MODULE 1 1.2

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Transport Adaptation and Resilience

SLOCAT Partnership on Sustainable, Low Carbon Transport

Transport, Climate and Sustainability Global Status Report - 3rd edition

Key findings

Context and key challenges

- Transport and mobility systems require not only infrastructure and operational resilience, but also resilience to shocks, macroeconomic and political disruptions, social events and climate change, to achieve financial sustainability.
- Climate change impacts – including sea-level rise and coastal flooding, more intense storms and rainfall, and more extreme temperature swings – increase the vulnerability of passenger and freight transport and heighten the impacts of other disruptors.
- Transport resilience initiatives are increasingly data dependent, but obstacles remain, including limited data collection capacity among many countries, cities, and companies, constrained access to existing data, and lack of information sharing.
- Transport systems tend to cross multiple jurisdictions, and resilience must involve non-traditional stakeholders, yet fragmentation of governance presents a continuing barrier.
- Resilience and adaptation must be balanced with the pressing need for decarbonisation and energy security, in the context of sustainability objectives.

Adaptation and resilience of transport systems

- Natural hazards cause an estimated USD 15 billion a year in direct damage to transport systems worldwide; of this, an estimated USD 8 billion occurs in low- and middle-income countries, which experience the highest costs relative to their gross domestic product.
- Cascading impacts of disruptions to other sectors can also disrupt transport networks. In extreme cases, these disruptions can undermine the viability of transport systems.
- Investment gaps continue to grow worldwide, and transport systems may become increasingly vulnerable as long-term stresses degrade assets.
- The monetary impacts of transport disruptions far exceed physical damages to assets. In low- and middle-income countries, this results in an estimated USD 107 billion in annual losses to businesses.
- Transport service interruption can bring harder-to-quantify, but no less impactful, secondary social consequences.
- Proactively adapting transport systems for future climatic conditions is far more cost-efficient than delayed adjustments or inaction.
- An "access-based" perspective on transport resilience can provide a more holistic, complex view of both the coming hazards and the available adaptation options.

Resilience through transport

- Transport is vital for supporting societal resilience during the response and recovery phases of a disaster and must be designed intentionally to serve these emergency functions.
- Transport increases people's access to jobs, health services, shelter, education and economic opportunities. These factors highlight transport's ability to deliver further "dividends of resilience": increased economic resilience and benefits for development.
- Recognition is growing of the interaction between transport investments and social inequalities, which can lead to asymmetrical impacts from climate-related events.
- Emergent approaches offer opportunities to create transport systems that both are climate resilient and have a minimal, or even beneficial, impact on the environment.
- Shifting to active modes of mobility where feasible can help deliver a host of resilience, social and environmental benefits.

International support for transport adaptation and resilience

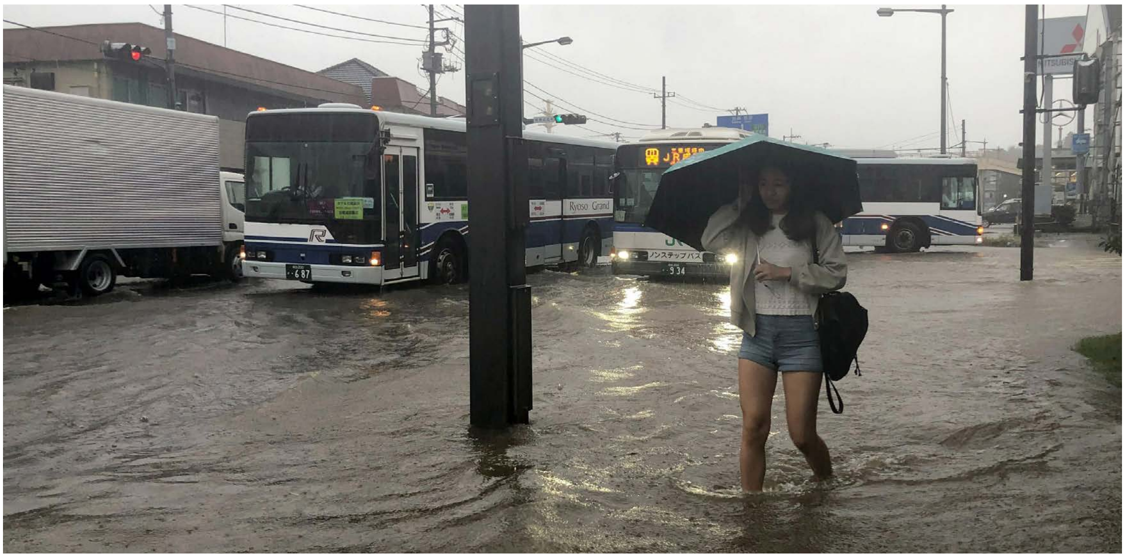
- A global shift in perspective is helping to create frameworks that support greater resilience in infrastructure at the international level, but few of these focus specifically on transport.
- A growing number of international tools are providing incentives for transport system resilience, but gaps in capacity remain, especially in the Global South.
- International financial institutions are highlighting climate risks in infrastructure, which is producing more resilient transport investments; yet the estimated gap in adaptation finance for low- and middle-income countries is 5 to 10 times greater than current investment.

National and sub-national planning on transport adaptation and resilience

- National and sub-national actors – including governments, businesses and civil society – have begun to nominally address climate adaptation and resilience for transport, but concrete action and expenditures remain insufficient.
- National Adaptation Plans (NAPs) show promise as a means for low- and middle-income countries to prioritise actions around transport system adaptation.
- Provincial/state and municipal governments are planning and implementing transport resilience and adaptation projects with support from the private sector and civil society.
- Public-private partnerships are showing potential to mobilise private sector funding and expertise to make transport systems more resilient.
- National standards applicable to transport systems are starting to incorporate climate adaptation, building on the example of standards provided by the International Organization for Standardization (ISO).

Measuring impact – how do we know we are moving in the right direction?

- Measuring resilience and adaptation outcomes is an ongoing challenge that can be approached in multiple ways. Several methodologies have emerged that include appropriate indicators for measuring resilience and adaptation.
- Consideration of transport resilience and adaptation in combination with other critical systems offers a more robust way to ensure improved societal resilience.



Overview

Transport plays a vital role in connecting people and communities around the world, and in supporting global supply chains. Yet in the last few years, most transport and mobility systems worldwide have become more vulnerable to systemic shocks, affecting their ability to provide reliable, efficient and safe service and with disproportionate impacts on people living in vulnerable situations. Meanwhile, uncertainty about the frequency and severity of future climate-related events is growing. It is therefore urgent to consider adaptation and resilience measures, in conjunction with mitigation actions, to ensure that transport and mobility systems are both resilient to future shocks and hazards and that their development and operation contributes to social resilience and to the overall decarbonisation of our economies.

Transport resilience can be defined according to two key aspects:

- **Resilience of transport:** Ability of transport and mobility systems to withstand, respond to, recover from and adapt to a range of shocks and stresses, both now and into the future. Key elements include operational and organisational resilience (e.g., offering redundancy and diversity of mode choice for communities of differing income levels and geographic locations and various types of goods) in addition to the physical resilience of the infrastructure itself.
- **Resilience through transport:** Capacity to enhance the resilience of people and communities through passenger mobility systems, and the resilience of enterprises, economies, and supply chains through freight transport systems. Resilient transport and mobility systems provide services and deliver benefits to communities that are most vulnerable to the impacts of climate change and to the most critical supply chains.[1]

Adaptation is an integral component of resilience strategies, particularly climate resilience; however, it is not the full story. A holistic approach to resilience also takes into consideration the shocks and stresses to transport systems created by *non*-climate-related disruptors (e.g., health crises, macroeconomic and political disruptions) as well as interdependencies that transport has with other systems, both "hard" (e.g., energy and communications) and "soft" (e.g., governance and regulation).

To guide decision making, some organisations have sought to define core principles or qualities for resilience. For example, the United Nations Office for Disaster Risk Reduction's (UNDRR) six principles characterise resilient systems as those that are: continuously learning, proactively protected, environmentally integrated, socially engaged, sharing responsibility and adaptively transforming.[2]

There are many current and promising approaches for implementing adaptation and resilience in the transport sector, with the goal of mainstreaming resilience. At the same time, both trade-offs and co-benefits exist between resilience and adaptation, and mitigation. This is the first edition of the SLOCAT Transport, Climate and Sustainability Global Status Report to dedicate a full section to resilience and adaptation, with a focus mainly on road and rail transport in addition to aviation and maritime transport.

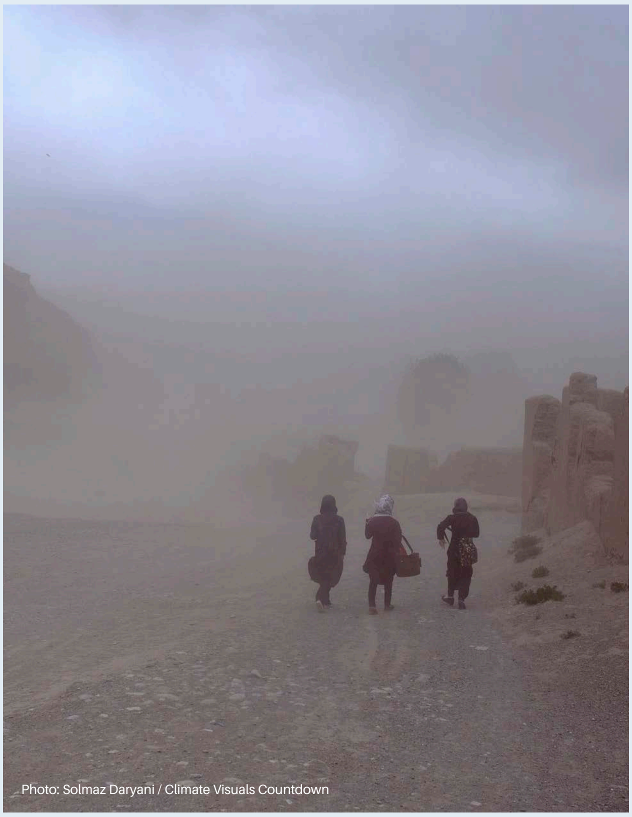


Photo: Solmaz Daryani / Climate Visuals Countdown

Context and key challenges

Transport and mobility systems require not only infrastructure and operational resilience, but also resilience to shocks, macroeconomic and political disruptions, social events and climate change, to achieve financial sustainability.[3] Several disruptors already impact transport networks around the world, and many of these are exacerbated by climatic factors.

Pandemics

In the United States, monthly total ridership on public transit dropped around 80% from 2019 to early 2020 due to the impacts of COVID-19.[4] In Brazil, the National Association of Urban Transport Companies estimates losses of around 90,000 jobs and BRL 36 billion (USD 7.3 billion) in the public transport sector between February 2020 and April 2023.[5]

Social unrest

In Peru's Amazon region, Indigenous groups blocked a large river in September 2022 to protest an oil spill, and in the United Kingdom transport unions held rail strikes throughout 2022 in a dispute over compensation and working conditions.[6]

Political conflict

As of May 2022, the Russian Federation's invasion of Ukraine had damaged up to 30% of the country's transport infrastructure, destroying 7 airports, 144,000 kilometres of roads, 1,242 bridges and nearly 6,300 kilometres of railways, with costs estimated at EUR 92.6 billion (USD 99.9 billion).[7] The impacts of the invasion on ports has affected trade flows and food security.[8] The invasion also has caused sharp increases in natural gas costs, which rose 170% from February to July 2022, in addition to impacts through inflation caused by effects on supply chains.[9]

Demographic changes and urbanisation

As more people live in cities globally, the urban population share is projected to rise from 56% in 2021 to 68% in 2050, putting greater demands on public transport systems.[10] Urbanisation will take different forms in different regions, with low-income countries expected to experience the highest urban sprawl as city land areas grow an expected 141% by 2070 (compared to 2020 levels).[11] Poor planning exacerbates this issue, and climate change will also affect land use and movement patterns, resulting in changes in transport demand.[12]

Technological innovation and disruption

Despite their benefits, new technologies can be highly disruptive, creating new pressures and vulnerabilities. For example, governments may struggle to keep up with rapidly changing transit networks for "mobility-as-a-service", often competing with established systems for users, resources and infrastructure capacity.[13] This emerging mobility trend remains largely unregulated, with an early attempt being Finland's Act of Transport Services in 2017.[14]

Ageing infrastructure assets

As insufficient maintenance budgets coincide with ageing assets and greater climate variability, this can lead to higher rates of deterioration and failure that further stretch budgets. Most road networks in high-income countries underwent major investment and expansion during the 1960s-1980s and are now approaching the end of their design life, necessitating critical upgrades.[15] Yet spending on transport systems will likely continue to be insufficient for the foreseeable future.

Consumption and commerce changes

Online shopping demand, accelerated by the COVID-19 pandemic, has resulted in a substantial increase in home deliveries. Delivery vehicles often carry poorly optimised loads along local roads that may not be well suited to freight transport, contributing to higher congestion and emissions.[16] Since the pandemic, there has been considerable upheaval in global value chains, with tendencies towards re-localisation and "friend-shoring".[17]

Climate change impacts – including sea-level rise and coastal flooding, more intense storms and rainfall, and more extreme temperature swings – increase the vulnerability of passenger and freight transport and heighten the impacts of other disruptors.[18] While uncertainty remains around specific factors and impacts, there is overwhelming scientific evidence that human-induced climate change has contributed to more frequent and intense extreme events.[19] Direct physical impacts on transport can include:

- **Sea-level rise and increased coastal flooding**, which combine with other hazards to damage ports and disrupt operations and shipping, flood airports, damage or isolate roads and railways, and impair or destroy natural coastal defences.[20]
- **More severe winds**, leading to traffic disruption, damage to bridges and to auxiliary road and rail infrastructure, and safety hazards for users.[21]
- **More intense storms**, increasing tree fall and causing damage to physical infrastructure and vehicles, widespread traffic disruption and unsafe travel conditions.[22]
- **More intense rainfall**, leading to infrastructure flooding, slope failures and landslides, washout of roads and tracks, and bridge scour.[23]
- **Changes in average rainfall**, contributing to drought and changes in the flow and sedimentation regime of rivers (affecting the navigability of inland waterways); poor road conditions and visibility; damage and obstruction to infrastructure (e.g., shrink-swell); and loss of protective vegetation.[24]
- **Increasing average and extreme temperatures**, resulting in pavement deterioration, rail deformation and buckling, air conditioning failures in vehicles due to overheating, expansion of bridge joints, impacts to underground systems through increased urban heatwaves and increased forest fires in non-urban areas, and health risks for transport workers and users.[25]
- **Unpredictable winters**, leading to potential extreme cold events, extreme snowfall and avalanche, thermal cracking of pavement, freeze-thaw deterioration and brittle failure of rails.[26]

Many of these impacts could potentially interact, creating compounded or cascading hazards.

Transport resilience initiatives are increasingly data dependent, but obstacles remain, including limited data collection capacity among many countries, cities, and companies, constrained access to existing data, and lack of information sharing. Although climate projection data are now widely available, many organisations lack the capacity to apply these to risk assessment. Data sharing among organisations is limited by barriers ranging from commercial to data security concerns.[27]

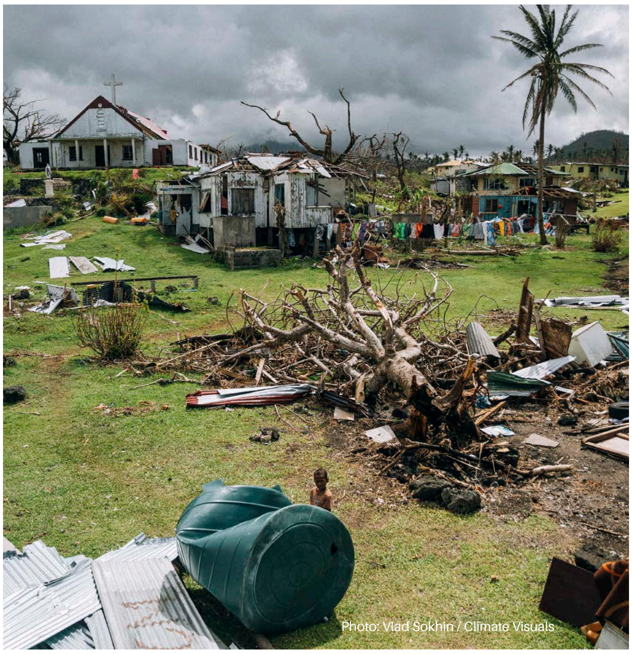


Photo: Vlad Sokhin / Climate Visuals

- Data on climate hazards are scarce in some regions, particularly in low- and middle-income countries, although efforts are under way to address these gaps in some cities and regions – for example, Rio de Janeiro's Centre of Operations links data on environment, transport and medical services.[28]
- A mismatch exists between the long-term planning required for climate adaptation and the short-term time horizons of many investors and government bodies, making it harder to secure funding.[29]
- There is a lack of consensus on metrics to track resilience and adaptation outcomes.

Transport systems tend to cross multiple jurisdictions, and resilience must involve non-traditional stakeholders, yet fragmentation of governance presents a continuing barrier.[30]

- Transport resilience requires new approaches to cross-organisational governance, such as New York City's Green Infrastructure programme, which oversees works formerly split between several city departments and resulted in the greening of nearly 850 hectares between 2010 and 2021.[31]

Resilience and adaptation must be balanced with the pressing need for decarbonisation and energy security, in the context of sustainability objectives. Because of the potential competition for attention and funding between adaptation and mitigation, it is essential to find opportunities to interweave these two focus areas. For example, improving transport infrastructure resilience improves the sector efficiency and reduces transport costs. Furthermore, using renewable resources improves sustainability and makes the sector less vulnerable to climate change and other disruptions. Finally, active travel is a resilience solution that can reduce emissions and thus can be interpreted as supporting sustainability.

Adaptation and resilience of transport systems

Natural hazards cause an estimated USD 15 billion a year in direct damage to transport systems worldwide; of this, an estimated USD 8 billion occurs in low- and middle-income countries, which experience the highest costs relative to their gross domestic product.[32] An estimated 27% of global road and rail assets are exposed to at least one cyclone, earthquake or flooding hazard.[33] Ports are even more exposed due to their placement along coastlines and rivers, with preliminary estimates indicating that 86% are exposed to three or more hazards.[34]

- Damage varies greatly among countries, with the most annual damage per kilometre of road and rail asset estimated in Vietnam, followed by Papua New Guinea and Myanmar.[35]
- In Pakistan, floods in 2022 caused more than USD 3.3 billion in damage to transport and communications, which was the third-largest sector with damages after housing (USD 5.6 billion) and agriculture (USD 3.7 billion).[36]
- Natural hazards continue to cause substantial physical damage and disruption to transport assets. In the European Union (EU), extreme weather alone contributed an average of EUR 2.5 billion (USD 2.7 billion) in direct damages to transport annually between 1998 and 2010, with indirect costs of disruption estimated at EUR 1 billion (USD 1.1 billion) .[37]
- In the aviation sector, extreme weather was responsible for around 7% of US flight delays in 2020, and a further 15% of delays were due to non-extreme weather conditions.[38]

Cascading impacts of disruptions to other sectors can also disrupt transport networks. In extreme cases, these disruptions can undermine the viability of transport systems.

An event that causes disruption to a critical infrastructure service – such as energy, water or communications – can also have substantial impacts on transport networks and public transport systems, even affecting systems that were not exposed to the initial hazard. Space weather events, for example, have the potential to cause global positioning and navigation satellite failures, which could lead to loss of communications and navigation technology, with severe consequences for all transport sectors.[39]

External stresses to upstream supply chains, such as fuel uncertainty, can also disrupt transport. Because of their complex nature, such cascading impacts are often poorly understood, with some dependencies not being appreciated until disaster brings them into focus. For example, the trend to electrify transport systems as a decarbonisation strategy creates new vulnerabilities from natural hazards that may affect power lines or transport stations.

As public transport services become more reliant on digital devices and electric vehicles, energy disruptions can have a high impact on operations.

- In 2019, an electricity outage due to a power failure affected three Indonesian provinces, rendering the MRT and the electric train inoperable and preventing customers from accessing electronic ticketing systems and ATMs to withdraw cash, thus restricting access to public bus services as well.[40]
- In Indonesia, rising floods and ground subsidence in Jakarta have led the government to begin relocating the capital to Nusantara; this points to the dual challenge facing Indonesian transport: frequent losses and damages due to natural hazards, and the need for vast new investment in the transition from existing assets to the new capital, at an estimated cost of more than USD 34 billion.[41]
- In the Maldives, 80% of the country could become uninhabitable due to sea-level rise by 2050, and climate change will have significant implications for transport connectivity, tourism and sustainability.[42]

Investment gaps continue to grow worldwide, and transport systems may become increasingly vulnerable as long-term stresses degrade assets. The projected global gap in financing for new transport infrastructure and maintenance is between USD 244 and USD 944 billion annually to 2030, for the business-as-usual development scenario, while infrastructure developments aligned to a 2-degree Celsius scenario would be lower and within the available infrastructure financing volumes.[43] Other studies estimate a financial gap of at least USD 440 billion for transport infrastructure to meet the United Nations Sustainable Development Goals by 2030.[44] This shortfall increases the maintenance and renewal backlog, further increasing the required investment and the vulnerability of assets.

The problem is compounded as climate change leads to more extreme physical stresses (e.g., shrink-swell cycles, extreme heat and precipitation), resulting in greater deterioration of assets and hence increased vulnerability to further deterioration and extreme events. For example, cracking of assets due to extreme heat leads to greater damaging infiltration of rainwater.[45] However, if decision makers act appropriately, ageing assets could provide an opportunity. As a generation of outdated infrastructure is replaced by forward-looking assets designed to withstand the future climate, resilience can be embedded – drawing on nature-based solutions, new material technology, and more flexible transport and mobility systems.

The monetary impacts of transport disruptions far exceed the physical damages to assets. In low- and middle-income countries, this results in an estimated USD 107 billion in annual losses to businesses.[46] Disruptions to transport networks have cascading impacts on the societies they exist to support. Regional economies suffer as staff and customers cannot travel, supplies are not delivered, and supporting services struggle. Climate change will exacerbate this challenge.

- Mozambique has suffered successive severe flooding events in recent decades, and changes in precipitation are projected to result in economic losses of USD 2.5 billion (roughly 15% of the country's GDP) annually to 2050.[47] This is due in part to the vulnerability of the food-transport nexus – especially in Africa – through the disruption of market access in rural areas.

Transport service interruption can bring harder-to-quantify, but no less impactful, secondary social consequences. Transport systems provide vital community links, and severing these links (particularly in remote areas) can lead to a loss of access to food, education, jobs, recreation, health, and social and government services. Disruption subsequently impacts the resilience, well-being and prosperity of affected individuals and communities.

- In Rio de Janeiro (Brazil), more affluent areas close to downtown have more resilient transport services (e.g., metro systems with multiple transfer points), while lower-income areas on the periphery are more vulnerable (e.g., bus systems dependent on infrequently maintained roads).[48] The impact of a failure in transport is therefore greater than the quantifiable monetary cost.

Proactively adapting transport systems for future climatic conditions is far more cost-efficient than delayed adjustments or inaction. When investment in resilience is used wisely, it can pay dividends that far outweigh the upfront costs. A 2019 analysis of potential infrastructure scenarios estimates that USD 1 of investment in strengthening infrastructure in low- and middle-income countries results in a median of USD 2 in benefits, which increases to USD 4 when climate change is considered.[49]

The "triple-dividend" of resilience includes avoided losses, induced economic benefits, and additional social and environmental benefits. Reduction of damages and loss of life is the first aspect of the triple-dividend; the other two aspects are discussed further in the next section.[50]

An "access-based" perspective on transport resilience can provide a more holistic, complex view of both the coming hazards and the available adaptation options. For example, the shift from mobility-based access to digitally based access (work from home, flexible work hours, satellite offices) can provide a vital risk mitigation tool. A "triple access transport planning" approach – which incorporates physical mobility, spatial proximity and digital connectivity – can be applied through the Futures Toolkit.[51]

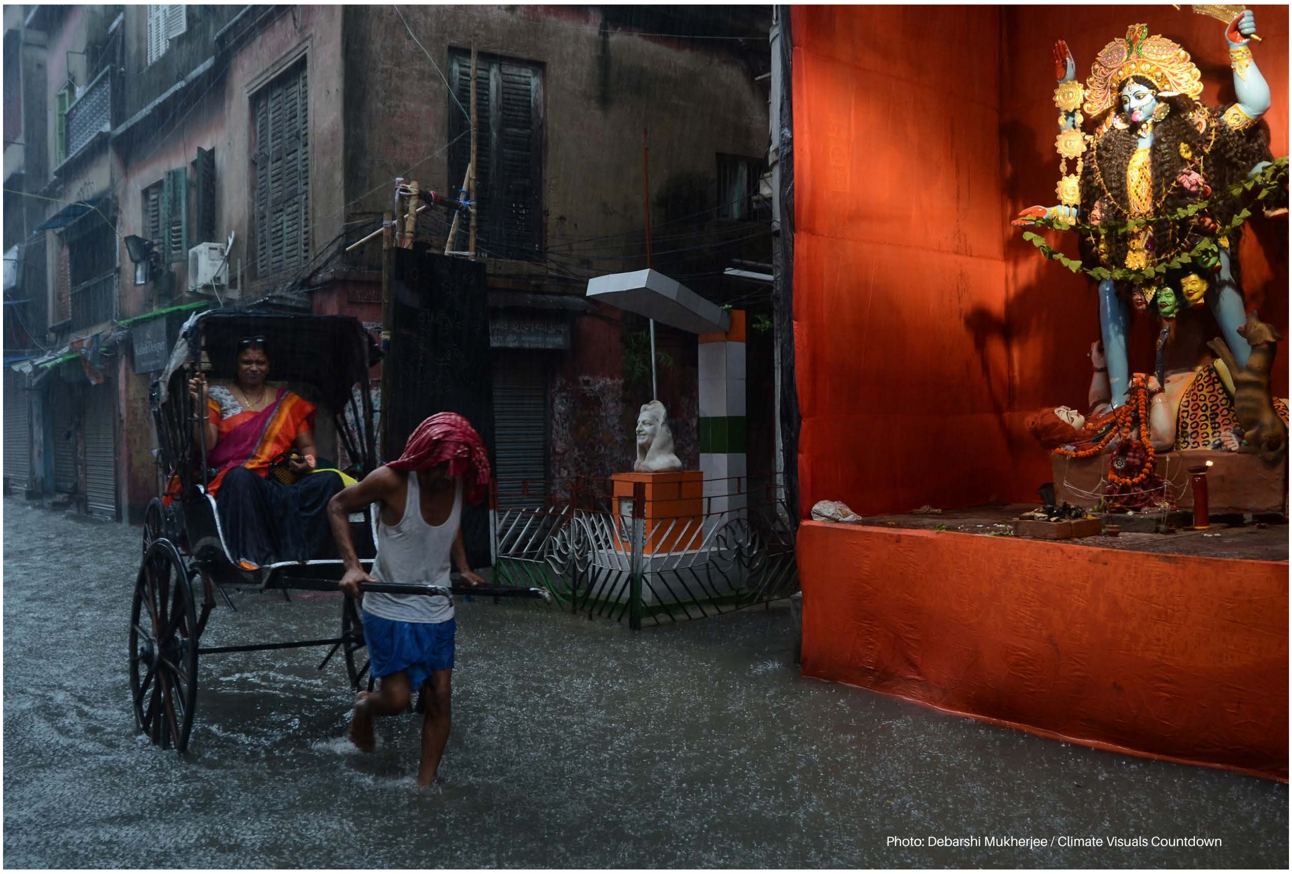


Photo: Debarshi Mukherjee / Climate Visuals Countdown

Resilience through transport

Transport systems can enhance societal resilience by providing a range of benefits. Such systems can contribute to more-resilient communities if they are planned, delivered and managed in a way that maximises social benefits, minimises negative impacts to society and the environment, and protects and leverages natural ecosystems.

Transport is vital for supporting societal resilience during the response and recovery phases of a disaster and must be designed intentionally to serve these emergency functions. Transport links are essential parts of disaster and emergency response plans. When a disaster results in widespread impacts and disruption to transport systems, or when infrastructure and planning are insufficient to meet surges in demand, the cumulative impacts can be catastrophic (see Box 1).[52]

- Aircraft are often the first feasible means of transport for emergency response, as the basic functionality of aviation infrastructure typically can be restored quickly. An earthquake in Pakistan in 2005 killed more than 80,000 people and left up to 3.5 million without food or shelter just before the onset of the harsh Himalayan winter; road closures due to landslides cut off land access to many geographies and communities, and 168 flights delivered nearly 3,500 tonnes of relief supplies.[53]
- Following an earthquake in Nepal in 2015, more than 4,000 rescue workers and supplies were flown into Kathmandu Airport, damaging the runway and leading to closure of the airport within a week.[54]
- Unmanned drones have been utilised for humanitarian aid, including search-and-rescue efforts in Kazakhstan and vaccine delivery in Vanuatu.[55]

Transport increases people's access to jobs, health services, shelter, education and economic opportunities. These factors highlight transport's ability to deliver further "dividends of resilience": increased economic resilience and benefits for development.[56] Poverty and lack of access to markets are associated with, for example, food insecurity and dependence on sensitive assets, crops and ecosystems.[57] Rural transport in low- to middle-income countries can be key for driving development, employment opportunities and national growth.

- In Ethiopia, connection to a rural road was associated with a 10.4% decrease in residents' likelihood of being in poverty and a 2.8% increase in waged employment, over a four-year period.[58]
- A 2018 study in India identified a 5% increase in school enrolment among 5-14 year-olds in villages given access to a rural road, likely due to increased access to teachers.[59]
- In Indonesia, a modest average improvement in road quality resulted in a 20% increase in labour earnings.[60]

BOX 1. Lessons learned from transport relief efforts in vulnerable communities

Multi-modal response plans can function effectively even when some links are overwhelmed. By ensuring that transport systems are prepared for and integrated with emergency response and disaster recovery plans, communities can be much better served.

When Hurricane Katrina struck New Orleans in the US state of Louisiana in August 2005, most of the population was evacuated by private road transport; however, an estimated 100,000 to 200,000 people were without private transport. The city's evacuation plan relied on public transit for these individuals – primarily city buses – but could not be properly executed. Many drivers evacuated themselves, buses were unprotected and damaged during the floods, and there were only enough buses for around 25% of the population. Nearly 70% of fatalities were among residents over the age of 65.

The importance of public transport's role in emergency evacuation was recognised after Hurricane Katrina, and recommendations were made to integrate public transport fully into emergency response and evacuation plans. For example, when Cyclone Fani struck the state of Odisha, India in 2019, the evacuation of 800,000 people from low-lying areas using public buses, railways and inland water transport was highly praised.

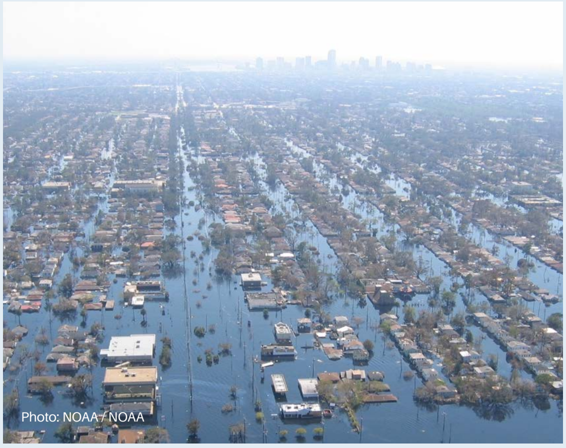


Photo: NOAA / NOAA

Source: See endnote 52 for this chapter.

- Rural trail bridges in Nicaragua were found to eliminate the 18% decline in labour earnings reported during flood events.[61]

Recognition is growing of the interaction between transport investments and social inequalities, which can lead to asymmetrical impacts from climate-related events. The benefits of transport systems are not distributed evenly across society. Gender, age, social or disability status often play an important role in how people use transport. Greater mobility options could have a particularly positive impact on traditionally disadvantaged or underrepresented groups.

- A study in India found that the provision of a rural road resulted in improvements in preventative health care for women, such as a 20% increase in women seeking antenatal care.[62]

There is also the asymmetrical climate-related vulnerability created by inadequate transport and access options. This includes informal settlements in African cities (e.g., Kampala, Uganda) forming in floodplains and on unstable hillsides, due to their proximity to economic opportunities that would otherwise be unavailable to the poorest residents due to unaffordable transport services.[63]

However, transport practitioners often overlook social inequalities, and investment and innovation can reinforce existing inequalities. For example, mobility services for first- and last-mile trips (such as ride hailing services) typically require a smartphone and bank account, but in the United States half of Black households are unbanked, and only 58% of Black individuals own a smartphone or computer.[64] Social inequalities lead to greater vulnerability to hazards, and people who are marginalised prior to a disaster often receive inferior support afterwards.[65]

Evidence reveals a gender discrepancy in disaster mortality, where women's life expectancy is affected more than men's; however, this discrepancy vanishes as women's socio-economic status increases (at lower socio-economic statuses, women tend to have most of the caring responsibilities, and in disaster settings, women are more likely to be at home protecting family members).[66] By ensuring that the needs of all users are considered, transport systems can deliver benefits that contribute to a more equitable society, and subsequently to more resilient communities.

Emergent approaches offer opportunities to create transport systems that both are climate resilient and have a minimal, or even beneficial, impact on the environment. There is a need to balance trade-offs between resilience and wider sustainability goals. Nature-based solutions and green infrastructure can create resilience of (and through) transport systems (see Box 2).[67]

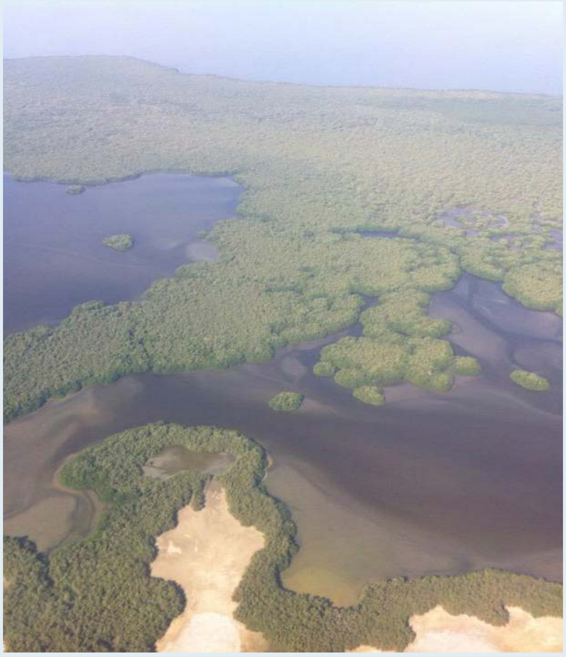
Green drainage solutions, such as permeable pavements, bioswales, retention basins, rain gardens, and engineered wetlands, can mitigate flooding hazards and support ecosystems, allowing a more natural water cycle. Planting trees and other vegetation along urban infrastructure can help combat heat-island effects, reducing peak summer temperatures by 1 to 5 degrees Celsius (°C) and surface temperatures by 11° to 25°C, easing heat stress on both road users and assets.[68]

Shifting to active modes of mobility where feasible can help deliver a host of resilience, social and environmental benefits. Active mobility options such as cycling and walking reduce emissions and create societal resilience by providing healthier and more active lifestyles. Simultaneously, greater flexibility provided by a variety of active mobility solutions creates a more resilient transport system than one dependent on large-scale fixed infrastructure.

With more than 75% of urban journeys potentially short enough for active travel (including electric-assist bicycles), this presents an enormous opportunity to achieve both resilience and sustainability goals.[69] During the COVID-19 pandemic, many cities created temporary infrastructure to reduce dependence on public transport and private vehicles, and the increase in remote working reduced the need for many journeys entirely; this has spurred rising interest in "15-minute cities" connected by active travel.[70]

BOX 2. Restoring mangrove forest to enhance the resilience of coastal highways

Colombia's Ciénaga Grande de Santa Marta marsh ecosystem has been more than 50% lost, due in part to highway construction. The government is now considering expanding the highway further. A "green-grey" solution to coastal erosion has been proposed that would restore 344 hectares of mangroves annually through strategic placement of elevated roadways. This solution would also sequester around 23 tonnes of carbon a year and has around half the cost of the proposed hard-engineered solution.



Source: See endnote 67 for this chapter.

International support for transport adaptation and resilience

A global shift in perspective is helping to create frameworks that support greater resilience in infrastructure at the international level, but few of these focus specifically on transport. This shift is promoting international co-operation through co-ordinated governance mechanisms and impact frameworks as well as establishing funding, tools and incentives for action at an international scale. The transport sector is a key focus across these global co-operation mechanisms, with several noteworthy international agreements and partnerships helping to encourage co-operation between public and private sector organisations.

- The Marrakesh Partnership for Global Climate Action (MPGCA) seeks to implement the Paris Agreement with a view towards adaptation and resilience alongside climate mitigation.[71] Initiatives include increasing climate preparedness and resilience in the maritime and road sectors, among others.[72]

- The Marrakesh Partnership is complemented by the Race to Resilience campaign, which aims to catalyse action by non-state actors. At the 2022 United Nations Climate Change Conference in Egypt (COP 27), the campaign endorsed a joint statement to create a climate-smart and resilient maritime sector.[73]

- The Coalition for Disaster Resilient Infrastructure (CDRI), Global Resilience Partnership and G20 Global Infrastructure Hub are prominent partnerships among various government bodies and private sector and academic institutions that aim to promote resilient action, awareness, knowledge sharing and policy.[74]

- The International Coalition for Sustainable Infrastructure hosted the Transport Infrastructure Implementation Lab at the 2022 United Nations Climate Change Conference (COP 27), exploring the implementation of resilience in transport through engineering with a range of organisations, including the MPGCA and CDRI.[75]

A growing number of international tools are providing incentives for transport system resilience, but gaps in capacity remain, especially in the Global South.

- The Intergovernmental Panel on Climate Change (IPCC) data platform presents global climate change data and scientific consensus.[76] The IPCC's comprehensive report on *Impacts, Adaptation and Vulnerability* outlines the latest scientific understanding of climate risks faced by the transport sector.[77]

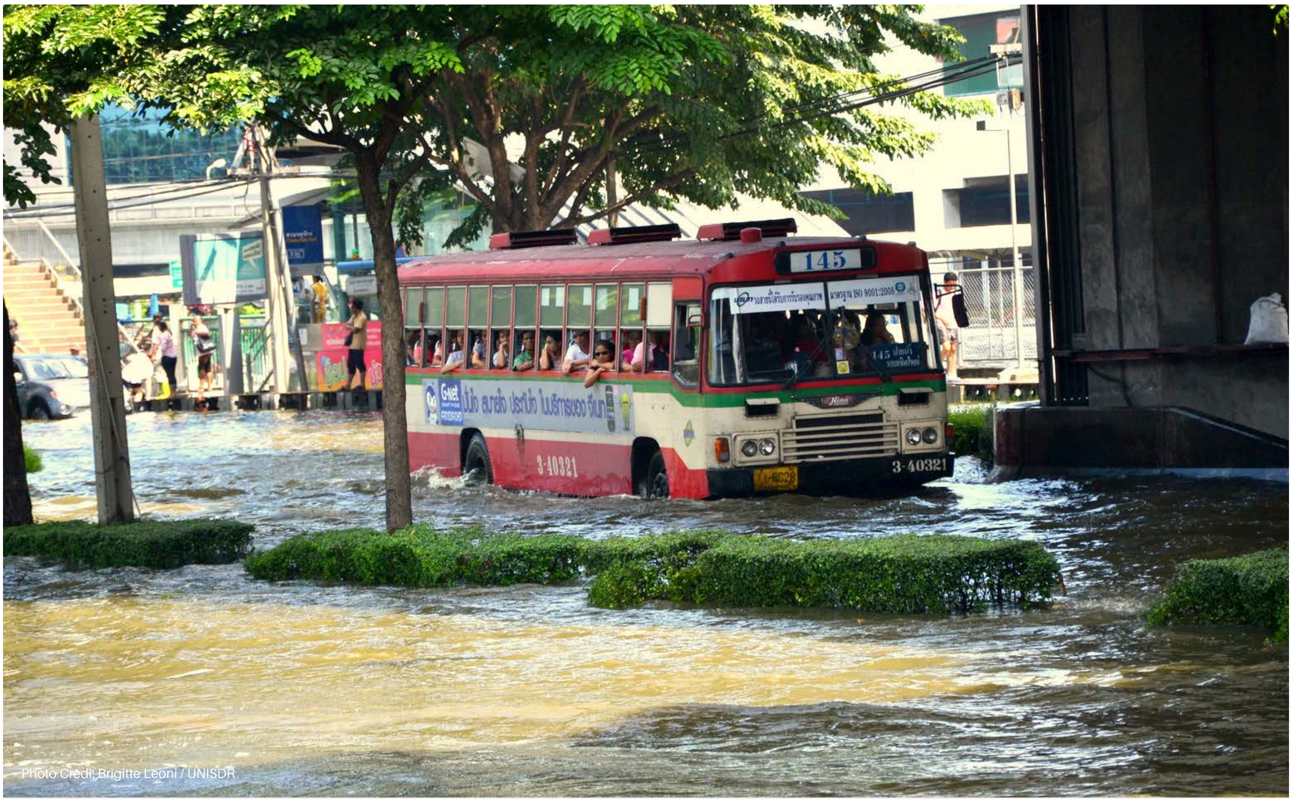


Photo Credit: Brigitte Leoni / UNISDR

- The Task Force on Climate-related Financial Disclosures' (TCFD) 2017 report recommends reporting on the financial impacts of climate change risks, including physical impacts, building resilience, addressing natural hazard risks and making transport more resilient.[78] As of 2022, more than 3,800 public and private companies supported the TCFD; for public companies in the transport industry, the average percentage of disclosure of TCFD-recommended information was 32%.[79]
- International standards include the International Organization for Standardization's ISO 14090:2019 (Adaptation to climate change – Principles, requirements and guidelines) and ISO 14091:2021 (Adaptation to climate change – Guidelines on vulnerability, impacts and risk assessment). The former details how organisations should monitor and evaluate their adaptation to climate change.[80]
- The Highway Development and Management Model Four (HDM-4) is a software tool for planning and management of road improvement and investment decisions. The tool is scheduled to be updated in 2023 by the Asian Development Bank, the World Road Association (PIARC), the UK Foreign, Commonwealth & Development Office and the World Bank) – with parameters to include resilience of highways to natural disasters.[81]

International financial institutions are highlighting climate risks in infrastructure, which is producing more resilient transport investments; yet the estimated gap in adaptation finance for low- and middle-income countries is 5 to 10 times greater than current investment.[82]

- At the 2021 UN Climate Change Conference in Glasgow, UK (COP 26), high-income countries pledged to double funding provided to low- and middle-income countries for adaptation action by 2025.[83] It remains to be seen how this will materialise for transport.[84]
- As of October 2022, USD 4.25 billion of the Green Climate Fund's USD 11.4 billion portfolio was focused on climate change adaptation; however, only USD 0.93 billion of the Fund's portfolio was invested in transport, and thus an even smaller fraction was invested in adaptation for transport.[85]
- At the 2022 UN Climate Change Conference in Egypt (COP 27), the Sharm el-Sheikh Implementation Plan established a dedicated fund to compensate vulnerable countries for climate disaster losses and damage, which is intended in part to help bridge the gap in adaptation investment in low-income countries.[86]
- The Multilateral Development Bank Joint Methodology for Tracking Climate Change Adaptation Finance assesses the climate resilience of investments (including in the transport sector) through a three-step approach based on a set of common principles.[87]

National and sub-national planning on transport adaptation and resilience

National and sub-national actors – including governments, businesses and civil society – have begun to nominally address climate adaptation and resilience for transport, but concrete action and expenditures remain insufficient.

National and sub-national actors are promoting resilience and adaptation for transport through the development of national adaptation plans, public infrastructure investment, and codes and standards – all aligned to the ambitions of global co-operation.

National governments are investing in resilience-enhancing programmes for their transport systems.

- In the United States, the Bipartisan Infrastructure Law provides USD 550 billion for new federal investments in infrastructure, which includes USD 108 billion to prioritise safety, modernisation, climate and equity in public transport.[88]
- The US Federal Highway Administration has provided USD 7.1 million in funds to 25 state transport departments as part of its Climate Challenge programme, including a grant to protect a coastal road in the state of Rhode Island with permeable pavement.[89]

Efforts by local governments to engage directly with civil society and the public have demonstrated the value of inclusive engagement in resilient transport projects.

- In Freetown (Sierra Leone), as part of data collection efforts for the road climate vulnerability assessment, local civil engineering students used mobile applications to map 4,038 kilometres of transport network.[90]
- Miami-Dade County in the US state of Florida engaged with the community while working to improve access to multi-modal and equitable mobility, through the use of an online platform where citizens could submit and vote on proposals to improve the transport network.[91]

While considerable progress has been made across multiple levels of government to promote the adaptation and resilience agenda – and to put in place adaptation plans – much work remains. Although governments are developing resilience plans that set out actions and priorities, there is less evidence of implementation and investment in these plans.[92] City and local governments will need to make much faster progress in the coming years to transform and embed resilience within transport systems.

Equally important is for the practice of transport planning itself to be more resilient. Emerging areas of research in "resilient transport planning" and "decision making under deep uncertainty" are still in their infancy, but they are growing in impact and influence around the topic of complex risk.[93] These principles were applied in the recent reform of the long-term transport planning practices of the City of Cape Town, South Africa and hold useful lessons for planning practices in other urban contexts.[94]

National Adaptation Plans (NAPs) show promise as a means for low- and middle-income countries to prioritise actions around transport system adaptation. Established in 2011, NAPs identify medium- and long-term adaptation needs for these countries as well as strategies to address them. A total of 21 NAPs were submitted between April 2021 and January 2023, out of 45 NAPs available in total since 2015.[95] All of these mention transport in some capacity, and more than 80% (17 NAPs) include an adaptation action or priority directly related to transport (compared with only 50% of the NAPs submitted between October 2015 and March 2021).[96] Meanwhile, 16 of the recently submitted NAPs refer to potential climate change impacts on transport.[97]

- Niger assesses climatic impacts on the transport sector in its NAP, including an analysis of the chain of impacts of climate change on transport and cross-cutting gender considerations. The NAP proposes five distinct transport-specific adaptation programmes, ranging from adaptation of design standards for road, air and rail to the reinforcement of protective dykes along roads and railways. Each programme outlines key objectives, the main activities over a five-year period, indicators, a budget and other considerations.[98]
- Tonga's NAP assesses both climatic impacts and adaptation issues surrounding transport infrastructure, including pointing to underdeveloped drainage and poor design in storm drains, flood mitigation devices and causeways.[99] Since 2019, the country has implemented the Tonga Climate Resilient Transport Project, which is financed under the World Bank's Pacific Climate Resilient Transport Program, which began in 2018 and includes seven projects to date.[100]

Provincial/state and municipal governments are planning and implementing transport resilience and adaptation projects with support from the private sector and civil society.

- Hong Kong (China) completed its most comprehensive assessment ever of the present and future flood risk to the city's rail infrastructure, combining climate projections and detailed urban topography datasets.[101]
- In Spain, a key component of the Barcelona Nature Plan is planting trees along streets, creating 1 additional square metre of greenery per resident with the aim of easing extreme heat and supporting biodiversity.[102]

- Montevideo (Uruguay), embraced large-scale, real-time data to improve the resilience of its transport network, including using a centralised Mobility Management Centre.[103]
- A thorough assessment of the climate resilience of the Port of Durban (South Africa), reviewed the port and its interdependent systems (road and rail) to assess their preparedness, options to adjust, and ability to rebound from various climate impacts, ultimately making recommendations for adaptation.[104]

Public-private partnerships (PPPs) are showing potential to mobilise private sector funding and expertise to make transport systems more resilient. In 2020, private investment in infrastructure in low- and middle-income countries reached a historic low due to the COVID-19 pandemic. However, investment has since recovered, led by the transport sector which received USD 43.8 billion in private investment in 2021, up from only USD 10.5 billion in 2020 (but still 9% below 2019 levels).[105]

- In Japan, a concessions-based PPP was used to procure funding for restoration and operations at Sendai International Airport following damage caused by the 2011 tsunami.[106] Although the high-risk environment presented a barrier to many private investors, the PPP was made possible by employing strict numerical systems for risk allocation.[107]

National standards applicable to transport systems are starting to incorporate climate adaptation, building on the example of standards provided by the ISO.

- In the United Kingdom, the 2021 standard BS 8631:2021 (Adaptation to climate change – Using adaptation pathways for decision making) builds on the ISO standards.[108]
- The American Society of Civil Engineers' ASCE MOP 140 standard is focused on Climate-Resilient Infrastructure Adaptive Design and Risk Management.[109]
- Austroads' Guide to Road Design for Australia and New Zealand incorporates means of accounting for the effects of climate change through the design of drainage for floodwaters.[110]
- In France, a systematic review of all standards applicable to transport systems, conducted in 2015, recommended that relevant climatic factors be included in revised standards in subsequent years.[111]

Other Initiatives

- CDRI's risk and resilience assessments of transport infrastructure include the Global Study on Disaster Resilience of Airports and the Strategy for Disaster Resilient Seaports and Port Communities in small island developing states. [112]
- The Sharm El Sheikh Adaptation Agenda, an outcome of the 2022 United Nations Climate Change Conference in Egypt (COP 27), sets out five key interventions for transport: two to make transport accessible and three to make transport resilient through infrastructure hardening, improved planning and management, and remote solutions.[113]
- UNDRR's Sendai Framework for Disaster Risk Reduction 2015-2030, now more than halfway through its duration, aims to support and implement measures to prevent and reduce hazard exposure and vulnerability.[114] Although few achievements specific to transport have been recorded to date, the framework encourages the development of early warning systems, risk monitoring and reporting, and establishing indicators and targets.[115]

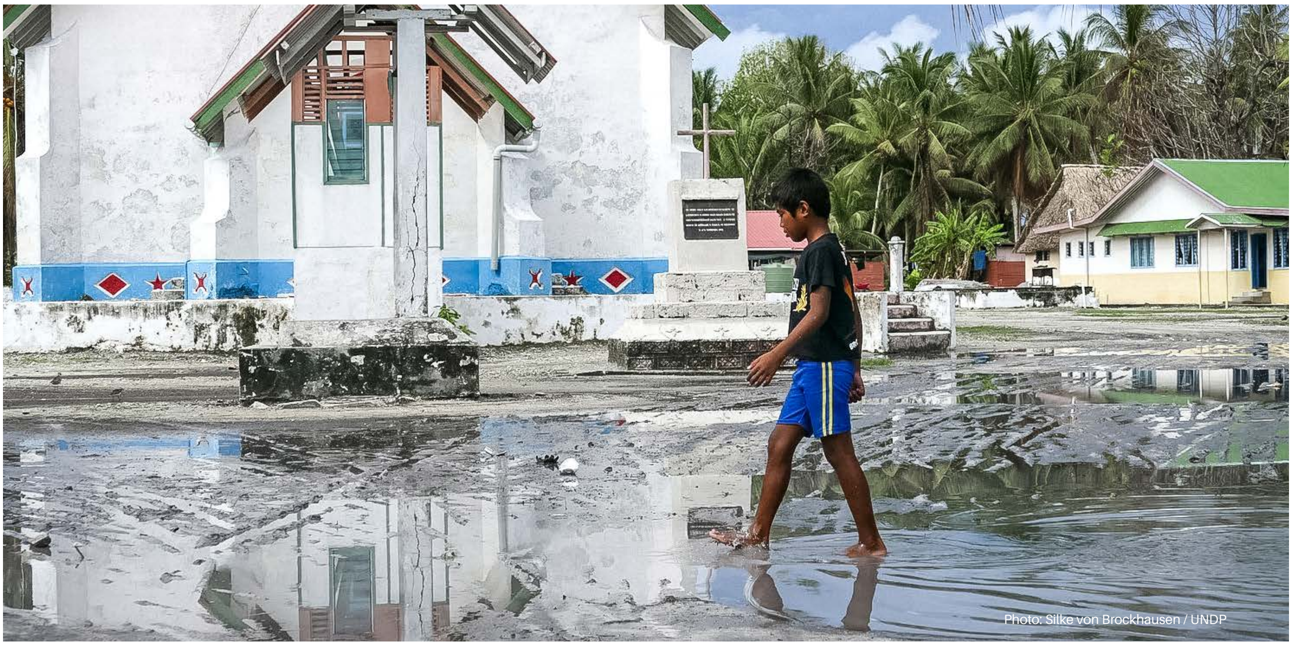


Photo: Silke von Brockhausen / UNDP

Measuring impact – how do we know we are moving in the right direction?

Measuring resilience and adaptation outcomes is an ongoing challenge that can be approached in multiple ways. Resilience-focused metrics and measurements are essential to help transport planners, designers and financers regularly assess the performance of transport systems in the face of changing climate-related shocks and stresses, to inform plans, investments and operational decisions. Measuring climate resilience and adaptation is more complex than measuring mitigation because no single metric is used to measure resilience; for example, metrics to measure the resilience of maritime and inland shipping transport may include resilience of trade flows, minimisation of port delays and reliability of schedules.[116]

Although avoided losses resulting from resilience and adaptation efforts are the gold standard, they are difficult to estimate accurately. Furthermore, defining *outcome* indicators and metrics is even more challenging than defining *output* indicators and metrics, which underscores the critical need to develop climate resilience metrics for transport investment.[117]

Co-benefits of resilience approaches (such as improvements to well-being) can also be measured, but this is complex because the benefits of resilience tend to be distributed across facets of society and over time. Process indicators of the collective movement towards a more resilient transport sector are more easily measured and are often used as a proxy. These indicators can include, for example, money invested in transport resilience projects, or the prevalence of regulations that recognise changing climate hazards. However, progress on process-related indicators does not necessarily translate to impact.

Several methodologies have emerged that include appropriate indicators for measuring resilience and adaptation (see Table 1).[118] However, consensus is lacking on which methodologies are most suitable for different situations.

Consideration of transport resilience and adaptation in combination with other critical systems offers a more robust way to ensure improved societal resilience. Increasingly, methods for long-term monitoring and evaluation of systemic impacts – such as the recent EU Directive on resilience of critical entities – consider the place that transport has among other critical infrastructure systems, including its dependencies and interdependencies.[119] Strategic performance indicators with an outcome-orientated design (as opposed to technical performance indicators that provide real-time insight into performance) can focus on future aspirations rather than past performance, thereby better managing transport systems for the communities they serve.[120]

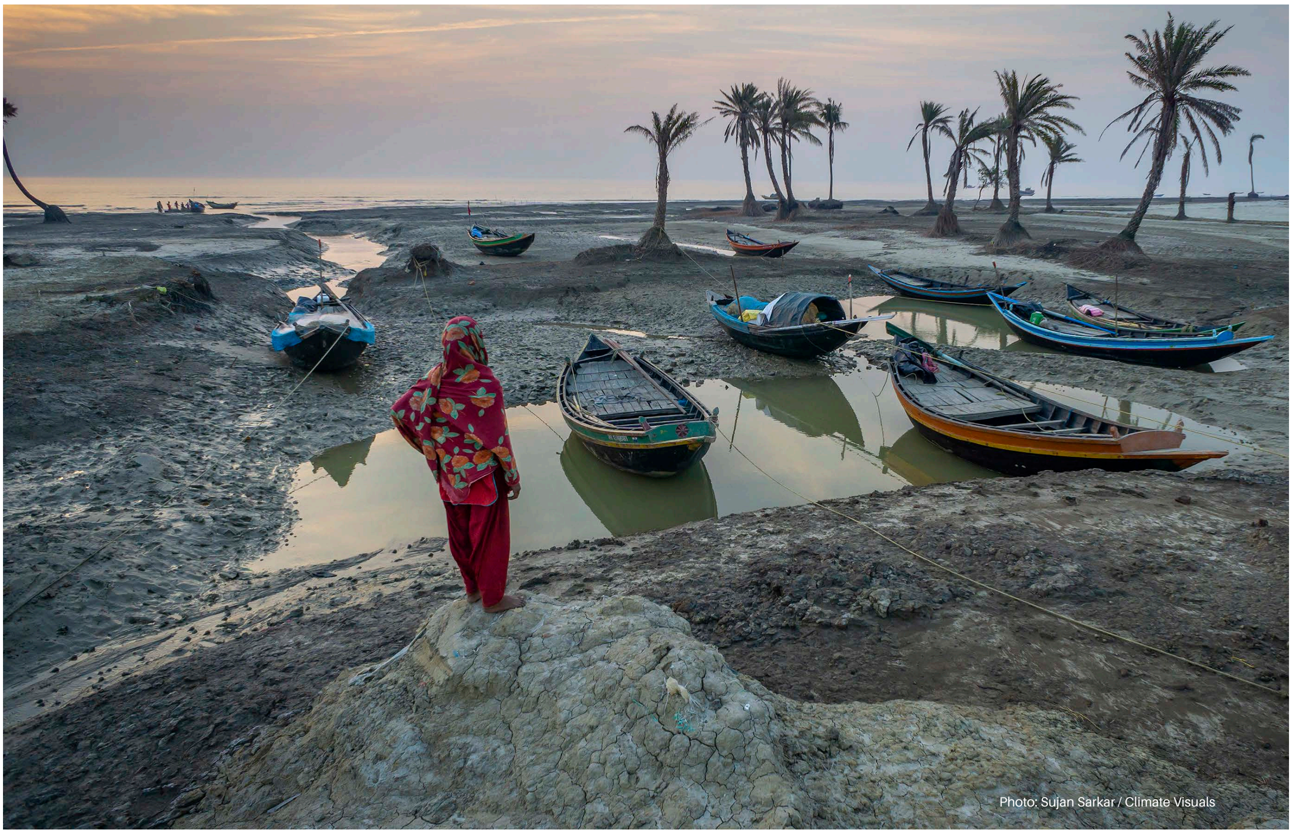


Photo: Sujan Sarkar / Climate Visuals

TABLE 1. Resilience and adaptation indicators

Source: See endnote 118 for this section.

Indicator	Description	
Service continuity	Resilience measurement of transport can be approached through assessing service continuity – for example, tracking cumulative delays resulting from disruptions. In the United Kingdom, National Highways tracks the difference between the observed travel time and the speed limit travel time, as well as the availability of the network and the time taken to clear incidents from it. Travel duration and its monetary value can then be used in cost-benefit analyses.	Global, National, Local; In Use; Impact
Risk assessments	By evaluating the likelihood and potential consequences of hazards to the transport system, risk assessments can help identify areas where systems are vulnerable and where investments in resilience can have the greatest impact. A risk assessment is a means of quantifying direct and indirect costs of not investing in resilience. It can also help track the effectiveness of the implemented risk reduction and management measures over time.	National, Local; In Use; Impact
Adherence to principles of resilience systems	UNDRR's six principles of resilient systems have associated quantifiable indicators that reflect the different qualities of a resilient system. For example, indicators that show that the system is "proactively protected" include the total number of possible alternative routes or modes to deliver the same critical service, or the depth and breadth of formalised emergency management mechanisms for critical infrastructure. A series of indicators exist for each of the six principles.	National; In Use; Impact
Life-cycle costs	Transport that is cheap to build but expensive to maintain can indicate poor resilience, as maintenance can interrupt service. Spending money up front often increases the cost of design and construction, but can save costs during operation, resulting in reduced overall life-cycle costs and increased resilience. Tracking the balance of costs across the whole life cycle of the transport is a proxy for resilience.	National, Local; In Use; Process
Standards uptake	Uptake of globally recognised standards for resilience and adaptation is a telling rubric for whether transport is moving in the right direction.	Global, National; Developing; Process
Finance allocated	The amount of finance dedicated to resilience and adaptation of transport infrastructure continues to rise but is far short of what is required.	Global, National, Local; In Use; Process
Post-disaster evaluations	These evaluations assess how well the transport system stood up to the hazards that it was exposed to, and how well it was able to maintain or quickly restore service. Post-disaster evaluations can identify vulnerabilities and weaknesses in the system including issues with infrastructure design, construction, or maintenance, as well as issues with emergency response or evacuation plans. Such evaluations can also help to identify the dependency and interdependency with other systems, such as the dependency of road transport on the availability of power, and the interdependency of different modes of transport.	National, Local; In Use; Impact
Policy and regulatory changes	This includes enforcement of regulations, construction codes and procurement rules (for example, NAPs). Peru, a country with significant exposure to natural hazards, recently adopted a Framework Law on Climate Change and a national disaster risk management plan that aims to develop a prevention culture and an integrated national system for disaster risk management, which all public entities must comply with.	National; Developing; Process
Triple bottom line	Quantification of co-benefits using triple-bottom-line approaches can support the business case for resilience and adaptation interventions in transport. Co-benefits can include economic, environmental, and social benefits, such as reduced maintenance costs, reduced greenhouse gases and improved accessibility. By quantifying the co-benefits of resilience investments in transport, the full range of benefits generated by the investment can be demonstrated, which can make it more attractive to potential funders and investors. The US city of San Francisco wanted to make its transport system more equitable and sustainable, so it used scenario planning and early involvement of external stakeholders to identify potential benefits (such as safety and economic vitality) and trade-offs (such as paying more taxes or giving up resources).	National, Local; In Use; Impact

Geographical Scope
- Global
- National
- Local

Implementation Stage
- In Use
- Developing

Processor Impact Indicator
- Impact
- Process

1.2
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