produced, and cheaper than the recommended upgrade for heavily trafficked highways. After monitoring, the intervention was successful and the method may be adapted by other countries in Sub-Saharan Africa (Masters, 2014; AFCAP, 2013).

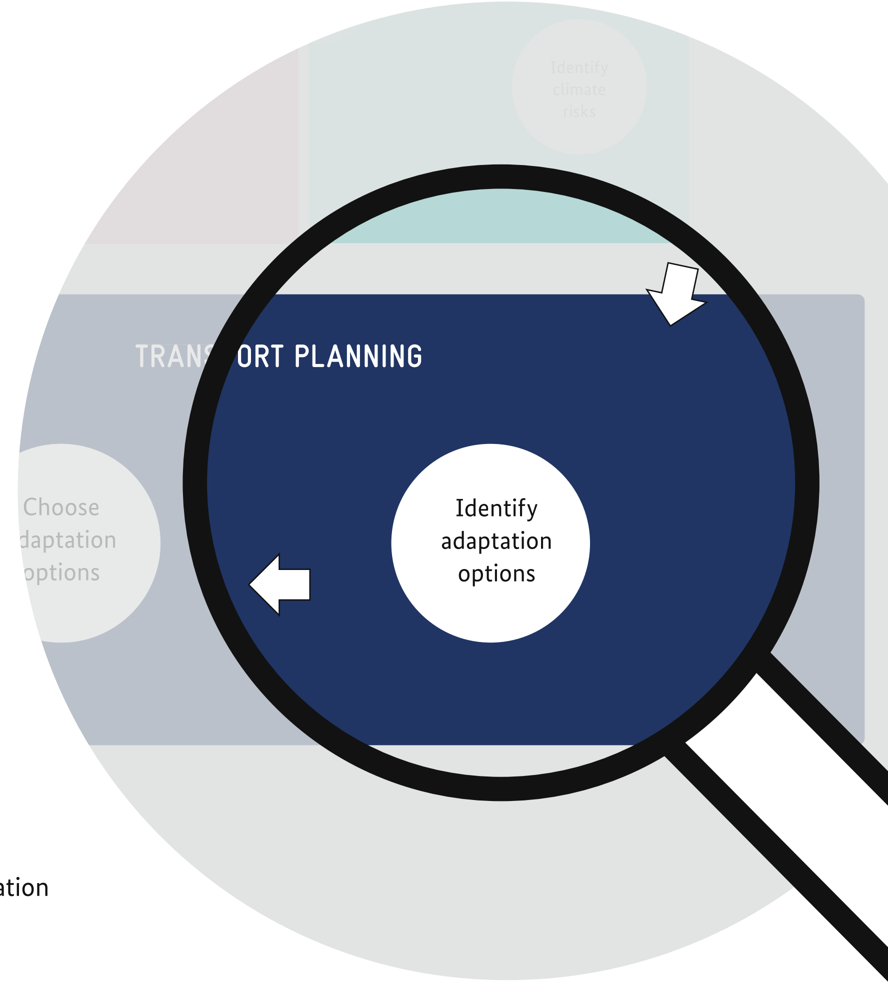
Source: Maters (2014)

3.2.3 Opportunities

Climate change can also bring new opportunities to create sustainable transport systems. For example:

- Longer dry periods can be an opportunity to encourage more people to cycle or walk rather than drive and therefore reduce emissions and improve people's health
- In urban settings, the expectation of more intense rainfall events means that conventional convex road structures that move water to the edge of the road can overwhelm the drainage system and push water toward properties, so increasing the risk of flood damage in those properties. In Scandinavia, there has been much success in making road surfaces concave. With the centre of the road lower than the edges, they have been successful in turning the roads themselves into a drain and move the water away from built up areas, so reducing surface water flood risk
- Natural flood management systems for reducing flood risk to transport infrastructure can be an opportunity to make attractive water features that improve well-being, biodiversity and even neighbouring property values
- Adaptation can also create opportunities for other useful activities e.g. upgrading the size of culverts to manage increased flood water capacity can provide opportunity to upgrade other parts of the infrastructure around it
- By better understanding the decision-making landscape, we can pinpoint when the opportunities to include adaptation to climate change become possible. (See box 7 above and section 5.2.1.2 below).

4 Part II: Step-by-step guide to incorporating adaptation planning in the transport sector



This section considers the different components of climate impact and managing associated risks in order to integrate adaptation planning into transport planning and implementation. It considers:

- how to plan for effective adaptation once climate risk is understood;
- key considerations during implementation of the plan;
- linkages with transport planning and operations through various case studies;
- elements of effective Monitoring, Evaluation and Learning (MEL) frameworks for enabling effective learning and,
- where necessary, identifying corrective actions.

This section also identifies guidelines and useful tools that support implementation of these steps.

4.1 Risk assessment

The components of risk were already introduced in chapter 2.1. Based on this conceptual framework, effective adaptation planning identifies:

1. The current climate hazard, vulnerability and adaptive capacity;
2. The level and nature of change in climate hazard and vulnerability that needs to be managed over the useful life of the transport system;
3. The adaptive capacity required to manage the anticipated hazard and vulnerability.

Understanding the causal structure of risk and its root causes is essential for identifying adaptation options. When analysing vulnerabilities, climate impacts on transport can be distinguished between 1) impacts on transport infrastructure and rolling stock, 2) impacts on operations and services and finally 3) impacts on mobility behaviour (of citizens), which also needs to be considered when planning for sustainable transport systems and operation. For example, increasing temperatures can impact mode-choice away from cycling or buses without air conditioning or shaded bus stops. Providing comfort in active transport under changing climatic conditions is therefore an important element of climate-resilient urban transport.

In order to illustrate the decision-making approach from hazard identification to vulnerability assessment and identification of adaptation options, figure 5 summarises the elements to consider in the case of urban mass transport with increasing storms, run-off, erosion and flooding. Additional, illustrations for other modes and infrastructure are provided in Annex A (see also box 8).

Box 12

DECISION TREES FOR URBAN TRANSPORT ADAPTATION

Building on the 1st edition of this sourcebook and on the basis of an internal IsDB adaptation guidance note, the decision tree in figure 5, as well as additional decision trees in Annex A, summarise the vulnerabilities of different transport modes and infrastructure to relevant climate hazards and identify consequent adaptation options. The decision trees cover:

- Urban mass transit for hazards:
  - Increasing storms, run-off, erosion and flooding
  - increased temperature & drought with decreasing precipitation
- Roads & cycle ways for hazards:
  - Storms, sea-level rise, run-off, erosion and flooding
  - Increased temperature & drought with decreasing precipitation
- Rail & tram ways for hazards:
  - Storms, sea-level rise, run-off, erosion and flooding
  - Increased temperature & drought with decreasing precipitation
- Port projects for hazards:
  - Storms, run-off, erosion and flooding
  - Increased temperature & drought with decreasing precipitation

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Module 5f: Adapting Urban Transport to Climate Change

FIGURE 5: DECISION TREE FOR URBAN MASS TRANSIT PROJECTS: STORMS, RUN-OFF, EROSION & FLOODS (PAGE 1)

CLIMATE HAZARD

- Increasing frequency and magnitude of storms
- Rising sea levels and increased storm surge heights
- Increasing precipitation or frequency of extreme precipitation events

SYSTEM IMPACTS

- Strong winds or lightning associated with more intense storms
- Stronger wave action and increased coastal erosion
- Increased run-off and erosion
- Increased flood risk

PROJECT VULNERABILITIES

- Potential service disruption if winds leave trees or other storm debris on tracks or roads
- Reduced stability of tracks or road bases due to erosion may require speed restrictions, which increase travel times, or temporary suspension of service
- Potential safety risk and temporary loss of service if land-/mudslides damage tracks or roads or make them temporarily impassable
- Damage to electrical equipment and power outages may disrupt service, tram stops, trams and tram storage
- Flood damage to under-ground transit systems, including subway stops, trams, and tunnels, may disrupt transit service
- Increased weather-related traffic accidents; traffic disruption, and congestion
- Damage to rail stations, bus stops, rolling stock, buses, bus storage lots, tram stops, trams and tram storage and maintenance facilities
- Temporary loss of service and/or inability to access transit until flooding subsides and related cleanup andrepairs are completed

ADAPTATION OPTIONS

General:

- ✓ Enhanced inspection and maintenance regimes
- ✓ Build back better if impacted and in-crease resilience at asset renewal stage

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- ✓ Construct strategic wind breaks
- ✓ Design railor roadside Frastructure and overhead lines to withstand higher wind speeds
- ✓ Improve weather forecasting capacity and implement early warning systems
- ✓ Implement system to proactively manage vegetation and debris near right-of-way

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- ✓ Avoid high-risk areas in routing new transit service; reroute existing bus service away from high-risk areas
- ✓ Consider a wide range of transit options (e.g. water taxis and ferries, cable cars, ride-hailing systems, and connectivity through informal modes, etc.) to create redundancy and provide temporary alternative transit options during service disruption
- ✓ Implement erosion control measures
- ✓ Construct green infrastructure near right-of-way to reduce run-off
- ✓ For wave-induced erosion, build new or enhance existing breakwaters and sea walls
- ✓ Develop and implement improved methods of detecting subgrade erosion
- ✓ Stabilize slopes using physical support structures (e.g. various types of retaining walls) and vegetative reinforcement
- ✓ Cut back steep slopes to a safer, shallower angle
- ✓ Improve slope and subgrade drainage
- ✓ Introduce hydraulic binding agents into earthwork material

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- ✓ Elevate and protect signaling and other electrical equipment
- ✓ Deploy mobile power supply substations to be used in case of power outages
- ✓ Increase redundancy in electrical systems
- ✓ Develop contingency plans for electricity disruption
- ✓ Consider a wide range of transit options to create redundancy and provide temporary alternative transit options during service disruption

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- ✓ Install and maintain emergency pumping capacity to evacuate water from underground transit systems and tunnels; enhance pumping capacity; deploy mobile pumps during intense rains
- ✓ Couple increased pumping capacity with passive rainwater evacuation and management systems
- ✓ Increase flood protections around and/or elevate transit stop entrances
- ✓ Use mobile barriers to prevent water from entering tunnels and underground transit systems
- ✓ Raise sidewalk-level ventilation grates so that water doesn't enter underground systems from flooded sidewalks
- ✓ Develop emergency management plans, including passenger evacuation plans for underground systems
- ✓ Upgrade transit tunnel lining to prevent groundwater infiltration

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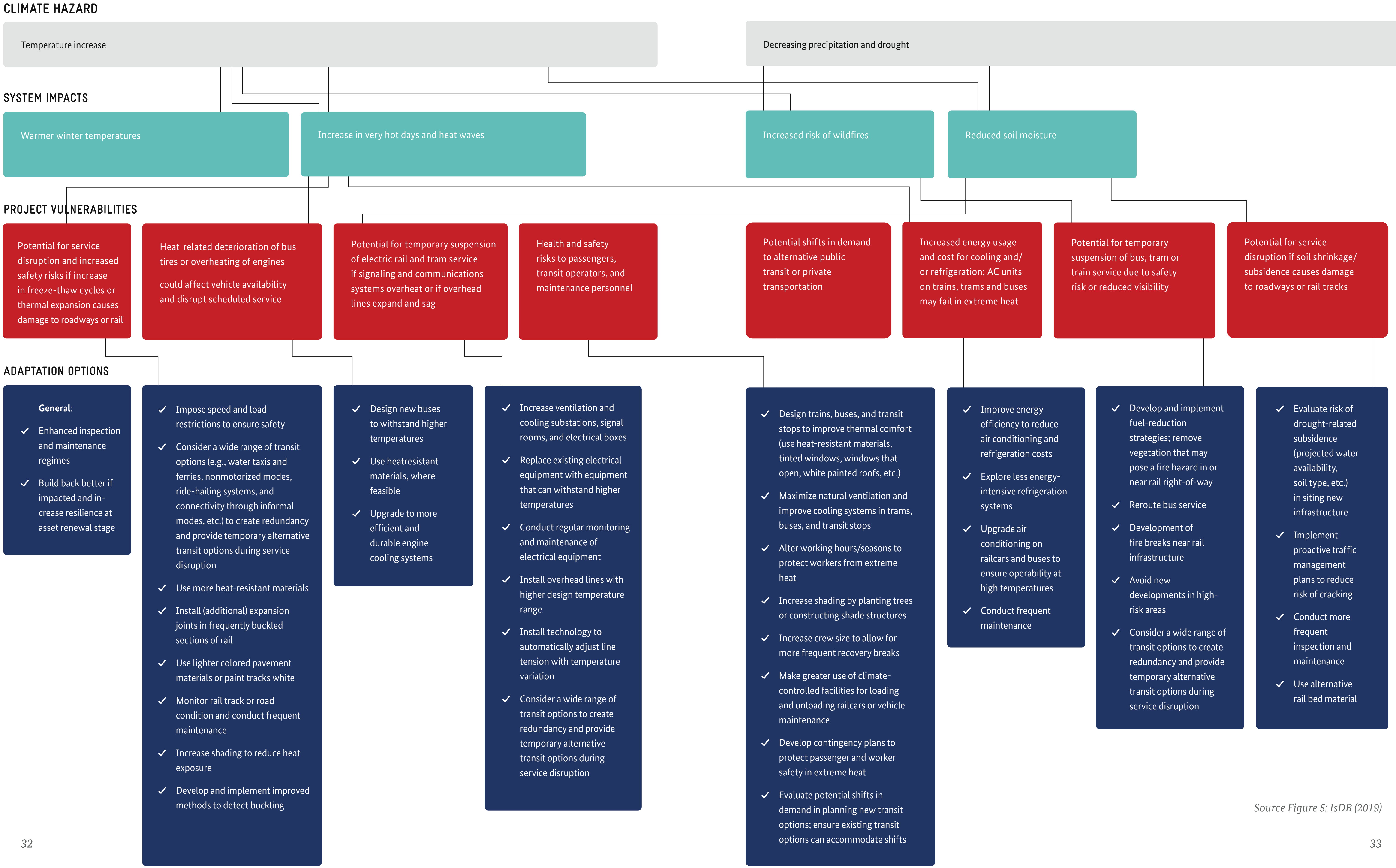
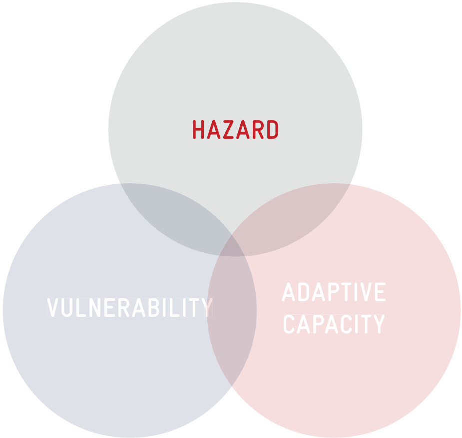
- ✓ Consider projected flood risk in routing new transit service and in siting associated facilities, including storage and maintenance facilities and transit stops; reroute existing bus service to avoid high-risk areas; relocate existing facilities away from high-risk areas
- ✓ Incorporate flood risk into design of stormwater management and drainage systems; retrofit existing systems to deal withincreased run-off
- ✓ Install flood-proofing measures (e.g. barriers, gates, shutters) at transit stations and enhance flood protections near right-of-way and around associated facilities
- ✓ Elevate road and railway infrastructure
- ✓ Increase water-retention capacity; use green infrastructure to divert ru-noff/increase infiltration Ensure safe, paved last-mile access to transit stations, including by nonmotorized modes
- ✓ Consider a wide range of transit options to create redundancy and provide temporary alternative transit options during service disruption
- ✓ Improve weather forecasting capacity and implement early warning systems
- ✓ Conduct frequent maintenance of drainage infrastructure

FIGURE 5: DECISION TREE FOR URBAN MASS TRANSIT PROJECTS: WARMER TEMPERATURES, HEAT, WILDFIRES, SOIL MOISTURE (PAGE 2)



Source Figure 5: IsDB (2019)

4.1.1 Hazard assessment



Hazard data often gives ranges of hazards from low to high case scenarios. The data available varies widely throughout the world, with useful guidance often included in National Adaptation Plans, where available. Box 13 provides information on tools that allow city officials and transport planners to conduct climate hazard assessments.

For those that do not have access to climate change data, it can be valuable to begin with an impact assessment based upon historical climate trends. The first step in adaptation planning is to assess the vulnerabilities to the current climate. When historical data is understood it is advisable to conduct a preliminary, rapid assessment of the key climate changes that urban transport can be vulnerable to (see box 2 for a summary of possible climate impacts).

Transport planners and managers have to make decisions and take actions despite 'significant uncertainty' about the precise nature of the hazard that their transport system will experience. With the assessment and planning tools available, coupled with the existing.

It is good practice to consider potential climate hazards from low to high case scenarios (RCP8.5 is a common high case scenario to consider, see Box 15). By using the adaptation pathways approach (see section 4.2.1.6 below), plans can be identified and constructed to be able to effectively manage this level of risk. Having a clear line of sight to these options through planning is an important element of climate adaptation.

Box 13

HAZARD ASSESSMENT TOOLS

For preliminary assessments using future scenario data, useful tools are:

- XDI software solutions;
- World Bank, Climate and Disaster Risk Screening Tool;
- Acclimatise, Aware;
- World Bank Climate Screening Tools
- International Institute for Sustainable Development, Community-Based Risk Screening Tool—Adaptation & Livelihoods (CRiSTAL).

Other guidance and approaches include:

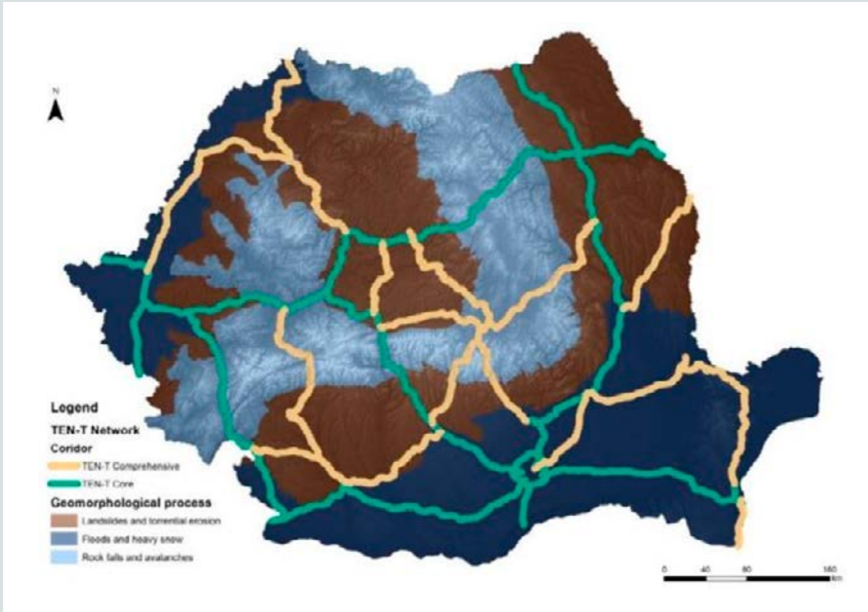
- ISO 14090:2019, Adaptation to climate change – Principles, requirements and guidelines,
- ISO 14091 -Climate Change Risk Assessment;
- ISO 31000:2018, Risk management – Guidelines

Box 14

CASE STUDY – INTELLIGENT EARLY WARNING SYSTEM FOR ROAD TRANSPORTATION RISK IN ROMANIA (UNECE, 2020)

The Trans-European Transport Network (TEN-T) is an EU-wide network of roads, rail, waterways, shipping routes, ports, airports and rail-road terminals. Due to climate change, more extreme temperatures, rising numbers of extreme weather events, precipitation and sea level rise are expected. As a result, the network must adapt to e.g. higher temperatures, floods, or wind. In Romania, for instance, landslides, torrential erosion, rock falls, avalanches, floods and heavy snow are expected to increase along the country's TEN-T, especially along the roads (figure 6).

FIGURE 6: HAZARD MAP OF THE TEN-T NETWORK IN ROMANIA



Source: UNECE (2020)

To avoid further deaths and road accidents, the government issued a transport development strategy called General Transport Master Plan (GTMP) in 2016 (Government of Romania, 2016). Among other areas, the GTMP strives to evaluate potential adaptation interventions by 2030. Therefore, the project was designed to identify hazards for road transportation, supply real-time safe-related traffic information for drivers using a web or mobile application, and spread information on the availability of the service.

For that matter, the programme analysed over 5000 road km, identifying 48 categories of hazards, collected data on the field and from relevant institutions. This project became Romania's first GIS geo-database developed for transport hazards and is available online on **https://mtransporturi.maps.arcgis.com.**

Box 15

CLIMATE MODELS AND SCENARIOS

Climate projections are based on climate models. These are numerical models that simulate the climate system at the global level. Climate models are the most advanced tools available for modelling the state of the climate system and simulating its response to changes in atmospheric concentrations of greenhouse gases and aerosols. Models for different geographical areas range in their complexity. This includes the range of spatial dimensions as well as the complexity of describing physical, chemical or biological processes. General Circulation Models (GCMs) aim to provide insight into global climate processes and their drivers, revealing the big picture on climate change. For more detailed regional climate impact assessments, regional climate models (RCMs) have been developed. RCMs are limited in area but can provide information on the climate in a higher horizontal resolution of between 2 and 50 km, which allows for a better representation of topographic features (e.g. mountain ranges) and of regional-scale climate processes. As a result, they can provide more detailed projections of changes in regional precipitation patterns, weather extremes and other climate events.

Climate projections inherently contain uncertainties. There are therefore substantial differences between the outcomes of different models. Nevertheless, the scientific community is confident that climate models provide credible quantitative estimates of future climate change, as these models are based on fundamental physical laws and are able to reproduce the key features of observed climate change. These projections are usually presented as a multi-model ensemble, in order to represent the spread of possible future climate change.

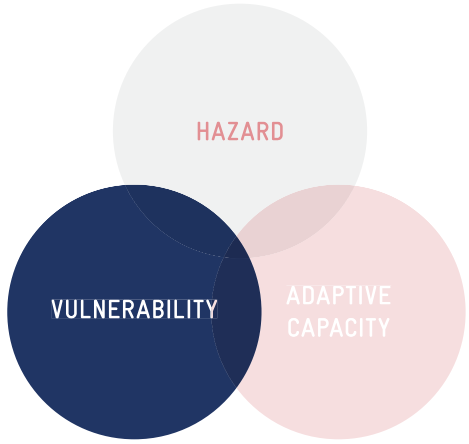
The input for a climate model is an emission/ concentration-scenario. Most commonly used are representative concentration pathways (RCPs). The RCPs make predictions of how concentrations of greenhouse gases in the atmosphere will change in the future as a result of human activities, looking at different scenarios.

There are four RCPs, ranging from very high (RCP8.5) to very low (RCP2.6) future concentrations:

- RCP8.5 is a high-emissions scenario, not unlikely following current emissions trends
- RCP6.0 is a stabilisation scenario in which total radiative forcing is stabilised at approximately 6.0 W/m2 shortly after 2100
- RCP4.5 is a stabilisation scenario in which total radiative forcing is stabilised at approximately 4.5 W/m2 shortly after 2100
- RCP2.6 is a 'peak and decline' scenario that leads to very low greenhouse gas concentration levels. In this scenario greenhouse gas emissions (and, indirectly, emissions of air pollutants) are reduced substantially, leading to net negative carbon dioxide emissions at the end of the 21st century. This scenario would meet the Paris Agreement targets, but would require much more concerted efforts to reduce emissions.

For a graphical illustration on how to use RCPs in planning for the future see ***CoastAdapt***.

4.1.2 Vulnerability assessment



To understand vulnerability – the physical, environmental, social and organisational framework to deliver mobility for people and goods needs to be understood. Vulnerability needs to be considered along a continuum of different levels of climate change impact to understand how most effectively to respond to it. Decision trees in Figure 5 and in Annex A illustrate the vulnerabilities of transport infrastructure to climate change.

Vulnerability assessments require both an insight into where climate hazard(s) may have an impact and judgements about what level of risk is tolerable. In doing so, it is useful not only to consider vulnerabilities from direct impact on transport systems but to also consider the impact on services or infrastructure upon which the system is dependent, e.g. electricity supply for trams and electric vehicles and their supply chains. The following is an outline of key considerations that need to be made when conducting a vulnerability assessment.

Scenarios

Climate change scenarios are a useful way of understanding the detailed characteristics of vulnerability under particular climate change conditions.

Risk levels

The range of vulnerabilities that need to be considered depend upon the level of risk that transport managers will tolerate. These are usually described in terms of percentage probability or "return period", e.g. 1% probability or 1 in 100 years event. Managing risk to 1% probability is a relatively high risk for adaptation. Other common risk levels are 0.025 % and 0.01% events.

As climate change progresses, probability levels will rise, i.e. extreme events will become more likely to occur more often; e.g. 0.01% flood risk for roads in some parts of the UK will become 1% risk by 2080 under very moderate climate change scenarios. For long term decisions vulnerable to climate change, setting a very low risk vulnerability target, e.g. 0.01%, may be one adaptation option for retaining reasonable functionality over the useful life of the asset of service.

Thresholds

A threshold is the set of climate conditions under which a part of a transport system is no longer effective, either economically, socially or environmentally. That is the point at which further adaptation measures are required. For example, a certain threshold of windspeeds may require a bridge to close traffic only for heavy-duty trucks without damaging the bridge itself. If alternative routes are viable, a planned diversion of truck traffic may be an acceptable adaptation option. Another higher threshold of windspeed, however, may cause damage to the infrastructure itself and therefore require adaptation of the physical infrastructure to secure serviceability.

Interdependencies

Urban transport systems are deeply embedded within the urban social and physical fabric. This creates interdependencies to other vulnerable parts of the urban system that transport is dependent upon and vice versa. The trigger for an adaptive action in one part of the transport system may be a threshold reached in another part of the system. Understanding the interdependencies between different parts of the system enables more effective vulnerability assessment and adaptation planning. **In general, adaptation planning benefits from a 'systems approach'**. A systems approach involves an understanding of the interdependencies between different parts of the transport system and its enabling environment.

Box 16

CASE STUDY – FLOODS AND EROSION IN TEGUCIGALPA, HONDURAS

Honduras is highly prone to climate change impacts and is experiencing a high rate of urbanisation. Flooding and erosion caused by heavy precipitation events and hurricanes especially affect settlements in Tegucigalpa's steep areas. To ensure safe housing and infrastructure services in the future, KfW supports interventions, such as afforestation, drainage systems or watersheds (KfW, 2019).

Afforestation projects may be located upstream and reduce flood run-off speed which in turn reduces the depth and speed of flooding.

Climate services for vulnerability assessment

Vulnerability assessments are becoming increasingly sophisticated. Urban transport organisations may not have, or need, the capacity to do this on their own at the level required to manage their risk on a day-to-day basis. Conducting the vulnerability assessment together with experts from research institutions or consultancies can be helpful.

Where climate adaptation is being supported by a development partner, these services are often provided by specialists through the project feasibility studies or project delivery stages.

For organisations addressing their climate risk without external support, there are a growing number of resources worldwide to support vulnerability assessments (see Box 18 for examples) for instance ***A Guidance on how to interpret climate information for the assessment of climate risks*** by GIZ (2020).

Box 17

RESOURCES TO SUPPORT VULNERABILITY ASSESSMENTS

GIZ:
A Guidance on how to interpret climate information for the assessment of climate risks

XDI Cross Dependency Initiative:
https://xdi.systems/

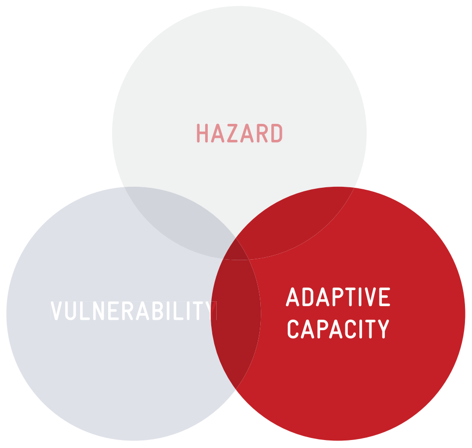
Climate Adapt:
https://climateadapt. eea.europa.eu/knowledge/tools/adaptationsupport-tool/step-2-0

The Climate Service:
https://www.theclimateservice.com

World Bank Climate Risk Screening Tools:
https://climatescreeningtools.worldbank.org/useful-resources

Adaptation community:
A Framework for Climate Change Vulnerability Assessments

4.1.3 Adaptive capacity



Improving adaptive capacity involves developing multiple factors in combination. It is pragmatic to describe these different factors of adaptive capacity separately, despite the fact that they are complementary to one another and should be assessed and developed collectively:

- **Design capability** – the extent to which technical transport infrastructure and their physical environment can accommodate or adapt to the risks posed by climate change, e.g. what are the limits of flooding and heat for which a transport system is designed to deliver an effective service?
- **Financial capability** – the extent to which financial resources can be mobilised to deliver effective adaptation. This could mean reserving resources for both proactive planning and for immediate reaction to hazards.
- **Organisational capability** – the extent to which human and organisational behaviours can respond to the risks posed by climate change, e.g. this can mean to create positions and a mandate for a climate risk manager to pay more attention to climate risk in an organization's transport planning.

The adaptive capacity of a planning department, transport operator or other organisation affects its capability to identify and respond to risk and is determined by the following capabilities:

- Identify the correct moments to take climate vulnerable strategic decisions (see also figure 12);
- The quality of leadership and its commitment to the adaptation process;
- The ability to mobilise financial resources;
- The awareness amongst key decision makers in relevant parts of the organisation of the need to address climate change;
- The access of decision makers and planners to expertise and evidence on climate change adaptation;
- Having a formalised organisational structure that
  - Defines adaptation roles and responsibilities clearly
  - Enables effective delivery of actions, and
  - Remains flexible to new opportunities for improved actions;
- The ability to mobilise human resources that are effective in climate adaptation (including project teams);
- Effective collaboration with stakeholders that it depends upon for climate resilience;
- Effective learning from experience to continuously improve adaptive capacity by embedding new knowledge and learning in decisions and practice;
- Developing a prioritised adaptation programme which is part of an overall organisational strategy.

Addressing these elements will greatly help organisations reduce their overall risk.

When developing adaptive capacity, it is important to recognise that knowing what to do does not automatically lead to effective implementation. Measurement of adaptive capacity across a range of organisations, including urban transport planners and managers, shows that adaptation practice often significantly lags the level of awareness in the organisation (Black and Pyatt, 2016).

A clear process and mandate to implement adaptation are therefore required when organisations embark on improving their adaptive capacity and seek to develop a strategy to increase their resilience to a changing climate. A first step would be to map the existing capabilities based on the list above and identify what capacity the organisation wants to develop in-house and what it will outsource from service providers. A capacity development action plan could then be developed.

Here, support from skilled mentors and coaches are useful in efficiently turning the plan into action.

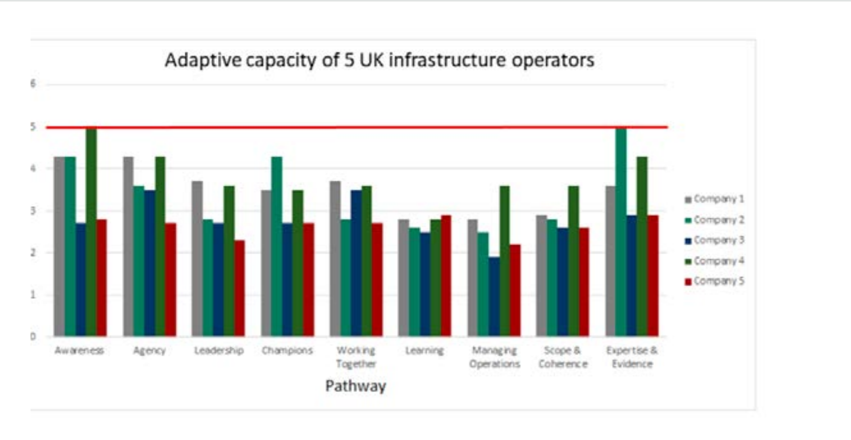
Box 18

CLIMATE RISK IS A FUNCTION OF ADAPTIVE CAPACITY

Observations of thousands of organisations world-wide, including transport infrastructure operators, can provide insights into the important capabilities for managing climate risk and opportunities. These insights can also guide the assessment of required adaptive capacity, current adaptive capacity and the most efficient organisational development steps to develop between them.

The figure below illustrates the adaptive capacity profiles of five UK infrastructure operators (including transport operators) and the required capacity as assessed by the adaptive Capacity Diagnosis and Development metrics ***www.cadd.global***

FIGURE 7: ADAPTIVE CAPACITY OF 5 UK INFRASTRUCTURE OPERATORS



Source: Trioss (2020)

The level of variability of adaptive capacity between this small sample of infrastructure operators makes clear that the capability of different organisations to understand and address their climate change pressures varies significantly. What is also noticeable in this group, and is common amongst organisations in the relatively early stages of their adaptation process, is that their adaptation practice (Managing Operations) lags behind their knowledge (Expertise and Evidence) available to them and their understanding of the issues (Awareness and Agency). This leads to a higher climate risk since it clearly shows that simply knowing climate hazards and vulnerability and having a plan to address them is not sufficient to manage climate risk in line with the adaptation needs.

Where there are numerous organisations responsible for delivering the adaptation plan, differences in adaptive capacity can affect the resilience of the whole system if the actions of a high capacity organisation can be undermined by a lower capacity organisation. For example, an electric transport provider with high adaptive capacity may be compromised by a low adaptive capacity electricity provider that does not make power delivery resilient to changing climate risk, thereby increasing risk of service failures for both.

Box 19

TRANSPORT CANADA'S CAPACITY DEVELOPMENT STORY

Transport Canada's (TC) mandate is a transportation system in Canada that is safe, secure, efficient and environmentally responsible. Responsibilities for transportation in Canada are dispersed throughout various levels of government. Municipal governments are primarily responsible for local transport investments, including urban transit operations. Climate change is a shared priority in Canada and as a federal department TC is expected to be aware of climate risks to their mandate, and to adapt their policies, programs and practices accordingly. The Federal Adaptation Policy Framework defines our federal government adaptation role as: 1) Generating and sharing knowledge; 2) Building adaptive capacity to respond and helping Canadians take action; and 3) Integrating adaptation into federal policy and planning (mainstreaming).

TC has a long history of addressing climate change, with a primary focus on mitigation efforts until 2011, when dedicated adaptation efforts began. It became evident early on that to achieve the department's adaptation policy objectives, the initial focus should be to strengthen TC's own adaptation knowledge and capacity. This was one of two key goals in the Department's first Adaptation Plan (2013-2016); the second goal being to improve upon how TC integrates adaptation into decision making. Since 2013, two key achievements with respect to generating and sharing knowledge have been:

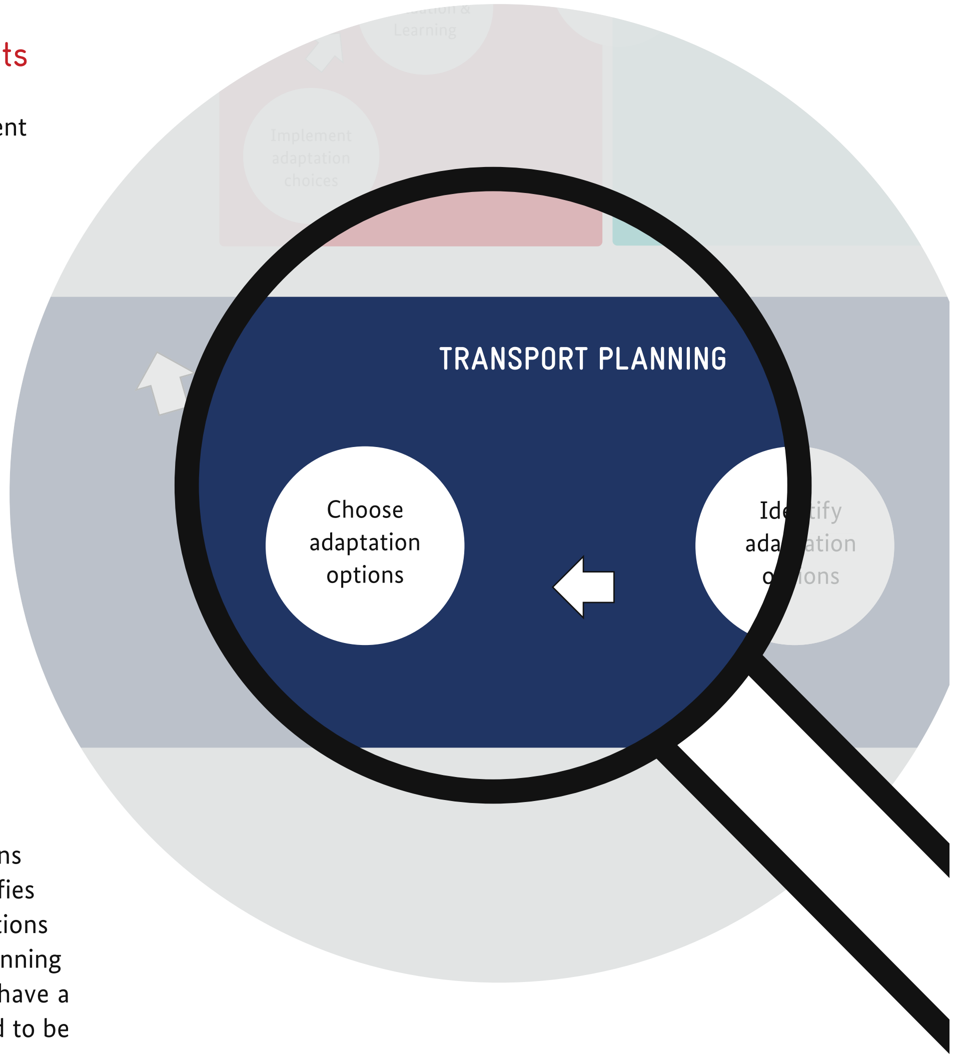
- the release of the 'Climate Risks & Adaptation Practices for the Canadian Transportation Sector 2016' report, a foundational knowledge synthesis for both TC staff and transportation sector practitioners alike; and,
- strengthening the knowledge and capacity of approximately 1000 transportation practitioners through a series of transportation adaptation webinars.

These capacity building efforts have helped position TC to undertake more advanced risk assessment and adaptation efforts. Through their Transportation Assets Risk Assessment (TARA) initiative, TC provides an opportunity to build the ability and capacity of its regional offices and staff to undertake climate risk assessments of their assets, through collaboration and their leading of projects. The experiences and expertise gained through the TARA initiative projects have led to presentations of lessons learnedand good practices at domestic and international fora, and peer-to-peer exchanges on gaps, challenges and opportunities for transportation climate risk assessments and adaptation. To support the mainstreaming of climate considerations into decision making, TC has also applied a climate change resilience assessment to project proposals submitted under the National Trade Corridors Fund. Additionally, recognizing the unique challenges and needs in our north, TC continues to implement its Northern Transportation Adaptation Initiative (NTAI), which aims to increase the capacity of Northerners to adapt transportation infrastructure to climate change.

Most recently, in 2018, a comprehensive climate change risk assessment was undertaken as part of the process to develop a new Climate Change Adaptation Plan for the department. As capacity building is a key ongoing endeavour, whether due to staff turnover or the need to better understand and apply new information, the need to build and maintain departmental capacity remains significant. As such, TC has also recently applied Trioss's climate Capacity Diagnosis and Development (CaDD) tool to assess its departmental adaptive capacity. The results of that assessment indicated that a more strategic approach to capacity building activities would be advantageous to further current successes and bridge gaps. For example, decision system mapping to support mainstreaming, integration of adaptation within departmental emergency planning, conducting cost benefit analysis to better demonstrate the economic value of adaptation, and identification of an adaptation champion. The implementation of prioritized actions identified in the CaDD assessment will be integrated into TC's Adaptation Plan alongside other proposed measures.

4.1.4 The context of risk assessments

There is no single way to conduct a risk assessment and approaches vary widely, e.g. depending on: time, financial resources, personal preferences and capabilities. The metrics used can also vary, depending on the working context and the system of interest under analysis, as well as available data or existing data gaps that force practitioners to work with proxies. There are a wide range of approaches that can be taken, often with different strengths that make them relevant to different contexts. Climate risk assessments should always be designed in a flexible way, allowing for methodological adjustments as experience, requirements, capacities and resources change.



4.2 Adaptation planning

Adaptation planning aims to identify the actions that will manage identified climate risks. It identifies (section 4.2.4) and prioritises (section 4.2.5) actions in the context of existing policies, strategies, planning and decision-making processes. For plans to have a strong chance of being implemented, they need to be incorporated into the organisation's strategy. The core qualities of an effective adaptation planning process are:

- A clear **adaptation objective**, e.g. the level of risk for which the transport system needs to be resilient;
- An assessment of the **adaptation planning needs and capability**, using decision-making methods suited to the context of the organisation and climate change and adaptation objective;
- **Involvement** of relevant decision makers and **stakeholders** during the planning process;
- A range of potential climate change **adaptation actions** which address its priorities, including those related to addressing gaps in adaptive capacity for implementing the plan;
- An assessment of which potential climate change adaptation actions are best suited to the organisation's mandate and structure and consequent **prioritisation of adaptation options**;
- **Sequences ("pathways") of action to manage changing vulnerability** to high case climate change scenarios (see section 4.2.1.6);
- **SMART targets**[4] for implementing activities;
- Identification of **entry points for the operationalisation of the plan** (see section 4.2.6);
- **Alignment of the plan with the resources required** to deliver it;
- Allowing for **review and feedback by external stakeholders**, such as civil society;

[4] *Please note that not all webinars found on the Climate Risk Institutes adaptation platform webinars page were prepared and hosted by TC*

- A **monitoring and evaluation system** to capture new knowledge and learning from the experiences of implementing the initial plan to enable improvement of adaptation decision making and implementation (see section 4.4);
- Identification of the **contingencies that will enable course correction** if any planned actions are not able to deliver the planned outcomes;
- **Communication the plan** to those responsible for its delivery and those affected by it.

In order to illustrate the decision-making approach from hazard identification to vulnerability assessment and identification of adaptation options, figure 5 summarises the elements to consider in the case of urban mass transport and increasing storms, run-off, erosion and flooding. More illustrations for other modes and infrastructure are provided in Annex A (see also box 8).

A checklist for a high-quality adaptation planning process is provided in Annex B.

Exemplary outcomes of good adaptation planning in the transport sector are illustrated in Table 1.

Box 20

CASE STUDY – INCLUDING CITIZENS IN DECISION-MAKING: WORKSHOP IN GUADALAJARA, MEXICO (KERBER & CORNEJO REINDL, 2021)

For a GIZ project on ICT-based adaptation to climate change in cities, citizens of Guadalajara in Mexico were engaged in a workshop for identifying threats and finding solutions to climate change. In the future, the city will most likely suffer from even higher temperatures and more extreme weather events. As a result, the citizens demanded investing in planting further trees in the city. Trees provide shade, help regulate water flows and prevent floods through increased permeability. At the same time, they bring mitigation co-benefits by binding CO2.

Indicator Type	Indicator
Impacts (long-term effect)	• Increased robustness of infrastructure design and long-term investment development • Increased resilience of vulnerable natural and managed systems, such as flood management or reliability of public transport services
Outcomes (process indicators)	• Percent reduction in road closures due to landslides and flooding in a certain year compared to a base year • Percent reduction in flooding where drainage capacity has been increased in a certain year compared to a base year • Climate risk manager appointed in organisation by certain date
Outputs	• Transport sector planning documents include adaptation strategies by certain date • Length of climate proofed roads constructed by certain date • Area of mangrove planted to protect coastal roads or rail routes by certain date

Table 1: Examples of possible indicators for measuring adaptation results in the transport sector

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Box 21

CASE STUDY – ADAPTING EGYPT'S RAILWAY TO CLIMATE CHANGE

In spring, wind storms in Egypt's desert impact rail infrastructure. Due to the accumulating sand, lines could not be operated. As a result, the Abou Tartour – Qena railway line in Egypt has been aerodynamically remodelled to reduce the sand accumulation on the tracks. Thanks to the prediction of especially vulnerable spots through 3D modelling, safe operation can now be ensured (Quinn et al., 2017).

Adaptation planning tools and guidance

This section describes some adaptation planning tools that can be particularly useful to incorporate into planning whether conducted by an in-house team or commissioning external support. The described tools and approaches may be used in different combinations depending on the planning approach taken. They are therefore described as standalone issues in separate sections as follows.

1. Identifying adaptation objective and options
2. Being clear about the scope of the risk to be managed by the plan to deliver the adaptation objectives
3. Identify the different decision lengths and which different approaches are required to address those different decision lengths
4. Understand interdependencies including cascading risks
5. Prioritising actions
6. Understanding decision systems and what decisions are required for effective implementation
7. Developing "pathways" of options to retain resilience to high case climate change scenarios
8. Develop adaptive capacity to implement the plan
9. Identifying entry points for introducing and embedding adaptation into mainstream activities.
10. Implement the plan
11. Monitor, evaluate and learn from previous experience to change future steps on the basis of implementation

4.2.1 Scope the risk to be managed

To develop an effective adaptation plan it is helpful to be clear about the risk that is to be managed: For example, is the resilience of the transport system managed solely by the Mayor's office / municipal transport authorities or could it be a multitude of stakeholders that affects the operation of a defined urban area? If the latter, the planning process may need to involve broader stakeholder involvement. This may include transport infrastructure managers and operators over which the municipality has no direct control, such as informal transport stakeholders. This affects the governance of the planning process and the scope of risks that need to be considered.

4.2.2 Decision lengths

An important element of managing climate risk is knowing how quickly and affordably a decision can be changed. The length of a decision also affects the complexity and uncertainty that climate change adds to a decision and the skills that need to be applied to managing it.

A rule of thumb incorporated into ISO 14090 standard for climate adaptation is:

- Decisions lasting up to 10 years are not very vulnerable to climate change and climate risk can be managed using business-as-usual approaches. Overcomplicating these decisions leads to inefficient management.
- Decisions lasting 10-20 years are vulnerable to climate change. By applying sufficient climate expertise, the risk is predictable and can be managed with a normal level of confidence in the outcome. Overcomplicating these decisions leads to inefficient management. Underestimating the adaptation requirements leads to unsuccessful adaptation.
- Decisions lasting longer than 20 years are vulnerable to climate change which results in an increasing level of uncertainty and unpredictability in the nature of the risk and the effective management options. Adaptive management therefore needs to be able to identify actions which will be resilient in the medium term and be able to recognize unexpected impacts and respond to them effectively. Underestimating the adaptation requirements leads to unsuccessful adaptation.

See figure 8 for an illustration of this rule of thumb.

Box 22

RETURN PERIODS CAN SHORTEN WITH CLIMATE CHANGE

A common way of referring to the risk of extreme climate events is the probable return period, e.g. 1 in 100 years for an event with a 1% probability in any given year. These return periods can shorten with climate change, e.g. flooding of the River Parrot in the UK can disrupt traffic within and between urban areas. By 2080, there will be a high probability of peak river flows increasing by 30% or more. When that scenario is reached, the 1 in 100 year return period for peak river flow will be the same as a 1 in 1000 year return period flood under current climate conditions (UK Environment Agency (2020)).

When setting resilience levels based on return periods for long term decisions it is useful to consider how the return periods for a given event might change over the life of a decision and what adaptation measures might be required to sustain resilience for the chosen return period.

Box 23

USE OF CLIMATE SCENARIOS IN ADAPTATION PLANNING (ALSO SEE BOX 15 ABOVE)

For infrastructure with a relatively long lifespan (e.g. 20+ years) that requires significant investments and few possibilities to adapt the infrastructure during its lifetime, it is wise to look at the severe scenarios (RCP 8.5). This is because there is a serious possibility that such a scenario might occur within the design criteria it has been built to. It is therefore better to be prepared for that eventuality. Otherwise, there is significant risk that the infrastructure will be confronted with damage or vast additional investments during its lifetime.

On the other hand, for an infrastructure which can easily be upgraded during its lifetime, it might be reasonable to look for the lighter scenario (e.g. RCP 2.6) as this will avoid unnecessary costs.

The assessment of a most appropriate scenario is not an easy task, regarding the complexity in the climate models. For complex installations and/or large investments it can be wise to consult a climate expert.

FIGURE 8: APPLYING THE RIGHT LEVEL OF CLIMATE RISK MANAGEMENT

Risk Characteristics	Approach Taken To Manage Climate Risk: Simple (Low Capacity Approach)	Complicated (Medium Capacity Approach)	Complex (High Capacity Approach)
Simple (0-10 years)	**Success** – tasks done quickly, efficiently and consistently	Inefficient	Inefficient
Complicated (10-20 years)	Unsuccessful	**Success** – complicated interactions understood and emergence managed	Inefficient
Complex (>20 years)	Unsuccessful	Unsuccessful	**Success** – complex emergent risk effectively managed

Source: adapted from Cowper et al. (2014)

4.2.3 Identifying Adaptation Options

Once a project team determines potential project vulnerabilities, it can proceed to identify possible adaptation solutions. An important preliminary step is defining the objective of adaptation. In setting objectives, project teams should consider what vulnerabilities they seek to address and what their desired outcomes are.

Seeking input from relevant stakeholders throughout the process will increase the likelihood of success.

Planning objectives would include specific timelines and measurable thresholds for successful adaptation under different levels of climate impact. For example, the objective could be to achieve a certain level of flood protection (e.g., protect facility from physical damage by 100-year flood event or ensure facility remains fully operational during 50-year flood events) or a certain degree of resilience by a certain date (e.g., ensure facility can resume operations within five days of a 100-year flood event).

Once the team defines its adaptation objectives, it should strive to compile a wide range of measures to meet them. Consulting with a variety of stakeholders (including the relevant range of transport infrastructure managers and operators, their regulators, community and non-governmental organisations, environmental specialists, engineers, transport end-users, and others) can help to identify a comprehensive list of adaptation options. The decision trees in Figure 5 and Annex A offer an initial, non-exhaustive list of potential adaptation options for addressing particular climate impacts in different transport types.

Adaptation is context-specific, and the adaptation options identified in the decision trees will not be applicable or appropriate in all cases. For example, some may be too costly, technically infeasible, or socially unacceptable in the project location. The steps described in the next section "appraising adaptation options" will help project teams determine the appropriateness of different adaptation options for particular projects.

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Box 24

CASE STUDY – NATURE-BASED SOLUTION FOR ADAPTATION AND MITIGATION IN MOZAMBIQUE

Mozambique's second biggest and low-lying city Beira is located along the river Chiveve. Informal settlements along the river but also the city centre, sometimes below sealevel, are disaster-prone, especially flooding and heavy rain. To adapt the city to potential climate hazards, the river has been restored and park installed to ensure drainage for the surrounding infrastructure. Moreover, pedestrian bridges over Mangroves and a 5.5 km cycle- and walkway will be installed and promote soft mobility (KfW, 2020).

River Chiveva after being restored, Source: Jan Heskamp, Inros Lackner SE (KfW, 2020).

Building resilience often requires a combination of hard and soft adaptation options, e.g. physical adaptations and organisation change, as well as engineered and nature-based infrastructure options within physical adaptations (GEF-UNEP 2017). Soft adaptation options are as important has hard ones. One example is anticipatory risk zoning for new investments and infrastructure development, avoiding building e.g. a new bus depot in an area that is expected to become flood prone in the future. In cases where increasing resilience of existing infrastructure in their location is no longer feasible "managed retreat" from high-risk areas, often along the coast, may be the only adaptation option.

Finally, in identifying adaptation options, project teams should remember that adaptation measures will ideally be aligned with:

- Existing adaptation plans for other sectors in the same urban area;
- Adaptation plans for other parts of regional or national transport systems which form part of the urban transport system, e.g. rail or bus services;
- National or sectoral resilience plans[5];
- Existing or planned sustainable urban mobility plans or other transport development plans;
- Transport climate action plans.

Figure 5 and Annex A provide examples of adaptation options from the transport sector.

5 *When identifying and evaluating adaptation options in the transport sector, it is important to also consider the mitigation implications of the investments. Globally, the transport sector is responsible for about one-quarter of energy-related CO2 emissions (IEA, 2021). This does not include the lifecycle emissions of construction materials. Cement alone is responsible for about 8% of CO2 emissions (Olivier et al. 2016). Therefore, it is critical to consider the embodied energy and emissions of construction materials used in transport projects (Lehne and Preston 2018). Moreover, the mitigation and adaptation implications of the broader transport network should be recognized.*

Box 25

CASE STUDY – SOLOMON ISLANDS: ADAPTATION OF BRIDGES (LAL AND THURAIRAJAH, 2011)

The Solomon Islands have always been exposed to climate hazards, such as cyclones, heavy rainfall or storm surges. For instance, the Guadalcanal Island experienced about 40 natural disasters between 1950 and 2009. It was classified as highly vulnerable to cyclones and coastal flooding. In 2009, heavy rainfall was responsible for severe damage to roads and bridges. In a 2011 study, landslides, debris in rivers and changing river directions were identified as the main issues following the extreme weather event (see photo).

Taking into account more extreme rainfall, temperatures, cyclone intensity, and sea-level rise under climate change, the Solomon Island Road Improvement Programme (SIRIP2) started to make road infrastructure more resilient. They conducted a hazard, risk and risk reduction assessment for North-western Guadalcanal. To do so, they (1) analysed the context in relation to hazards and identified problems and possible solutions, (2) assessed risk reduction measures and selected the most suitable options, (3) conducted a cost-benefit analysis, (4) designed the project, and (6) analysed climate change scenarios and climate proofing for the preferred adaptation option.

The chosen interventions included using sturdier materials for bridges, e.g. for the Sasa Bridge, or elevating the bridge, e.g. at the Tamboko River. To ensure fewer interference with debris, debris catchers were installed. As a result, bridges and road infrastructure will be more resilient to extreme weather events in the future. The authors of the risk assessment study concluded that communication between stakeholders was essential and that future infrastructure projects will benefit from climate change risk considerations.

Source: Tony Telford, Cardno Acil Ltd (Lal & Thurairajal, 2011).

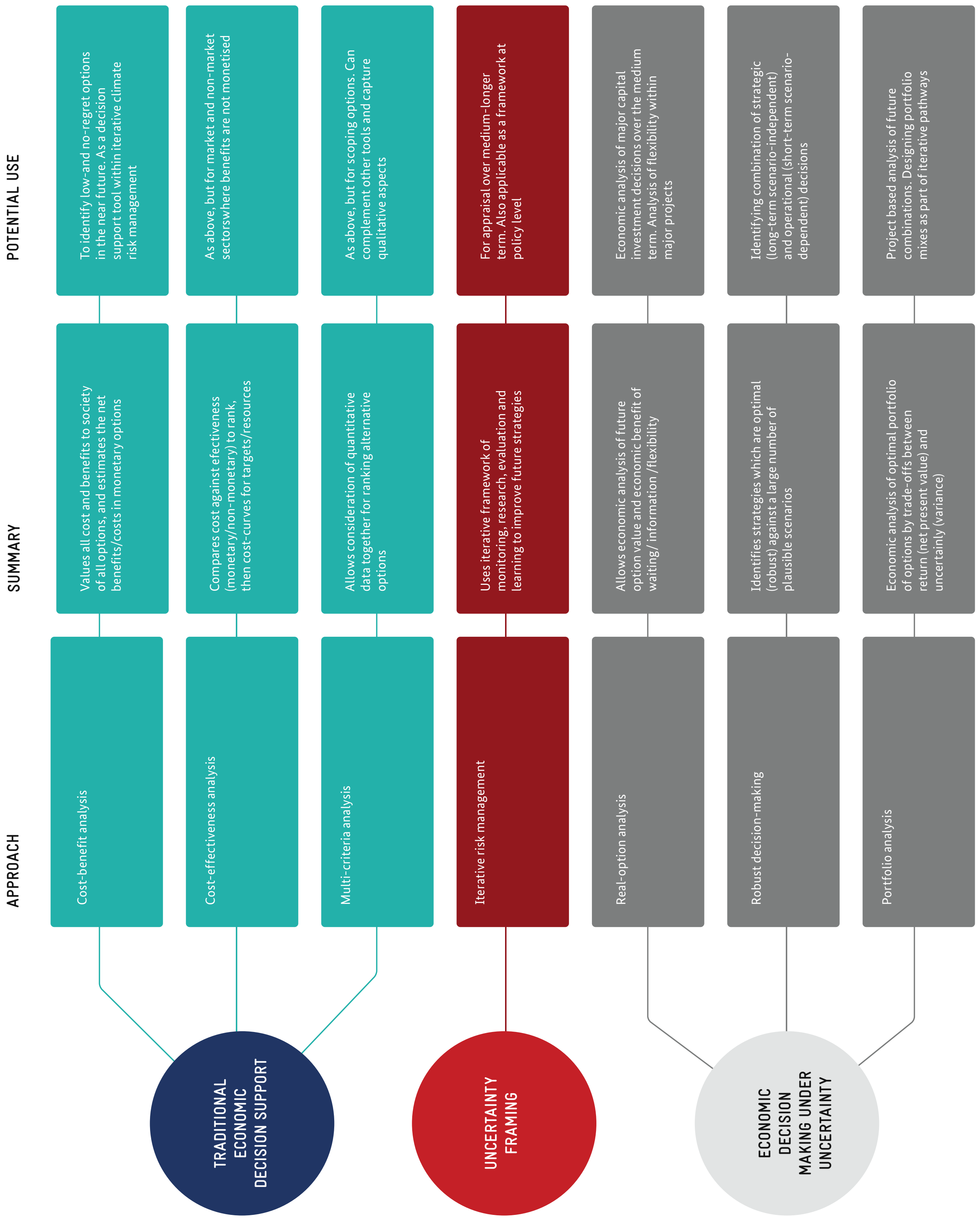
4.2.4 Appraising Adaptation Options

There are a growing number of methods for prioritising adaptation options. Relevant approaches range from traditional approaches such as cost-benefit, cost-effectiveness or multi-criteria analyses, to using methods that are specifically designed to support robust adaptation strategies under uncertainty. These include iterative risk management, real options analysis, robust decision making, and portfolio analysis. Each has different strengths and weaknesses for selecting adaptation options.

Figure 9 summarises the main groups of option prioritisation tools and their potential use.

Figure 10 compares their strengths and weaknesses. There are no hard-or-fast rules on which tool to use in which application. Neither is there a "one-size-fits-all" approach to options appraisal. Each method presents a unique set of strengths and challenges. It is important to carefully select the most appropriate approach for each individual adaptation decision making situation. The insight of suitably experienced service providers may be useful in selecting and applying the most appropriate option.

FIGURE 9: MAIN GROUP OF METHODS IN ADAPTATION OPTIONS APPRAISAL AND THEIR POTENTIAL USE



Source: Rouillard et al. (2016)

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FIGURE 10: MAIN STRENGTHS AND LIMITATIONS OF ADAPTATION OPTIONS APPRAISAL TOOLS

METHOD	STRENGTHS	CHALLENGES	DEALING WITH UNCERTAINTY
COST-BENEFIT ANALYSIS	Most useful when climate risk probabilities are known and sensitivity is small. Also where clear market values can be used	Valuation of non-market sectors/non-technical options. Uncertainly limited to probabilistic risk/ sensitivity testing	Does not explicitly deal with uncertainty, but can be combined with sensitibity testing and probabilistic modelling
COST-EFFECTIVENESS ANALYSIS	As above, but for non-monetary sectors and where pre-defined objectives must be achieved	Single headline metric difficult to identify and less suitable for complex or cross-sectoral risks. Low consideration of uncertainty	Does not explicitly deal with uncertainty, but can be combined with sensitibity testing and probabilistic modelling
MULTI-CRITERIA ANALYSIS	When there is a mix of quantitative and qualitative data	Relies on expert jugdement or stakeholders, and is subjective, including analysis of uncertainty	Can integrate uncertainty as an assessment criterion, however usually relies on subjective expert judgement or stakeholder opinion
ITERATIVE RISK MANAGEMENT	Useful where long-term and uncertain challenges, especially when clear risk thresholds	Challenging when multiple risks acting together and thresholds are not always easy to identify	Deals explicitly with uncertainty by promoting iterative analysis, monitoring, evaluation and learning
REAL-OPTION ANALYSIS	Large irreversible decisions, where information is available on climate risk probabilities	Requires economic valuation (see CBA), probabilities and clear decision points	Deals explicitly with uncertainty by analysing the performance of adaptation for different potential futures
ROBUST DECISION-MAKING	When uncertainty and risk are large. Can use a mix of quantitative and qualitative information	Requires high computational analysis and large number of runs	Explicitly incorporates uncertainties and risks, in particular, systemic dependend risks, to derive robust solutions
PORTFOLIO ANALYSIS	When number of complementary adaptation actions and good information.	Requires economic data and probabilities. Issues of interdependence.	Deals explicitly with uncertainty by examining the complementarity of adaptation options for dealing with future climates

Source: Rouillard et al. (2016)

Box 26

CASE STUDY – MULTI-CRITERIA ASSESSMENT FOR URBAN TRANSPORT ADAPTATION PLANNING IN THE NETHERLANDS

The Netherlands used Multi-Criteria Analysis (MCA) in the development of its national adaptation plan, including urban transport planning. The process included:

- Identification of adaptation options
- Characteristics of the options
- Definition of criteria
- Determining the scores
- Determining the weights

MCA was used for ranking the adaptation options. There were two levels of scoring:

Level 1: Evaluation criteria

- Importance
- Urgency
- No-regret characteristics
- Co-benefits
- Effect on mitigation

Level 2: Feasibility criteria

- Technical complexity
- Social complexity
- Institutional complexity

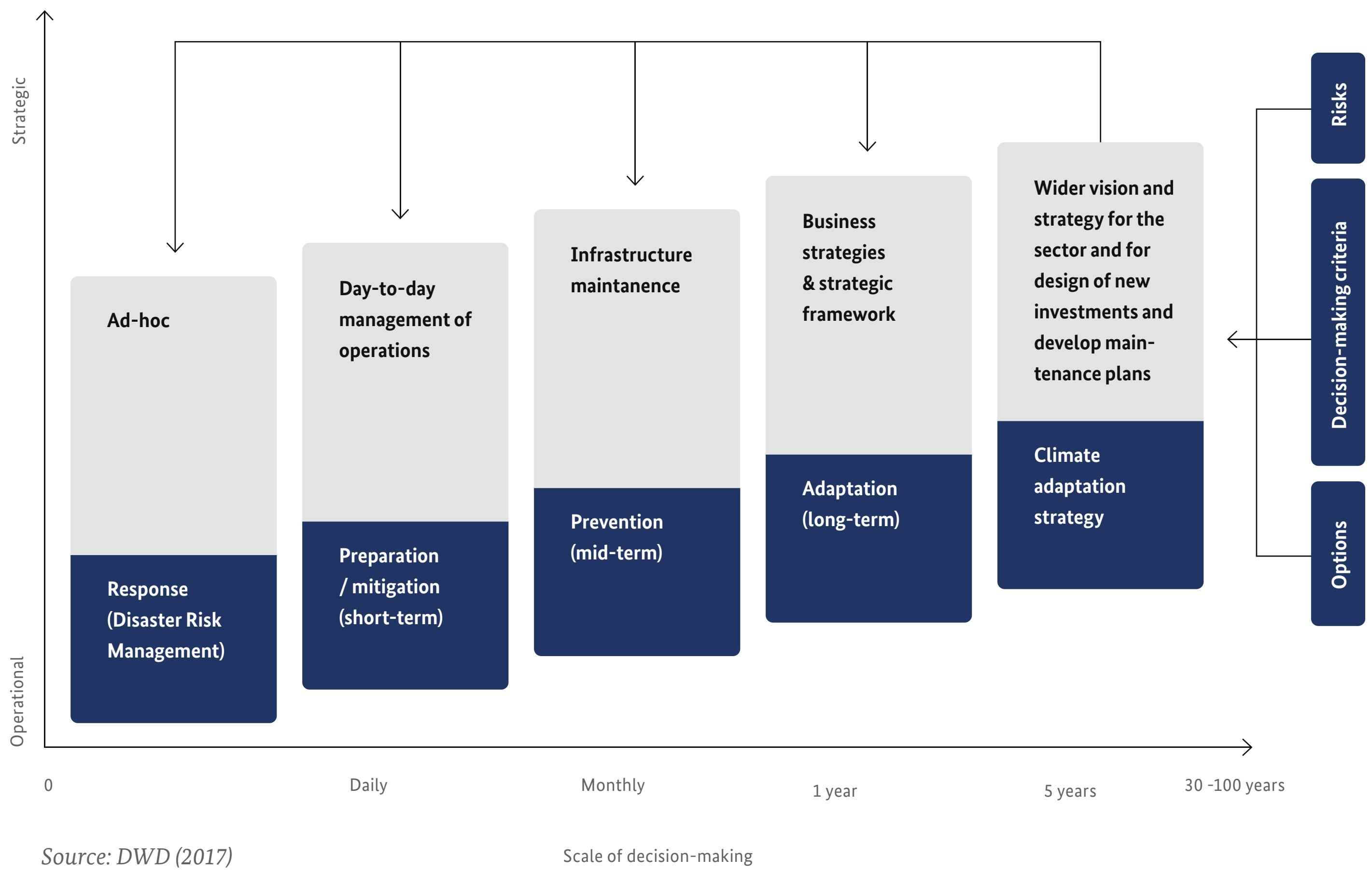
Of the 96 adaptation options identified, two of the top ten involved urban transport: change modes of transport and making existing and new cities more robust.

4.2.5 Decision systems mapping

How effectively a plan is implemented is affected by the decisions that are made within the organisation(s) responsible for planning and implementing the adaptation actions. This includes the stakeholders that affect the options available to those responsible for delivering adaptation, e.g. regulators and end users. One of the challenges for developing an integrated urban transport adaptation plan is that there can be a range of infrastructure managers and operators with different regulatory frameworks. Their planning and business decisions which affect where passenger housing and destinations will develop over time also need to be considered and the terms on which transport planners and operators can serve them. How well these usually disconnected decision-maker are able to integrate risk assessments, adaptation planning and implementation is a key dimension of adaptive capacity for urban transport systems.

Mapping what decisions currently affect climate risk management options and how that will need to change to deliver the adaptation plan is an important part of effective adaptation planning. Figure 11 illustrates the different types of decisions that can affect adaptation within a single organisation. Decision systems mapping will identify how these impact on one another within and between the similar decision frameworks in other organisations.

FIGURE 11: CLIMATE ADAPTATION DECISION MAKING LEVELS



Source: DWD (2017)

Box 27

KEY STAKEHOLDERS FOR ADAPTING URBAN TRANSPORT TO CLIMATE CHANGE

1. **Public authorities** are in charge of providing suitable regulatory frameworks and resilient infrastructure. This mainly includes transport and urban/spatial planners, but also other departments, such as construction and housing departments, environment agencies and disaster or flood risk managers.

2. **Transport service providers** are responsible for ensuring reliable transport services, including contingency plans and provision of rolling stock, but certain vehicle requirements/design standards can be formulated by urban authorities. In the case of informal transport, adaptation planning is confronted with dispersed responsibilities and lack of regulatory frameworks.

3. **Port or airport authorities and managers** are responsible for (air)port activities and securing their infrastructure

4. **Every pedestrian, cyclist, public transport user and road user** is affected by climate impacts and will make individual or corporate choices. Nevertheless, these choices depend on the provision of accessible, reliable, comfortable and safe mobility options, even under challenging weather conditions. They are therefore closely connected to public policy on transport system design and maintenance.

4.2.6 Adaptation Pathways

By applying a thresholds approach (often referred to as Adaptation Pathways or Adaptive Pathways approaches) to adaptation planning (see section on "thresholds" under 4.1.2), it is possible to construct sequences of actions that can maintain efficient and sustainable services as climate hazards develop into the future. When a given action reaches its threshold, another action can be introduced to maintain service delivery and reduce disruptions.

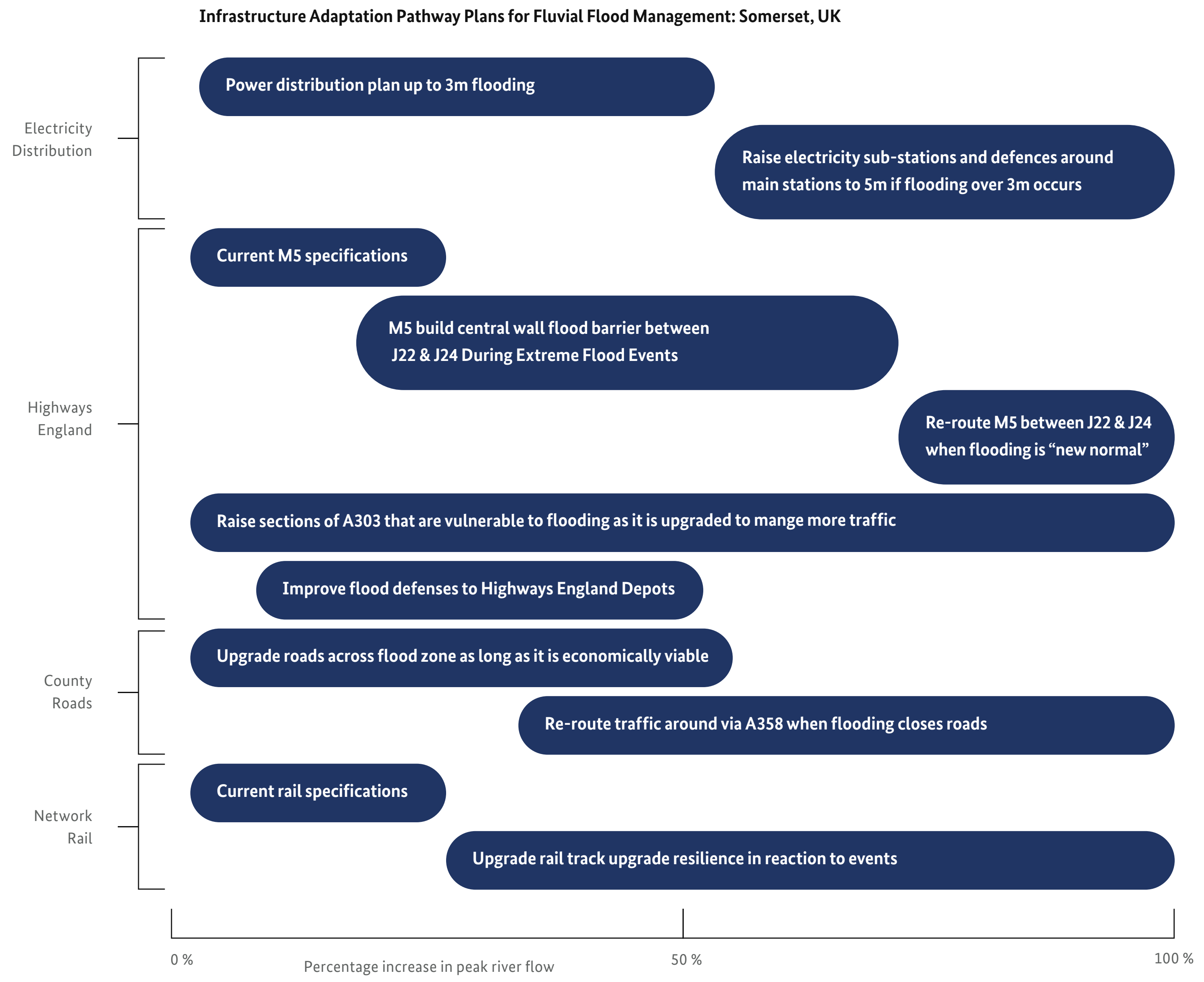
Therefore, the lead time required to put the action into operation, is important to consider. With the lead time understood, planners know how far in advance of a threshold being reached they need to begin putting the next action in place. Monitoring systems can then prompt these judgements (see section 4.4 below). By applying an adaptation pathway approach, it becomes possible to identify the point at which new adaptation actions are needed. This includes being able to pinpoint when to begin the lead-in processes for implementing adaptive actions. By the time actions begin, it is likely that there will be greater certainty about when the threshold will be reached, and so action can be triggered. This allows adaptation to unfold at the pace of climate change without having to know in advance what that pace or level of change is (an example of a transport related adaptation pathways plan is provided in Figure 12).

Knowing these sequences also enables preparation for future adaptation action to be accommodated in the design of earlier actions. This can make transition between actions more cost efficient and effective.

Sometimes hazard levels may reach a point where current objectives cannot be achieved beyond a certain level of climate change, e.g. a scenario which considers that sea level rise beyond a certain level makes further defence unaffordable and continued transport in an area unviable. Incremental change is no longer viable at these thresholds and transformational change is therefore required. Communities and their transport options need to be relocated.

It therefore proves invaluable to understand what these thresholds are. It helps guide planning to avoid further development in vulnerable areas and develop lower cost and timely options to meet new objectives.

FIGURE 12: ADAPTATION PATHWAYS PLAN FOR TRANSPORT INFRASTRUCTURE RESILIENCE TO DIFFERENT LEVELS OF FLOODING

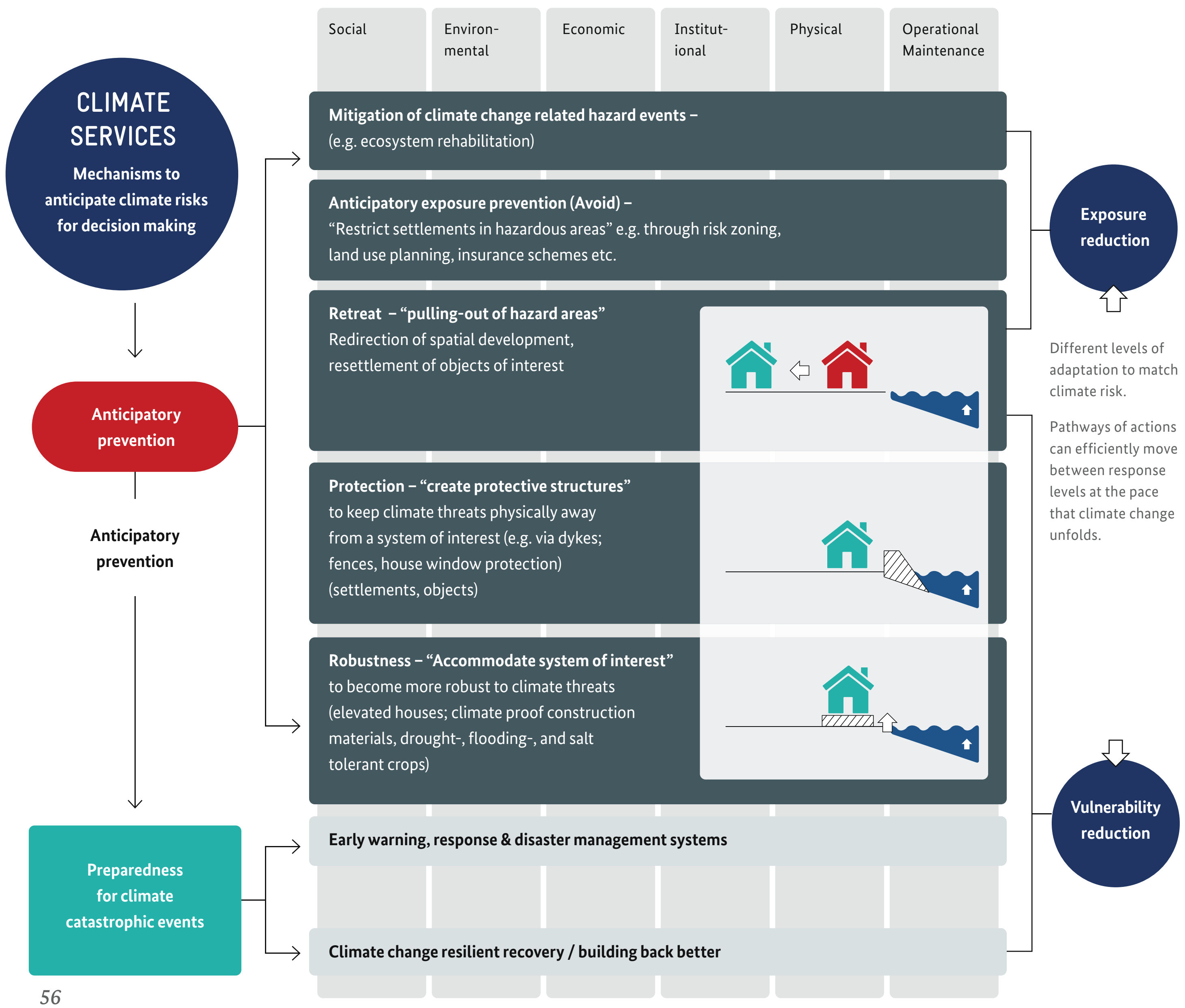


Legend: M5: Motorway 5, J22: Junction 22, A303: a trunkway

It is good practice to plan for resilience up to a high case climate change scenario, e.g. climate scenario RCP8.5 (see box 15 above), even if the higher scenario plans are not needed. This helps manage the uncertainty over the level of climate change. If change is less than the high case scenario, adaptation can be limited to a required level. If a high case scenario does occur, then there is a plan to address it which can be implemented efficiently. If a high case scenario unfolds without a plan, adaptation options may be more limited or costly.

Figure 13 below illustrates types of adaptation responses to different levels of climate risk. The threshold of the ability to sustain one level of risk management might be reached whereby another risk management strategy may become more appropriate. It also illustrates that as climate risk changes different climate services may be required.

FIGURE 13: CLIMATE RISK MANAGEMENT APPROACHES AT DIFFERENT LEVELS OF CLIMATE CHANGE



4.2.7 Entry points for Climate Risk Management in Urban Transport

An important part of planning is working out how to turn the plan into action. The entry-points for climate risk management in urban transport policy, planning and investments will differ depending upon the transport mode, its location/s, intended end users, sources of investment and the resources available, and whether this is a new or existing transport system. Specific examples of climate change impacts and potential responses for each transport mode can be found in Figure 5 and Annex A. Common entry points for climate risk management include:

- **Investment Decisions** – It can be particularly effective to include climate change responses as an integral part of investment decisions about new infrastructure and vehicles. Investment decisions can stimulate inclusion of climate change considerations at an early stage of the design process. It is more effective to include adaptation at an early stage rather than to apply it as an upgrade or to an existing transport system. Drivers for responding early can come from those who are delivering the intended investment project. Financial institutions and donors are increasingly making it a requirement that climate change be given due consideration before funding is made available. The Islamic Development Bank (IsDB), for example, undergoes a climate risk management process for each project, beginning with climate risk screening, followed by project impact and adaptation assessments, and ending with project implementation. Requirements by funding bodies can be particularly effective in stimulating adaptation actions and can be utilised by climate change conscientious practitioners to leverage action in their organisations.

- **Operational maintenance** – Operational maintenance decisions can often appear to be routine 'business as usual' decisions. However, they can provide an opportunity to upgrade components of a system (s) (e.g. when replacing a road pavement, it may provide the opportunity to simultaneously increase the road camber and capacity of drainage ditches). The balance has to be made between whether it is efficient (technically and financially) to upgrade the system through normal planned replacement cycles, or whether it is better to overhaul the infrastructure (e.g. re-route the entire road to avoid problematic locations). Nevertheless, mainstreaming adaptation responses through making them an obligatory consideration during maintenance activities is advisable.

- **Betterment following events** - Climate change resilience should be an integral component of disaster and / or emergency response planning. Important lessons can be learned from reviewing the consequences of historical or current extreme events. These events reveal the parts of the transport system that fail, or are disrupted most, and therefore provide insight into priority areas needing upgrades. Where elements have failed, replacing like for like will often result in an increased risk of failure (due to the increased likelihood of similar or more extreme events happening in the future). This provides an opportunity for betterment – an opportunity to embed more resilience or adaptiveness within the maintenance intervention.

Box 28

CASE STUDY – WHITE TOPS ON LONDON BUSES; ADAPTATION AND MITIGATION

Transport for London introduced white panels on the capital's buses in its climate-adaptation plans. White panels reflect the rays of the summer sun, keeping the vehicles cooler. After 10 years, 98.5 percent of the fleet of 8,700 buses had white roofs. This improved the overall conditions for passengers and drivers as well as reducing fuel consumption for air conditioning systems.

Source: Shutterstock, (2021)

Box 29

CASE STUDY – BETTERMENT AFTER FLOODING IN KERALA

After immense flooding as a result of heavy monsoon rains in 2018, the infrastructure of the densely populated Indian state Kerala was severely damaged. With extreme events like this likely to become more frequent, and sometimes even more intense under climate change, the redevelopment of the infrastructure was planned to be more resilient. Roads would be elevated, drainage systems installed, and steep areas secured (KfW, n.d.).

There is usually a necessity to recover quickly following an event and this often creates pressures to employ familiar responses using familiar skillsets. Emergency planning should explore potential new responses as part of a collaborative pre-planning process. It can prove challenging to introduce new responses during or immediately following an event. Effective pre-planning can avoid replicating the same climate vulnerable situation. Maintenance improvements can often require different resources and expertise. Longer-term cost-benefit analysis may be needed to justify any additional expenditure.

- **Development of strategy and policies**

Public authorities and senior management have an important role to play in setting objectives to improve resilience of the transport system and promote coherence between different delivery organisations. Existing frameworks (e.g. franchise, contracts, output specifications, regulatory powers) should be used where possible, however new regulation, capacity building or awareness raising may also be required.

Decision-makers have the opportunity to ensure core strategy and recognise climate impacts as a potentially significant threat to its core activities. They can allow a programme of activity to flow from this. This can be achieved either by developing independent climate change strategies and policies, or by embedding climate change resilience within existing policies and strategies.

This involves more than just an explicit mention of climate change and its impacts. They need to be explicit about climate change impacts as a potentially significant threat over strategic timescales and illustrate that it will trigger action to respond. This is important because it shows that the policy is not only functional (e.g. held by the environment department) but is accountable at a more corporate level as part of core strategy.

In organisations where this is relevant, delivering on an organisation's adaptation targets could be included in the performance contracts of employees of transport ministries and authorities or private companies.

- **Influence of laws and regulations**

Climate change legislation and regulations are becoming increasingly common across the world. These can act as drivers to develop and report on climate change resilience. These external drivers can prove invaluable in ensuring action is kick-started and progress is sustained into the future. It is not possible for transport organisations to just decide to be high capacity, they need to learn how to be high capacity through learning from their own delivery experience and the experience of others. Laws and regulations create the enabling environment for action to take place at the local level.

In order to align adaptation practice, regulators, legislators and other sectors that can set the operating options for transport systems, e.g. the financial sector, can standardize assessment and reporting criteria. This makes approaches and reporting more directly comparable, which in turn can make it easier to share good practices across the sector. National legislation, international and regional standards, such as ISO 14090 for Climate Adaptation EU asset management standards, and the finance sector's TCFD reporting scheme are all examples that may already influence adaptive practice. Whether or not there is significant guidance, it is always useful to make adaptation requirements an integral part of Strategic Social and Environmental Assessments (SSEAs) and Social and Environmental Impact Assessments (SEIAs) throughout the investment cycle [NOTE: limiting climate vulnerability assessments to environmental impact can miss significant social implications of climate change for transport systems. This can lead to maladaptation and additional burdens on communities and businesses]. It is also important to ensure that investment and operational decision makers are held to account for accommodating these findings in their decisions. The disconnect between assessment findings and operational decisions is a key barrier to effective adaptation.

Care must be taken not to overprescribe approaches. It is possible to focus too much on kick-starting action with organisations who have not yet started, at the expense of stifling innovation for those who are moving ahead of the game. Legislation and regulation must be able to stimulate action as well as accommodate new ways of doing things as they evolve.

Box 30

CASE STUDY – CLIMATE CHANGE IMPACTS ON TRANSPORT CAN HAVE MUCH WIDER STRATEGIC IMPLICATIONS

In 2013/14, flooding in a relatively small stretch of road and two rail routes in the UK? contributed to nearly EUR 200 million of economic damage, some of it being interruption of businesses 250km away. Only a small part of the cost of the damage related to upgrading the transport system to be more resilient. As a result of these wider consequences, these localised transport vulnerabilities have become a regional strategic issue.

4.2.8 Cascading risk

Climate risk is systemic. A system is as resilient as its weakest point. This is true for physical risk and the organisational capabilities for managing the physical risks.

Cascading physical risk

Cascading physical risk reflects the interacting and interconnected nature of transport systems. This means that impact at one part of the physical system can be compounded as a result of the connections throughout the physical system. Effective adaptation planning considers these interconnections and how vulnerability at one point in the system can cascade risk more widely in the system (Pescaroli and Alexander, 2015).

Cascading risk and organisational capability

The pressure put on one part of the risk management process is affected by how well the previous steps have been implemented. A common way of considering the experience of the sort of extreme events that are expected to increase with climate change is a cycle of planning, absorbing the event, recovering from it, learning from the experience, and reflecting that learning into future planning. How well each stage is managed affects the pressure experienced at the future stages in the cycle. An example of how the level of pressure experienced can vary is the amount of unpredicted activity that needs to be managed. The better the planning, the less the unpredicted activity that needs to be absorbed or recovered from or learned from. Yet if there has been good planning and poorer implementation of the plan, risks that "should" have been managed are not and pressure on resources and the need to improvise and re-act in the moment increases, which increases pressure and risks poorer performance. If there is difficulty in absorbing the event, then the greater the recovery job is. It is almost inevitable that there will be some unpredicted pressure at each phase. As described above, the longer the useful life of the decision, the more likely this is. Each phase therefore needs to anticipate some level of unexpected activity and plan for the resources to spot and respond to it. How well lessons are learned from the unexpected in one event affects the quality of future planning.

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Box 31

CASE STUDY – CASCADING RISK SOUTH WEST ENGLAND FLOODING

Somerset is a County at the start of the long peninsula in South West England. Flooding in Somerset, closed rail and road routes for weeks. Cut off rail links reduced business activity 225 km away. The strategy for re-routing road traffic around the flooding dramatically reduced business to companies in unflooded areas within the diversion zone because people assumed it was flooded, causing significant difficulty and even closures.

Lessons learned have led to: a more resilient rail system which under the same flood would close for days rather than weeks; key sections of road being raised; traffic control messaging changed to encourage people to support businesses in communities that it is safe to enter.

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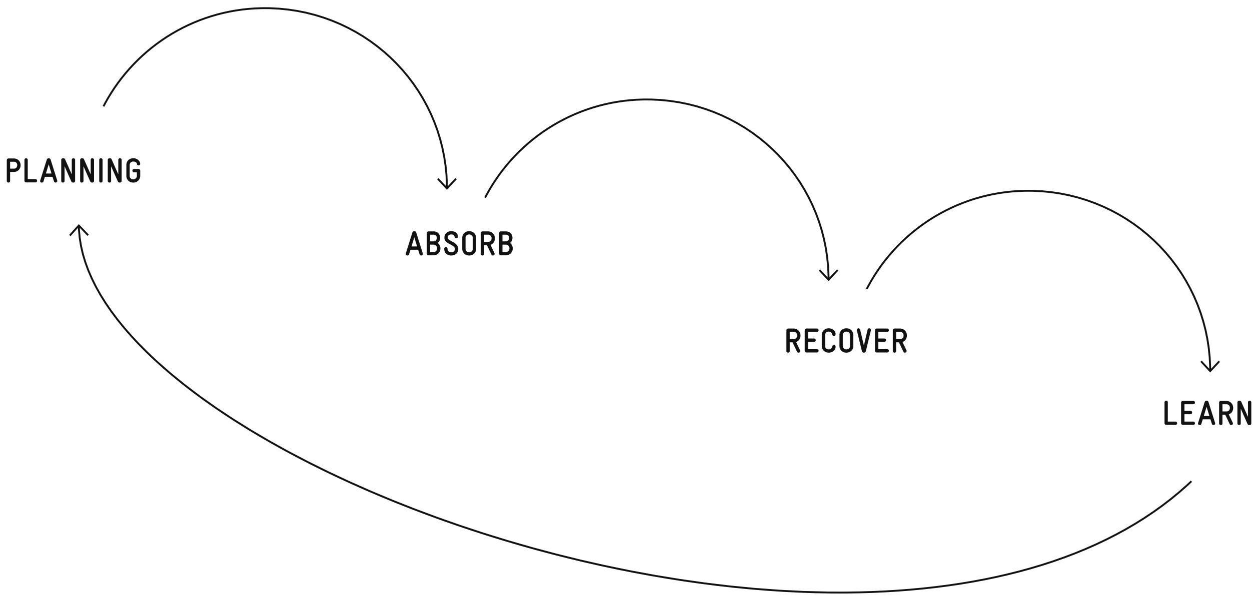
2-© Coatesy/Shutterstock

FIGURE 14: EXTREME EVENT MANAGEMENT; CASCADING IMPACTS



Source: After Pescaroli (2017)

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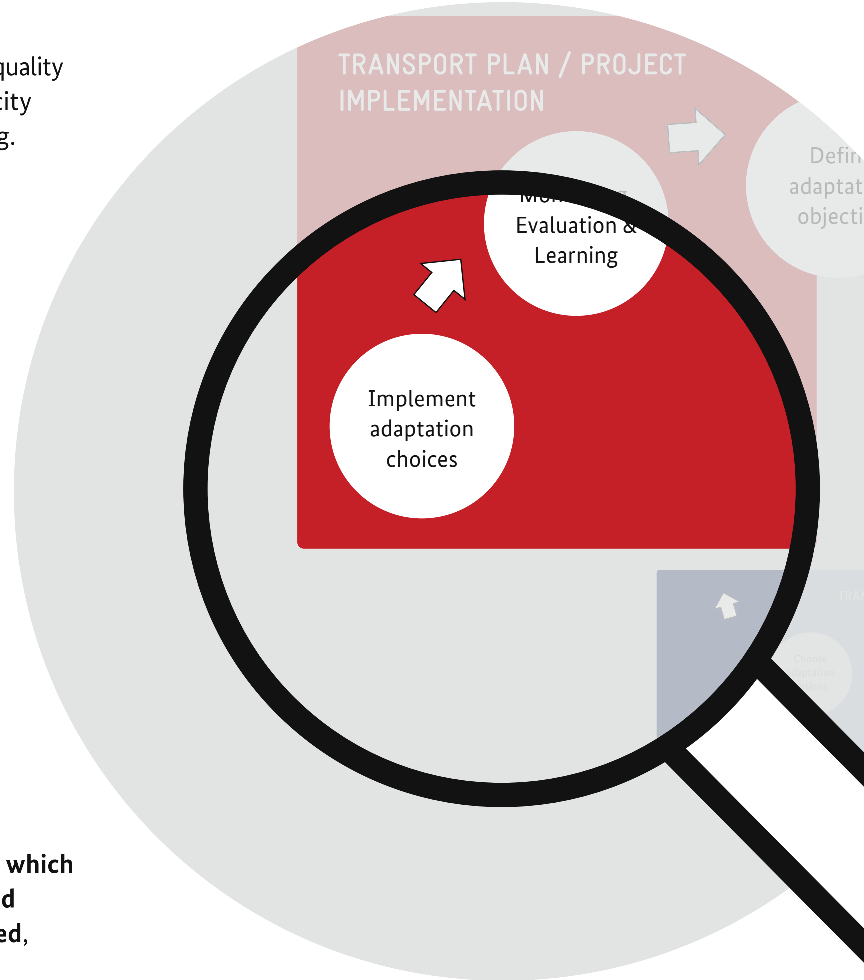
4.3 Implementation



Effective implementation will depend upon the quality of the adaptation plan and the adaptive capacity of the organisations responsible for delivering. A perfect plan which is poorly delivered will not deliver effective adaptation.

Leadership and commitment are key qualities that will affect delivery. Outcomes from these qualities that will be important include:

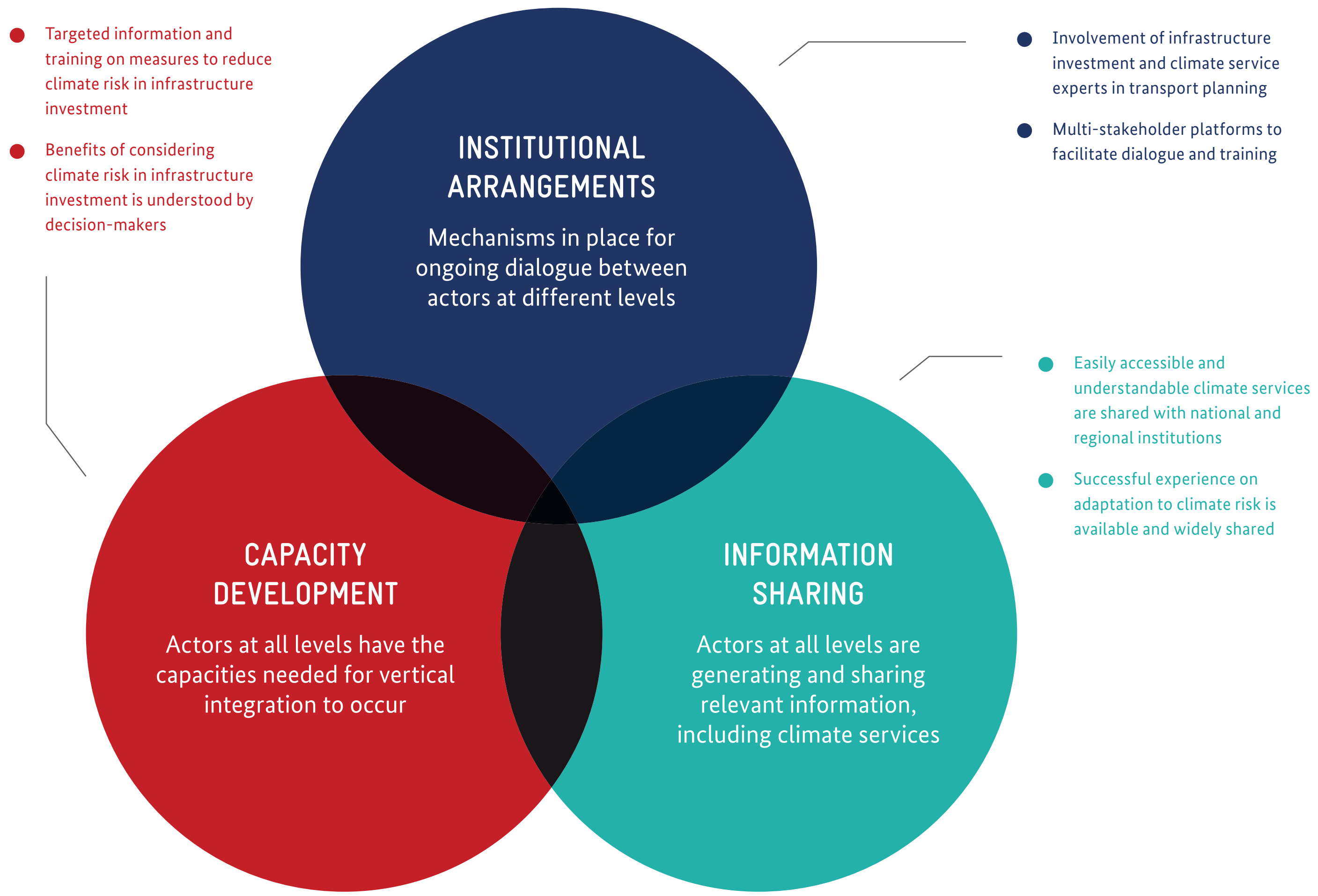
- Effective **operational** structure put in place to turn the plan into action;
- Where delivery depends on the operations of more than one organisation, e.g. multiple transport infrastructure managers and operators with different governing bodies, regulators and geographical reach:
  - there need to be **governance structures which ensure that shared objectives developed during the planning phase remain shared**,
  - where there is pressure on one or more participant to change objectives, this is recognised and the implications managed collectively,
  - **learning is shared** and their collective actions are coherent and efficiently implemented.
- There is **clear accountability for the effectiveness of the adaptation action**; e.g. for retrofitting culverts to increase their capacity to manage long term increased peak flood levels;
- The **adaptation policy and objectives are formalised within the organisation**(s) and are compatible with its strategic direction and the context of the organisation(s); e.g. risk registers, job descriptions and performance KPIs are updated;
- The adaptation plan is **integrated into the organisation's business processes**; for example, adapted requirements for infrastructure design, such as larger drainage capacity or requirements on rolling stock such as maximum operating temperatures for air conditioning are integrated into procurement processes or infrastructure updates are integrated into regular maintenance processes;
- The **resources** needed for the adaptation action **are available**;
- The **importance of climate change adaptation** has been effectively **communicated** to those whose decisions affect the quality of implementation;
- Providing **effective direction and support** to those that contribute to the effectiveness of the adaptation action; e.g. the company leadership decisions and public statements are consistent with the adaptation plan, budgets include delivery of adaptation actions, training and mentoring is provided required to work with new skills to deliver the plan;
- Promoting **continual improvement**.

Box 32

CASE STUDY - ADAPTATION THROUGH COLLABORATION IN THE PHILIPPINES (ADPC, 2007)

Due to a variety of natural hazards, such as floods or typhoons, the road system in the Philippines is vulnerable to road damages. To reduce the negative impacts, a number of different stakeholders, including the Regional Consultative Committee (RCC), the National Disaster Coordinating Council (NDCC) and the Department of Public Works and Highways, have started to collaborate to improve and adapt the transport system in the country. A multi-actor technical working group took over the lead. Together, they identified potential risk factors and conducted hazard assessments and recommended the integration of adaptation measures into future planning.

FIGURE 15: ENABLING FACTORS FOR CLIMATE PROOFING



Source: NIRAS IP, adapted from Terton (2017)

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Box 33

THE ROLE OF INSURANCE

It is likely that the adaptive capacity of an organisation will not mitigate all climate risks. The remaining risk is often called “residual risk”.

Insurance is a common way to manage that residual risk. If using insurance as part of risk management, it must be recognised that if the risk gets too high, then insurers will respond by increasing premiums or even withdrawing cover e.g. an asset that starts to become regularly flooded may no longer be able to get insurance cover.

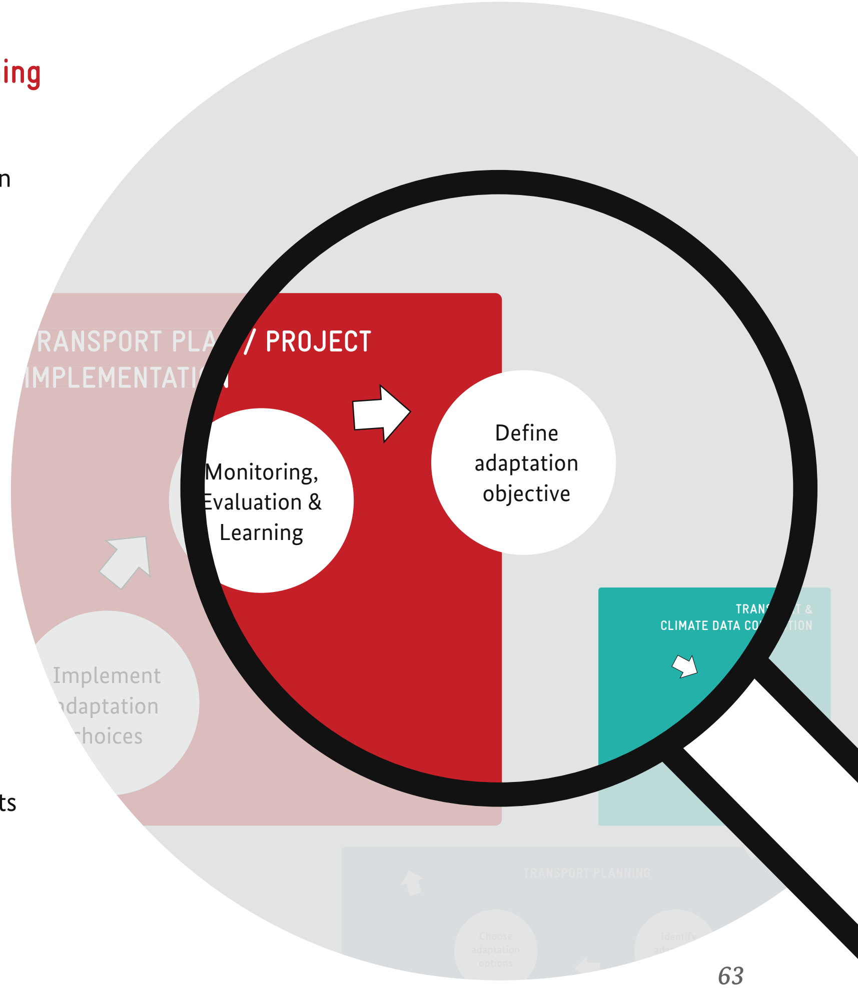
In general, the insurance sector wants to support effective adaptation. It can be useful to engage insurers during the adaptation planning process e.g. in risk identification and options assessment and prioritisation. They can then point out what measures would reduce insurance risk and so make insurance more reliably available as a residual risk backstop.

4.4 Monitoring, Evaluation and Learning (MEL)

The development of a Monitoring, Evaluation and Learning (MEL) system begins by being clear about the objectives of the adaptation plan, what needs to be learned from the monitoring and evaluation of data and who needs to learn and possibly change their practice on the basis of the data.

MEL systems for climate adaptation can incorporate a variety of metrics. These commonly include climate parameters, climate change impacts, vulnerability, implementation of adaptation measures, or the impact of adaptation measures (also see Table 1 above). These are all important but might not be enough for an urban transport system.

A “results chain” approach is one that compliments the need for managing long term adaptation.



Box 34

CASE STUDY – KENYA'S NATIONAL ADAPTATION PLAN

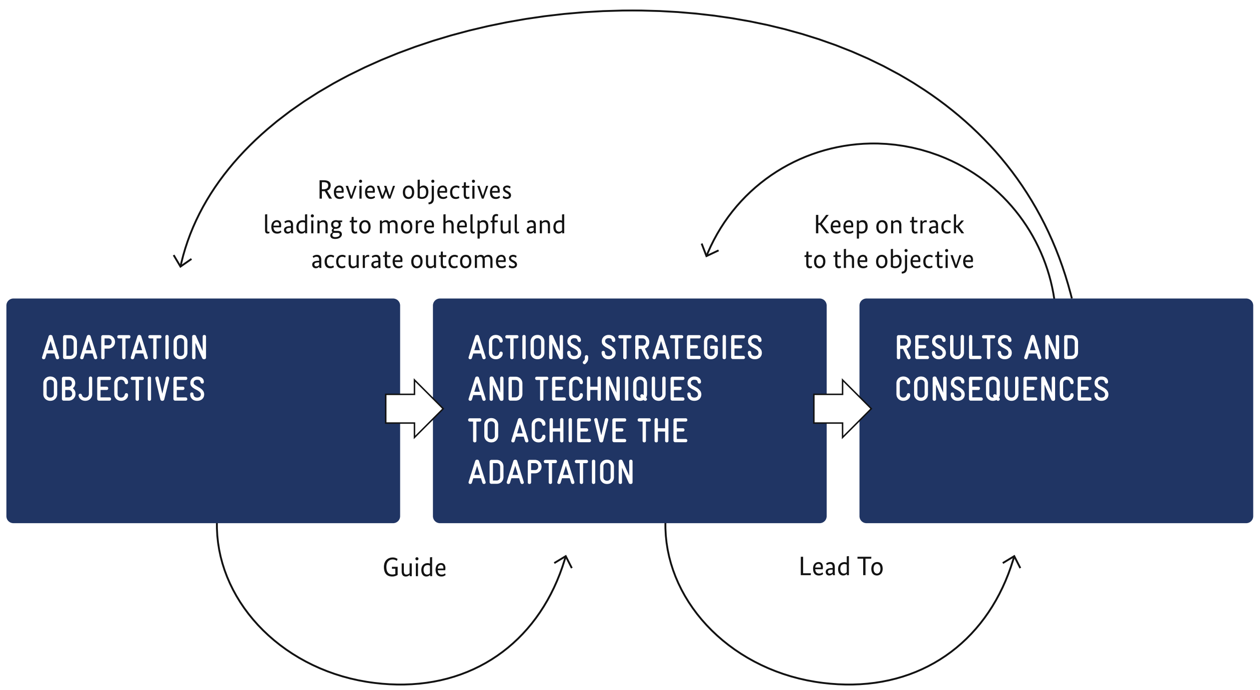
National Adaptation Plans (NAPs) are means to ensure medium- and long-term climate change adaptation on a national level. Established in 2010 during the United Nations Framework Convention on Climate Change (UNFCCC), NAPs include stakeholder engagement, policy coordination and capacity building. For instance, Kenya's NAP, published in July 2016, includes long-term endeavours to adapt transport and infrastructure. Among other interventions, the plan aims to improve infrastructure development using climate smart design on a county level. Kenya's NAP moreover includes Monitoring and Evaluation (M&E) from national to county level for interventions planned until 2030 to ensure successful resilience building (GoK, 2016).

"Results chains describe a logical sequence from inputs (money, time, knowledge) invested in activities to achieve first outputs with short term or medium-term effects (outcomes) that contribute to long term effects (impacts). Results chains involve assumptions of how each category leads to the next, i.e. under what circumstances a certain output leads to the associated outcome." *(Eberhardt et al. 2013:42)*

These are useful disciplines for learning from the alignment of activities to the objectives of the plan. This is the first "loop" of learning in effective MEL.

Since climate adaptation may need to manage significant uncertainty over long time periods, it is useful to also allow for a second loop of learning (see Figure 16). This is to consider from time to time whether the objective is still the best for the resilience and adaptability of the transport system.

FIGURE 16: DOUBLE LOOP LEARNING PROCESS



To ensure that relevant lessons are captured, the governance of the adaptation programme needs to establish a formal structure to capture learning from the monitoring and evaluation. That needs to document lessons learned and use the findings to test whether the current plan is still valid. Where necessary, it must be possible to change policies, strategies or plans to work with the new understanding. How often or at what points in the project monitoring takes place needs also to be decided. Furthermore, it is important to be able to carry out ad hoc monitoring where a relevant learning opportunity is identified.

A relevant range of indicators should be established, which are quantitative where possible and qualitative where not. It is also helpful to monitor performance over time, benchmark against other relevant organisations and initiatives and compare progress against a baseline (ISO14090:2019).

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Box 35

LIST OF USEFUL INDICATORS

- Progress against work plan milestones;
- Availability of relevant information to those that need it;
- Availability of relevant knowledge and expertise to those that need it;
- Budget/ spend on adaptation physical measures;
- Budget/ spend on adaptation capacity building / training;
- Number of times 'adaptation' is mentioned in policies, strategies, and plans;
- Number of assets adapted as a result of the plan;
- Job descriptions and KPIs amended to enable climate adaptation;
- Numbers of staff attaining a relevant degree of competence/ training in adaptation sufficient for their adaptation role and responsibilities;
- Adaptation pathways plans developed;
- Number of standards changed to reflect future climate;
- Number of defects occurring as a result of climate hazard split by asset type (e.g. for rail: plain track / points and crossings / signalling/ power / level crossings / rolling stock (by fleet type) / bridges / earthworks / drainage - essentially analyses of 'what was' and 'now is' the norm for performance, related to climate / weather;
- Incidence of imported failures from external suppliers e.g. energy, telecoms providers;
- Thresholds crossed beyond which performance becomes unacceptable and further adaptation is required;
- Number of standards changed as a result of new learning;
- Number of modifications made to policies, strategies and plans as a reaction to the adaptation plan;
- Improvement of performance during extreme weather under the current climate;
- The thresholds identified beyond which performance will become unacceptable. Thresholds can be considered in terms of both climate hazard and asset or service type;
- Duration of disrupted services under different levels of climate impact;
- Time taken to recover normal services under climate impacts addressed in the plan;
- Participation of key identified stakeholders.

Source: Tony Telford, Cardno Acil Ltd (Lal & Thurairajal, 2011).

Box 36

FURTHER TRAINING OPPORTUNITIES FOR GETTING STARTED

The GIZ Sustainable Urban Transport Project (together with IsDB) offers trainings on adaptation of urban transport to climate change. The main goal of these workshops is to raise awareness of climate change risks for the transport sector and equip decision makers with knowledge and capacities to integrate climate change into their planning. This includes, increasing the trainee's knowledge with regards to:

- The science base on climate change and why transport and infrastructure planning has to take into account climate risks for resilient planning;
- Learning from adaptation project experiences;
- Methods and approaches of climate proofing transport projects and infrastructure investments with a focus on identifying and assessing specific climate risks as well as defining and selecting adaptation measures to increase resilience;
- Familiarize decision makers from IsDB member countries with the bank’s transport policy framework as well as the climate change implementation framework, it's action plan and related tools.

Interested parties can get in touch ***here***.

Further the IsDB organises periodic trainings and capacity development workshops for staff, trainers, and government stakeholders at national and regional level across its member countries. If you would like to learn more about future workshops and training, kindly contact ***climatechange@isdb.org*** or visit ***https://www.isdb.org/climate-change***

5 Concluding remarks

Urban transport is the life blood of cities. Disruption to urban transport has huge implications to people's wellbeing and the wider economy. In many developing cities, the impacts of extreme weather events on urban transport systems can already be severe. Without adaptation, climate change will make this significantly worse as extreme event become more frequent and sometimes more intense. Since most cities are close to the coast, the threat of sea level rise also casts a shadow over their futures.

Adaptation of urban transport in developing cities must be seen in the larger context of the economies and wellbeing of the nation. Significant investment is underway in developing urban transport. Where those opportunities arise, if climate adaptation is not a central part of investment planning and design, the long-term nature of the infrastructure means that these decisions are locking in unnecessary future disruption, and barriers to economic growth and future wellbeing. The cost of undoing investments that did not factor in climate change can be significant, when future realities hit. At the same time, we do not need to adapt to the highest case scenarios in one step if we do not want to. The uncertainties about the levels of climate emissions in the future, amongst other things, mean that at the time of writing this source book we cannot know the pace and nature with which climate change will unfold.

This source book module shows how to lay the foundations for efficient further adaptation steps if required. This way we can know how to adapt to the highest case climate scenarios and have development plans in place to respond as required, without needing to commit to that expenditure to begin with. Some issues will remain for cities and organisations, such as a lack of climate data. Nevertheless, this guide can help identify possible tools and guidelines for local contexts, following the adaptation cycle of Assessment, Adaptation Planning, Implementation and Monitoring, Evaluation, and Learning. While case studies show examples of how risk assessment can be used, every city will have to identify its own strategy in adapting to long-term climate change implications as well as to extreme weather events. Stakeholder involvement, cost-benefit analyses or PIEVC protocols can help cities find solutions to climate risks. To ensure proper adaptation measures, cascading effects must be considered, i.e. holistic developments supported in order to minimise further damages and effects. Especially for cities in the Global South, vulnerability and hazards are often high while the adaptive capacity is low due to financial or technical issues.

Planners are not always familiar with responding to risks that do not yet exist, having usually been trained to trust the past as a guide to the future. The past is no longer a guide to the future. Planners need to be supported to develop new skills to work new ways. The organisations they work for need to adapt to support adaptive action, not sticking with old values and being a barrier to adaptive thinking. This means changes for leaders, human resource planners, financiers and the definition of the roles they are to undertake. Urban planners and transport managers cannot do this alone. They are often dependent on the decisions of others to be able to act in an adaptive way. Making urban transport resilient to a climate future is therefore a systemic issue. It is therefore ever more important to find solutions, to partner up and to support climate adaptation in the transport sector.

Through the adaptation plan the organisation(s) responsible for its delivery will be able to demonstrate:

Checklist for a High-quality Adaptation Planning Process	✓
A clear adaptation objective is set	
Adaptation planning needs and organisational capability are assessed	
Identify interdependencies with climate impacts on other organisations whose decisions affect the delivery of the adaptation objectives	
Key stakeholders actively participate in the process, including review by third parties	
Potential climate change adaptation actions are identified that meet the objective	
Adaptation actions address gaps in adaptive capacity for implementing the plan - capacity building needs are identified (at individual and organisational level)	
Adaptation options are prioritised based on the mandate of the organisation	
Adaptation options include sequences of action to manage changing vulnerability to high case climate change scenarios	
Roles and responsibilities to implement the planned measures are clearly defined	
Governance structures to implement the plan are created	
Entry points for the operationalisation of the plan have been identified	
Resources are allocated to implement the plan	
SMART indicators for reporting on progress and achievements are identified	
A process for monitoring and reporting, evaluation and learning is in place that allows flexibility to update the implementation plan as required	
Contingencies are identified that will enable course correction if any planned actions are not able to deliver the planned outcomes	
The adaptation objective and planned measures are communicated to those responsible for its delivery and those affected by it	

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Annex A: Decision trees

FIGURE 17: DECISION TREE FOR ROAD AND CYCLE WAY PROJECTS (PAGE 1)

Module 5f: Adapting Urban Transport to Climate Change

CLIMATE HAZARD

Increasing frequency and magnitude of storms

Rising sea levels and increased storm surge heights

Increasing precipitation or frequency of extreme precipitation events

SYSTEM IMPACTS

Strong winds associated with more intense storms

Rising relative sea levels and Saltwater intrusion

Stronger wave action and increased coastal erosion

Increased run-off and erosion

Increased flood risk

PROJECT VULNERABILITIES

Increased operating costs reduce the economic viability of some routes and increase maintenance costs which, if not met, can lead to degradation of the road and knock-on damage vehicles.

Safety risk to cyclists and high sided vehicles leading to slower travel and even closures on bridges for some vehicles

Possible wind damage to roadway infrastructure; service disruption if winds leave trees or other debris on roads

Exposure to salinity can deteriorate / corrode roadway surfaces and base layers, culverts, or metal bridge components

Erosion of unpaved roads or road bases may cause road failure or reduce road stability

Increased risk of land-/mudslides, which can damage roads and make them temporarily impassable

Damage to bridge structures; increased scour and erosion of bridge foundations

Increased weather-related traffic accidents; traffic disruption and congestion

Inability to access or safely use roads (esp. unpaved roads) until flooding subsides and related cleanup and repairs are completed

Drainage works overwhelmed; damage to tunnels and underpasses

Deterioration of pavement and road foundations, increasing repair costs and decreasing service life of infrastructure

Damage to electrical equipment and power outages for EV recharge systems leading to reduced travel range and increased traffic blockages from vehicles running out of charge Risk from Flood and Erosion; both run-off and coastal wave action

Knock-on effects for communities and businesses. Prolonged road closures due to flooding has led to business interruption and closures, difficulty in access to schools and health facilities with knock-on effects for mental health in affected communities, especially those that remain at risk due to insufficient adaptation

ADAPTATION OPTIONS

General:

- ✓ Enhanced inspection and maintenance regimes
- ✓ Build back better if impacted
- ✓ Increase resilience at asset renewal stage

- ✓ Construct strategic wind breaks
- ✓ Design roadside infrastructure and bridges to withstand higher wind speeds
- ✓ Improve weather forecasting capacity and implement early warning systems
- ✓ Implement system to proactively manage roadside vegetation and debris

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- ✓ Employ corrosionresistant materials, where feasible
- ✓ Relocate or elevate critical equipment
- ✓ Treat with protective coatings to slow corrosion
- ✓ Construct new or enhance existing coastal protections (levees, seawalls, dikes); enhance nature-based protections, including coastal wetlands and mangroves
- ✓ Increase attention to corrosion prevention in asset management

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- ✓ Implement erosion control measures
- ✓ Pave unpaved roads where cost-effective
- ✓ Increase the capacity for rapid repairs where paving roads is not cost effective
- ✓ Use pavement materials that are less susceptible to erosion
- ✓ For wave-induced erosion, build new or enhance existing breakwaters and sea walls
- ✓ Reroute sections of coastal road exposed to wave action
- ✓ Design new bridges to withstand stronger wave action
- ✓ Introduce hydraulic binding agents into earthwork material

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- ✓ Stabilize slopes using physical support structures (e.g., retaining walls) and vegetative reinforcement
- ✓ Cut back steep slopes to shallower angle
- ✓ Improve slope and subgrade drainage
- ✓ Introduce chydraulic binding agents into earthwork material
- ✓ Increase monitoring of slopes, subgrade material, and related drainage systems
- ✓ Avoid high-risk areas in siting new infrastructure
- ✓ Construct green infrastructure near roads to reduce run-off

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- ✓ Raise bridge decks to accommodate increase in flood volumes
- ✓ Reinforce bridge piers and abutments and strengthen foundations (e.g., deepen bridge footings)
- ✓ Scour risk assessments
- ✓ Forecasting sys-tems which can be prioritised
- ✓ Stabilize stream banks (by installing revetments, gabions, riprap or by increasing vegetation) to prevent erosion
- ✓ Construct retention dams upstream to reduce flood flows
- ✓ Conduct more frequent inspection and maintenance

- ✓ Consider projected flood risk in siting new roadway infrastructure; relocate existing infrastructure away from high-risk areas
- ✓ Avoid disruption to regional hydrology and wetlands, which can increase flood risk, in siting new roads
- ✓ Raise road surface level to reduce flood damage and ensure continued access during flood events
- ✓ Consider flood risk in design/capacity of drain and stormwater systems over the useful life of new infrastructure
- ✓ Upgrade existing road drainage systems to accommodate greater flows; increase culvert capacity
- ✓ Increase pumping capacity to evacuate water from tunnels; deploy mobile pumps during intense rains
- ✓ Ensure positive cross-slopes to help with water evacuation
- ✓ Upgrade unpaved roads (if cost-effective)
- ✓ Increase flood protections near roadways; use green infrastructure and retention basins to divert run-off/increase infiltration
- ✓ Regular inspection and maintenance of drainage systems
- ✓ Improve weather forecasting, develop and implement emergency management plans and early warning systems
- ✓ Reduce travel speeds in extreme weather
- ✓ Design for cost-effective raising of flood defenses in future if required.

- ✓ Use pavement materials that are better sealed and less susceptible to moisture
- ✓ Increase base strength (thickness and/or quality) to increase protection of subgrade layers
- ✓ Alter selection of subgrade materials to withstand higher moisture contents; Use hydraulic binding agents in road foundation
- ✓ Conduct more frequent maintenance; seal cracked and distressed areas
- ✓ Have traffic management plans in place to reduce damage with minimised disruption to affected communities

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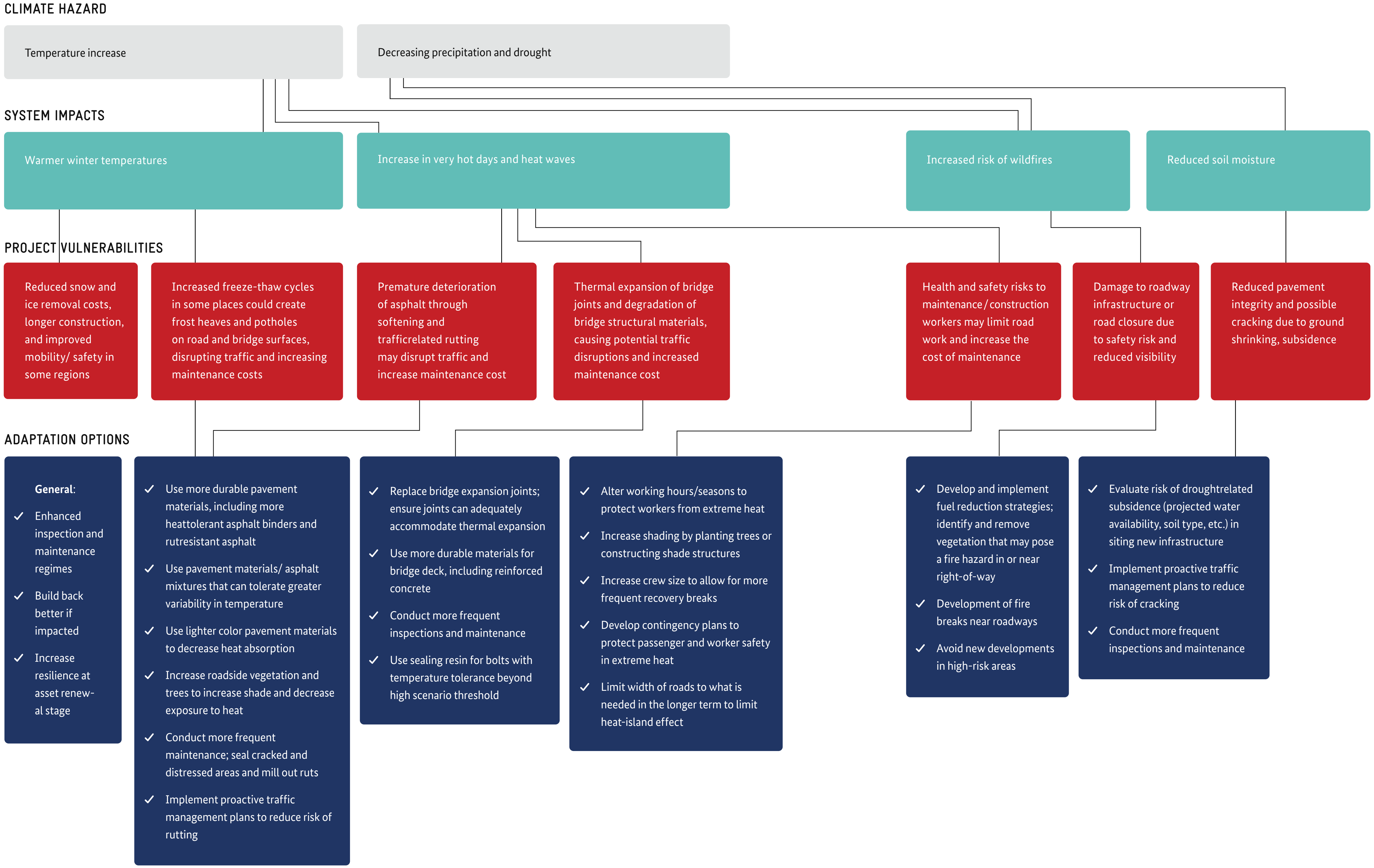
- ✓ Protect signaling and other electrical equipment
- ✓ Deploy mobile power supply substations to be used in case of power outages
- ✓ Increase redundancy in electrical systems
- ✓ Develop contingency plans for electricity disruption

FIGURE 17: DECISION TREE FOR ROAD AND CYCLE WAY PROJECTS (PAGE 2)

Module 5f: Adapting Urban Transport to Climate Change



Source Figure 17: IsDB (2019)

FIGURE 18: DECISION TREE FOR RAIL AND TRAMWAY PROJECTS (PAGE 1)

CLIMATE HAZARD

Increasing frequency and magnitude of storms

Rising sea levels and increased storm surge heights

Increasing precipitation or frequency of extreme precipitation events

SYSTEM IMPACTS

Strong winds associated with more intense storms

Rising relative sea levels and Saltwater intrusion

Stronger wave action and increased coastal erosion

Increased run-off and erosion

Increased flood risk

PROJECT VULNERABILITIES

Potential wind damage to railway infrastructure; service disruption if winds leave trees or other storm debris on tracks

Exposure to salinity, salt spray can increase corrosion of tracks, electrical equipment, and metal bridge components

Increased erosion of track subgrade can wash away ballast and reduce track stability, increasing maintenance costs and potentially requiring speed restrictions

Increased risk of land-/ mudslides, which can damage tracks and make them temporarily impassable

Damage to electrical equipment and power outages may cause track circuit failures and other operational disruption, including to signaling systems, disrupting service

Flood damage to underground transit systems, including subway stops, trains and tunnels, may disrupt transit service

Flood damage to rail stations and tram stops, rolling stock, and maintenance facilities

Temporary loss of service until flooding subsides and related cleanup and repairs are completed

Damage to bridge structures; increased scour and erosion of bridge foundations

ADAPTATION OPTIONS

General:

- ✓ Enhanced inspection and maintenance regimes
- ✓ Build back better if impacted
- ✓ Increase resilience at asset renew-al stage

- ✓ Construct strategic wind breaks
- ✓ Design rail-side infrastructure and overhead lines to withstand higher wind speeds
- ✓ Improve weather forecasting capacity and implement early warning systems
- ✓ Implement system to proactively manage track-side vegetation and debris

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- ✓ Enhance coastal protections (e.g., sea walls, levees)
- ✓ Employ corrosion-resistant materials, where feasible
- ✓ Relocate or elevate critical equipment
- ✓ Treat with protective coatings to slow corrosion

- ✓ Stabilize slopes using physical support structures (e.g., various types of retaining walls) and vegetative reinforcement
- ✓ Cut back steep slopes to a safer, shallower angle
- ✓ Improve slope and subgrade drainage
- ✓ Introduce hydraulic binding agents into earthwork material
- ✓ Increase monitoring of slopes, subgrade material, and related drainage systems
- ✓ Avoid areas with high risk of slides in siting new railway infrastructure
- ✓ Introduce hydraulic binding agents into earthwork material
- ✓ Implement erosion control measures
- ✓ Construct green infrastructure near rail tracks to reduce run-off
- ✓ For wave-induced erosion, build new or enhance existing breakwaters and sea walls
- ✓ Develop and implement improved methods of detecting subgrade erosion

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- ✓ Elevate and protect signaling and other electrical equipment
- ✓ Deploy mobile power supply substations to be used in case of power outages
- ✓ Increase redundancy in electrical systems
- ✓ Increase resilience of overhead lines by design and retrofit
- ✓ Develop contingency plans for electricity disruption

- ✓ Install and maintain emergency pumping capacity to evacuate water from underground transit systems and tunnels; enhance pumping capacity; deploy mobile pumps during intense rains
- ✓ Couple increased pumping capacity with passive rainwater evacuation and management systems
- ✓ Increase flood protections around and/or elevate transit stop entrances
- ✓ Use mobile barriers to prevent water from entering tunnels and underground transit systems
- ✓ Raise sidewalk level ventilation grates so that water doesn't enter underground systems from flooded sidewalks
- ✓ Develop emergency management plans, including passenger evacuation plans for underground systems
- ✓ Upgrade transit tunnel lining to prevent groundwater infiltration

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- ✓ Integrate projected flood risk into site assessments for new railway infrastructure
- ✓ Relocate existing infrastructure away from high-risk areas
- ✓ Elevate railway infrastructure, including tracks, rail stations, and electrical equipment
- ✓ Incorporate flood risk into design of stormwater management and drainage systems; retrofit existing systems to deal with increased run-off
- ✓ Conduct frequent maintenance of drainage infrastructure
- ✓ Enhance flood protections near railway infrastructure
- ✓ Increase water retention capacity; use green infrastructure to divert run-off/increase infiltration
- ✓ Install flood-proofing measures (e.g., barriers, gates, shutters)
- ✓ Improve weather forecasting capacity and implement early warning systems
- ✓ Provide temporary alternative transit option

- ✓ Raise bridge decks to accommodate increase in flood volumes
- ✓ Reinforce bridge piers and abutments and strengthen foundations (e.g., deepen bridge footings)
- ✓ Stabilize stream banks (by installing revetments, gabions, riprap or by increasing vegetation) to prevent erosion
- ✓ Construct retention dams upstream to reduce flood flow
- ✓ Conduct more frequent inspection and maintenance Scour risk assessments
- ✓ Forecasting systems which can be prioritised

FIGURE 18: DECISION TREE FOR RAIL AND TRAMWAY PROJECTS (PAGE 2)

CLIMATE HAZARD

- Temperature increase
- Decreasing precipitation and drought

SYSTEM IMPACTS

- Warmer winter temperatures
- Increase in very hot days and heat waves
- Increased risk of wildfires
- Reduced soil moisture

PROJECT VULNERABILITIES

- Reduced snow and ice removal costs, longer construction, and improved mobility / safety in some regions
- Increased freeze-thaw cycles or thermal expansion of rail track may cause buckling, and increase safety risks, travel delays, and maintenance costs
- Potential for electrical signaling and communications systems to overheat and malfunction
- Overhead lines may expand and sag, requiring lines to be shut down and potentially disrupting service
- Health and safety risks to passengers, transit operators, and maintenance personnel
- Increased energy usage and cost for cooling and/or refrigeration; AC units on trains may fail in extreme heat
- Thermal expansion of bridge joints, increasing safety risks, travel disruption, and maintenance costs
- Damage to railway infrastructure or service disruptions due to safety risk or reduced visibility
- Soil shrinkage may cause earthworks failure and uneven rail settlement

ADAPTATION OPTIONS

General:

- ✓ Enhanced inspection and maintenance regimes
- ✓ Build back better if impacted
- ✓ Increase resilience at asset renewal stage

- ✓ Replace track elements and rail with more heat-resistant materials
- ✓ Install (additional) expansion joints in frequently buckled sections of rail
- ✓ Impose speed restrictions to ensure safety
- ✓ Consider restricting train loads in extreme high temperatures to avoid buckling
- ✓ Monitor rail track condition and conduct frequent maintenance
- ✓ Paint track white to absorb less heat
- ✓ Increase shading to reduce heat exposure
- ✓ Develop and implement improved methods to detect buckling

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- ✓ Increase ventilation and cooling substations, signal rooms, and electrical boxes
- ✓ Replace existing electrical equipment with equipment that can withstand higher temperatures
- ✓ Conduct regular monitoring and maintenance of electrical equipment
- ✓ Install overhead lines with higher design temperature range
- ✓ Install technology to automatically adjust line tension with temperature variation
- ✓ Provide temporary alternative transit option (bus)

- ✓ Design trains and transit stops to improve thermal comfort (use heat-resistant materials, tinted windows, windows that open, white painted roofs, etc.)
- ✓ Maximize natural ventilation and improve cooling systems in trains and transit stops
- ✓ Alter working hours to protect workers from extreme heat
- ✓ Increase shading by planting trees or constructing shade structures
- ✓ Increase crew size to allow for more frequent recovery breaks
- ✓ Make greater use of climate-controlled facilities for loading and unloading rail cars
- ✓ Develop contingency plans to protect passenger and worker safety in extreme heat

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- ✓ Improve energy efficiency to reduce air conditioning costs
- ✓ Explore less energy-intensive refrigeration systems for freight
- ✓ Upgrade air conditioning on railcars and trams to ensure operability at high temperatures; conduct frequent maintenance
- ✓ Paint trains and trams in lighter colours

- ✓ Replace bridge expansion joints
- ✓ Use more durable materials for bridge deck, including reinforced concrete
- ✓ Conduct more frequent inspections and maintenance
- ✓ Use sealing resin for bolts with temperature tolerance beyond high scenario threshold
- ✓ The replacement of joints and durable materials sound more related to roads.

- ✓ Develop and implement fuel-reduction strategies; identify and remove vegetation that may pose a fire hazard in or near rail right-of-way
- ✓ Develop fire breaks near rail infrastructure
- ✓ Avoid new developments in high-risk areas

- ✓ Consider projected water stress in siting new infrastructure; relocate existing infrastructure away from highrisk areas
- ✓ Conduct more frequent inspections and maintenance
- ✓ Use alternative rail bed material
- ✓ Rapid response track remediation arrangements
- ✓ Rapid response electrical / signalling arrangements
- ✓ Alternative earthing arrangments by design and retrofit in risk-prone areas.

- ✓ Rapid response electrical / signalling arrangements
- ✓ Alternative earthing arrangments by design and retrofit in risk-prone areas.

Source Figure 18: IsDB (2019)

FIGURE 19: DECISION TREE FOR PORT PROJECTS (PAGE 1)

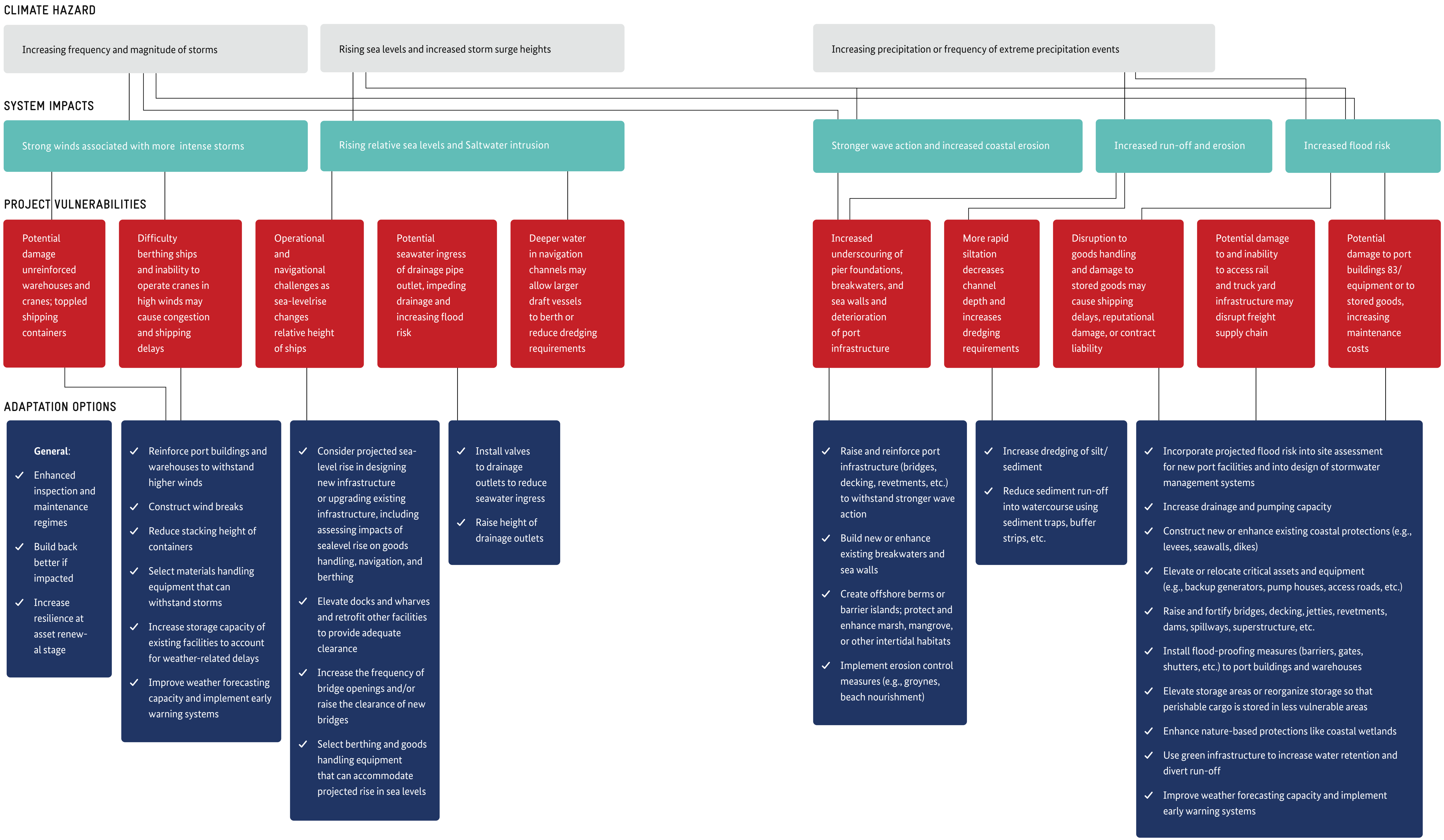
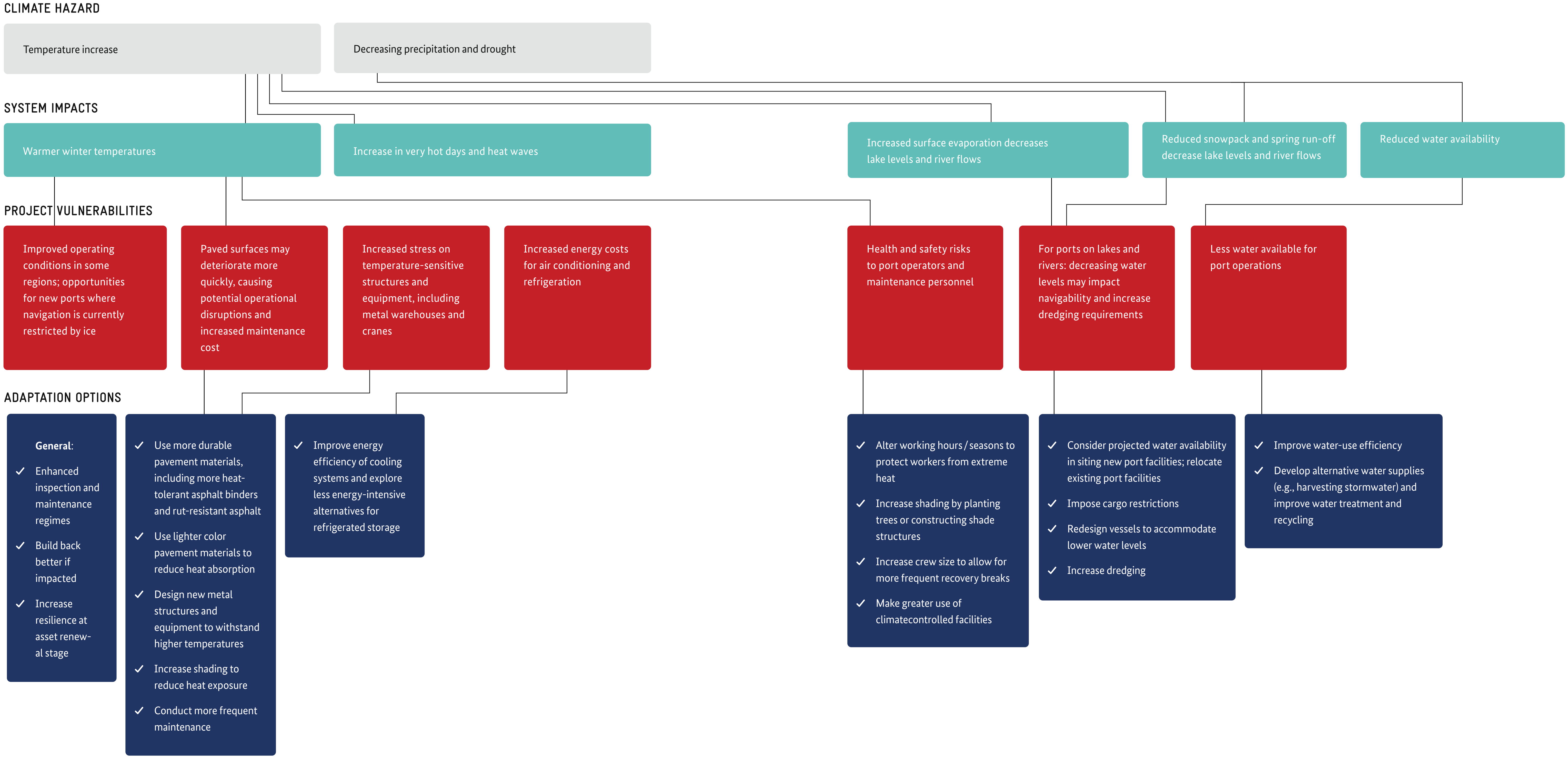


FIGURE 19: DECISION TREE FOR PORT PROJECTS (PAGE 2)



Source Figure 19: IsDB (2019)

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