International Transport Forum

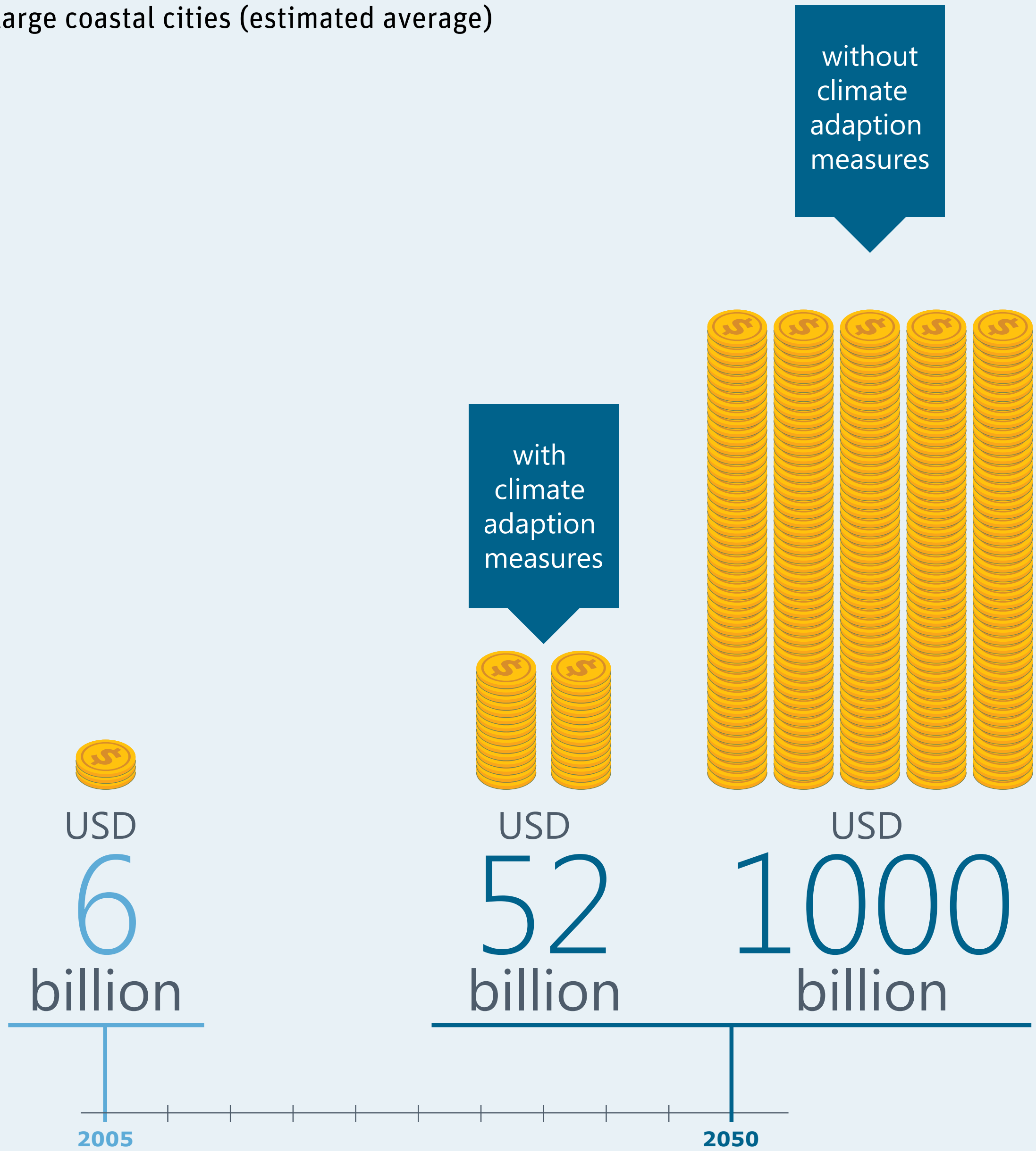
Adapting Transport Infrastructure to Climate Change

How to Protect Assets Against Increased Risks from Extreme Weather

International Transport Forum: Global dialogue for better transport

Global flood losses

in large coastal cities (estimated average)



Source: S. Hallegatte et al., (2013), "Future flood losses in coastal cities", Nature Climate Change

The issue

From meteorological risks to climate uncertainty

Transport infrastructure represents a significant sunken investment — by the public and private sectors — that is fundamental to the functioning of society. Transport assets are often long-lived and designed to deliver, if regularly maintained, specified and predictable services over their entire lifetime.

Hazards that may degrade the performance of assets or interrupt network services are generally well-known, and they are accounted for in asset and network planning and design. Extreme weather events have caused significant disruptions in the past, but as these risks were known it has been possible to mitigate their impact.

With climate change, this is no longer true. Transport asset managers face a fundamentally uncertain future regarding the vulnerability of infrastructure and networks to climate change and future extreme weather events. Broad evidence supports the view that man-made emissions of greenhouse gases are changing the climate. Yet considerable uncertainty remains over the exact scale, scope and regional impacts of climate change, and this complicates adaptation efforts.

Generally, meteorological and climate factors fall into the range of manageable risks that asset managers have to contend with. In many ways, they are one of the principal risks that asset owners must address, because they have the potential to significantly — and sometimes quite suddenly — degrade assets and impair network performance.

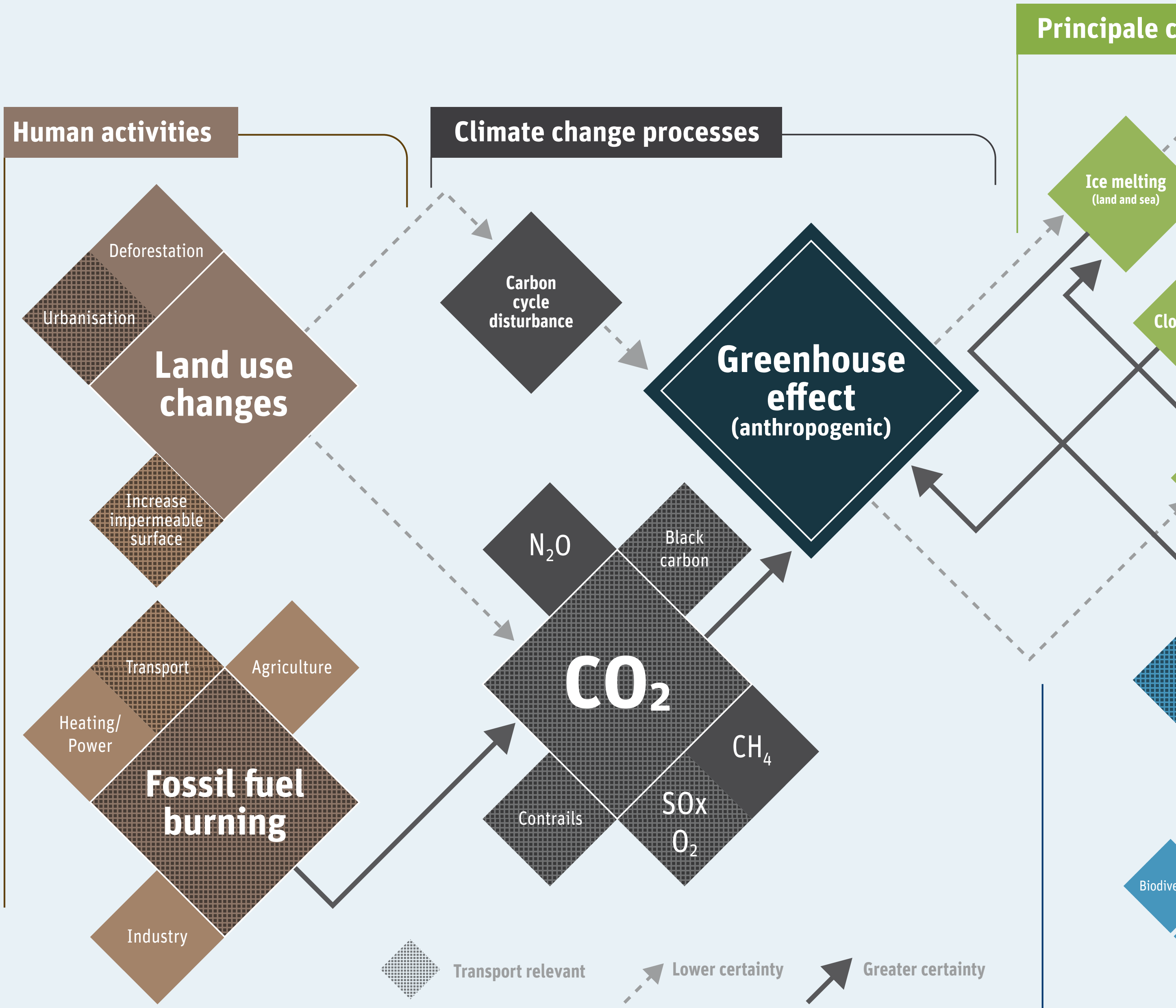
For this reason, historic meteorological and climate variables are included in both site selection and design specifications for transport assets such as roads, rail lines, ports or airports. This should ensure that transport infrastructure continues to operate under a range of expected meteorological conditions and weather phenomena. Asset owners who undertake due diligence in both the planning and design phases of infrastructure deployment can generally contain these risks, at least to a certain degree.

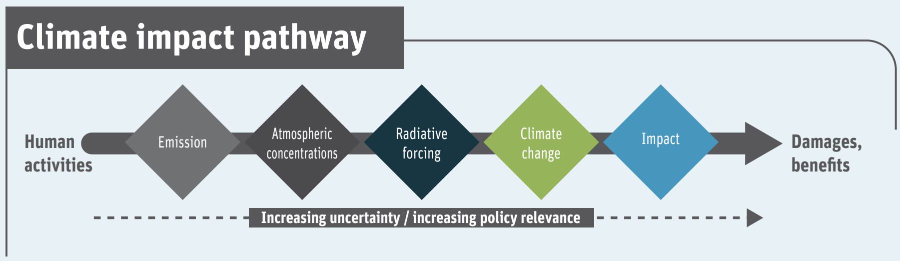
With climate change, however, both meteorological and climate parameters are changing in uncertain ways, and this makes it difficult to predict end states. Already today, many infrastructure owners and managers have to come to grips with the implications of climate change for the performance of their assets and networks.

Here, the "embeddedness" of climate variables in transport infrastructure places assets and network service continuity at risk – at potentially significant cost. Climate change will have an impact on many hazards that affect transport assets and alter transport system performance. These hazards operate on different spatial scales as well as time horizons and may disrupt services temporarily, durably or even permanently.

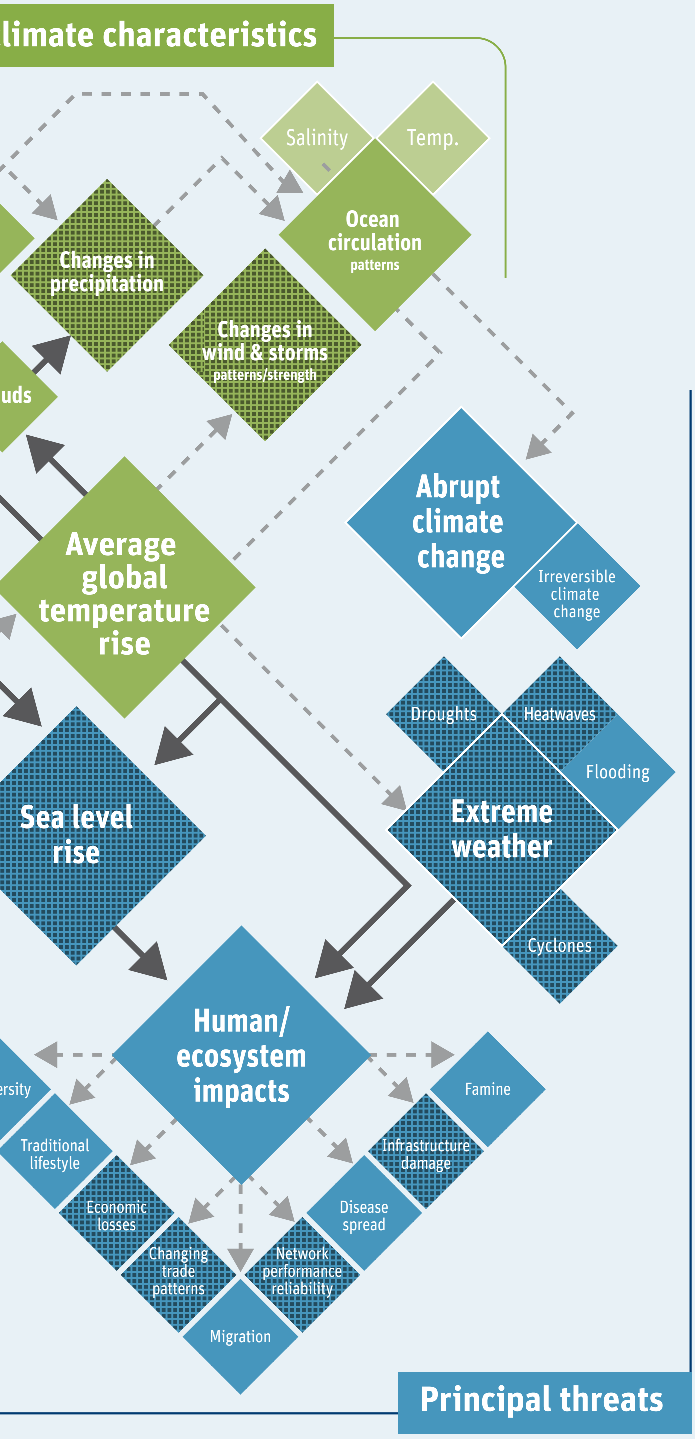
The range of potential hazards is broad. Increases in mean temperatures can lead to accelerated wear and damage to roads, contribute to track buckling in rail systems and can mean reduced working hours for maintenance and construction crews. Higher precipitation and sea level rise can undermine infrastructure or render it inaccessible. Extreme events like flooding or hurricanes can damage or destroy transport assets. Some climate change-related effects can be positive, at least in certain regions – for instance reduced snow cover and shorter duration of ice drift on waterways. But many potential climate-change effects threaten the reliable performance of transport services, and asset managers will need to prepare for new and more complex challenges.

How human activity leads to climate change impacts





Adapted from UNEP-GRIDA and den Elzen et al. (2005)



The approach

Reviewing climate threats to transport infrastructure

The International Transport Forum's Working Group on "Infrastructure Adaptation to Extreme Weather and Climate Change" reviewed the range of threats to transport system performance that are posed by climate change. Its work provides evidence-based guidance to transport asset owners and network managers that can help them ensure continued network performance under growing uncertainty regarding network resilience in a changing climate.

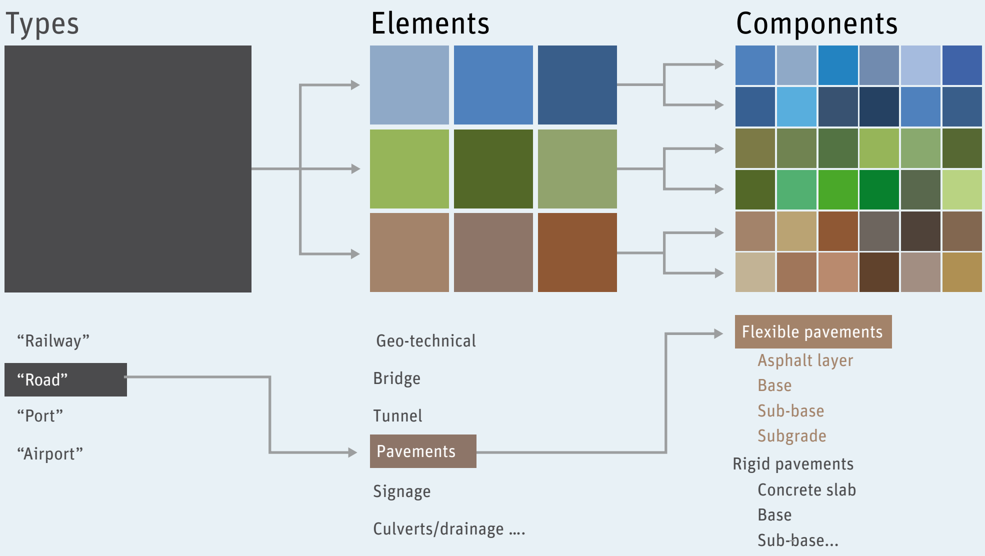
Climate change poses two fundamental challenges to infrastructure owners. First, they must ensure continued asset performance under sometimes significantly modified climate conditions – conditions which may decrease the present value of their networks or increase maintenance and refurbishment costs (or vice versa). Second, public authorities or private operators must design and build new or replace old assets in the context of these changing, and largely uncertain, climate variables.

Uncertainty regarding these variables creates the risk of over- or under-specification of infrastructure design standards. Over-specification results in stranded or unproductive investments. Under-specification, on the other hand, may lead to asset failure or a degradation of the network service. These are trivial risks neither for public authorities responsible for delivering satisfactory, predictable transport services, nor for private operators who must realise expected returns on capital for their investors.

Among the potential climate trends that may have an impact on transport operations and the viability of transport infrastructure are the following:

Infrastructure building blocks

Assets consist of multiple components with unique vulnerabilities



- Summer temperatures will increase; heat extremes will become more frequent and last longer.
- Winter temperatures will become milder, but temperature amplitudes may remain or increase. More frequent and damaging freeze-thaw cycles may result.
- Arctic regions will warm more than other regions, leading to deeper permafrost melting (and permafrost soil heaving) with loss of summer sea and land ice.
- More winter precipitation will fall in the northern hemisphere. This will more often be in the form of rain than is the case today.
- Large portions of the southern hemisphere and lower northern hemisphere may become dryer on average.
- Extreme rainfall will become even stronger and more frequent, even in regions experiencing lower levels of average precipitation.
- Extreme storm strength may increase, especially for extra-tropical cyclones and arctic cyclones.
- Sea levels will rise. This will contribute to more damaging storm surges. In some instances, rising sea levels may lead to permanent flooding of low-lying and subsiding land areas.
- Elevated levels of CO_2 in the atmosphere will accelerate the deterioration of concrete. More CO_2 in seawater will more rapidly damage submerged and exposed marine infrastructure elements.

These general changes can be expected to occur as atmospheric greenhouse gas concentrations increase. But adaptation efforts are complicated by the fact that model-based projections of future climate are ill adapted for use by transport asset owners and network managers. First, model outputs broadly characterise potential climate impacts but rarely provide specific insight on particular impacts at specific locations. Second, model-based data is not equivalent to historic meteorological data and cannot be used as such by asset planners, designer and managers using conventional engineering, planning and assessment tools.

Strategies exist to manage the gap between available data, network planning and asset design input requirements, but these cannot address certain irreducible uncertainties. Ultimately, new models for decision making under uncertainty are required to ensure continued and reliable transport network performance in the face of climate change. Some options for decision makers are outlined below.

The insights

Assess vulnerability, focus on resilience, develop new tools

Owners of transport assets and network managers should act now to preserve asset value and system performance. Transport systems comprise multiple, interconnected assets and asset components each of which plays a role in ensuring continued and reliable system performance. These components have different lifespans and different maintenance and refurbishment schedules. Addressing climate considerations will therefore not be uniform across all asset classes.

For some asset components, exposure to climate change is minimal because their design life is shorter than the period over which significant climate changes may occur – this is the case for road surfaces, for instance. For other asset classes whose design life (or effective period of use, in the case of existing assets) extends well within climate timescales of 50-plus years, the potential exposure to climate hazards is significant.

In the former case, asset owners and network managers must anticipate climate impacts when renewing infrastructure components and prepare for managing more frequent extreme events. In the latter case, the asset planning process will have to more comprehensively assess whether or not asset plans, including siting decisions, are robust to a wide range of uncertain future climate impacts.

To protect transport infrastructure against present and future climate impacts, it must be properly maintained. Maintenance reduces vulnerability to such impacts and, as such, is a powerful hedging strategy in the face of climate change. Climate factors already reduce asset and network performance today; these impacts will be exacerbated by insufficient maintenance. When budgets are tight, however, funding for maintenance is often postponed on the expectation (and hope) that this will not necessarily lead to immediate asset failure and network disruption.

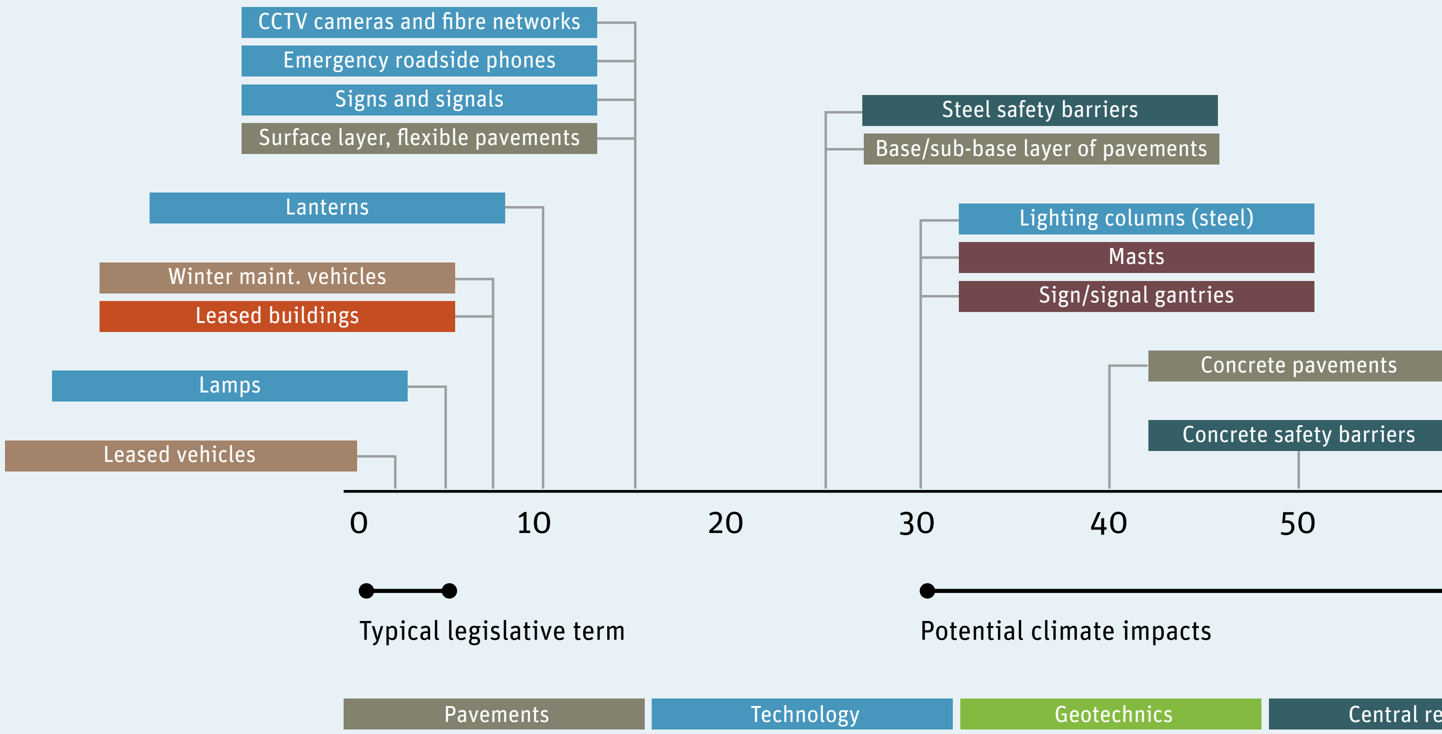
This is an increasingly untenable assumption in the face of climate change. The cumulative effect of deferred maintenance increases vulnerability of assets and networks to (local or systemic) disruption. Assets and asset components exposed to hydraulic forces – such as culverts, embankments, cuts and bridge pilings, for instance – are particularly susceptible to damages resulting from poor maintenance. The use of sensors and communication technologies that allow for "self-aware" and "self-reporting" infrastructure provides new opportunities for more effectively targeting maintenance interventions when and where the actual condition of assets and their components make it advisable.

Nevertheless, more frequent and unexpected asset failures will occur under a changing climate, so asset managers and operators must prepare. In particular, asset managers must anticipate scenarios where multiple hazards lead to unexpected or cascading failures – such as the combined impact of a storm surge at high tide combined with extreme precipitation and inland flooding.

Connected networks and systems can propagate the initial impact beyond the directly affected infrastructure to other vital transport and non-transport systems. Co-located infrastructure (for instance a bridge carrying road and rail traffic while also hosting water, fibre optic and electric conduits) poses special risks in this respect that need to be anticipated and mitigated. Preparing for these hazard scenarios will require much greater cooperation and communication among stakeholders and different asset managers than is typically the practice today.

Asset management strategies will need to assess the vulnerability of infrastructure and networks to changing climate and extreme weather events. Vulnerability assessments allow asset owners to understand what hazards they are exposed to and to prioritise adaptation efforts based on potential consequences. Such assessments must address vulnerabilities at asset level as well as at network level.

Risk analysis is a core component of these exercises. Asset managers and network owners must ask themselves "What can happen?", "How likely is that?" and "What are the



consequences?" Though challenging, answering the first and third questions is generally possible with the present state of knowledge. Answering the second question is more difficult since climate projections cannot provide the certainty that historical climate records impart. In many instances, the question of likelihood may be unanswerable, but this does not obviate the need for alternative measures of vulnerability.

Overall, climate change adaptation must focus on system resilience, not just on designing robust transport infrastructure. Resilience-based approaches accept asset failure as an unwanted but sometimes unavoidable consequence of climate change. Rather than avoiding failure completely, resilience-based approaches focus on minimising the consequences of asset failure.

This means moving away from an approach based solely on the passive defense of assets to an approach based on establishing proactive processes that ensure as little system downtime as possible. Novel approaches that enhance resilience include contingency planning that allows for safe failure of an asset – a small bridge, say – , combined with ahead-of-time contracting for emergency repairs and pre-positioning of necessary replacement materials.

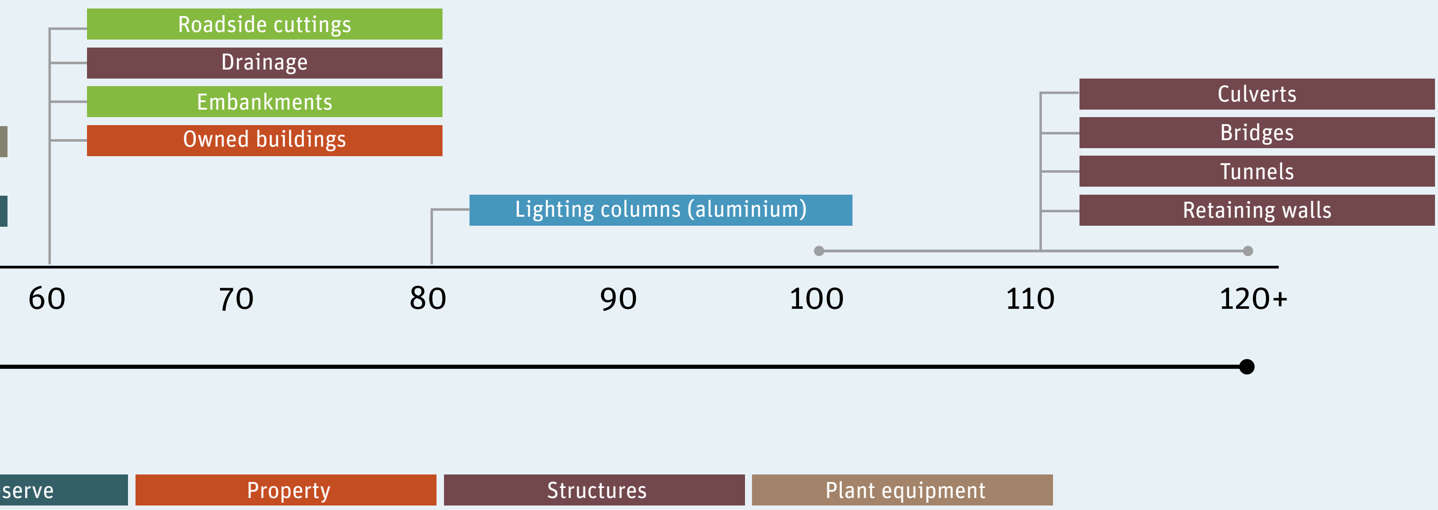
Transport authorities may also need to re-evaluate their stance regarding redundant infrastructure. Preserving or enhancing network redundancy has value in light of the potential for more frequent and unexpected asset failures in a changing climate. This may go counter to past efforts to reduce "wasteful" redundancy in transport networks and will require new methodologies for assessing the value of redundancy. Redundancy or network robustness assessment should include operation during a crisis as well as recovering from critical link failures.

This assessment should also account for accessibility-reducing impacts (such as the lack of alternative routes) as well as the demand-weighted importance of each link. Network robustness assessments that incorporate alternative modes can lay the groundwork for better cross-modal preservation of overall transport service levels during disruptions.

In the light of uncertainty regarding climate impacts on transport, authorities should no longer rely solely

Lifespan matters

Long-lived assets are more exposed to climate change impacts than short-lived infrastructure, but their lifespan exceeds the political decision cycle



Adapted from UK Highway Agency Asset System 2011

on Cost-Benefit Analysis (CBA) for appraisal of assets and networks. CBA assigns monetary values to revenue streams, costs as well as non-monetised impacts of projects and converts future costs and impacts into present values via a discount rate. CBA represents an "agree on assumptions" approach: It first seeks agreement on current and future conditions (e.g. either discretely as in the statistical value of life or through a probability distribution regarding future demand levels), then analyses options and finally picks an "optimal" outcome.

"Agree on assumption" appraisal works best when stakeholders find consensus on how to quantify impacts and how these should be valued over time. Where the probability of future climate impacts can be robustly assessed and agreement can be found on the above, CBA remains useful. Adjusting discount rates for risk and providing decision makers with explicit assessments of climate-related uncertainties can help improve CBA.

However, many climate-change impacts are subject to deep, unquantifiable uncertainty and cannot be assigned objective (or even subjective) probabilities. Likewise, agreement on other inputs to CBA may be difficult to obtain in light of a changing climate. These shortcomings limit the usefulness of Cost-Benefit Analysis as a stand-alone approach to guide transport investments for long-lived infrastructure.

Incorporating such deep uncertainty into asset appraisal requires a new set of decision-support tools. With time, society will gain better knowledge about the scale and scope of climate impacts. There is a value to flexibility that can be captured by appraisal techniques such as Real Option Analysis (ROA) which is particularly suited for large, up-front, irreversible investments. This flexibility refers both to the timing of the investment decision ("build now" v. "build later") as well as to the ability for the infrastructure to adjust to changing conditions over time (e.g. "build for, but not with"). The formal application of ROA requires probabilistic inputs about climate impacts and therefore may be less suited to cases where deep uncertainty exists.

Robust Decision Making (RDM) is an alternative approach adapted to situations where no probabilistic information exists regarding impacts or outcomes. RDM seeks to select those strategies and investments that are consistently robust under the widest range of plausible climate outcomes and impacts.

RDM represents an alternative "agree on outcomes" approach to decision making, where outcomes are selected first and then tested for their robustness.

In this way, RDM avoids having to find consensus on future climate change impacts which otherwise hampers "agree on assumption"- based approaches. Crucially, RDM may favour outcomes that are optimal in no single situation but that are good enough in most circumstances. RDM seeks to minimise regrets rather than optimise specific (but perhaps vulnerable) outcomes.
Although they have been applied in some cases, neither ROA nor RDM have so far worked their way into mainstream project appraisal for transport infrastructure. Among the reasons for this are regulatory structures governing appraisal as well as insurance requirements regarding risk assessment. Developing and understanding how these approaches can be usefully integrated into transport investment appraisal remains a work in progress.

Further reading

"Asset Management for Sustainable Road Funding", ITF Discussion Paper, Paris, 2013

OECD/ITF, *Adapting Transport Infrastructure to Climate Change and Extreme Weather: Decision-making under Uncertainty*, Paris, (forthcoming)

About the International Transport Forum

Who we are
The International Transport Forum at the OECD is an intergovernmental organisation with 57 member countries. It acts as a think tank for transport policy and organises the Annual Summit of transport ministers. ITF is the only global body that covers all transport modes. The ITF is administratively integrated with the OECD, yet politically autonomous.

What we do
The ITF works for transport policies that improve peoples' lives. Our mission is to foster a deeper understanding of the role of transport in economic growth, environmental sustainability and social inclusion and to raise the public profile of transport policy.

How we do it
The ITF organises global dialogue for better transport. We act as a platform for discussion and pre-negotiation of policy issues across all transport modes. We analyse trends, share knowledge and promote exchange among transport decision-makers and civil society. The ITF's Annual Summit is the world's largest gathering of transport ministers and the leading global platform for dialogue on transport policy.

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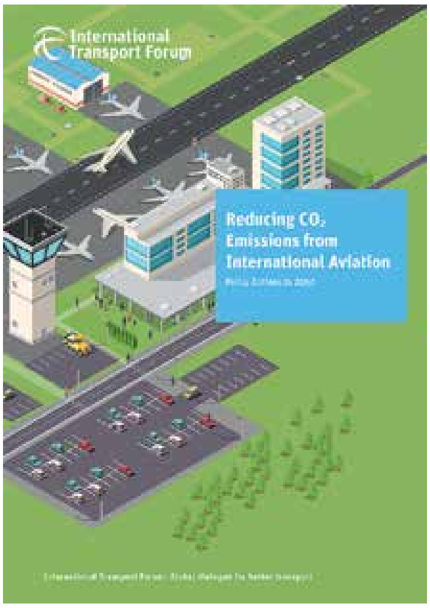

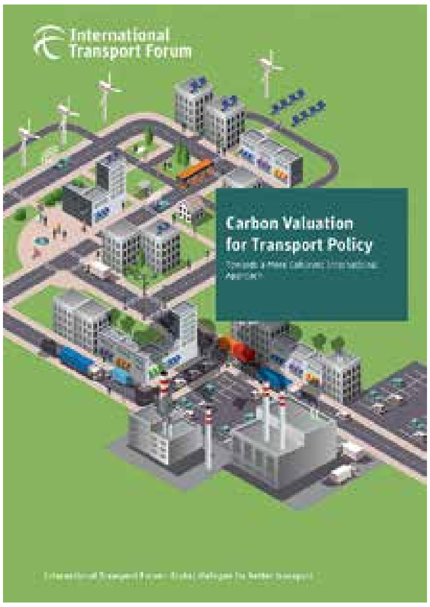

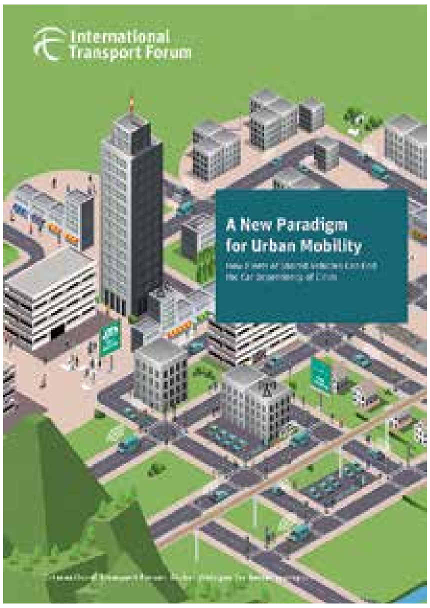

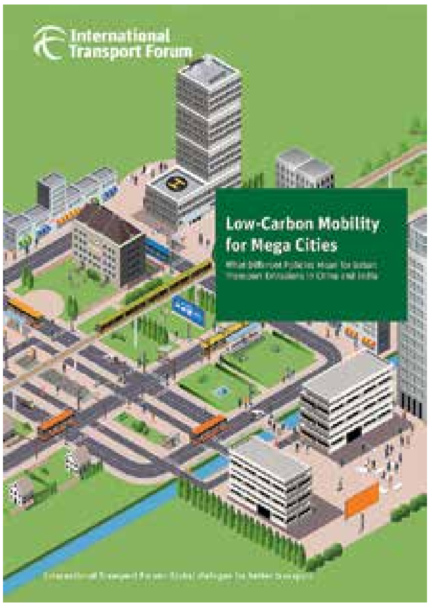

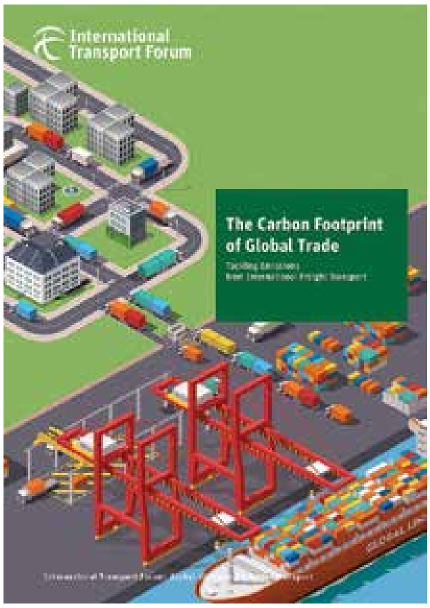

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