United Nations ECE/TRANS/WP.5/GE.3/2023/2/Rev.1

Economic and Social Council

Distr.: General
13 February 2024
English
Original: English, French and Russian

Economic Commission for Europe

Inland Transport Committee

Working Party on Transport Trends and Economics

Group of Experts on Assessment of Climate Change Impacts and Adaptation for Inland Transport

Twenty-sixth session
Geneva, 7 and 8 March 2024
Item 5 of the provisional agenda
Database on adaptation measures

Framework for developing adaptation pathways for transport professionals

Revision

Note by the secretariat

I. Background

1. At its twenty-fourth session, the Group of Experts on Assessment of Climate Change Impacts and Adaptation for Inland Transport (GE.3) reviewed and provided comments on the draft guidance on adaption pathways in the transport sector prepared by a group of volunteers who engaged in the intersessional work to elaborate the guidance.

2. In response to comments received, two documents have been prepared for consideration by GE.3. This document, as second of the two documents, provides the draft framework for developing adaptation pathways for transport professionals.

3. The main author of this document is Dr. S.A. Hashmi, University of Birmingham. Substantive inputs were provided by Dr. E Ferranti and Prof A. Quinn, University of Birmingham, T. Popescu, Directorate General for Infrastructure, Transport and Mobility of France and GE.3's Vice-Chair, C. Evans, PIARC, R. Burbidge, Eurocontrol and L. Wyrowski (United Nations Economic Commission for Europe (ECE) secretariat).

4. GE.3 is invited to review it.

II. Framework for developing adaptation pathways for transport professionals

5. This section provides and discusses an adaptation pathways framework (as shown in Figure I) suited for use by transport infrastructure owners, managers and operators to structure short- medium- and long-term climate preparedness planning.

6. An effective adaptation planning begins with the identification and prioritisation of options based on the risks/vulnerabilities identified by the climate change risk assessment and builds on chosen scenarios that reflect the projections on climate change and address stakeholder concerns and issues. The development of adaptation pathways will often involve a mix of approaches, mainly depending on the scales and complexities of the set goals and objectives and thus may require multiple iterations. The two deciding factors when selecting a mix of approaches will be the degree of certainty of present information and knowledge and the agreement on goals within the transport sector [25]. Depending on the specific circumstances, the mix of approaches may include:

- Flexible and learning approaches: These approaches emphasise continuous learning and adaptation as new information and knowledge about climate impacts become available. It involves regularly revisiting and updating adaptation plans based on emerging data, monitoring the effectiveness of measures, and being responsive to changing climate conditions.
- Scenario-based approaches: Scenario planning is used to explore a range of potential future climate scenarios. By considering different possible futures, decision-makers can identify adaptation options that are robust across multiple scenarios. This approach allows for greater flexibility in response to uncertain climate projections.
- Incremental approaches: These involve making gradual adjustments and improvements to existing transportation infrastructure and operations to enhance climate resilience. Incremental approaches may include measures such as reinforcing coastal defences, elevating roads in flood-prone areas, or improving drainage systems.
- Transformational approaches: Transformational approaches involve more fundamental changes to transportation systems, often driven by the need to adapt to significant climate risks. For example, in regions where climate change is causing increased instances of landslides and erosion along railway tracks, if a particular stretch of railway track is repeatedly affected by landslides due to changing precipitation patterns, the rail company could decide to relocate that section to higher ground or reinforce the area to prevent future disruptions.
- Stakeholder engagement: Stakeholder engagement is a crucial approach that involves involving diverse stakeholders, including local communities, businesses, NGOs, and policymakers, in the adaptation planning process. Engaging stakeholders ensures that adaptation pathways are inclusive, consider different perspectives, and address diverse concerns and priorities.

7. Potential tipping, turning and trigger points should be identified based on the current situation and possible futures analyses (see section on Identifying critical decision points below). Also, the aim should be focused on identifying alternative options to achieve objectives (see section on Considering interdependencies and determining alternative adaptation options below) so that stakeholders in the transport sector can justify, prioritise and implement actions that take climate change and associated changes in economic, socio-political, knowledge, values and ecosystems into consideration. It must be noted that any potential adaptation option should be assessed in terms of its robustness and flexibility with respect to the range of potential futures expected (see section on Evaluating pathway options below).

8. Additionally, in the adaptation planning process and the development of adaptation pathways, consideration of the geographic scale at which adaptation responses are needed is very important. For example, the geographic scale on which pathways are formulated can range from a small coastal stretch to perhaps a large delta area with different land uses and drivers of change. Also, the geographic scale can also help determine the relevant stakeholders and sectors that might be included in the development process, which then further determines the generation of options. One case study demonstrated that a mismatch between geographic and institutional scales resulted in fuzzy thresholds, a large array of options and unclear institutional responsibilities [33]. Another important consideration involves capacity building through developing and sharing information, resources and decision-making tools for adaptation measures; community sharing and understanding on the need to adapt, and collaborating with the community to achieve agreed responses [34].

Guiding steps to develop adaptation pathways for transport professionals

9. To develop adaptation pathways, there is a certain expected level of knowledge and understanding that is needed from transport infrastructure professionals and is discussed in ECE/TRANS/WP.5/GE.3/2023/1. This is important to fully comprehend the guidance and thereafter implement it. This section elaborates the steps 4 and 5 shown in the figure in ECE/TRANS/WP.5/GE.3/2023/1. For any particular goal or objective, the development of adaptation pathways is expected to broadly follow the following steps:

(a) Reviewing vulnerabilities and interdependencies

(b) Identifying critical decision points

(c) Considering interdependencies and determining alternative adaptation options

(d) Evaluating pathway options

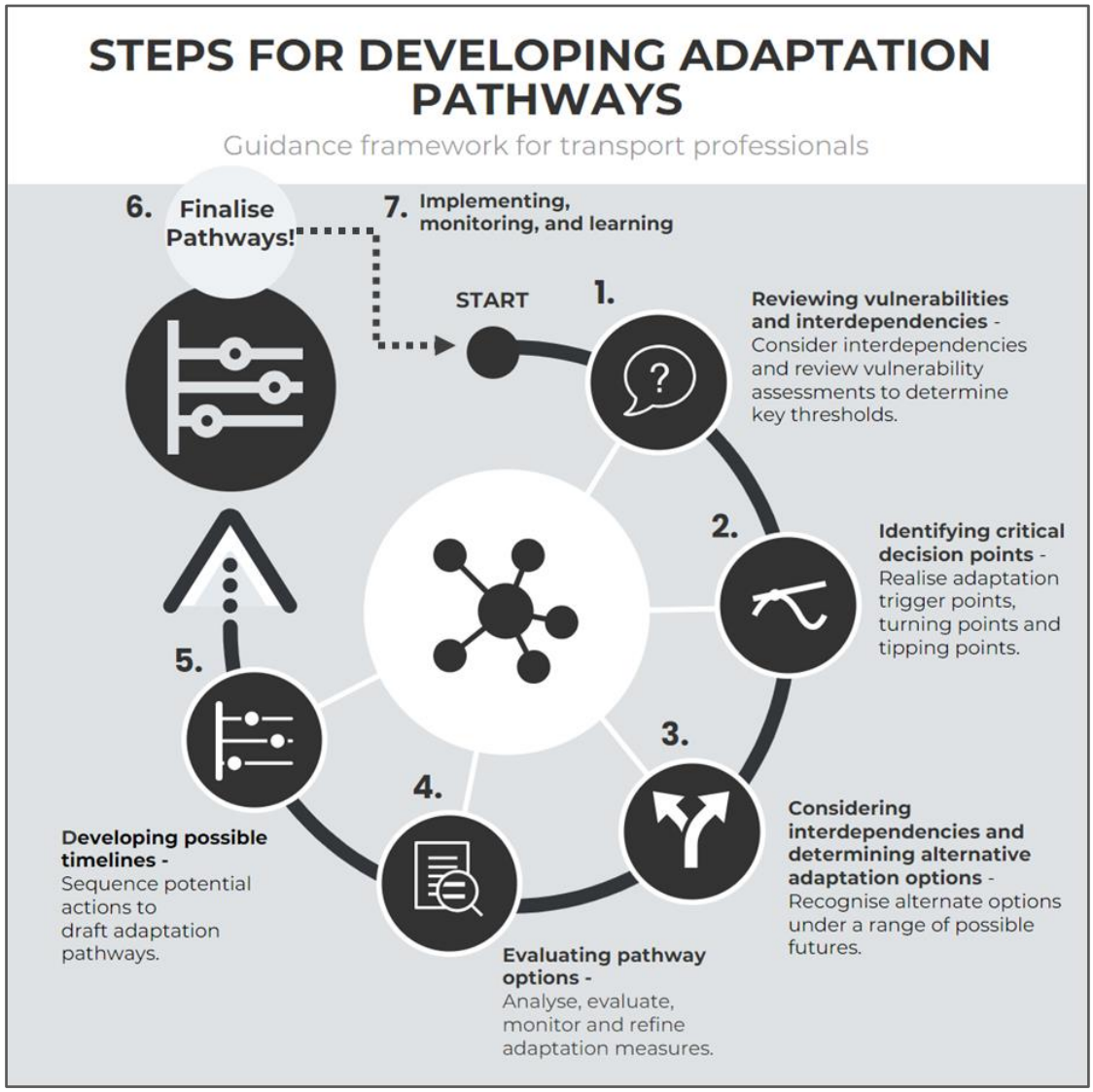
(e) Developing possible timelines

(f) Finalising and visualising adaptation pathways

(g) Implementing, monitoring and learning

Figure I

Steps for developing adaptation pathways for transport infrastructure owners and managers as well as other transport professionals



1. Reviewing vulnerabilities and interdependencies

10. The development of adaptation pathways commences by the identification of what is presently being done to manage systems and issues related to the particular objective. Ongoing practices are usually in place for particular weather events and climate patterns, depending on the current and historical times. These practices have existing management strategies which have their own strengths and vulnerabilities. Over here, this step entails reviewing and revisiting the vulnerability analysis of key infrastructures to understand about the existing vulnerabilities (i.e. reviewing step 2 of the prerequisites) and to determine thresholds which can help identify additional actions that may be needed to address the objectives within existing constraints [25]. Looking at the current or baseline capabilities (i.e. assessing the technical and the institutional capabilities for responding to climate and extreme weather) is an important step which must be carried out prior to seeking improvements in those capabilities.

11. Understanding of the current situation and possible futures should be used to further determine management actions that may lead to reducing the vulnerabilities and/or increasing the adaptability for the individual assets. Evidence-based, robust, 'no-regret' options should be identified here as it can enable organisations to implement short-term adaptation actions and commence the adaptation process, instead of waiting and analysing the situation [23].

12. Also, investigating previous vulnerabilities can mark a suitable starting point for addressing future vulnerabilities. Indeed, this step also requires to review the analysis of future vulnerabilities, performed as part of step 3 of the prerequisites. The objective is to use the already performed vulnerability analysis and/or the stress tests to identify thresholds of impacts at which the transport system operates significantly differently. This step could help determine and assess the key thresholds of climate impacts for the transport system, based on the known existing and future vulnerabilities with regards to those impacts (for example, in the case of sea level rise, a certain level of rise may lead to increased risks of flooding or damage to coastal embankments).

13. Furthermore, interdependencies can also be important vulnerabilities when it comes to climate change adaptation. In the context of adaptation planning for transport infrastructures, interdependencies refer to the connections and interactions between different systems, sectors, or infrastructure networks that can influence their resilience to climate change impacts. Interdependencies can create vulnerabilities in several ways:

- Cascading effects: Climate change impacts on one sector or system can have cascading effects on interconnected sectors or systems. For example, a port is often well-connected to its hinterland through a network of roads, railroads, and other transportation infrastructure. However, an extreme weather event can cause significant damage to the transportation systems connecting the port to its hinterland. This includes disruptions to transportation networks, impacts on supply chain, economic consequences, unutilised port capacity, and other short-term and long-term challenges
- Critical dependencies: Some sectors or systems may have critical dependencies on others. If a critical dependency is compromised due to climate change impacts, it can significantly impact the dependent system. For example, energy infrastructure relies on transportation systems for the delivery of fuel, and disruptions in transportation can affect energy supply.
- Cross-sectoral interdependencies: Interdependencies can exist between sectors that have shared resources or depend on common infrastructure. For instance, public transportation systems rely on energy sources to operate. If the energy supply is disrupted due to climate-related events, such as storms damaging power infrastructure or heatwaves affecting energy generation, public transport services could be interrupted.

14. Interdependencies in the context of adaptation planning for the transport infrastructure sector should be considered in a much broader way, encompassing not only other drivers within the transportation system but also with other societal, economic, and ecological goals, including those related to mitigation efforts. These broader interdependencies play a vital

role in shaping effective and sustainable adaptation strategies [4]. Transport infrastructure owners and managers must identify and understand the critical interdependencies between their infrastructure and other infrastructure networks (for instance the interdependencies between energy supply and road transport), as this will be crucial for continuing work on climate change adaptation planning. This includes the consideration of potential cascading failures between interlinked natural and socioeconomic systems and sub-systems. For example, a period of prolonged and widespread severe weather can affect the transport network which may then have an impact on the availability of and access for transport personnel (such as lorry drivers), compromising vessel loading and unloading efficiency, and creating a backlog that ultimately affects the wider supply chain. Alternatively, a power outage may affect the safety and function of the transport operations and services. Also, transport departments not expected to suffer from a particular climate risk can also be expected to suffer at some point due to interdependencies and therefore indirect impacts. Thus, the transport sector must be fully resilient to climate change and including the interdependencies element in climate adaptation planning and developing adaptation pathways can be a key entry point for a more holistic approach to enhancing resilience. Additionally, along with climate and cross-sectoral interdependencies, transport professionals could also assess the socio-economic, environmental, technological and engineering, governance and institutional and financial interdependencies.

Guiding and learning questions for transport professionals for reviewing vulnerabilities.

How can the existing vulnerability assessment be used to identify thresholds of impacts at which the transport system is significantly affected (or the vulnerability is significantly increased)?	What is currently being done, and what else could be done, to produce specific outcomes under the present conditions?

2. Identifying critical decision points

15. Adaptation pathways begin with current management options. These management options can be affected by the potential implications of climate change. Such implications for both the system being managed and current management options inform where decisions should be made. Existing management options can be considered in a range of possible futures, which then helps in addressing the next step. Through combination of information from the current situation and future analyses, it becomes possible to identify probable thresholds or tipping points and turning points for adaptation options [25]. Those thresholds are defined through indicators which enable monitoring risk levels. Indeed, the thresholds need to be associated to the levels of risk used to define the adaptation objectives [27]. Each risk level can then be quantified based on those thresholds.

16. In adaptation planning, the idea of thresholds is quite common, however requires special efforts to apply. For transport professionals, the concepts of thresholds are relevant in understanding when managers need to change from one response option to another. Thresholds can be defined as points at which a system starts to operate in a significantly different manner. In the transport sector, a threshold can be defined as a set of climate conditions under which a part of the transport system is no longer effective, either in terms of economic, environmental, physical or social aspects. Thus, at that point, a further adaptation measure is needed. For instance, due to a certain threshold level of windspeeds, traffic for heavy-duty trucks at a bridge may be required to be stopped to prevent the

destruction of the bridge. In such a case, if alternate routes are possible, an example of an adaptation option would be to divert truck traffic. Furthermore, in extreme cases, such as at a much higher threshold level of windspeed, the bridge infrastructure may be damaged and thus in such a scenario, adaptation of the physical infrastructure to secure serviceability will be needed [13].

17. Trigger points mark the beginning of necessary lead time for an action before reaching a tipping or turning point. In adaptation planning for transportation systems, trigger points are specific indicators or thresholds that serve as signals to initiate adaptation actions or strategies. They help decision-makers identify when it is necessary to implement proactive measures to address the impacts of climate change on transportation systems.

18. Trigger points account for how long a decision to adapt takes to be made and implemented. The latter originates from the next stages of identifying alternative options. Trigger points are a crucial element in the development of adaptation pathways approach, allowing for plans to be anticipatory and strategic. Also, in the transport sector, triggers for adaptive action can be influenced by events or thresholds in different parts of the system, even if the direct impact is not immediately evident. For example, a threshold reached in one segment of the transport system, such as a critical road being inundated due to sea-level rise, can serve as a trigger for adaptive actions in other parts of the system, such as diverting traffic or implementing alternative transportation routes. Identifying and recognising these interconnected triggers is essential for a holistic and integrated approach to adaptation planning in the transport sector. Understanding how impacts in one area can cascade to affect other parts of the transport system allows decision-makers to develop comprehensive adaptation pathways that account for system-wide resilience and efficiency [13, 25]. Positive trigger points can also be identified for possible opportunities such as: political will and readiness of additional funds.

19. Triggers may occur without a threshold being reached and should be easily monitored to enable prompt action. It must be noted that thresholds and triggers have different meanings. For instance, at a particular location, an increase in sea level may indicate a large storm which can possibly destroy infrastructure. In such a case, even if this has not occurred in reality, a threshold would be the actual failure of the infrastructure involved, leading to a disruption of the functions of the infrastructure. The trigger in this example is the rise in sea level reaching a point at which a decision needs to be made [14]. For example, if an asset becomes vulnerable when mean sea level has risen by 0.50m, a trigger level of 0.45m of sea level rise may provide enough notice to start implementing relevant adaptation measures. It must be noted that preventive adaptation actions can be taken at trigger points, providing early warning indicators for approaching critical environmental conditions. While some adaptation actions at threshold stages may be curative, it is essential to also implement additional preventive measures to build resilience and reduce future risks. A combination of preventive and curative actions is often more effective in adaptation planning, with preventive measures at trigger points to minimise damages and disruptions, curative actions addressing immediate challenges, and long-term adaptation actions enhancing resilience against future events.

20. Trigger points can be based on various factors, including climate variables, infrastructure conditions, and operational considerations. For example:

(a) Climate Variables:

- Thresholds for extreme weather events - Establishing trigger points based on specific thresholds of climate variables such as heavy rainfall, wind speed, or temperature extremes can help trigger actions to reinforce infrastructure, enhance drainage systems, or implement emergency response plans.
- Sea-level rise thresholds - Defining trigger points based on projected sea-level rise can help determine when protective measures like elevating roads or implementing coastal defences need to be implemented.

(b) Infrastructure Conditions:

- Structural degradation - Setting trigger points based on the deterioration or damage of infrastructure elements such as bridges, culverts, or pavements can prompt repair or

replacement actions to ensure the continued functionality and safety of transport systems.

- Monitoring critical assets - Implementing monitoring systems for critical transportation assets, such as bridge foundations or slope stability, and establishing trigger points based on pre-defined performance criteria can help detect early signs of potential failure and initiate timely interventions.

Guiding and learning questions for transport professionals in identifying critical decision points.

How to identify what decision points would be most important and what tipping points would trigger the next phases of the adaptation pathway?	What is needed to enable the transitional or transformational action?

21. Overall, it must be remembered that refining trigger points is a natural part of the adaptive planning process. It ensures that adaptation pathways remain dynamic, flexible, and responsive to changing circumstances, providing a more effective and sustainable approach to climate change adaptation. As new information and experiences emerge along with the identification of adaptation options, decision-makers can adjust trigger points to maximise the benefits of proactive and timely adaptive actions.

22. Adaptation Turning points indicate situations in which a social-political threshold is reached. This may be due to changes in climate, social values and interests or policy objectives [25]. In adaptation planning, turning points refer to critical moments or junctures where significant changes or shifts occur in the approach to managing climate change impacts. These turning points represent opportunities for decision-makers to reassess their strategies, update their actions, and make more informed choices in response to new information, emerging risks, or changing circumstances. These may occur due to new scientific information, crisis or catastrophic events, policy and regulatory changes, technological advancements, shifts in public awareness and perception, learning from monitoring and evaluation, changing socioeconomic conditions and international agreements and commitments.

23. For transport infrastructure owners and operators, turning points refer to critical moments or key events that prompt significant changes in the approach to managing the impacts of climate change on transportation systems. These turning points may arise due to various factors and can influence decisions and actions taken by infrastructure owners and operators to enhance the resilience and sustainability of their assets and services. A few examples of these include [36, 37]:

- Extreme Weather Events: A severe weather event, such as a hurricane, flood, or wildfire, can act as a turning point for infrastructure owners and operators. The damage and disruption caused by such events may lead to a reassessment of vulnerability, prompting the adoption of more resilient construction practices and improved emergency response plans.
- Infrastructure failure or deterioration: When critical transport infrastructure experiences significant failures or deterioration due to climate impacts, it becomes a turning point. This could trigger the need for immediate repairs, replacement, or redesign to withstand future climate stresses.
- New climate projections or risk assessments: Updated climate projections or risk assessments may reveal higher levels of climate-related risks than previously

anticipated. This new information can prompt infrastructure owners and operators to adjust their adaptation strategies accordingly.

- Funding opportunities or budget constraints: A significant increase in funding opportunities for climate adaptation or budget constraints that limit traditional maintenance and construction can lead to turning points in prioritising and allocating resources to climate resilience measures.
- Regulatory changes and compliance requirements: New regulations or compliance requirements related to climate resilience can serve as turning points. Infrastructure owners and operators may need to align their operations with these regulations, influencing the scope and timing of adaptation planning.
- Technological innovations: Advancements in technology for climate adaptation, such as improved forecasting tools, monitoring systems, or construction materials, can be turning points that drive more effective and efficient adaptation strategies.
- Community engagement and feedback: Input from local communities and stakeholders can act as turning points, as it may reveal previously unrecognized vulnerabilities and inform the development of more inclusive and community-driven adaptation plans.
- Business continuity concerns: The realisation that climate impacts could disrupt business continuity or supply chains can be a turning point, leading infrastructure owners and operators to invest in adaptation measures to safeguard operations and economic viability.
- Changing land use patterns: Changes in land use patterns due to urbanization or population growth can influence the demand for transportation infrastructure. This may prompt infrastructure owners and operators to reconsider future expansion plans and incorporate climate resilience into new projects.

24. Adaptation Tipping points identify thresholds where magnitude of change because of climate change consequences (such as flooding events) exceeds the present capabilities of the management strategies to meet current objectives. Thus, with the identification of tipping points, it is possible to understand whether and when a management strategy may fail and other strategies will be needed. Also, with adaptation tipping points, it becomes possible to understand how much climate change the system can cope with using current practices [25].

25. In the context of adaptation planning for transportation systems, tipping points refer to critical thresholds or situations beyond which the impacts of climate change on transportation systems become so severe that traditional adaptation measures may no longer be sufficient or feasible. These tipping points can result in abrupt and irreversible changes in transportation infrastructure, operations, and mobility patterns, making it challenging for the transportation sector to function effectively and meet the needs of society.

26. Some examples of potential tipping points in adaptation planning for transport include:

- Sea-level rise and coastal erosion: For coastal regions, sea-level rise and coastal erosion can lead to the inundation or damage of transportation infrastructure such as roads, bridges, and ports. At a certain point, maintenance and repairs might become too costly or impractical, and relocation or major redesign of transportation networks may be necessary.
- Extreme Weather Events: More frequent and intense extreme weather events, such as hurricanes, floods, and wildfires, can cause significant damage to transportation infrastructure and disrupt travel. If the frequency and severity of such events surpass manageable levels, adaptation measures like reinforcing structures and creating alternative routes might no longer be adequate and thus in some cases the need for potential relocation of critical transportation assets and infrastructure may arise.
- Heatwaves and temperature Extremes: Prolonged heatwaves can lead to pavement buckling, railway track deformation, and increased stress on transportation assets. If extreme temperatures become more frequent or reach intolerable levels, it may be

necessary to redesign infrastructure to withstand higher temperatures or explore alternative transportation modes.

- Disruption of supply chains: Climate change impacts can disrupt supply chains, affecting the availability and cost of materials needed for transportation infrastructure maintenance and repair. At a certain point, it might become difficult to maintain reliable transportation services, especially in remote or vulnerable regions.
- Loss of access to critical routes: Some transportation routes may become inaccessible due to changing conditions, such as landslides, melting permafrost, or glacial retreat. If these routes serve as vital lifelines for communities or crucial trade corridors, alternative solutions and investments in new infrastructure may be required.

27. An example of identifying adaptation tipping points in the context of coastal defences for vulnerable coastal transport infrastructure was made by determining the level of sea-level rise at which the defence is no longer able to meet its defined performance threshold [35]. In terms of transport infrastructures, weather-proofing these may need a high initial investment, however, over the longer-term this is a necessary step in order to prevent the escalating costs or even expensive retrofitting. In such cases, it is vital to identify the tipping point at which the cost of additional adaptation becomes disproportionate to the added benefits achieved [**Error! Reference source not found.**3]. Overall, potential tipping points for transport infrastructure and assets can be identified through conditions under which:

(a) Action(s) may no longer be effective,

(b) Asset or system thresholds might be reached, and

(c) Asset or system might change (probably due to climate changes).

3. Considering interdependencies and determining alternative adaptation options

28. In the development of any adaptation pathways, one important step is the identification and consideration of alternative adaptation measures and thereafter adaptation options to help address the objectives defined relatively to different risk levels. For each adaptation measure identified, it is important to determine to which adaptation goal it leads. A same action can lead to several adaptation goals, or only one or some of them [27]. Also, to identify adequate adaptation measures, an important element to consider once again is the interdependencies (as discussed in section 1).

29. Knowledge of the critical decision points (as discussed in section 2) is used to recognise what options can be useful in avoiding, limiting, or removing the climate change impacts as well as other environmental, economic and socio-political factors. These actions need to be reviewed in order to determine what triggers could make them necessary and to also examine if they are robust across possible futures (see section 4. about the evaluation of adaptation actions). It is understood that identifying new or alternative options can be a challenging task and thus it is best to have a diverse, creative and constructive participation and collaboration to raise, discuss and consider unusual elements [25]. Thus, the guiding questions for transport professionals to think here are: How does an option contribute to achieving the objectives or goals? and what are the roles of the relevant stakeholders, including transport sector organisations?

30. Based on IPCC's Fifth Assessment Report (AR5), adaptation measures can be categorised into three broad categories based on their nature and focus [38]. These categories are:

(a) Physical measures: Physical adaptation measures refer to actions that involve changes to the physical environment, structures, or technologies to reduce vulnerability and enhance resilience to climate change impacts. They can include:

(i) Structural measures: These involve the construction or modification of physical infrastructure to withstand climate-related hazards. Examples include building sea walls, flood barriers, coastal dunes, and water management infrastructure.

(ii) Technological measures: These involve the development and implementation of new technologies or the application of existing technologies to improve resilience. Examples include advanced weather forecasting systems, early warning systems, irrigation systems, and climate-resistant crop varieties.

(b) Social measures: Social adaptation measures focus on behavioural, operational, and societal changes to reduce vulnerability and increase resilience to climate change. These measures can include:

(i) Behavioural changes: These involve individual or community-level actions and adjustments to reduce exposure and enhance adaptive capacity. Examples include changing consumption patterns, altering agricultural practices, and implementing water conservation measures.

(ii) Operational changes: These involve modifications in the way organizations or institutions operate to adapt to climate change. It can include changes in management practices, diversifying income sources, or modifying land-use practices.

(c) Institutional measures: Institutional adaptation measures encompass changes in policies, laws, governance systems, and economic instruments to support adaptation efforts. These measures can include:

(i) Policy and regulatory changes: These involve developing and implementing policies and regulations that promote adaptation, integrate climate considerations into planning processes, and enhance coordination among relevant stakeholders.

(ii) Economic measures: These include financial mechanisms, incentives, and economic instruments that encourage and support adaptation actions. Examples include climate change insurance, funding programs for adaptation projects, and pricing mechanisms that internalize the costs of climate change impacts.

31. It can be useful to identify to which of those categories the identified action belongs, and to seek actions from various categories in order to ensure various adaptation pathways possibilities. It is also advised to define whether an adaptation action is an adjustment (for instance, a modification of a current infrastructure, using a road paving more resilient to heavy rains) or a transformation action (for instance, relocating an infrastructure threatened by rising sea levels).

32. Furthermore, this guide recommends transport professionals to make use of various useful resources such as the WEATHER [39], EWENT [40], MOWE IT [41] and SIRMA [42] project deliverables as well as online databases such as Copernicus [43] and The European Climate Adaptation Platform Climate-ADAPT [44] to explore what adaptation measures and options are currently being used in the transport sector. In addition, there are various sectoral guides that specifically focus on climate change adaptation in the transport sector such as the Transport Research Laboratory (TRL)'s "Climate Change Adaptation for the Road Network: Technical Advice Note and the CEDR's "Climate Change Adaptation in the Road Sector - A Synthesis of National Practice".

33. Moreover, according to PIARC [45], adaptation measures for the road transport sector can be listed as:

- Infrastructure related hard measures (e.g. barrier walls for protection from erosion, levees, alternative surfacing), and also involve the use of soft measures (e.g. creation of wetlands, barrier islands, green infrastructure to cope with high precipitation events);
- Traffic hazard/incident management measures such as establishing well-prepared command and management structures, providing appropriate information systems or training personnel for managing catastrophes, early warning systems or traffic re-routing;
- Maintenance measures for periodic, routine or self-restoration;
- Strategic and network planning measures e.g. amendments to regulations or standards, legal frameworks.

Guiding and learning questions for transport professionals in considering interdependencies and identifying alternative adaptation options.

How does an option/action contribute to achieving the objectives or goals?	What are the roles of the relevant stakeholders, including transport sector organisations?
How to best combine activities varying from physical interventions to capacity-building and governance arrangements into the development of pathways to create and support the transformational changes needed?	What steps are being considered currently to address the critical and important areas of decision-making?
How does the potential climate change or extreme weather impacts on a transport infrastructure affect other sectors or assets in the region? (i.e. same transport mode, different transport mode, energy transport or distribution, telecommunications and other relevant sectors)?	Will climate change influence the success of measures being considered to address key areas of decision-making? If yes, which aspects of the changing climate are important and how long witll the current practices remain successul for?

4. Evaluating pathway options

34. As with all transportation budgeting processes and any planning process, it may not be possible for departments of transportations to fund their entire preferred list of adaptation strategies. There may also be several adaptation options available to achieve the same goal, between which a transport manager or operator will have to choose. Therefore, in order to narrow potential options, it is useful to utilise a systematic evaluation process. The following criteria or questions may prove useful as a starting point for evaluating and selecting adaptation measures [31, 25] in adaptation pathways.

Guiding and learning questions for transport professionals in evaluating and selecting adaptation measures.

Costs and Benefits – What are the up-front costs of implementation and the ongoing operations and maintenance costs? If implemented, what is the value of the damages from climate change that would be avoided?
Will there be any co-benefits (such as biodiversity gain, climate mitigation, etc.)?

Technical and Political Feasibility – How practical it is for a particular strategy to be implemented, accounting for engineering, policy, legal, and insurance considerations?

Flexibility – How easy would it be to revise the strategy at a later date? What is the adaptive management potential of the strategy?

Sustainability – What are the impacts to the economy, society, and the environment?

What are the synergies with other actors (does the action improve the adaptive capacity of other sectors?)?

What are the climate mitigation contributions?

Efficacy – if implemented, to what extent would the strategy reduce the risk?
Will the strategy make sure it does not put new constraints on physical, socio-political, financial, or social systems?

Maladaptation – Will the strategy ensure that it does not create a 'dead-end' by impacts on other assets and infrastructures (including stranded assets) or by having negative impacts on mitigation of climate change or on the environment ?

Social acceptability – What is the outcome of a collective judgment or collective opinion regarding the strategy?

35. Potential options need to be evaluated for costs, benefits, technical and political feasibilities, flexibility, sustainability (environmental benefits, contribution to climate mitigation, increasing the adaptability of other sectors/transport infrastructure), efficacy, social acceptability and the ability to avoid maladaptation [4, 27]. This can be done through a multi-criteria analysis, using different weights for the different criteria. For instance, a higher weight could be used for the cost-benefit criterion in order to prioritise the measures with the smallest overall cost. The idea is to determine what methodology and what effort

level would suit best to the needs of the organisation. Along with considering cost-benefit analysis and multi-criteria analysis, this may also include participation, modelling and co-creation with potential stakeholders [4].

36. In terms of co-benefits of adapting, it is very important that transport departments identify and account for the possible benefits as well as co-benefits of integrating particular adaptation strategies into the management of transportation systems and operations programs. Usually, a qualitative assessment of co-benefits helps in identifying win-win strategies that can enhance resilience to climate change along with assisting in achieving other program objectives, like mitigation of climate change for instance. Typically, it is also easier to acquire support for funding such types of solutions as they can achieve several goals. One common example here is the upsizing of culverts, often justified by departments of transportation as the benefits include the increase spaces fish passages as well as the increased capacity offered for increases in future extreme precipitation events. Some other prime examples of co-benefits include: increased roadway safety, reduced operating costs, mitigation of greenhouse gas emissions, improved air quality, sustainability through improvements to environment, economy and/or social equity and overall improvements in other performance measures [31].

37. Furthermore, to assess the sustainability of adaptation options for the transport sector, it is very important that mitigation implications of investments are considered carefully. Universally, the transport sector is accountable for around one-quarter of energy-related carbon emissions, which does not include the lifecycle emissions of construction materials. The use of cement only is accountable for about 8 per cent of carbon emissions. Thus, it is vital to take into consideration the embodied energy and emissions of construction materials used in transport projects, including projects aiming at enhancing the resilience of transport infrastructure by making it more robust to the impacts of climate change [13]. Moreover, in the transport sector, evaluation of adaptation measures can be done qualitatively and/or quantitatively, mainly depending on the needs of an individual organisation. For most transport departments, a qualitative assessment is usually sufficient when choosing priorities, however, in order to justify funding sought, a quantitative assessment may be needed. For a qualitative evaluation a simple 3-point (i.e. low, medium, high) or a 5-point scale can be used or even in some cases, a narrative description of the positives and negatives of the adaptation strategies can be relied upon. On the contrary, an effective quantitative evaluation requires the demonstration of benefits in quantitative evaluation metrics such as reduced traffic delay, which can then be translated into further financial benefits in the economic assessment of the strategy [31]. Although such metrics are a useful tool in informing the decision-making processes, it is important to remember that these also have limits and should therefore not be relied upon wholly and should not be the basis for the entire decision-making process. During the strategy selection process, it is important to also consider inputs from staff who are involved on the respective projects on a daily basis as well the relevant stakeholders and decision makers who probably have a better understanding of the needs. In addition, it is also suggested that the total number of evaluation metrics are kept to a small set of valued measures to enable meaningful outputs to be generated [31].

38. In terms of prioritising measures, it is important to consider implementation time frames. Adaptation measures can be prioritised into short-term (such as 0-5 years), medium-term (such as 5-10 years), and long-term (such as 10+ years) actions, depending on the urgency of adaptation (i.e. how soon does the strategy to protect the asset or infrastructure against the projected climate changes need to be implemented by the transport infrastructure manager) and the time needed for implementation (i.e. how much time it will take for the adaptation strategy to be implemented based on the plans, funds, and construction/programming time). In this regard, the below table presents some typical examples that can be used to further understand the concept of how implementation time periods and the level of urgency could be factored into prioritising any adaptation measure [31].

Generic examples demonstrating typical relationships between the prioritisation of adaptation measures and the implementation time, level of urgency and multi-criteria analysis (Adapted from [31]).

Adaptation measure	*Time Period for Implementation*	*Level of Urgency*	*Prioritisation*
Requires 0-5 years to implement, but does not need to be undertaken for another 30 years	Short	Low	Low
Requires 0-5 years to implement, but should be undertaken now in order to be effective	Short	High	Medium
Requires 30 years to implement, but should be undertaken now to ensure effectiveness	Long	High	High
Should be undertaken in the near term because it will influence future decisions	Ongoing	Medium	Medium

39. When considering implementation timeframes, it is also important to analyse the necessary anticipations for each adaptation measure, such as the acquisition of a technique, of knowledge, or the need for communication, or urban planning [31]. The goal is to identify when actions need to be launched to ensure long-term robustness, considering the adaptation tipping points, turning points and trigger points.

40. After the individual evaluation of each adaptation measure, actual adaptation pathways, consisting of feasible sequences of adaptation options need to be designed, so that the pathways are also evaluated. This evaluation of the developed adaptation pathways can be based on the same criteria as for the individual actions. Some of the key factors that could be considered in the evaluation of developed adaptation pathways for transport infrastructure include:

- Effectiveness in achieving objectives: Assessing the extent to which the adaptation pathway successfully achieves its intended objectives and outcomes. Evaluating the alignment of the adaptation pathway with current and projected climate change scenarios and determining whether the pathway addresses the specific climate risks and vulnerabilities that the transportation infrastructure may face in the future.
- Infrastructure vulnerability: Analysing the effectiveness of the adaptation pathway in reducing vulnerabilities of transport infrastructure to climate impacts such as sea-level rise, extreme weather events, and temperature extremes.
- Lifecycle assessment: Considering the full lifecycle of the infrastructure and assessing how the adaptation pathway addresses short-term and long-term climate risks over the transport infrastructure's entire lifespan.
- Risk reduction and resilience building: Measuring the pathway's ability to reduce risks associated with climate impacts and enhance the overall resilience of transportation systems to future changes.
- Adaptability to uncertainty: Assessing the adaptability of the adaptation pathway to uncertainty, considering potential changes in climate projections and other dynamic factors over time.
- Cost-effectiveness: Evaluating the cost-effectiveness of the adaptation pathway, taking into account the financial, technical, and institutional capacity required for implementation as well as comparing the benefits gained from the measures with their associated costs. This could also include considering both the immediate costs and long-term savings from avoided damages.

- Technical feasibility: Considering the feasibility of financing and implementing the pathway. This could also include considering engineering requirements, construction practices, and availability of suitable materials.
- Environmental impact: Assessing the environmental impact of the adaptation pathway, including potential ecological consequences of proposed measures.
- Synergy with mitigation goals and co-benefits: Evaluating how the adaptation pathway aligns with efforts to reduce greenhouse gas emissions and promoting low-carbon transportation options. Identifying opportunities for synergies between adaptation and mitigation measures.
- Multi-stakeholder acceptance and engagement: Measuring the level of stakeholder acceptance and engagement with the adaptation pathway. Considering feedback from stakeholders on the pathway's relevance and appropriateness.
- Monitoring and evaluation mechanisms: Ensuring that the adaptation pathway includes robust monitoring and evaluation mechanisms to track progress and adjust strategies as needed.
- Communication and Transparency: Clearly communicate the findings of the evaluation to decision-makers, stakeholders, and the public. Transparency in the evaluation process fosters trust and accountability.
- Learning, communicating and iterating: Promoting a learning-oriented approach to adaptation planning. Communicating the findings of the evaluation to relevant decision-makers and stakeholders. Evaluating results to inform future iterations of the adaptation pathway and building knowledge for future planning efforts.

41. Additionally, transport professionals should also consider the current repair and replacement cycles for their infrastructures prior to implementing any stand-alone projects. Usually, proactive measures are sensible choices for high-value infrastructures and assets that are likely to be severely damaged during extreme weather events. Whereas, in some cases, continuous repair and maintenance work is often the best opportunistic adaptation effort and approach for dealing with smaller and more frequent weather events and for infrastructures that are less vulnerable to the changing climate. Overall, the selection of preferred adaptation pathways is one that is an iterative process with priority given to actions and options that can be immediately implemented or supported. Usually, these will be the ‘no-regret’ and ‘low-regret’ options and those that are robust across many futures [28, 31].

5. Developing possible timelines

42. This step entails the development of a sequence of potential actions into drafting adaptation pathways by drawing together all previous inputs to meet short and long-term adaptation needs under uncertainty. The trigger, turning and tipping points discussed earlier are utilised here to recognise when and under what conditions, a specific option may no longer work along with identifying when an action can or must be taken. Documentation of current activities is done first and decision points are identified to put in place ‘no-regret’ options and actions that shall be robust across most futures. This sequencing process can demonstrate any potential gaps between existing management practices and the resources, political and community support required to enable the adaptation pathway. One crucial aspect for transport professionals to remember is to make comparisons between current organisational conditions and adaptation goals for each scenario when developing the sequence of actions. This would allow to identify the key issues, risks and success factors that need prioritising and addressing [25, 28, 30, 32].

43. To develop sequences of potential actions, it is also important to analyse which actions are incompatible, from the technical (for instance, building a coastal dyke is incompatible with the restoration of coastal wetlands), financial or planning (some actions reduce the possibilities of adaptation on the long term) point of views [27, 30].

44. Further, it is important that uncertainty regarding drivers of change guides the adaptation pathways development [33]. Uncertainty indicates that it is not useful to set predetermined and fixed implementation dates, instead it is much useful to set a decision

criterion that shows when the circumstances are right for implementation [46]. Planning of adaptation pathways can enable actors such as transport professionals to get prepared for future risks and uncertainties by stipulating which measure(s) should be implemented now, and which should be planned for the future, to be implemented once a certain scenario or condition(s) is apparent. Also, the extent to which measures are flexible, reversible, 'low-regret', or robust (i.e., can perform reasonably under a range of future scenarios) must be considered by transport professionals [32, 46].

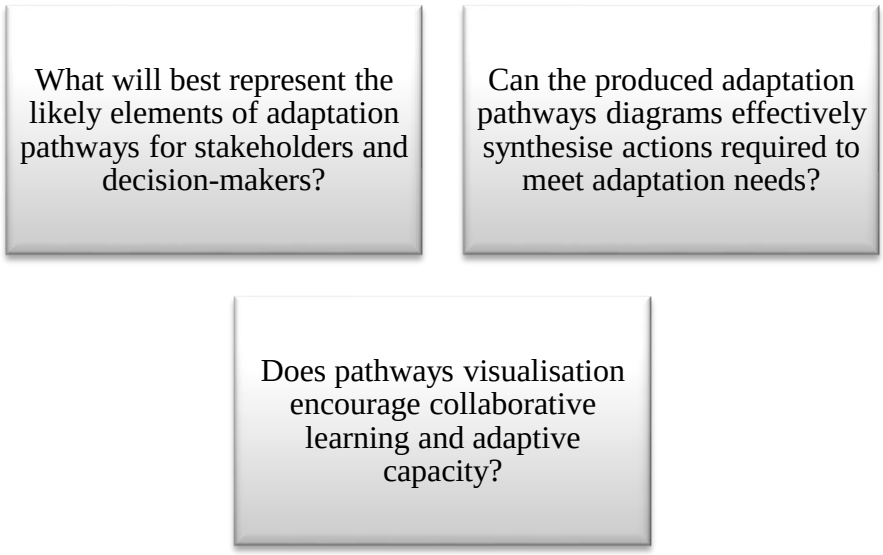
Guiding and learning questions for transport professionals in sequencing potential actions for drafting adaptation pathways.

How can measures be sequenced into pathways that meet short and long-term adaptation needs under uncertainty?	In the sequencing of activities and interventions, what role can the following play?: Lead-time, reversibility, flexibility, interdependencies, trade-offs, and robustness

6. Finalising and visualising adaptation pathways

45. This is the final step in developing adaptation pathways and involves mapping out or visually documenting the sequence of potential actions. This visual representation of pathways can help with communicating outputs from the adaptation planning process [11] and assist with shared decision making to imagine a dynamic response to changing conditions, and to navigate the adaptation process [47, 48]. Currently, there are computer-aided tools and methods available that can assist transport professionals to portray potential adaptation pathways. Visual communication of such pathways can promote collective learning on the process of adaptation. Pathway diagrams can envisage the manner in which future adaptation needs are coupled with adaptation actions [49]. Also, the visual representation of policy decisions as a sequence of various smaller decisions over time can allow decision-makers to overcome some of the challenges linked with carrying out longer-term climate adaptation decisions [48, 50]. Once the possible adaptation pathways are defined, the decision-makers can then decide on their adaptation strategy based on the adaptation pathways, the level of risk to which their territory is exposed, their preferred adaptation strategy and their operational objectives [27].

Guiding and learning questions for transport professionals finalising and visualising adaptation pathways.



46. It must also be noted that incorporating multiple stakeholder engagements and their feedback, is not embedded in a specific step but relevant for each of the steps discussed above, in developing adaptation pathways. Certainly, engaging stakeholders that each have a set of values, goals, and knowledge base, across different levels and sectors can facilitate collective learning on the potential need for transformation. Those stakeholders may be, for instance, policymakers, local authorities, infrastructure managers, transport operators, transport engineers, transport agencies, climate change experts, logistics companies, local environmental protection associations, financial institutions and groups of local residents. All these different actors may provide differing goals, values and assumptions linked with the present and future. However, their different attitudes, expectations and perceptions about the nature of climate change and how to achieve future goals along with their individual knowledges on guiding future possibilities may prove very useful for responding equitably to the changing climate, especially in the transport sector [32, 48]. Undoubtedly, integrating the knowledge and expertise of multiple stakeholders has the potential to improve the quality of decisions made, mainly because of the comprehensiveness and inclusivity of diverse information inputs. Relevant stakeholders can play an active role in the identification of critical decision performance metrics, especially by providing their perspectives on real-life issues faced by the transport departments. It is recommended that transport professionals interested in developing adaptation pathways for their transport infrastructure understand what type of stakeholder engagement would encourage collective learning about climate change, a common agenda for the future and an adaptive and transformational planning. Also, they must consider how stakeholder inclusion can support dealing with uncertainty and ambiguity in adaptation pathways [32]. As events become more frequent, the need to protect and transform becomes important, or even managed retreat. Here, stakeholder engagement is critical in informing and validating the adaptive responses, and to ensure that the needs of different groups are met.

7. Implementing, monitoring and learning from developed adaptation pathways for transport professionals

47. Any adaptation pathway map is aimed at reflecting the steps that have already been taken to increase climate change preparedness, identify decision points, consider alternative options and present possible timelines. Adaptation pathway maps should be shared, continuously revised, and updated as new information becomes available. As adaptation is dependent on learning and responding effectively to lessons learnt along with experience gained, changing circumstances, and new knowledge acquired, it is crucial that monitoring and evaluation is done regularly for ensuring an effective adaptation is carried out over time [50, 51].

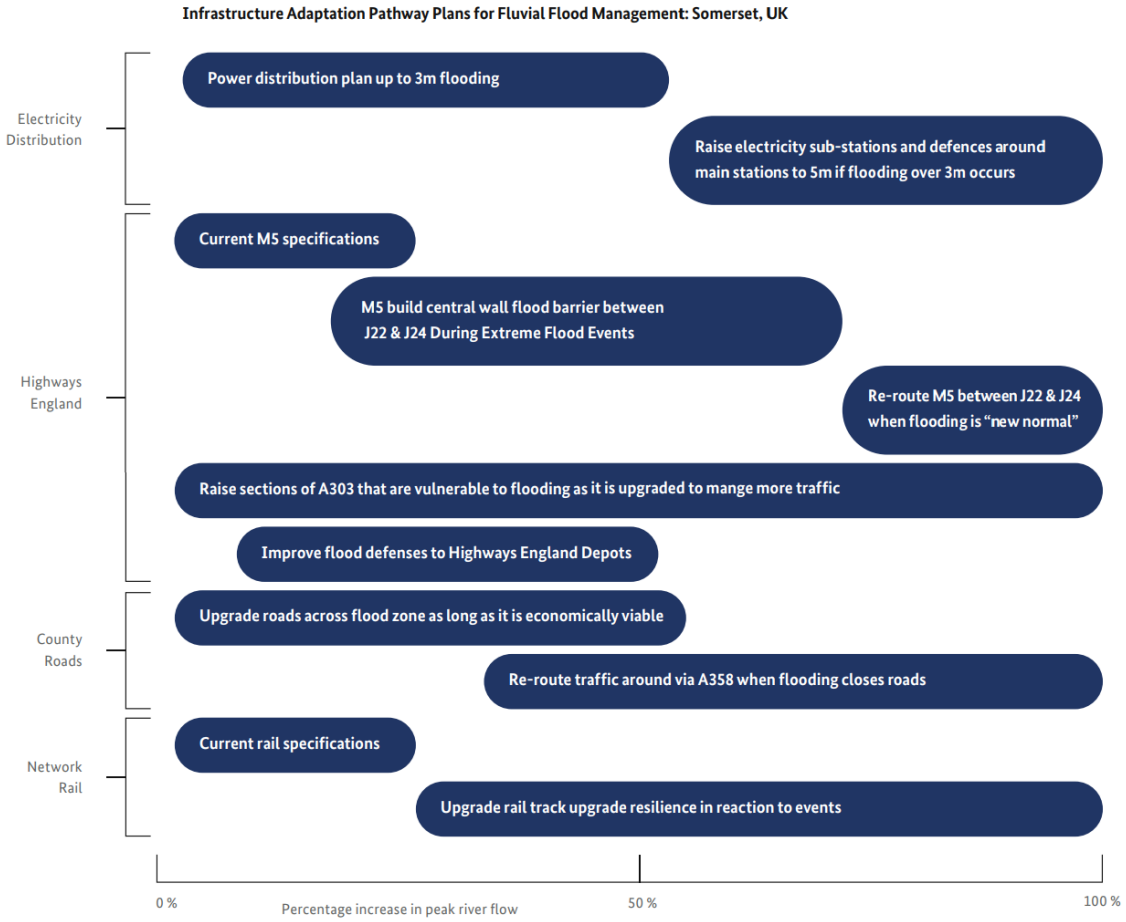
48. Systematically monitoring implemented adaptation pathways can inform on-going decision-making and trigger follow-up activities that may be needed. This would allow for identifying when to re-evaluate the course of actions. Thus, the value of an adaptation pathway is proved when it is adopted, implemented and then updated over time within the sector.

49. It is evident that adaptation pathways are developed through the consideration of a sequence of actions based on the information that is available at the present time of elaborating the pathway. It is expected that when applied over time, the pathway will meet challenges and possible barriers from the changing climate and its impacts, the social changes, economic and financial constraints and other crises. Taking into consideration the goals of sustainable transport, triggers to monitor will include climate change impacts like for instance extreme weather events, higher temperatures, more severe storms and flooding that can potentially affect the reliability and capacity of transportation systems while damaging transportation infrastructure. Transport infrastructure owners and managers should be keen observers of seasonal changes and monitoring systems. These professionals could work with local, regional and at times international agencies along with local communities, researchers, consultants and industries to share information and implement climate preparedness actions. Finally, transport professionals need to find a way to ensure that the adaptation pathways will be reviewed regularly, as new information becomes available, as climatic conditions change and as adaptive capacity grows. For this, professionals also need to also recognise what processes are in place to increase the adaptive capacities of stakeholders. It is suggested that with constant review of the pathways, there may be a possibility of updating the pathways map in few years, if needed, as shown by the cyclic nature of the framework in Figure I. Thus, the proposed framework suggests that the development of adaptation pathways for transport infrastructures and assets should be a circular and iterative process that allows taking into account new knowledge, socio-economic changes or modification of the transport infrastructure as well as any additional information that would be relevant to incorporate over time.

50. Figure II presents a recent example of an adaptation pathways plan for transport infrastructure resilience to different levels of flooding as part of the fluvial flood management in Somerset, UK [13]. Such an adaptation pathways map or framework allows decision-makers to have the flexibility to change the course of adaptation (i.e. switching pathway to implement suitable adaptation options) as new information becomes available [4]. The knowledge of the sequences of actions also allows to prepare for accommodating future adaptation actions in the designs of earlier actions. Through this, transitions between actions can be more effective and cost-efficient. The different phases in an adaptation pathways approach each contribute to a greater plan and are thus designed to allow for flexibility for future options, avoiding actions that may compromise effective actions in the future. Also, the effectiveness of the appropriate options can be monitored and evaluated with time and any learnings can be fed back into the next development cycle [3].

Figure II

Adaptation pathways plan for transport infrastructure resilience to different levels of flooding in the UK [13]



III. References

1. Seneviratne, S.I., N. Nicholls, D. Easterling, C.M. Goodess, S. Kanae, J. Kossin, Y. Luo, J. Marengo, K. McInnes, M. Rahimi, M. Reichstein, A. Sorteberg, C. Vera, and X. Zhang. (2012). Changes in climate extremes and their impacts on the natural physical environment. In: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 109-230.

2. Ara Begum, R., R. Lempert, E. Ali, T.A. Benjaminsen, T. Bernauer, W. Cramer, X. Cui, K. Mach, G. Nagy, N.C. Stenseth, R. Sukumar, and P.Wester. (2022). Point of Departure and Key Concepts. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 121–196, doi:10.1017/9781009325844.003.

3. Quinn, A. et al. (2018). "Adaptation becoming business as usual: A framework for climate-change-ready transport infrastructure," Infrastructures, 3(2), p. 10. Available at: https://doi.org/10.3390/infrastructures3020010.

4. Ferranti, E, Greenham, S & Wood, R. (2021). Adaptation pathways for infrastructure operators and policymakers.

5. UNECE. (2023). Guidelines for integrating climate change considerations in planning and operational processes. Stress test framework. Inland Transport Committee. United Nations Economic Commission for Europe. ECE/TRANS/WP.5/GE.3/2023/3.

6. Jaroszweski, D.; Chapman, L.; Petts, J. (2010). Assessing the potential impact of climate change on transportation: The need for an interdisciplinary approach. J. Transp. Geogr. 18, 331–335.

7. Haasnoot, M., Kwakkel, J.H., Walker, W.E. and ter Maat, J., (2013). Dynamic adaptive policy pathways: A method for crafting robust decisions for a deeply uncertain world. Global environmental change, 23(2), pp.485-498.

8. Star, J. et al. (2016). "Supporting adaptation decisions through scenario planning: Enabling the effective use of multiple methods," Climate Risk Management, 13, pp. 88–94. Available at: https://doi.org/10.1016/j.crm.2016.08.001.

9. Kwakkel, J.H., Haasnoot, M. and Walker, W.E. (2016). "Comparing robust decision-making and dynamic adaptive policy pathways for model-based decision support under Deep uncertainty," Environmental Modelling & Software, 86, pp. 168–183. Available at: https://doi.org/10.1016/j.envsoft.2016.09.017.

10. ADEME. (2021). ADEME comparative study, En entreprise, comment prendre des décisions pour s'adapter au changement climatique? Méthodes et études de cas en France et à l'international

11. Ranger, N., Reeder, T. and Lowe, J. (2013). Addressing 'deep' uncertainty over long-term climate in major infrastructure projects: four innovations of the Thames Estuary 2100 Project. EURO Journal on Decision Processes, 1(3-4), pp.233-262.

12. Haasnoot, M., Warren, A. and Kwakkel, J.H. (2019). Dynamic Adaptive Policy Pathways (DAPP). In Decision Making under Deep Uncertainty (pp. 71-92). Springer, Cham.

13. Black, Doogie and Pyatt, Nick. (2021). Adapting Urban Transport to Climate Change. Module 5f Sustainable Transport: A Sourcebook for Policy-makers in Developing Cities. 2nd Edition.

14. IPCC. (2019): Annex I: Glossary [Weyer, N.M. (ed.)]. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 677–702. https://doi.org/10.1017/9781009157964.010.

15. Siebentritt, M.A. and Stafford Smith, M. (2016). A User's Guide to Applied Adaptation Pathways Version 1. Seed Consulting Services and CSIRO.

16. Walker, W.E., Rahman, S.A. and Cave, J. (2001). Adaptive policies, policy analysis, and policy-making. European Journal of Operational Research, 128(2), pp.282-289.

17. Chopra, K.R. (2005). Ecosystems and human well-being: Policy responses. Volume 3. Findings of the Responses Working Group. Washington. Island Press. Millennium Ecosystem Assessment.

18. Gregg, R.M., Kershner, J.M., & Hansen, L.J. (2013). Strategies for Climate Change Adaptation: A Synthesis. Environmental Science. DOI:10.1016/B978-0-12-409548-9.09365-9.

19. U.S. Climate Resilience Toolkit (nd). Decision Making Under Deep Uncertainty | U.S. Climate Resilience Toolkit. Available at: https://toolkit.climate.gov/content/decision-making-under-deep-uncertainty (Accessed: January 30, 2023).

20. C40 Cities. (2017). Infrastructure Interdependencies and Climate Risks. London: C40 Cities. Available at: https://unfccc.int/sites/default/files/report_c40_interdependencies_.pdf

21. Barnett, J., Graham, S., Mortreux, C., Fincher, R., Waters, E. and Hurlimann, A. (2014). A local coastal adaptation pathway. Nature Climate Change, 4(12), pp.1103-1108.

22. Rosenzweig, C. and Solecki, W. (2014). Hurricane Sandy and adaptation pathways in New York: Lessons from a first-responder city. Global Environmental Change, 28, pp.395-408.

23. Aastha Lamichhane et al. (2022). IOP Conf. Ser.: Earth Environ. Sci. 1016 012034.

24. Martin, S. (2012). Examples of 'no-regret', 'low-regret' and 'win-win' adaptation actions. ClimateXChange. RBGE.

25. Coulter, L. (2019). Climate Change Adaptation Pathways Framework: Supporting Sustainable Local Food in B.C. Prepared for the B.C. Ministry of Agriculture through the 2018-19 Mitacs Science Policy Fellowship. Victoria.

26. Serrao-Neumann, S., Cox, M., Schuch, G. and Low Choy, D. (2015). Adaptation Pathways. Climate Change Adaptation for Natural Resource Management in East Coast Australia Project, Griffith University.

27. ADEME. (2019). Construire des trajectoires d'adaptation au changement climatique du territoire - Guide méthodologique.

28. PIANC. (2022). Managing Climate Change Uncertainties in Selecting, Designing and Evaluating Options for Resilient Navigation Infrastructure. EnviCom PTGCC Technical Note 1. The World Association for Waterborne Transport Infrastructure. Available at: https://www.pianc.org/publication/climate-change-adaptation-planning-for-ports-and-inland-waterways-2/

29. The World Road Association (PIARC). (2015). International Climate Change Adaptation Framework for Road Infrastructure. Available at: https://www.piarc.org/ressources/publications/8/23557,SpecialProject-ClimateChange-EN.pdf.

30. PIANC. (2020). Climate Change Adaptation Planning for Ports and Inland Waterways. EnviCom WG 178. The World Association for Waterborne Transport Infrastructure. Available at: https://www.pianc.org/publication/envicom-ptgcc-technical-note-1/

31. Asam, S., Bhat, C., Dix, B., Bauer, J. and Gopalakrishna, D. (2015). Climate Change Adaptation Guide for Transportation Systems Management, Operations, and Maintenance. U.S. Department of Transportation, Federal Highway Administration.

32. Werners, S.E. et al. (2021). "Adaptation pathways: A review of approaches and a learning framework," Environmental Science & Policy, 116, pp. 266–275. Available at: https://doi.org/10.1016/j.envsci.2020.11.003.

33. Zandvoort, M. et al. (2017) "Adaptation Pathways in planning for uncertain climate change: Applications in Portugal, the Czech Republic and the Netherlands," Environmental Science & Policy, 78, pp. 18–26. Available at: https://doi.org/10.1016/j.envsci.2017.08.017.

34. Siebentritt, M., Halsey, N. and Stafford-Smith, M. (2014). Regional Climate Change Adaptation Plan for the Eyre Peninsula. Prepared for the Eyre Peninsula Integrated Climate Change Agreement Committee. Available at: https://cdn.environment.sa.gov.au/environment/docs/ep-regional-climate-change-adaptation-plan.pdf.

35. Buijs, F., Simm, J., Wallis, M. & Sayers, P. (2007). EA and DEFRA Performance and Reliability of Flood and Coastal Defences: R&D Technical Report FD2318/TR1, Environment Agency.

36. Werners, S. E., J. v. Loon, and A. Oost. (2015). Method selection in adaptation research: the case of the Delta Programme for the Dutch Wadden region. Regional Environmental Change (Special Issue "Approaches to Problem-Oriented Adaptation Research"). In press. http://dx.doi.org/10.1007/s10113-015-0799-9.

37. Werners, S. E., E. van Slobbe, T. Bölscher, A. Oost, S. Pfenninger, G. Trombi, M. Bindi, and M. Moriondo. (2015). Turning points in climate change adaptation. Ecology and Society 20(4):3. http://dx.doi.org/10.5751/ES-07403-200403

38. Intergovernmental Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the

Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

39. WEATHER. 2022. Weather-project.eu. [online]. Available at: https://weather-project.eu/weather/index.php. Accessed 06 March 2023.

40. CORDIS. 2022a. Cordis.europa.eu. [online]. Available at: https://cordis.europa.eu/project/id/233919. Accessed 06 March 2023.

41. CORDIS. 2022b. Cordis.europa.eu. [online]. Available at: https://cordis.europa.eu/project/id/314506/reporting. Accessed 06 March 2023.

42. SIRMA. 2022. sirma-project.eu/. [online]. Available at: https://sirma-project.eu/. Accessed 06 March 2023.

43. Copernicus. 2022. Copernicus.eu. [online]. Available at: https://www.copernicus.eu/en. Accessed 06 March 2023.

44. Climate ADAPT. 2022. [online]. Available at: https://climate-adapt.eea.europa.eu/. Accessed 06 March 2023.

45. World Road Association, PIARC. (2019). Adaptation methodologies and strategies to increase the resilience of roads to climate change – Case Study Approach.

46. Abel, N. et al. (2016). "Building Resilient Pathways to transformation when 'no one is in charge': Insights from Australia's Murray-Darling Basin," Ecology and Society, 21(2). Available at: https://doi.org/10.5751/es-08422-210223.

47. Lempert, R.J. and Groves, D.G. (2010) "Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American West," Technological Forecasting and Social Change, 77(6), pp. 960–974. Available at: https://doi.org/10.1016/j.techfore.2010.04.007.

48. Wise, R.M. et al. (2014) "Reconceptualising adaptation to climate change as part of pathways of change and response," Global Environmental Change, 28, pp. 325–336. Available at: https://doi.org/10.1016/j.gloenvcha.2013.12.002.

49. Kingsborough, A., Borgomeo, E. and Hall, J.W. (2016) "Adaptation Pathways in practice: Mapping Options and trade-offs for London's Water Resources," Sustainable Cities and Society, 27, pp. 386–397. Available at: https://doi.org/10.1016/j.scs.2016.08.013.

50. Hermans, L.M. et al. (2017) "Designing monitoring arrangements for collaborative learning about adaptation pathways," Environmental Science & Policy, 69, pp. 29–38. Available at: https://doi.org/10.1016/j.envsci.2016.12.005.

51. Murti, R, Mathez-Stiefel, S-L, Rist, S. (2019). A methodological orientation for social learning based adaptation planning: Lessons from pilot interventions in rural communities of Burkina Faso, Chile and Senegal. Systemic Practice and Action Research. DOI: http://dx.doi.org/10.1007/s11213-019-09495-8.

52. Mukheibir, P., Kuruppu, N., Gero, A. et al. (2013). Overcoming cross-scale challenges to climate change adaptation for local government: a focus on Australia. Climatic Change 121, 271–283. https://doi.org/10.1007/s10584-013-0880-7

53. Lin, B.B., Capon, T., Langston, A., Taylor, B., Wise, R., Williams, R. and Lazarow, N. (2017). Adaptation pathways in coastal case studies: lessons learned and future directions. Coastal Management, 45(5), pp.384-405.

54. Bloemen, P., Reeder, T., Zevenbergen, C. et al. (2018). Lessons learned from applying adaptation pathways in flood risk management and challenges for the further development of this approach. Mitig Adapt Strateg Glob Change 23, 1083–1108. https://doi.org/10.1007/s11027-017-9773-9