Division 44
Water, Energy, Transport

Adapting Urban Transport to Climate Change

Module 5f

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

gtz Transport Policy Advisory Services

On behalf of
Federal Ministry
for Economic Cooperation
and Development

OVERVIEW OF THE SOURCEBOOK

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

What is the Sourcebook?

This *Sourcebook* on Sustainable Urban Transport addresses the key areas of a sustainable transport policy framework for a developing city. The *Sourcebook* consists of more than 27 modules mentioned on the following pages. It is also complemented by a series of training documents and other material available from http://www.sutp.org (and http://www.sutp.cn for Chinese users).

Who is it for?

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

How is it supposed to be used?

The *Sourcebook* can be used in a number of ways. If printed, it should be kept in one location, and the different modules provided to officials involved in urban transport. The *Sourcebook* can be easily adapted to fit a formal short course training event, or can serve as a guide for developing a curriculum or other training program in the area of urban transport. GTZ has and is still further elaborating training packages for selected modules, all available since October 2004 from http://www.sutp.org or http://www.sutp.cn.

What are some of the key features?

The key features of the *Sourcebook* include:

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

How do I get a copy?

Electronic versions (pdf) of the modules are available at http://www.sutp.org or http://www.sutp.cn. Due to the updating of all modules print versions of the English language edition are no longer available. A print version of the first 20 modules in Chinese language is sold throughout China by Communication Press and a compilation of selected modules will be sold by McMillan, India, in South Asia from June 2009. Any questions regarding the use of the modules can be directed to sutp@sutp.org or transport@gtz.de.

Comments or feedback?

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

Manfred Breithaupt
GTZ, Division 44
P. O. Box 5180
65726 Eschborn, Germany

Further modules and resources

Further modules are under preparation in the areas of *Financing Urban Transport*, *Transport and Health* and *Parking Management*.

Additional resources are being developed, and Urban Transport Photo CD-ROMs and DVD are available (some photos have been uploaded in http://www.sutp.org – photo section). You will also find relevant links, bibliographical references and more than 400 documents and presentations under http://www.sutp.org, (http://www.sutp.cn for Chinese users).

Modules and contributors

About the author

Urda Eichhorst is a research fellow at the Wuppertal Institute for Climate, Environment and Energy, Germany. She holds an MSc in Environmental Change and Management from the University of Oxford and a BA in Chinese Studies. Urda has worked in both Germany and China. Her current focus of work is on international climate policy and transport policy in developing countries, including energy efficiency and adaptation. At the Wuppertal Institute she is responsible for all questions related to adaptation to climate change in an international context and is the key contact person for the insitute's activities in China.

Acknowledgements

This module would not have been possible without Daniel Bongardt and Armin Wagner who stimulated its development and were closely engaged in the entire process from the first conceptualization to the final editing. The author would also like to thank Thorsten Koska (Wuppertal Institute) for his contributions to text and ideas. Special thanks go to Anumita Roychowdhury (Center for Science and Environment), Oscar Reutter (Wuppertal Institute), Lloyd Wright (Viva Cities), David Dodman (International Institute for Environment and Development) and Sharad Saxena (Asian Development Bank) for review and valuable comments. Most comments have been incorporated, but not all suggestions could be adequately addressed within the scope of this module and any remaining mistakes or omissions are the sole responsibility of the author.

Module 5f

Adapting Urban Transport to Climate Change

Findings, interpretations and conclusions expressed in this document are based on information gathered by GTZ and its consultants, partners and contributors from reliable sources. GTZ does not, however, guarantee the accuracy or completeness of information in this document, and cannot be held responsible for any errors, omissions or losses which emerge from its use.

Author: Urda Eichhorst
(Wuppertal Institute for Climate, Environment and Energy)

Editor: Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH
P. O. Box 5180
65726 Eschborn, Germany
http://www.gtz.de

Division 44, Water, Energy, Transport
Sector Project "Transport Policy Advisory Services"

On behalf of
Federal Ministry for Economic Cooperation and Development (BMZ)
Division 313 – Water, Energy, Urban Development
P. O. Box 12 03 22
53045 Bonn, Germany
http://www.bmz.de

Manager: Manfred Breithaupt

Editing: Daniel Bongardt

Cover photo: Flooded road, PhotoDisc

Layout: Klaus Neumann, SDS, G.C.

Eschborn, November 2009

1. Introduction

Transport is linked to all aspects of urban life: leisure, education, business and industry. Ensuring a resilient urban transport system is therefore necessary to avoid large and costly disruptions of urban life. As current weather impacts on transport will become more frequent and more extreme in the future, the number of days on which the transport system is confronted with extreme stressors will increase. If no adaptive measures are taken, more frequent disruptions and higher economic costs must be expected.

Many transport decision-makers in developing countries are already confronted with extreme weather events, such as flooding, subsidence and storms, all of which are expected to increase with climate change. In the worst case, transport systems may not be able to recover between such events, resulting in exponential damages. Hence, building a climate-resilient urban transport system is vital to:

- Safeguard transport infrastructure and its embedded value;
- Ensure reliable mobility and economic vitality/development; and
- Guarantee the health and safety of urban residents.

While we can learn from existing disaster risk management, more information and new approaches to transport planning are needed to develop urban transport systems that are resilient under changing climatic conditions.

This module of the GTZ *Sourcebook* for Decision-Makers in Developing Cities is intended to raise awareness, describe the expected impacts of climate change on urban passenger transport[1] (Section 2 and 3) and provide an orientation on how to integrate climate proofing into urban transport planning and policy implementation (Section 4). The Paper concludes with a discussion on synergies between adaptation and mitigation (Section 5).

Figure 1
Why adapt urban transport to climate change?

Although the transport sector lies at the heart of urban conglomerations, little attention has been paid specifically to the vulnerabilities of the urban transport system. Nevertheless a few studies on the overall impacts of climate change on transport have emerged in recent years in Europe and North America. This paper gives an overview of these findings and sets them in the context of adaptation in developing cities.

> The GTZ Sustainable Urban Transport Project (SUTP) and its Urban Transport *Sourcebook* provide lots of information on sustainable transport policy for decision-makers in developing cities. In addition to the *Sourcebook*, which currently consists of 27 modules, technical papers give detailed background information on specific questions that cannot be explored in the *Sourcebook* modules.
>
> All GTZ *Sourcebook* modules on sustainable urban transport are available online at http://www.sutp.org.

Adaptation in transport cannot be viewed in isolation nor be reduced to technical infrastructure fixes. In order to deal with climate change, transport systems must be designed to cater for the mobility demands of all urban populations, including the poor, under changing climatic

(continued on page 4)

[1] Although many impacts on freight transport are similar to passenger transport, in particular regarding transport infrastructure, freight transport is subject to different dynamics and requires a separate assessment, which is beyond the scope of this paper.

Background
Adaptation to a changing climate

Humankind and nature have always adapted to changing climatic conditions. However, the speed of man-made climate change is unprecedented. Already today, average global temperatures have increased 0.74 °C over the last century and warming of the climate system is unequivocal (IPCC, 2007). The emission of greenhouse gases since industrialisation has been identified as the primary cause for man-made climate change (see Box 1).

Without efficient climate policies and mitigation actions, global warming is expected to surpass 2 °C by the middle of the century (Meinshausen *et al.*, 2009) and might culminate in a global temperature increase between 1.1 °C to 6.4 °C until 2100, depending on different scenario assumptions (IPCC, 2007).

The consequences of global warming are multifaceted. They include *rising sea levels* due to thermal expansion of the oceans, melting glaciers, ice caps and polar ice sheets. According to recent calculations, sea levels could rise between 0.5 to 1.5 metres by 2100 above the 1990 level (Rahmstorf, 2007), however, uncertainties remain and higher levels of sea-level rise cannot be ruled out. Already a sea-level rise of 38 centimetres could increase the number of people flooded by storm surges five times (Nicholls *et al.*, 1999). The hydrological system is also prone to severe changes induced by global warming. Depending on the region, this can lead to *changed annual* and/or *seasonal water availability*, in turn leading to more *droughts* and/or *floods*. More droughts can worsen desertification and increase air-borne dust and sand. The melting of glaciers affects freshwater availability in spring, and more extreme rainfall events (more concentrated rainfalls) will further heighten flood risk. *Temperature extremes*, *i.e. heat waves* or *cold spells*, are expected to occur more often and *tropical storms* are likely to increase in intensity and frequency, posing the risk of *storm surges* and damages (IPCC, 2007). Figure 3 shows the expected temperature increases at the end of the 21st

Summary of climate impacts:

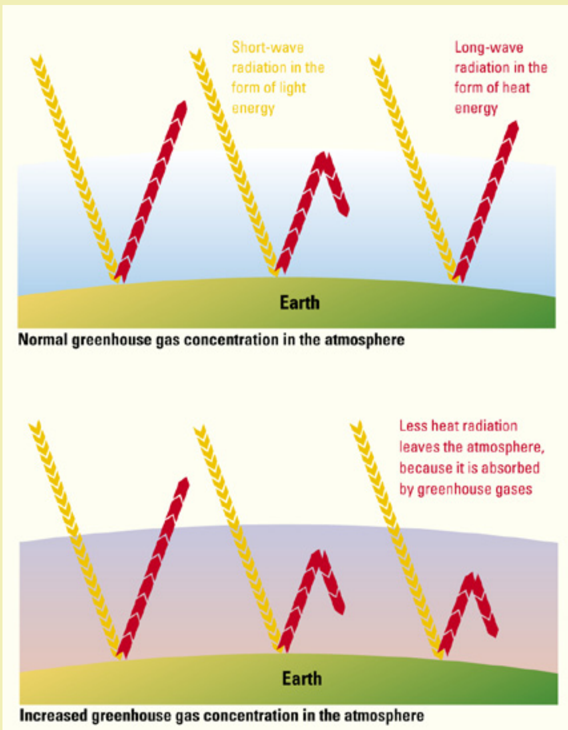
- higher temperatures
- more heat waves
- more droughts
- more cold spells
- more extreme rain
- more flooding and extreme floods
- more intense and frequent storms
- sea-level rise
- changed water availability
- melting of glaciers and permafrost

Box 1: The greenhouse effect

The Earth's temperature is controlled by a balance between energy input from solar radiation (short-wave radiation) and reflection of this back into space. As illustrated in Figure 2, about one third of solar radiation is directly reflected back into space while the other two thirds are absorbed by the Earth's land, oceans and atmosphere. As the Earth's surface warms, it emits long-wave infrared radiation. Greenhouse gases trap and re-emit some of this radiation warming the planet. The higher the concentration of greenhouse gases, the more radiation is trapped, increasing global temperatures.

The natural greenhouse effect is intensified by the emission of greenhouse gases, such as carbon dioxide and methane, through human activities; mainly burning of fossil fuels and agriculture. Global greenhouse gas emissions have grown since industrialisation in the 19th century and increased 70 % between 1970 and 2004. Thus atmospheric concentrations of greenhouse gases, in particular CO_2 and methane, now exceed by far the natural range over the last 650,000 years and continue to increase (IPCC, 2007). As a consequence, ever more solar radiation is trapped, leading to ever greater warming of the earth system.

Figure 2: *The greenhouse effect*



Source: Wuppertal Institute based on Goudie (1990) century compared to the end of the 20th century based on IPCC scenario A1B[2)].

The effects of these natural processes on human activities vary in extent with the rate of temperature increase, adaptive capacities and the regional socioeconomic context in general (see Box 2 for definitions). Although the impact of regional climate change can be observed on all continents and most oceans, countries of the developing world are particularly affected by changes in the physical environment. The World Bank Climate Change Data Portal provides summaries of expected climate change impacts based on different models on a country-basis for the entire world. The data is freely accessible online at Worldbank Climate Change Data Portal http://sdwebx.worldbank.org/climateportal/home.cfm?page=globlemap (slow internet connections may require some patience when downloading data).

Despite enormous progress in climate predictions, a lack of definite or comprehensive information about climate change impacts and vulnerability remains, especially at the local level. Hence, a degree of uncertainty will always remain in planning for adaptation. This uncertainty can, however, be taken into account by robust planning approaches and should not be used as a false pretext not to plan for adaptation today. There is a need to significantly reduce vulnerability and ensure that big public investments in long-lasting transport infrastructure are not lost in twenty years time due to changed climatic conditions. Designing sustainable transport systems means to minimise the effects of climate change by pursuing adaptation and mitigation in parallel.

[2)] The A1 storyline assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B).

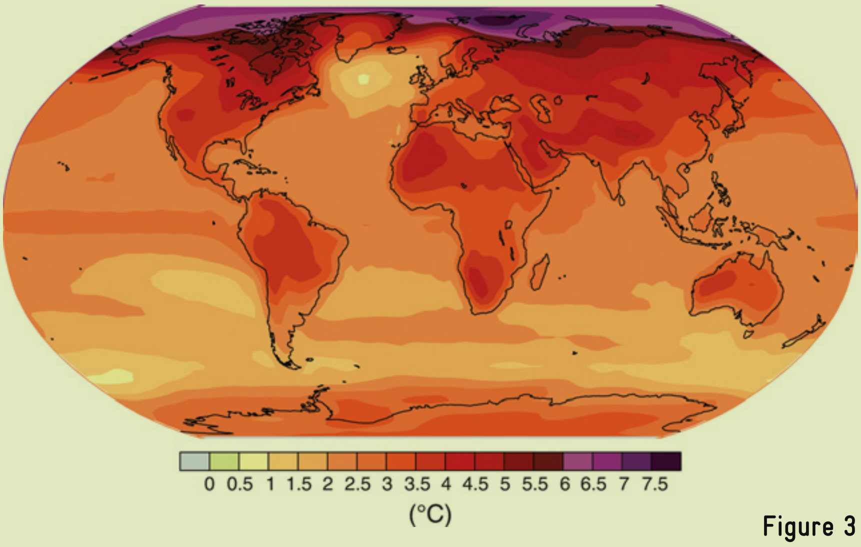


Figure 3
Surface warming at the end of the 21st century.
Source: IPCC, 2007

Box 2: Definitions: Adaptation, vulnerability and resilience

Adaptation

"Adaptation is the **adjustment in natural or human systems** to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (Parry *et al.,* 2007: 27).

Adaptation can take many different forms. Adaptation to floods, for instance, can include planned or anticipatory adaptation measures, such as the limitation of new developments in flood-prone areas or the extension of protective infrastructure, such as sea walls or the improvement of drainage systems. But it can also include reactive response measures such as using emergency schedules for public transport that avoid flooded areas.

Vulnerability

Vulnerability is the **degree to which a system is sensitive to and unable to cope with adverse effects** of climate change, including climate variability and extremes. As such vulnerability is a function of exposure to impacts, sensitivity of a system to climate change and the capacity to adapt. Strengthening adaptive capacity can therefore decrease vulnerability (Parry *et al.,* 2007; Kelly and Adger, 2000).

For instance, the vulnerability of an underground railway system to floods depends on:

- The exposure of the system to flooding, *e.g.* once every 5 years or several times a year;
- The sensitivity of the underground system to flooding, *e.g.* delays or total disruption of services when flood water reaches a certain level; and
- The capacity of local service providers or institutions and their respective infrastructures to deal with the floods, *e.g.* through an adequate pumping system (tompkins and adger, 2003; adger and vincent, 2005).

Resilience

Resilience indicates **a capacity to maintain core functions of a system** in the face of hazards and impacts, in particular of vulnerable populations. In the context of cities, resilience is a product of governments, groups of society, enterprises and individuals with strong adaptive capacity, *i.e.* to anticipate climate change and to plan required adaptations. Resilience to climate change also interacts with resilience to other dynamic pressures, such as poverty, economic change or conflict (Satterthwaite *et al.,* 2009).

conditions; but also try to minimise transport-related greenhouse gas emissions. This includes considering the consequences of adaptation strategies for mitigation.

Integration with other sectors, especially with urban planning is most vital to maximise benefits. Transport decision-makers and city planners are holding the levers to stimulate a climate proof, inclusive and sustainable urban development.

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

Available online at http://www2.gtz.de/dokumente/bib/gtz2009-0175en-climate-change-information.pdf

To provide a framework for better understanding the impacts of climate change on urban passenger transport, the following background text shortly introduces the general climate change science and adaptation challenges.

2. Cities and climate change

Currently about half of the world's population is living in urban areas. Even in Africa, which has long been considered a rural continent, close to 40 % of the population is living in cities. Urbanisation rates average 2 % globally, but are higher in many developing countries. Being home to more than three billion people, cities are major sources of greenhouse gas emissions. Up to 80 % of global greenhouse gas emissions are estimated to originate in urban areas (MunichRe, 2004), providing large mitigation potentials. At the same time, with high population and infrastructure densities as well as concentrated economic activities, cities are particularly vulnerable to the impacts of climate change and need to adapt.

With urbanisation, the concentration of both population and economic activities in low-lying coastal areas has greatly increased, adding to the vulnerability of coastal cities due to sea-level rise and increasing storm activities. The Low Elevation Coastal Zone (LECZ), defined by McGranahan *et al.,* (2007) as the continuous area along the coast that is less than 10 metres above sea level, covers 2 % of the world's land area, but hosts 13 % of the world's urban population[2]. While small island states have the largest shares of their population living in low-lying coastal zones, the largest absolute numbers of people living in this risk-prone area are in large countries with heavily populated delta regions, such as China or India (see Figure 4).

[2] All estimates are for the year 2000.

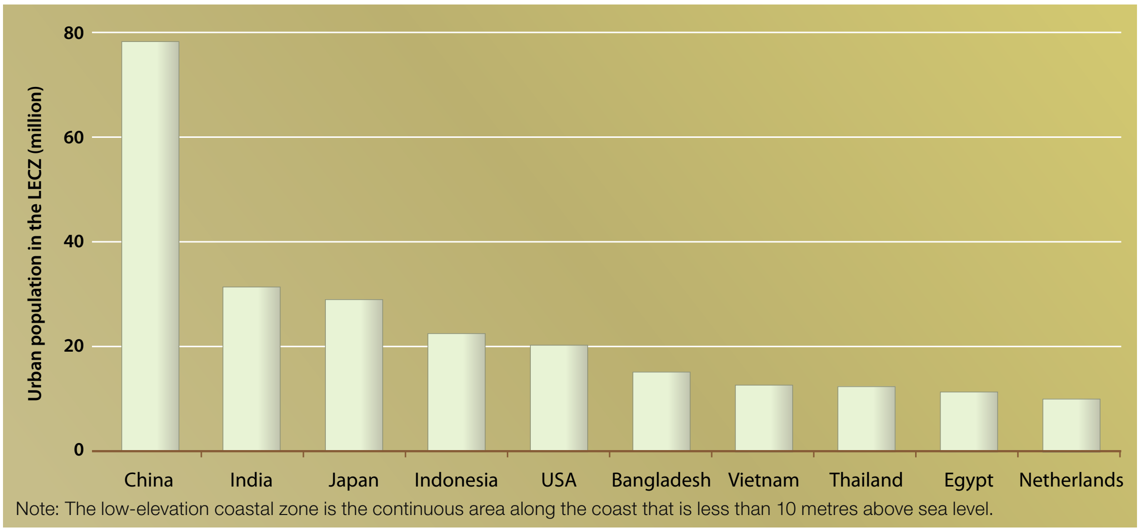


Figure 4
Countries with the largest urban populations in low-elevation coastal zones.
Source: own illustration based on CIESIN dataset

2.1 Expected impacts

Urbanisation trends in coastal areas will further increase the exposure of populations and economic assets to sea level rise.

Coastal cities are particularly affected by climate change, but inland cities will also face a number of increasing climate risks as summarised in the next section. The type of impacts and their expected severity differ for each city. Nevertheless, generally expected impacts of climate change on cities can be summarised as follows (based on Dawson, 2007; IPCC, 2007):

- *Increased temperature* and more *heat waves*, will lead to worsened heat island effects in cities. This can negatively affect comfort and health of city dwellers, *e.g.* through heat stress, but also damage infrastructure material, such as asphalt or rails, designed for lower temperatures. Increased temperature and heat waves will also raise the demand for cooling; in private homes, as well as in industry or transport. More air conditioning may constrain electricity generation and/or supply. Higher temperatures together with changed precipitation patterns will result in exotic species, including pathogens and pests, in new areas. While cold-related disruptions are likely to decrease in general, some areas will be confronted with *more cold spells* with likely impacts on health and infrastructure material, as well as disruptions of businesses and transport.
- *Droughts* are expected to become more frequent in many areas, limiting water availability and quality. Water shortages may affect electricity generation, disrupt human consumption, industrial processes, water-borne transport and neighbouring agricultural activities. Access to clean water already is a challenge in many developing countries, which will become more daunting with higher temperatures and reduced water availability.
- *Sea-level rise* will increase the risk of storm-surge flooding and coastal erosion threatening coastal cities. Depending on the level of sea level rise, certain low-lying urban areas are at risk of being submerged entirely. Higher sea levels can also hold back drainage of extreme flows in urban drainage systems and rivers and lead to saltwater intrusion. Coastal wetlands will be squeezed, reducing the natural buffers against tidal flooding and storm surges further.
- *More extreme rainfall events* (including seasonal changes) are expected in most cities and can lead to *more flooding* and *more extreme floods*, in particular in combination with sea level rise. More intense rains will heighten the pressure on urban drainage and flood systems. They can also increase disruptions for inhabitants, businesses and transport and could damage buildings and infrastructures. More extreme rainfall may also trigger more landslides.
- *More intensive and frequent storms* pose a risk for people's health and for urban

Figure 5
Dusty road in Cairo, Egypt.
Photo by Karl Fjellstrom, 2002
GTZ Photo DVD

Figure 6
Storm and rain damages in the USA.
Photo by PhotoDisc

infrastructure alike. Storm-related loss of life, injuries and damages are likely to increase. In particular in coastal cities also affected by sea-level rise the likely increase in storm activity further heightens the risk of storm surges.

- *Health* may not only be affected by heat waves and storm activities. Higher temperatures also encourage photochemical smog and ozone. At the same time, changed distribution of vector-borne diseases due to warming can be expected. Infectious diseases could spread particularly fast in densely populated urban areas.

In addition to adaptation, potential impacts may require new insurance policies and demand enhanced disaster risk strategies and evacuation plans.

Many of the climate impacts are made worse in an urban context, *e.g.* where flood risk has already been increased by certain aspects inherent to urban development: water drains faster from built-over land and drained wetlands in coastal areas reduce the buffer against tidal flooding. Another important problem is the so-called heat island effect, caused by the storage of solar energy in the urban fabric during the day, which is released again during the night. On top of that, urban activities, such as transport, air conditioning and industrial processes directly emit heat into the urban area. At the same time, increased surface roughness in cities hinders wind speeds, convective heat loss and evapotranspiration, which can reduce air quality.

Figure 7
Flooded dwellings in Bangladesh.
Photo by Robert Heine, GTZ

2.2 Vulnerability in cities

It must also be noticed that not all people are equally vulnerable. Their vulnerability basically depends on two factors: the exposure to climate hazards and their ability to adapt to or avoid those impacts. In general, the urban population most vulnerable include children, ill and disabled people or the elderly, who are less able to cope with heat stress or to flee quickly in the case of a disaster. But also the urban poor —especially those most exposed, *e.g.* by living on floodplains or in poor quality housing– who are not able to move or change jobs if their livelihood is threatened. These are also often the people least able to recover from a disaster, loss of home or income. At the same time, many urban dwellers live on illegally occupied land or with very limited abilities to pay rent, so that neither landlords nor city authorities are

Box 3: Case Study – Failed evacuation for hurricane Katrina

Hurricane Katrina hit the Gulf Coast on 25 August 2009. It was the most destructive and costliest natural disaster in the history of the United States (Grenzeback and Lukmann, 2007). But how "natural" was the disaster really? "Katrina began as a hurricane but only became a disaster because of significant, preventable planning and management failures" (Litman, 2006: 3). Namely, evacuation of the poor population without access to cars failed. There was no effective evacuation plan for residents dependent on public transport, despite official being aware of the problem that between 100,000 and 300,000 people had no access to reliable personal transportation (Litman, 2006). While Katrina's evacuation plan, using all lanes on highways for outbound vehicle traffic, functioned relatively well for motorists despite very slow traffic speeds, those without access to a car were left behind with little rescue efforts and a severe lack of adequate guidance (Litman, 2006; Renne, 2005). Many aspects of disaster planning and response could have been improved in the case of hurricane Katrina. Providing free public transport to evacuate the less well-off from New Orleans would have been at the heart of a more equitable and effective strategy and could have avoided much of the suffering and many of the deaths resulting from Katrina (Litman, 2006).

incentivised to invest in a more resilient infrastructure in these areas.

Wealthy people on the other hand, are better positioned to take protective measures or escape when disaster occurs. For instance, a response to tropical storm warnings is to evacuate high-risk areas. However, due to limited access to (private) mobility this is not easily possible for the urban poor, when evacuation plans do not include sufficient (and free) provision of public transport to evacuate. This was striking in the case of hurricane Katrina in New Orleans (see Box 3). The Katrina example underlines that the vulnerability of low-income urban dwellers cannot be put down to their poverty alone. It largely depends on local policies. City governments can improve the resilience of their poor and vulnerable populations by catering to their specific needs. This includes the provision of an affordable, safe and inclusive urban transport system; especially in times of crisis. Poor neighbourhoods will have to be actively integrated into city, land-use and transport planning —not segregated— in order to increase the resilience of the urban majority and urban systems as a whole.

2.3 Specific challenges in developing cities

In many developing cities current transport systems are especially inadequate to cater to the transport needs of the majority of their populations. Addressing these needs at the planning and design stages of urban (transport) development is, however, a prerequisite to reduce vulnerabilities. Successful adaptation will hence go beyond merely adjusting *existing* transport networks to the impacts of climate change.

Moreover, "you cannot adapt infrastructure that is not there" (Huq and Satterthwaite, 2008: 2): In many cases, *adapting* transport infrastructure will actually mean building resilient infrastructure.

As many urban areas in developing countries are still undergoing (rapid) development, the time to build climate-proof urban systems is now. At the same time, maladaptation, *i.e.* developments that increase the vulnerability of cities by ignoring climate change implications, must be avoided. Examples could be allowing new residential and transport developments on flood plains or reducing provisions for non-motorised transport.

"In many cases, adapting transport infrastructure will actually mean building resilient infrastructure."

Transport and city planners, as well as transport providers are at the forefront of creating sustainable, resilient and inclusive urban systems. For instance, the provision of social housing could offer an alternative for the poor, who live on illegal lands prone to floods or mudslides with no investments in building security. Even though limitations at the city level are often linked to shortcomings of national governments to support effective urban policies and local governance, there is much room for action at the city level. The transport system is the lifeline of any urban system and therefore at the heart of its resilience. To better understand its vulnerabilities, the following chapter will systematically assess the adaptation needs and opportunities of different transport modes.

Figure 8
Flooded road in Bangkok, Thailand.
Photo by Matthias Müth, GTZ

3. Likely impacts on urban transport systems and potential adaptation measures[3)]

The interconnectivity of urban (transport) infrastructures can lead to a domino effect, causing disruptions that are larger than the climate impact itself. For instance, failure of urban transport due to flooding can lead to far reaching economic losses, because people cannot get to work or goods cannot be distributed. Worse, in inadequately designed systems, ***cascading effects*** can also lead to avoidable human suffering or death. An example is the case that critical urban infrastructure such as hospitals cannot be reached (fast enough) because access routes are flooded or disrupted.

> In Asia, windstorms and floods between 1996 and 2005 caused over 70,000 deaths and economic loss of around $190 billion, a large part of which could be attributed to the lack of adequate infrastructure (Satterthwaite and Dodman, 2009).

Adverse effects can be particularly large, when already poorly connected areas are completely cut-off, central transportation hubs are affected or the transport system is working close to its capacity.

To prevent this, it is necessary to:

- Plan for inclusive high-quality public transport;
- Prepare for potential alternative routes; and
- Identify critical infrastructure.

For instance, the day after a collapsed highway overpass had closed a critical freeway in Los Angeles due to the Northridge earthquake, ridership on a parallel commuter rail line grew to more than twenty times its normal daily average. These (indirect) social costs and economic effects need to be taken into account in addition to the direct costs of infrastructure damages, when weighing the expenses of more resilient transport system design and infrastructures.

The climatic impacts on transport can be classified into three aspects:

1. Impacts on transport infrastructure;
2. Impacts on vehicles;
3. Impacts on mobility behaviour.

Infrastructure will need to be built and maintained to withstand hotter temperatures, worse storms, more intense rain and flooding, as well as higher sea levels. *Vehicles* will need to be adapted to function well under hotter weather conditions and still provide travel comfort. *Behaviour* will mainly be affected on days of extreme weather, such as heat waves, floods, intense rains, high wind speeds and storm activity.

Different groups of actors are in the position to act on these distinct aspects of mobility:

Figure 9

Nasty weather makes cycling an uncomfortable challenge. Jinan, China.

Photo by Carlosfelipe Pardo, GTZ

[3)] This section presents the expected impacts of climate change on urban passenger transport and possible response strategies. We acknowledge that cities have a large footprint and rely on infrastructures beyond the urban area as such. Due to limited resources, in this paper only transport elements in the urban area can be considered. As a result, aviation, long-distance road and rail transport or ports are not covered. Furthermore, the focus is on direct impacts, such as heat stress of public transport passengers. Indirect effects, such as a decrease in tourist numbers due to changed temperatures, resulting in less transport demand are not considered.

1. ***Public authorities*** are in charge of providing resilient infrastructure. This mainly includes transport and urban/spatial planners, but also other departments, such as construction and housing departments, environment agencies and disaster or flood risk managers.
2. ***Transport service providers*** are in charge of providing suitable vehicles for public transport, but vehicle requirements/design standards can be formulated by city governments. Private vehicles are provided by private enterprises and may require changes in vehicle configurations or accessories, such as air conditioning.
3. ***Every road user, public transport user, cyclist or pedestrian*** is affected by climate impacts on transport and will make individual or corporate choices. Nevertheless these choices are influenced by the provision of accessible, efficient, comfortable and safe mobility options, even under bad weather conditions, and are therefore closely connected to (public) policy choices on transport system design, infrastructure and vehicles.

Box 4:
How to read Tables 1 through 4

Tables 1 through 4 below summarise climate impacts and adaptation responses for different transport infrastructure and services. They are a synthesis of the current state of the art in adaptation research. Note that information provided represents the whole spectrum of potential impacts and possible adaptation strategies. It intends to raise awareness of the potential risks that need to be considered. To what degree adaptation strategies will be adequate under local circumstances depends on the severity of expected impacts and characteristics of existing systems. Please refer to Section 3, for a presentation of a step-by-step approach to identify and prioritise adaptation measures. In such an approach the tables can be used as check lists for identifying adaptation needs and options.

There is clearly more research needed into the specific adaptation needs of transport in less developed countries. This paper necessarily had to draw on the existing studies, all of which are set in an industrialised country context. While some of the response measures discussed therein may not be adequate for less developed countries, these studies still provide a wealth of information that draws attention to the main areas where adaptation is needed.

Affecting so many aspects of life, adapting urban transport to climate change requires cross-departmental cooperation and decision-making. Climate change considerations must be integrated into the general transport system design, new transport developments, as well as maintenance activities of existing transport networks to make transport systems more resilient against future impacts. Cooperation is also needed on evacuation and disaster risk management planning.

> ***"Adapting urban transport to climate change requires cross-departmental cooperation and decision-making."***

The following chapters discuss in more detail the adaptation needs of urban transport. Chapter 3.1 explores the impacts on infrastructure: road, rail and waterways. Chapter 3.2 then elaborates the challenges for public transport services, with a focus on vehicles and operation. Chapter 3.3 briefly discusses implications for private transport; both non-motorised and motorised. Finally, Chapter 3.4 summarises the discussion on costs and benefits of adaptation.

3.1 Transport infrastructure

3.1.1 Road infrastructure, bike lanes, walkways

Road infrastructure, including infrastructure for non-motorised transport (bicycle lanes and walkways), provides the foundation for most public, private and commercial mobility in developing cities. At the same time, it is one of public authority's assets with the largest (replacement) value. Providing resilient road infrastructure is therefore critical for any sustainable urban system and the economic well being of cities. Road infrastructure in this chapter is used as a collective term for roads, bicycle lanes and walkways, all of which will similarly be affected by climate change. Table 1 gives a detailed overview of the relevant climate impacts on road infrastructure and possible adaptation measures.

The above impacts and their resulting restrictions in road use can cause congestion,

Table 1: Summary of key climate change impacts and adaptation responses for road infrastructure

Relevant climate impacts	Impact on road infrastructure	Possible adaptation measures
Increased temperature and more heat waves	■ Deformations of roads, slowing down or disrupting transport; melting of asphalt/ dark surfaces ■ Increased asphalt rutting due to material constraints under severe exposure to heat	■ Planting roadside vegetation to decrease the exposure of roads to heat ■ Reduce overall exposure and provide cooling through green and blue infrastructure, such as parks and lakes, but also road-side trees or other shading ■ Proper design/construction, overlay with more rut-resistant asphalt or more use of concrete ■ more maintenance, milling out ruts
	■ Thermal expansion on bridge expansion joints and paved surfaces ■ Bridge structural material degradation	■ New design standards may be needed to withstand higher temperatures ■ Increased maintenance
More frequent droughts (and less soil moisture)	■ Dry soils in combination with more intense rains will lead to more landslides and subsidence ■ Road foundation degradation due to increased variation in wet/dry spells and a decrease in available moisture ■ Dust and sand on roadways can be a safety hazard from several perspectives including reduced friction in braking, as well as less sighting of roadway markings	■ Assess the likeliness of impacts on road infrastructure (risk mapping) ■ Avoid new developments in high-risk areas ■ Monitoring of soil conditions of existing roads ■ Increased cleaning and maintenance of roadways
Sea level rise and coastal erosion	■ Risk of inundation of road infrastructure and flooding of underground tunnels in coastal cities ■ Degradation of the roadway surface and base layers from salt penetration	■ Create vulnerability maps to identify areas most at risk ■ Restrict developments in high-risk areas, *e.g.* along the shoreline; zoning ■ Integrate transport planning with coastal zone management ■ Enhance protective measures, such as sea walls, protection of coastal wetlands (as buffers) ■ Managed retreat, possibly including abandoning of certain transport infrastructure in the mid to long term ■ Build more redundancy into system ■ Design and material changes towards more corrosion-resilient materials ■ Improved drainage, pumping of underpasses and elevating roads

Figure 10

Flood damaged road in Guatemala.

Photo by Gunter Zietlow, 2001, GTZ

Relevant climate impacts	Impact on road infrastructure	Possible adaptation measures
More extreme rainfall events and flooding	■ Flooding can affect all transport modes. The risks are greater in flood plains, low-lying coastal areas and where urban drains are overloaded or non-existent ■ Flooding of roadways and subterranean tunnels, especially where drainage is inadequate ■ Road damages and decrease of structural integrity due to erosion, landslides and increasing soil moistures levels.	■ Improve drainage infrastructure to be able to deal with more intense rainfall events, increasing capacity of drainage infrastructure to deal with increased run-off; include tunnels under large roads to facilitate speedy drainage ■ Audit drains regularly ■ Enhanced pumping ■ Create flood maps to identify most vulnerable areas, where infrastructure needs to be protected/improved/ avoided in the future and assess alternative routes (this is vital for evacuation plans) ■ Make flood-risk assessments a requirement for all new developments ■ Restrict developments in high-risk areas ■ Improve flood plain management/ coastal management and protective infrastructure ■ Early warning systems and evacuation planning for intense rainfall events and floods ■ Install signs high-above the ground that can alert pedestrians and motorists of unsafe zones, such as low-lying areas
	■ Higher rivers or canals can lead to undermining and washing off of bridges	■ Ensure that bridges and related infrastructure is resilient to expected levels of flooding ■ Rainfall monitoring
	■ Dirt roads and other roads with limited foundations and poor or no drainage are at risk of being washed away or scoured	■ Enhance foundations ■ Build all-weather roads ■ Improve green spaces and flood protection
	■ Subgrade material underneath roads or pavements may be degraded more rapidly, loosing strength and bearing capacity	■ Enhance condition monitoring of subgrade material especially after heavy rains, flooding ■ Regular maintenance
	■ Increased weathering of infrastructures	■ Use more durable material, such as more corrosion resistant material
More intensive and frequent storms	■ Damage to infrastructure fabric, bridges, flyovers, street lighting, signs and service stations ■ Risk of inundation by the sea during high winds, especially in combination with high tides and sea level rise	■ Assess if currently used design standards can withstand more frequent and intense storms ■ Adapt design standards for new bridges, flyovers, buildings, etc. to expected increases of wind speeds and heavy rains
	■ Obstruction of roads due to fallen trees, buildings or vehicles because of strong winds ■ Disruptions and consequent safety and socioeconomic impacts	■ Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management) ■ Emergency planning and evacuation routes omitting high-risk areas

Sources: Cochran (2009), ODPM (2004), Savonis *et al.,* (2008), Transportation Research Board (2008), own, Wooller (undated) accidents and disruption of mobility services; and they can seriously affect evacuation in case of extreme weather events. The main adaptation measures are:

- More resilient ***design standards*** and materials for infrastructure construction;
- Improved ***drainage systems***;
- Regular ***maintenance*** of all infrastructure;
- ***Urban planning*** that avoids high risk areas;
- Minimise the need for road infrastructure through ***compact urban planning***;
- Provide ***sufficient redundancy*** to allow for alternative ways of passage, when obstruction occurs.

Redundancy, *i.e.* building some spare capacity into the system, can greatly reduce the vulnerability of the transport system for if many alternative routes can be chosen, the influence of an impact on the capacity of the transport system remains small (Transportation Research Board, 2008). This is particularly important in densely populated cities undergoing rapid growth, where transport systems often already operate at full capacity. Such systems are hardly able to compensate unexpected changes in demand, *e.g.* caused by rerouting traffic in case of partial flooding. Redundancy should be provided both for motorised and non-motorised modes, but it does not stop at infrastructure construction, it also includes providing the relevant public transport services and may require innovative thinking. For instance, during the floods in Manila in September 2009, the elevated light rail and metro transit proofed to be the most reliable transport modes (see also Box 10). Redundancy is also vital for disaster risk management to ensure efficient evacuation.

Some of the above adaptation measures have benefits beyond increasing road infrastructure resilience. For instance, good drainage systems and natural water storage systems, such as lakes, can also be used for rainwater harvesting to improve the storage capacity and the recharge of ground water in urban areas, while helping with flood management. Such concepts hold great potential as water stress is expected to increase in many developing cities, both due to socioeconomic and climatic developments, Designing compact cities in combination with good public transport services may also help to reduce transport-related emissions.

However, there are also limits to adaptation. The combined result of the above-mentioned impacts may be that certain portions of the roadway network may need to be abandoned due to the unsustainable maintenance costs. This will particularly be true in developing nations, where maintenance funding deficits already lead to portions of the network being closed. Measures, such as encouraging urban development in more environmentally suitable locations or adapting settlements to reduce their vulnerability have long lead times and therefore need to be planned in good time. In cities, still undergoing urbanisation, avoiding high-risk areas is an opportunity. Most urban infrastructure, including transport, is immobile and long lasting, making fast shifts in existing urban locations very difficult and costly.

3.1.2 Rail-based public transport

The climate impacts on rail infrastructure are in large part similar to those on road infrastructure; nevertheless, a few features of rail infrastructure are decisively different to road networks and deserve special attention when it comes to adaptation:

- Infrastructure materials (*e.g.* iron);
- Signalling equipment and electricity circuits;
- Underground infrastructure (tunnels).

Increasing temperatures may be an even bigger problem with underground rail networks. In London, for instance, temperatures in some underground stations can be more than 10 °C above ambient temperatures above ground (see also Box 5).

To ensure that rail is resilient to partial system failure, *e.g.* when one or several lines are flooded, the electricity network for rail should be designed in a way that allows operating different lines or groups of lines independently. Otherwise flooding or other damage to one line may result in complete system shutdown and related cascading disruptions of mobility and economic costs.

Providing reliable rail infrastructure is vital to ensure efficient rail services, thereby helping to guarantee the appeal of rail systems (see Chapter 3.2 for further discussion).

A summary of expected impacts on rail-based transport and related adaptation measures are presented in Table 4.

Box 5: Case study – The London Underground

Climate change poses two major risks for London's underground network: Overheating and Flooding.

The London Underground is the oldest underground railway in the world and a vital part of the city's public transport network. Its ventilation system, based on fans and draft relief shafts, is already inadequate today and temperatures on the trains can reach 40 °C on hot summer days. These extremes are very likely to occur more often with increasing outside temperatures.

Overcrowding of the Underground further contributes to thermal discomfort, especially on the trains. Apart from climate change, improving the capacity of the Underground through more frequent trains and related acceleration and braking also contributes to yet higher temperatures if no counter measures are taken. Increasing discomfort on the underground trains could lead to a decline in attractiveness of the London Underground and could cause users to switch to other transport modes, such as buses (increasing the pressure on an already very busy road transport) or even air-conditioned cars (resulting in more fuel use and greenhouse gas emissions).

So, several measures have been taken to improve passenger transport:

- Audit of fan and ventilation capacity and identification of additional ventilation and cooling needs;
- Design of local ventilation installations;
- Purchase of new air-cooled trains.

Photo by Carlosfelipe Pardo, London

Further recommendations include:

- Detailed, strategic monitoring programme of temperature and humidity in the in stations and inside trains;
- Further research to examine the behaviour of passengers in response to higher temperatures and identify potential risks and thresholds, where a change in transport mode, *e.g.* to buses, may be triggered;
- Establish costs and benefits of adaptation measures, such as air conditioning.

The London underground is also vulnerable to flooding. Between 1992 and 2003, over 1,200 flooding incidents and 200 station closures were recorded by London Underground Limited. A total of 75 stations are at risk from flooding by the Thames and its tributaries. With intense rainfalls expected to increase flood risk will get worse with climate change.

Response measures include flood mapping and physical barriers at high-risk stations. Further measures to reduce flood risk will need to be implemented and could include source control, *e.g.* through green roofs or permeable pavements, flood storage and improved drainage.

Source: Greater London Authority (2005 and 2008)

Table 2: Summary of key climate change impacts and adaptation responses for rail infrastructure

Relevant climate impacts	Impact on rail	Possible adaptation measures
Increased temperature and more heat waves	■ Buckling of rails and rail track movement because of thermal expansion leads to slowing down or disruption of transport	■ Adapted maintenance procedures, such as rail stressing in the US[a)] ■ New design standards may be needed for rails to withstand higher temperatures (this will have to be communicated to/undertaken by the national level) ■ Management procedures to impose differentiated speed limits ■ Improve systems to warn and update dispatch centres, crews, and stations. Inspect and repair tracks, track sensors, and signals. ■ Distribute advisories, warnings, and updates regarding the weather situation and track conditions.
	■ Increased temperatures in underground networks (and trains)	■ Better (and flexible) cooling systems or air conditioning for underground networks, vehicles (trains) and metro stations ■ Temperature monitoring for underground infrastructures ■ Hot weather contingency plans ■ Design standard for power supply to meet anticipated demand within the life of the system (especially higher demands due to increased air conditioning needs in trains)
	■ In cold regions higher temperatures may lead to less disruptions due to snow or ice, frozen rails, frozen signalling equipment, etc.	
More frequent droughts (and less soil moisture)	■ Dry soils in combination with more intense rains will lead to more landslides and subsidence	■ Assess the likeliness of impacts on rail infrastructure (risk mapping) ■ Monitoring of high risk tracks and regular maintenance ■ Avoid new rail lines in high-risk areas
Sea level rise and coastal erosion	■ Risk of inundation of rail infrastructure and flooding of underground tunnels in coastal cities	■ Create vulnerability maps to identify areas most at risk ■ Restrict developments in high-risk areas ■ Integrate transport planning with coastal zone management ■ Enhance protective measures, such as sea walls, protection of coastal wetlands (as buffers), pumping of underground systems ■ Managed retreat, possibly including abandoning of certain transport infrastructure in the mid to long term

Figure 11
Public transport in Buenos Aires, Argentina.
Photo by Carlosfelipe Pardo, 2008, GTZ

Relevant climate impacts	Impact on rail	Possible adaptation measures
More extreme rainfall events and flooding	■ Flooding can affect all modes of transport. The risks are greater in flood plains, low-lying coastal areas and where urban drains are overloaded. ■ Increases in flooding of rail lines and underground tunnels ■ Railbed damages and decrease of structural integrity due to erosion, landslides and increasing soil moistures levels	■ Improve or build drainage infrastructure to be able to deal with more intense rainfall events, increasing capacity of drainage infrastructure to deal with increased run-off ■ Audit drains regularly ■ Create flood maps to identify most vulnerable areas, where infrastructure needs to be protected/ improved/avoided in the future and assess alternative routes – for rail systems bypassing flooded areas will be more difficult than for roads and disturb operation ■ Make flood-risk assessments a requirement for all new developments ■ Restrict developments in high-risk areas ■ Improve flood plain management/coastal management and protective infrastructure
	■ Underground systems/tunnels may be flooded, especially where drainage is inadequate	■ Passenger evacuation plans for underground systems ■ Enhanced pumping ■ Create vulnerability maps to identify areas of high flood risk ■ Restrict developments in high-risk areas
	■ Stability of earthworks can be affected by intense precipitation due to build up of pore water pressures in the soil, especially after periods of hot and dry weather ■ Subgrade material underneath rails may be degraded more rapidly, loosing strength and bearing capacity	■ Enhance condition monitoring of earthworks, bridges, etc. especially after heavy rains, flooding (or storms) ■ Improved maintenance
	■ Failure of track circuits with subsequent disruptions due to inability to detect the presence or absence of trains on rails and inability to send related signals	
	■ Increased weathering of infrastructures	■ Use more durable material, such as more corrosion resistant material
More intensive and frequent storms	■ Damage to stations/infrastructure fabric, bridges, flyovers, electrified tracks with overhead cables, train platforms, street lighting and signs	■ Assess if currently used design standards can withstand more frequent and intense storms ■ Adapt design standards for bridges, flyovers, stations, etc. to expected increases of wind speeds and heavy rains
	■ Risk of inundation by the sea during high winds, especially in combination with high tides and sea level rise	■ Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management)
	■ Obstruction of roads or rails due to fallen trees, buildings or vehicles due to strong winds ■ Leaf fall may be concentrated, decreasing rail security/adhesion ■ Increased occurrence of lightning strikes to rail signalling or electronic systems ■ Lightning strikes disrupting electronic signalling systems *e.g.* axle counters electromagnetic compatibility of railways	■ Wind fences for open rail infrastructure ■ For overhead lines: circuit breaker protection ■ Adapt design standard for signalling equipment ■ Emergency planning

Sources: Cochran (2009), Eddowes *et al.,* (2003), ODPM (2004), Savonis *et al.,* (2008), Transportation Research Board (2008), own, Wooller (undated), Woolston (undated)

a) Rail stressing means that continuous welded rail is stressed (either through compression or through extension) into a state where fracturing (due to rail shrinking in cold) or buckling (due to rail extension in heat) of rails due to extreme temperatures can be avoided.

3.1.3 Waterways

Urban waterways provide important transport infrastructure for freight transport, but also for public and private transport in some cities. Their importance and characteristics are very case-specific. In general, waterways are mainly affected by either a lack of water availability or by flooding. The potential impacts and adaptation measures are summarised in Table 2. Where impacts are severe, certain waterways may have to be abandoned entirely or the construction of new waterways may become necessary.

Table 3: Summary of key climate change impacts and adaptation responses for urban waterways

Relevant climate impacts	Impact on waterways	Possible adaptation measures
Increased temperature and more heat waves	■ Increased aquatic vegetation growth could lead to clogging	■ Intensify maintenance of relevant waterways
More frequent droughts (and less soil moisture)	■ Decreased water availability in waterways could restrict their use and lead to more use of road networks	■ Assess the likeliness of constraints on urban waterway usage and plan for alternatives ■ Changes to navigation ■ Assess the viability of flow augmentation
Sea level rise and coastal erosion	■ Port facilities and coastal waterways could become unusable	■ Enhance flood defences such as sea walls, protection of coastal wetlands (as buffers) ■ Managed retreat, possibly including abandoning of certain infrastructure in the mid to long term; integration with coastal zone management
More extreme rainfall events and flooding	■ Reduced clearance under waterway bridges ■ Reduced navigability of rivers and channels	■ Plan for usage of alternative transport modes ■ Incorporate higher levels of flooding into future bridge design
	■ Increase in silt deposits	■ Increased dredging of silt
More intensive and frequent storms	■ Storm damage on waterways	■ Increase structural monitoring and maintenance
	■ Obstruction of rivers and channels due to floating debris	■ Contingency planning

Sources: Cochran (2009), Savonis *et al.*, (2008), own

3.2 Public transport

Public transport encompasses different means of transport: busses, mini-buses, vans, metro and trams, taxis, as well as rickshaws or three wheelers. In most developing cities, much of the public transport is concentrated on (mini) busses, as well as multiple forms of paratransit, using road infrastructure. Nevertheless, rail-based transport is currently developed in many rapidly growing mega-cities in Asia (*e.g.* Beijing, Bangkok, New Delhi). To ensure the sustainability of rail-based transit, its vulnerability to climate impacts should be considered in the planning phase. Importantly, planning for public transport must also be closely integrated with planning for road infrastructure (adaptation) to design an efficient and resilient system.

Public transport and informal paratransit needs to be resilient, because

1) it is the only motorised mobility option for large parts of developing city populations, and
2) to remain attractive also for those who could afford private motorised mobility to avoid modal shift towards more emission-intensive transport, which would further exacerbate climate change.

Since the impacts on transport infrastructure have already been presented, this chapter focuses on vehicles and related mobility behaviour (drivers and customers).

Vehicles will essentially have to be designed to withstand higher temperatures: On the one hand, rising temperatures will increase heat stress for passengers and drivers of busses and trains without cooling or air-condition, on the other hand the functionality of engines and the equipment of railway vehicles may suffer from extreme temperatures.

Furthermore, the impact of high temperatures on public transport without cooling could further reduce the quality and attractiveness of public transport systems and hence, in the long run, might support a modal shift towards air-conditioned private cars for those who can afford them. In this case, adaptation to increasing temperature goes hand in hand with building sustainable transport systems suitable for developing cities and providing an alternative to further motorisation.

> The SUTP *Sourcebook* Module 3a and 3b on *Mass Transit* as well as the SUTP *BRT Planning Guide* give further information: Free download at http://www.sutp.org

To the extent air-conditioning systems become more utilised in public transport systems, the higher ambient temperatures will require more costly and more energy intensive systems.

More frequent events of difficult driving conditions due to adverse weather can increase accidents and delays, resulting in economic costs for transport operators and businesses. Here training public transport drivers and separate bus lanes could help to lessen these effects. Rather than excluding informal paratransit operators, they should also be actively involved in any adaptation activities. Paratransit plays an important role in many developing cities both as door-to-door service and as feeder to formal public transport networks, providing mobility services to areas not connected to formal public transport. Ensuring their resilience to climate change is an important feature of guaranteeing a well-functioning urban (transport) system.

Importantly, ***public transport plays a key role in disaster risk management*** and evacuation planning. As mentioned above, due to limited access to private mobility of the urban poor, evacuation plans for weather hazards (storms and floods) should provide sufficient (and free) public transport services for evacuation. This includes designating and training drivers for extreme situations. Also for less severe extreme weather, which does not require evacuation, public transport operators should have contingency plans in place. This may include hot weather contingency planning for underground rail-networks or emergency routing for bus services during flood events.

Table 3 gives an overview of relevant climate impacts on public transport vehicles and operations.

Figure 12
BRT service in Changzhou, China.
Photo by Jie Chen, 2003, GTZ

Table 4: Summary of key climate change impacts and adaptation responses for vehicles and operations

Relevant climate impacts	Impact on vehicles or driving conditions	Possible adaptation measures
Increased temperature and more heat waves	■ Increased temperatures in busses and trains possibly leading to passenger and driver discomfort and heat exhaustion ■ Driver discomfort and exhaustion can lead to heightened accident levels ■ May lead to shifts from public to air-conditioned private transport if resources allow or to air-conditioned taxis ■ Use of more costly and more energy-intensive air conditioning systems	■ Sufficiently large opening windows ■ Tinted windows to shade off the sun ■ White painted roofs ■ Improved thermal insulation and cooling systems ■ Air conditioning, ideally using systems without F-gases (if available and affordable) ■ Driver training ■ For overhead buses: design standard for power supply to meet anticipated demand within the life of the system (especially higher demands due to increased air conditioning) and withstand higher wind speeds ■ For underground rail: develop hot weather contingency plans ■ Include new design standards in public procurement requirements of the public transport fleet
	■ Wearing off or melting of tires ■ Overheating of equipment, such as diesel engines	■ New design standards may be needed to withstand higher temperatures (this will have to be communicated to/undertaken by the national level)
More extreme rainfall events and flooding	■ More events of difficult driving conditions with implications for safety, performance and operation, *e.g.* speed restrictions causing delays ■ Flooding of the public transport fleet, causing economic damages	■ Manage speed limits in bad weather conditions, *e.g.* reduce the running speed of trains ■ Drivers of public transport vehicles should be appropriately trained for extreme weather conditions, such as heavy rains, hail and wind ■ Planning for emergency routes ■ Early warning systems to evacuate high-risk areas ■ Flood insurance
More intensive and frequent storms	■ More events of difficult driving conditions or impossibility to drive, as well as derailments or collisions leading to disruptions and consequent safety and socioeconomic impacts ■ Overturning of vehicles or trains	■ Driver training ■ Speed restrictions ■ Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management) ■ Emergency planning and identification of evacuation routes omitting high-risk areas

Sources: ODPM (2004), Transportation Research Board (2008), own, Wooller (undated), Woolston (undated)

3.3 Private transport

Impacts on the infrastructure for walking and cycling and motorised private transport have already been discussed in Chapter 3.1 under road infrastructure: they include flooding, destruction of foundations and subsidence, deformation through extreme heat and storm damages. Unpaved foot or bike paths and roads are at risk of being washed away in intense floods. In this chapter the focus is therefore on mobility behaviour and vehicles.

3.3.1 Non-motorised transport

Increasing events of adverse weather conditions like heavy rains, strong winds and extreme temperatures may lead to less walking and cycling trips, at least beyond a certain trip length. This can either lead to a shift to motorised transport modes, where those are available and affordable or it can severely impede the overall mobility of urban residents, who rely on walking and cycling. For short trips on the other hand, the impacts of extreme weather can be expected to be rather low. This underlines the importance of sustainable and dense urban design for resilient mobility. Dense urban design, at the same time, benefits the development of sustainable transport, reducing travel demand and related transport emissions, in turn reducing the climate impact and improving air quality.

In cold regions, warming temperatures may actually make walking and cycling more attractive, but in warm regions, extreme heat can make non-motorised travel very burdensome. Here, green and blue spaces can offer relief: trees planted alongside walkways and bicycle lanes provide shade and cooling, at the same time improving the micro-climate, increasing attractiveness and even acting as a minor carbon sink. Lakes and rivers also have a cooling effect on the urban microclimate.

Measures improving the quality and safety of non-motorised transport, such as shaded dedicated bike lanes and walkways will become even more important to maintain the attractiveness and comfort of non-motorised transport, when adverse weather conditions occur more often. Preserving (or improving) the attractiveness of non-motorised transport is vital in order to avoid a modal shift towards more emission intensive motorised transport, which would further worsen climate change (see Section 3 for further discussion).

> Please refer to the GTZ *Sourcebook* Module 2a: *Land Use Planning and Urban Transport* (GTZ, 2004).

Changes in temperature are already forcing cities to provide infrastructure for shading. The following image from Hangzhou (China) is typical of the shaded cycle way shadings that have been installed at intersections in China.

Figure 13
Cycle way shadings in Hangzhou, China.
Photo by Karl Fjellstrom, ITDP

3.3.2 Motorised private transport

Similarly to non-motorised transport, behavioural responses can be expected during adverse weather conditions. Empirical studies point to slower traffic speeds during rainfall events, leading to delays and disruptions. Accidents also become more likely under adverse weather conditions, although accident severity appears to decrease during precipitation, likely due to lower traffic speed. Consequently, precipitation leads to an increase in travel time with the most severe impacts on already congested routes and during peak hours (see Koetse and Rietveld, 2009 for an overview of different studies). This is particularly relevant for many large cities already suffering from traffic congestion.

The behavioural response depends on the severity of the precipitation, the road infrastructure and probably also the cultural context or the

Figure 14a, b
Demolishing an urban highway in Seoul created urban greenspace and valuable redevelopement opportunities.
Images by Seoul Development Institute

degree to which drivers are used to adverse weather conditions. For instance, unexpected snowfall in Beijing, China in November 2001 lead to massive transport congestion, because road users were a) not prepared for snow, b) not used to driving under snow conditions and c) vehicles were not equipped with winter tires. Changing climatic conditions can lead to more unexpected or (for a particular region) unusual adverse weather events, increasing the numbers of days with heavy congestion and accidents[4)].

In terms of vehicles, increasing temperatures are very likely to increase the demand for air-conditioning in cars and other vehicles and may require adaptations in engine design or tires to cope with higher temperatures.

As for non-motorised transport, land-use planning favouring short-distances can reduce travel demand and hence the exposure to adverse climate conditions.

3.4 Costs and benefits of adaptation

Calculating the costs of adaptation is a difficult issue. Often, the "additional" costs caused by the need to adapt to climate change are estimated. For infrastructure investments, this means that the incremental cost of adaptation should be identified, *i.e.* the additional amount that would be needed to ensure that already occurring investments in new infrastructure or improvements of existing infrastructure will result in infrastructure that is resilient to expected future climatic conditions. Different studies estimate the incremental cost for climate proofing investments in infrastructure, which are sensitive to climate change, at between 5 % and 20 % of the new investment (UNFCCC, 2007; Stern, 2007; World Bank, 2006). However, these estimates lack a robust empirical grounding and must hence be considered uncertain. Moreover, they are likely to be case-specific and vary more widely.

In reality, adaptation is so closely entwined with development that often it is not possible to clearly identify, which part of a new investment or activity is "additional" adaptation and which is development. For example, building an all-weather road to avoid dirt roads being washed away after intense rains is a development need as much as it is adaptation, as intense rains are expected to increase. In countries, where investments in infrastructure are itself lacking, what really needs to be considered is the cost of *providing* infrastructure, which is resilient to climate change (Satterthwaite and Dodman, 2009). Transport infrastructure is but one aspect of the costs of adaptation. Developing the institutional capacity to plan and implement adaptation in the transport sector does not come for free. It means that personnel have to be trained and additional personnel with a mandate to deal with climate change have to be resourced in local governments.

Despite high costs of adaptation measures, its benefits often outweigh its costs, as several studies have found (see for instance Stern, 2007; ADB, 2005). This is due to avoided damages, *i.e.* costs that would occur in the absence of any adaptation measures. Avoided damages include costs of damaged infrastructure, but also indirect social and economic costs due to transport service disruptions (in passenger and freight transport), injuries and casualties of residents, etc.

Usually, the incremental cost of upgrading new, *i.e.* not-existing, infrastructure is less than for upgrading existing infrastructure, making the integration of adaptation planning into the early stages of transport planning only the more important. An analysis of climate change risk reduction measures in the Cook Islands and the Federated States of Micronesia, for instance, showed that it is possible to avoid most of the infrastructure damage costs attributable to climate change cost-effectively if climate proofing is undertaken at the design stage (ADB, 2005). An illustrative example of the cost-effectiveness of pro-active as well as reactive adaptation measures in transport is given in Box 6.

"The costs of adaptation are intimately linked to the efforts on mitigation."

Note that planning for adaptation will always be subjected to uncertainty, as climate projections at the local scale are often associated with rather high uncertainties or lacking altogether. This is a challenge for decision-makers when

4) This is not to say that the snowfall in Beijing in 2001 was caused by climate change.

Box 6: Case study – Climate proofing road development in Kosrae, Federated States of Micronesia

In Kosrae a 16-kilometre gap was planned to be closed in the road around the island to promote all-weather land access to the remote village of Walung, the only community without reliable links to other municipalities in the island. The drainage works for the original road design (both existing and planned) were based on a maximum hourly rainfall of 178 millimetres (mm) with a return period of 25 years. However, analysis of new data indicated that an hourly rainfall with a 25-year return period was 190 mm already. By 2050 the amount is expected to grow to 254 mm.

The state government of Kosrae accepted recommendations to modify the road design to accommodate an hourly rainfall of 254 mm. For the new section, the incremental, *i.e.* additional cost was $511,000 for 6.6 km ($77,000 per km). Although the capital cost of the climate-proofed road would obviously be higher, the accumulated costs including repairs and maintenance would be lower already after about 15 years due to avoided damages; resulting in an internal rate of return of 11 %.

In comparison, retroactive climate proofing of a 3.2 km section of existing road and drainage cost $776,184 ($243,000 per km). Although more than three times as expensive as climate proofing proactively, a cost-benefit analysis showed that the measures would still be cost-effective, resulting in an internal rate of return of 13 %.

The Kosrae case provides a good example for the economic feasibility of adaptation measures, even without taking indirect damages of transport infrastructure disruptions into account. Of course, costs and benefits still need to be assessed on an individual basis and funding options for the additional capital cost need to be identified (see also Box 11).

identifying adaptation needs and options, as well as when justifying their associated costs. Meeting this challenge calls for robust decision-making, *i.e.* identifying adaptation measures that work under different degrees of climate change scenarios (see the next chapter) and identifying no- or low-regret measures, which provide net benefits regardless of climate change. As the worst impacts may well be those, we do not yet know about, a precautionary approach is required, including minimising transport-related emissions.

The costs of adaptation are intimately linked to the efforts on mitigation. The more climate change can be avoided, the lower the costs for adaptation will be. In other words, climate proofing urban transport must include both mitigation and adaptation, to keep the costs of adaptation as low as possible.

Figure 15
Storm damages by hurricane Katrina.
Photo by PhotoDisc

4. Taking action on adaptation

First of all, information and awareness raising about the need to start adaptation today are important components to improve the capacity and the acceptance of both decision-makers and society to adapt. As adaptation of urban passenger transport cannot be limited to simple technical fixes, but also requires behavioural changes of transport users and a shift in thinking in planning approaches, adaptation must be understood as a social learning process. Convincing municipal government officials across departments of the local relevance of adaptation is a prerequisite for a successful adaptation strategy (this is illustrated in the case study on Durban, South Africa, in Box 7). In many cases this will require training key personnel and identifying so-called "adaptation champions" who will push the adaptation agenda within their departments.

Box 7: Case study – Integrating climate change at the municipal level in Durban

The largest port and city on the east coast of Africa, Durban has a population of 3.5 million and spans a total municipal area of 2,300 km^2. It was one of the few African cities that developed a local Agenda 21 and established an Environmental Management Department in 1994. Between 2000 and 2006, Durban participated in the International Council for Local Environmental Initiatives' (ICLEI) Cities for Climate Protection campaign (CCP)[a]. During this time, a greenhouse gas emission inventory by sector was developed for the municipality, triggering regular greenhouse gas emission reporting even after 2006 and other follow-up activities.

However, despite participation in the Cities for Climate Protection campaign and other related activities, municipal government officials were not given the opportunity to gain a good understanding of the underlying climate change science and its local relevance. Amongst other things, because technical work was outsourced to external consultants, little institutional momentum and knowledge was built.

So in order to understand the relevance of climate change for Durban, in 2004, the Environmental Management Department started developing a Municipal Climate Protection Programme (MCPP). The aim was to inform local officials of the implications of climate change for Durban. The MCPP has three phases. After review and assessment of the expected climate impacts at the local level (Phase 1), a Headline Climate Change Adaptation strategy was developed to highlight how key sectors in the municipality, such as infrastructure or human health, should start responding to climate change (Phase 2). For the transport sector it was found that it might be necessary to revise road design standards and avoid routes in areas of high flood risk.

Crucially, climate change was also incorporated into long-term city planning by developing an Urban Integrated Assessment Framework (Phase 3). This included developing a model to simulate, assess and compare strategic urban development plans in the context of climate change. To support this pioneering work, collaboration with the UK's Tyndall Centre for Climate Change Research was established to build the model.

Based on the model, the effectiveness of different approaches to both adaptation and mitigation can be tested and inform the city's long-term integrated development plan. The integrated assessment framework also includes a vulnerability assessment of key sectors such as coastal infrastructure, water, disaster management and biodiversity. A review of past and present events of extreme weather and their related damages can help to identify who or what infrastructures are most vulnerable to certain aspects of climate change. For example, the infrastructure damage from high tides and waves in March 2007, helped raise the attention of government officials to the kinds of impacts climate change will bring.

The MCPP also resulted in institutional change: a new branch has been created in the Environmental Management Department to deal specifically with climate change, adaptation and mitigation. This followed the realisation that in order to properly implement the activities of the MCPP, it needed to be adequately resourced both with human and financial resources.

The experience in Durban showed that key decision-makers in city governments need to understand the underlying science of climate change and its implications at the local level, before adaptation and mitigation will be integrated into everyday planning and investment decisions.

Source: Roberts (2009); Roberts (2008)

a) http://www.iclei.org/index.php?id=800

The case of Durban shows that each department of a city government needs to consider the effects of climate change within its departmental responsibilities, *e.g.* separately for rail, roads or housing, but also work together to develop an effective and integrated strategy, *e.g.* for the whole transport sector, striking a balance between providing access to mobility for all, increasing resilience and limiting greenhouse gas emissions. Subsequently, transport planners need to interact with multiple other actors, including spatial or city planners, construction or housing agencies, environment agencies and climate change experts, flood and disaster risk managers, but also transport providers, businesses and civil society.

4.1 Basic approaches to adaptation

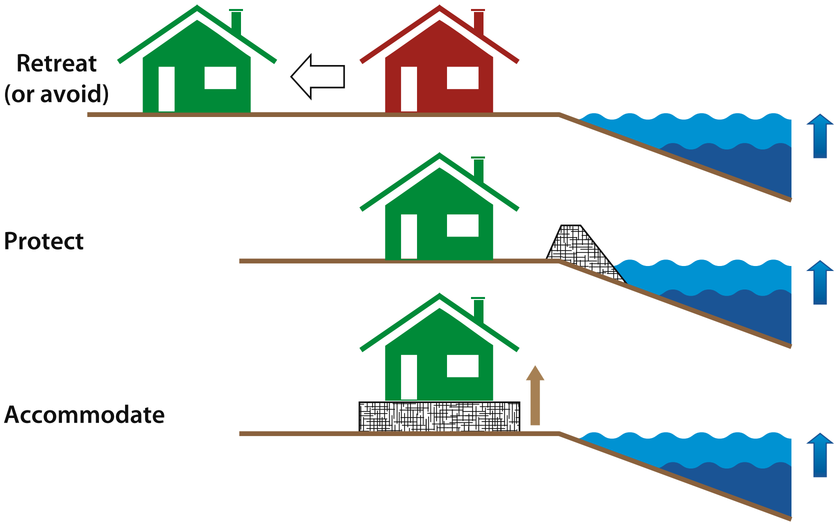
Three basic approaches to adaptation can be identified:

- Retreat (or avoid);
- Protect;
- Accommodate.

These three approaches have been developed in the context of adaptation to sea level rise as illustrated in Figure 17, but in general they are applicable to all climate risks.

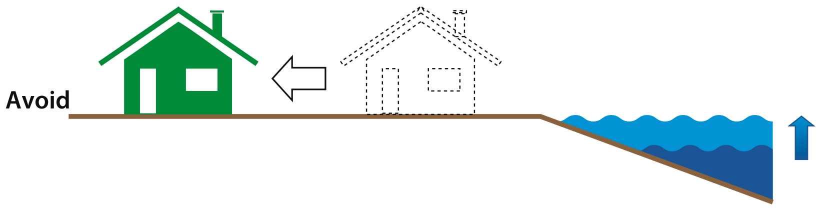
Figure 16
Flooded dwellings in South East Asia.
Photo by Karl Fjellstrom, 2004, GTZ Photo DVD

Figure 17: *Three fundamental approaches to adaptation*



Whereas *retreating* from areas at high risk of a climate hazard (be it sea-level rise, flooding, landslides or any other risk) may be a measure of last resort, in a planning context retreat translates into *avoiding* developments in high-risk areas in the first place and may be the cheapest option (illustrated in Figure 18).

Figure 18: *Avoiding high risk areas for new developments*



Protection can include both hard (*e.g.* sea walls) and soft measures (*e.g.* protection of mangroves to buffer storm surges). Protective measures are also not limited to sea level rise, or riverine flooding, but include any other means that help protect transport infrastructure or even mobility in the wider sense, such as green spaces or trees that provide shading, wind fences or additional drainage.

Whereas protection can be seen as "external" measures, *accommodation* means adapting the transport system or infrastructure itself. Accommodation also includes both hard (mostly infrastructure and vehicles) and soft measures (concerning the transport systems as a whole). Hard measures could be changing design standards and construction materials to withstand higher levels of flooding or temperature or including air conditioning in vehicles, whereas soft measures could encompass planning for emergency bus routes or even strengthening public transport networks to increase overall system resilience.

4.2 A framework for climate-proofing transport

Previously a stationary climate was assumed when planning and developing transport systems; this is no longer possible. ***Now, transport planning and operations need to take current and future climatic changes into account.*** This means that new tools, such as regional climate scenarios, vulnerability and risk assessments or practitioners' guides for climate proofing need to be integrated into transport planning. In particular, assumptions in models for long-term transport planning have to be revisited and potentially adjusted. For instance, old assumptions for land-use may no longer be viable when new areas become susceptible to flood risks due to climatic change.

Climate change adds to the dynamics of urbanisation and increases the uncertainty in decision-making. Here, robust decision-making is required that takes different scenarios into account, combining both climate change and socioeconomic scenarios. Different studies show that society knows enough to develop plausible scenarios (Dessai *et al.*, 2009; eca, 2009) to take informed decisions, which can significantly reduce vulnerability, such as avoiding new developments in high-risk areas.

Designing robust transport policies or projects aims to create transportation systems that function well under a range of potential global warming scenarios, rather than creating the most efficient system for a precisely specified set of assumptions. For example, different ranges of expected sea level rise and related levels of flooding would be analysed to design coastal road networks that perform acceptably under different scenarios.

To create a high-quality and reliable transport system, decision-makers carry out a multilevel planning process. To promote climate-proof urban transport design, mitigation and adaptation strategies need to be integrated into

Box 8: Decision-making tools

Such a process requires decision-makers to use different risk assessment and planning tools. A rather large portfolio of tools exists already. Decision-makers can choose between complex tools that may require certain technical standards and expertise or even licenses and simpler tools, depending on the experience, expertise or technical and financial resources available at the city level. External expertise may be required for specialised problems, such as choosing the most suitable tarmac for increasing temperatures and precipitation or assessing flood risk, but it is essential that each department involved in adaptation planning for transport understand the science and implications of climate change. Only relying on external expertise will not be sustainable in the long run.

Tools and guidelines for decision-making:

- **Climate adaptation: Risk, uncertainty and decision-making – UKCIP Technical Report:** This comprehensive report guides through each step of developing an adaptation strategy, including key questions to be answered for each step, a generic checklist for climate risk assessments and guides to suitable tools and techniques. http://www.ukcip.org.uk/images/stories/Pub_pdfs/Risk.pdf
- **UKCIP tools:** The UK Climate Impacts Programme (UKCIP) provides a comprehensive set of tools for adaptation planning on its website. http://www.ukcip.org.uk/index.php?option=com_content&task=view&id=23&Itemid=127
- **Preparing for Climate Change – A Guidebook for Local, Regional and State Governments:** Although with a focus on the United States, a very comprehensive step-by-step guide to adaptation planning. http://www.iclei.org/fileadmin/user_upload/documents/Global/Progams/CCP/0709climateGUIDEweb.pdf
- **Adaptation Learning Mechanism:** http://adaptationlearning.net/about
- **wikiADAPT:** a wiki-based information portal on adaptation issues including background information, decision-making tools and case studies. http://wikiadapt.org/index.php?title=Main_Page

the transport planning process (see Box 8 for decision-making tools).

Largely based on the approach developed by the UK Climate Impacts Programme (UKCIP) the following main steps can be recognized for developing an integrated adaptation strategy for urban transport development.

Figure 19 illustrates the process steps of developing an adaptation strategy for urban transport and how they integrate into the main steps of transport planning and decision-making. These steps can be equally applied to:

- Individual investments and maintenance decisions (*e.g.* new roads and public transport facilities);
- Mobility concepts in urban areas (*e.g.* public transport routings, accessibility schemes for selected urban areas);
- Comprehensive transport master plans (with medium to long-term investment and policy implications);
- As well as ex-post climate proofing of existing transport networks and infrastructures.

Step 1: Identify potential climate impacts

At the beginning of each transport planning process, the status quo of the transport system is evaluated to identify existing problems. Transport data, as well as social and economic development scenarios are collected to identify transport development needs. Since the transport development should also take potential sensitivity to climate change into consideration, now there is also a need to gather information on potential climate impacts and vulnerabilities (see Box 9 for information sources). This should also cover affected user groups and communities with a strong focus on groups with potentially limited choices such as women, children, elderly and disabled. On this basis, objectives for the further development of urban transport are formulated (Step 2).

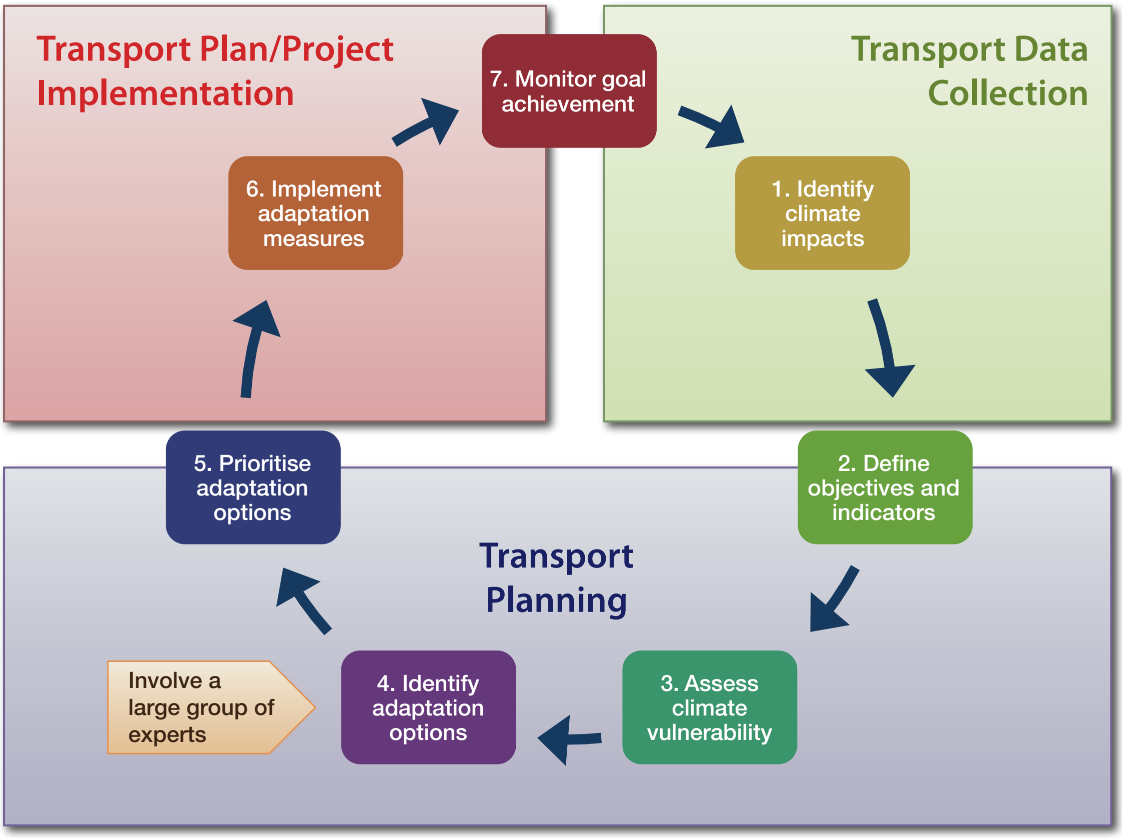


Figure 19

A framework for developing an adaptation strategy for urban transport development.

Graphic by Urda Eichhorst, Daniel Bongardt

Step 2: Define objectives and indicators for climate proof transport systems

In parallel to the definition of transport system objectives, adaptation objectives can be identified. For instance, climate change may affect the planned road, existing infrastructure or attractiveness of public transport, but the transport system should be resilient to climate change, *e.g.* by performing well under more extreme temperatures or increased rainfall.

Box 9: Information sources for climate impacts and vulnerability assessment

- Reports from national environmental agencies or UNDP often provide easily understandable reports on climate impacts at the national level.
- **GTZ practitioner's manual:** focus on how to gather and interpret relevant climate information with a view to development practitioners (both governmental and non-governmental). http://www2.gtz.de/dokumente/bib/gtz2009-0175en-climate-change-information.pdf
- The **WB Climate Change Portal** is intended to provide quick and readily accessible climate and climate-related data to policy makers and development practitioners (because of large amounts of data a fast internet connection is recommended). http://sdwebx.worldbank.org/climateportal/home.cfm?page=globlemap&undpcc=ar
- **UNFCCC (2008) Compendium on methods and tools** to evaluate impacts of and vulnerability and adaptation to climate change (no transport sector-specific tool section).
- **SERVIR** is a regional visualisation and monitoring system for Mesoamerica and Africa that integrates satellite and other geospatial data for improved scientific knowledge and decision-making. http://www.servir.net

The **Climate Change Explorer** provides users with an analytical foundation to explore the climate variables relevant to their particular adaptation decisions. It is a desktop client that provides an interface for downloading, managing and visualising scaled down model outputs. You will need to apply for a separate password to download a version of this tool. http://www.wikiadapt.org/filestore/wikiADAPT/Climate_Change_Explorer_an_introduction_v1.pdf

Based on the identified objectives, operational criteria or indicators need to be defined, against which different transport development and adaptation options can be assessed. This could be limiting flood-related disruptions of transport in a specific area to once a year or keeping flood-related damages below a certain economic threshold, etc.

Step 3: Assess vulnerability and risk of transport-related interventions

After developing a draft plan for a transport related intervention, the vulnerability of the plan should be assessed against the risks of the expected climate impacts under different climate change scenarios, *e.g.* different degrees of sea-level rise, using the data gathered in Step 1 (see checklist on risk assessment in the annex):

- How do expected risks affect existing or planned transport system elements or those who depend on them?
- Who would be most affected by those impacts?

At this stage the implications of the draft plan (and its alternatives) for greenhouse gas emissions should be reflected as well.

To exploit synergies and build on existing institutional/procedural structures as far as possible, climate risk assessment could be integrated into or conducted in parallel to strategic environmental assessments (SEAs) for plans or environmental impact assessments (EIAs) for climate proofing projects. This may also improve the cost-effectiveness of climate proofing (ADB, 2005). An EIA is conducted after a project has already been chosen for implementation, so at a rather late stage, whereas climate proofing should ideally be integrated early in the planning process to inform decisions; more similar to SEAs.

See the checklist in the annex of this module that provide guidance for the assessment of vulnerability and risk.

Step 4: Identify adaptation options

Based on the risk assessment of the transport plan, different adaptation options can be identified:

- What are suitable adaptation options (see Section 2 for a comprehensive list of adaptation options)?

- Do they meet the decision-making criteria (Step 2)?
- Do they take local circumstances into account (Step 1)?
- Are the right partners involved in the assessment?

At the outset, a wide range of potential options should be considered, not to overlook viable options. To be able to do so a large group of experts should be involved. Especially where information of future impacts is uncertain, measures that contain low or no regret options should be identified.

> See the checklists in the annex of this module that provide guidance for:
>
> a) Who should be involved?
> b) What are the options for adaptation of road infrastructure?
> c) What are the options for adaptation of rail infrastructure?
> d) What are the options for adaptation of waterways infrastructure?
> e) What are the options for adaptation of vehicles (focus public transit)?
>
> The checklists are based on the more detailed Tables 1-4 in Section 3.

Step 5: Prioritise transport development alternatives and adaptation options

There is a need to prioritise the adaptation options in order to use limited resources most effectively: Based on the vulnerability and risk assessment in Step 3, the long list of adaptation options of the draft development plan and its alternatives (Step 4) can be appraised. At the same time, the assessment can also take other implications of each option into account, such as the resulting CO_2 emissions and pollution of different development and adaptation options and other public objectives, such as cost effectiveness or equal access to mobility.

The choice of a certain transport solution over another can itself be an adaptation option, *e.g.* the development of Bus Rapid Transit instead of Underground Rapid Transit may reduce vulnerability against flooding, depending on local circumstances.

Prioritisation of transport development and adaptation options should be a multi-stakeholder process. For the prioritised adaptation options, key actors to successfully implement the adaptation actions need to be identified.

Step 6: Implement transport development and adaptation measures

The implementation of adaptation measures becomes an integral part of the transport project implementation itself. For instance by including adaptation requirements in public tenders, *e.g.* purchasing buses with tinted windows or air conditioning, or building new roads according to climate-proof design standards.

Step 7: Monitor and evaluate progress and climate impacts

Monitoring and evaluation are important not only to assess the success of the transportation system and the corresponding adaptation measures, but also to revisit risk assessments (Step 3) as new information becomes available or as monitoring results point to new problems (Step 1). Thus, integration of adaptation in plans and projects results in an iterative process.

4.3 Supportive policy context for effective adaptation

The previous chapter outlined the systematic approach towards identifying the adaptation needs and options for urban transport developments. This chapter highlights policies and measures that can support decision-makers and planners in integrating adaptation into transport projects and plans.

In many cases, adaptation of the transport system to climate change may in fact begin with tackling existing vulnerabilities and infrastructure deficiencies. The city of Jakarta is flooded 2–3 times per monsoon season, requiring annual maintenance of road infrastructure, and subsidence is already a problem in many Indian cities. All these impacts will potentially get worse with climate change and could reach a critical threshold beyond which system performance can no longer be guaranteed if no adaptation measures are taken.

Monitoring and gathering data on intense weather events and their consequences for the transport system (both now and in the past) can improve our understanding of the implications of climate change for transport, including their direct and indirect costs. This knowledge can then strengthen the basis for taking decisions on adaptation. Data should be systematically assessed, entered into a database and ideally be exchanged between cities to enhance mutual learning.

For adapting transport *infrastructure* an overarching strategy is needed, which basically consists of four elements:

1. Careful *spatial planning* that avoids high-risk areas, includes green and blue spaces to counter heat island effects and creates relatively dense urban areas to avoid unnecessary transport demand. Nevertheless providing redundancy to cope with unexpected stressors, while integrating and connecting poor neighbourhoods. Spatial planning should be combined with *risk mapping*, as well as with *regulatory policies*, such as zoning, and safety requirements for road-side billboards and trees to avoid the risks of uprooted trees or billboards on the roads during floods or storms.
2. Improving *design standards* of transport infrastructure to be resilient under changing climatic conditions, including the improvement of urban drainage and building codes. This will require an assessment of the suitability of current design standards under different climate change scenarios. Here, external expertise may be required. Design standards should be *regularly audited* and revised as required. Updated design standards can be *integrated into procurement processes* for infrastructure developments, giving conditional clearance to projects to ensure that climate resilient features have been incorporated.
3. *Insurance* for transport infrastructure to divert (at least part of) the risk of climate impacts from city governments. Insurance premiums may be subject to *regular maintenance* of existing infrastructure and could thus function as incentive to ensure proper maintenance.
4. *Adaptation auditing* of the urban transport network to first of all identify vulnerabilities and later on monitor progress and suitability of adaptation measures, as well as identifying new adaptation needs. Cities should also carry out regular *road safety audits* for all hierarchies of roads, as well as safety audits of other transport related infrastructure, such as bridges and drainage systems.

For adapting *vehicles*, new design standards or configurations need to take hotter temperatures into account. Here transport authorities will have to cooperate with transport service providers and vehicle manufacturers. New *design standards* can be integrated into vehicle *procurement requirements*, alongside requirements for more efficient vehicles to reduce transport emissions.

To prepare for more frequent extreme weather events, *disaster risk management and contingency planning*, including early warning systems, needs to become a vital component of transport planning. City governments should be mandated to develop disaster risk management plans, while transport providers need to be closely integrated into evacuation planning to ensure the provision of public services in the case of crisis. This includes identifying critical nodes of transport systems, *e.g.* for accessibility of vital facilities, such as hospitals and evacuation routes, including ensuring safe pedestrian access to such facilities (this can be done using network models, see for instance some of the contributions in Murray and Grubesic (2007); but also designated drivers for evacuation, who are well trained and committed to operate the emergency services.

Box 10: Stranded commuters turn to elevated rails

When in September 2009, Metro Manila's major thoroughfares were rendered impassable to vehicular traffic by flash floods, the Light Rail Transit (LRT) and the Metro Rail Transit (MRT) provided an alternative for commuters trying to get home. LRT Authority administrators were pride that their maintenance personnel were able to keep LRT Lines 1 and 2 running efficiently and without disruption. The main problem encountered was the unavoidable congestion at the LRT stations in the flooded areas. As a form of relief assistance to thousands of commuters, passengers were charged a reduced fare. In order to accommodate the surge of passengers the number of trains was increased from 9 to 16.

Source: The Philippine Star, 2009, September 28

All this will not be possible without support both from city and national governments in developing countries and from the international community. Box 11 shows where to get support for and how to channel resources to adaptation.

One of the big challenges of urban adaptation planning is to also plan for the "unplanned"; that is to also consider adaptation needs in informal settlements or of informal paratransit. Over 800 million urban dwellers live in informal or illegal settlements in low- and middle-income nations, often without much infrastructure at all. The needs of over 800 million people cannot simply be ignored if resilient urban centres are to be created. This underlines the intimate link between development and adaptation, highlighting once more the need to improve urban transport systems as a whole.

Due to the existing deficiencies on the one hand and the long life-span of investments in the transport system, as well as its immobility, adaptation should already be considered in transport planning today to create sustainable urban systems. To exploit the full potential of sustainable transport planning, synergies with low-carbon transport development should also be considered.

Box 11: Where to get support

At the international level, under the United Nations Framework Convention on Climate Change (UNFCCC), the *Nairobi Work Programme* aims at information exchange on and development of methods and tools for risk assessment, climate modelling and adaptation planning, as well as the exchange of experiences with adaptation[a]. It has been very successful and provides lots of useful information.

One means to find support for adaptation projects are international multi- and bilateral funds for adaptation. Four funds with a focus on adaptation were set up under the Global Environmental Facility (GEF) and the Kyoto Protocol to the UNFCCC, respectively (illustrated in Figure 20):

- The Least Developed Country Fund (LDCF);
- The Special Climate Change Fund (SCCF);
- The Strategic Priority on Adaptation (SPA);
- The Adaptation Fund (AF).

So far, however, resources within these funds have been woefully inadequate to meet adaptation needs. Considerably scaling up funding for adaptation is one of the most pressing issues in the international climate negotiations. Any new climate agreement must include adequate and reliable finance to meet the adaptation needs in developing countries.

Figure 20: *Funds addressing adaption*

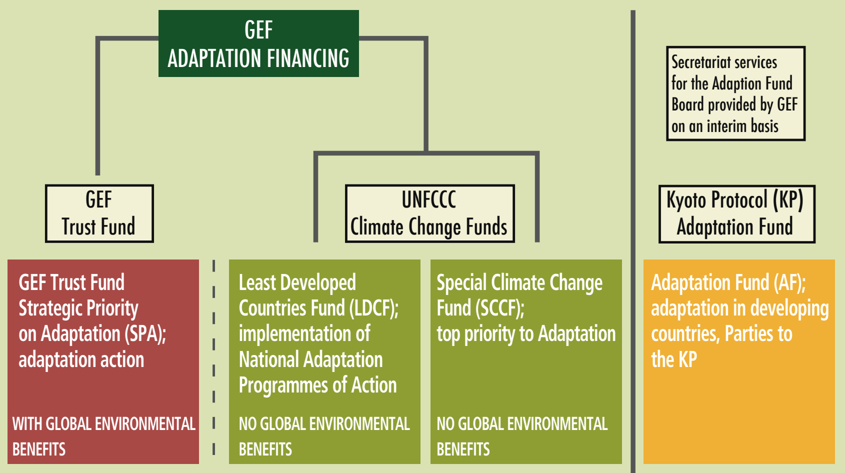


Illustration by GEF, 2009

In addition to the above, several other funds exist outside the UNFCCC. A comprehensive overview of all existing climate change funds and related projects can be found online at http://www.climatefundsupdate.org/listing.

Other ways to channel resources to adaptation at the city level include:

- Integrating adaptation within local and national planning;
- Working with international (development) organisations on adaptation[b];
- Working with international, national or local NGOs on adaptation;
- Provision of adaptation infrastructure and services by private actors, such as public transport operators, or public-private partnerships, such as introducing road-tolls;
- Mobilising funds for adaptation (and mitigation) through travel demand management measures, such as private vehicles taxes, congestion charges, parking fees, etc.

In order to adequately address adaptation, city (and national) governments will have to allocate additional resources for capacity building of key government personnel, adaptation planning and implementation (see Box 7 for the case of Durban, South Africa).

[a] http://unfccc.int/adaptation/sbsta_agenda_item_adaptation/items/3633.php

[b] Development and adaptation are closely linked and often cannot be easily distinguished. All development activities should be climate proofed to avoid maladaptation. In that sense development aid can also be used for adaptation activities without diverting finance from development activities.

5. Synergies of mitigation and adaptation in urban passenger transport

Adaptation to climate change in the transport sector has to be seen in the framework of climate proof urban design, where climate proof means both resilient and as low-carbon as possible. Transport cannot be viewed in isolation if benefits should be maximised and negative effects of adaptation strategies be avoided. This also means that sustainable transport not only needs to be resilient, but also try to minimise transport-related emissions. Only if both aspects are tackled, the risks of climate change can be minimised.

Transport accounts for 23 % of energy-related CO_2 emissions globally (IEA, 2008) and is one of the few sectors in which emissions are actually growing. Reducing travel demand is therefore at the heart of climate proof transport development. Avoiding emissions is always beneficial for adaptation, because fewer emissions translate into lower climate change and therefore less need to adapt.

> How to reduce emissions from urban transport is discussed in more detail in the GTZ *Sourcebook* Module 5e: *Transport and Climate Change* (GTZ, 2007a).

Efforts in reducing transport emissions focus on the "Avoid-Shift-Improve Approach":

1. ***Avoiding or reducing the distances travelled*** through careful land-use planning aims to maintain mobility while reducing the kilometres travelled. This notion of mobility is defined by the possibility to achieve different human activities such as business, work, purchase, leisure and other social and cultural activities. Integrated and dense structures of housing, working and shopping facilities and places for leisure allow people to practice their activities without long transport distances. A transit-oriented development further increases the density along highly efficient public transport.

> How to tackle land-use is discussed in more detail in the GTZ *Sourcebook* Module 2a: *Land-use Planning and Urban Transport*, available at http://www.sutp.org.

2. ***Modal shift*** aims at satisfying the remaining transport needs with the most environmentally friendly transport modes. The different transport modes —walking, cycling, busses, trains, ships and cars— have different environmental impacts. The non-motorised modes have the lowest impact on the environment, followed by bus and train, while cars have the highest impact. Therefore, modal shift aims at strengthening (or maintaining) non-motorised and public transport. Here Transport Demand Management (TDM) measures, such as congestion charging, parking limitations and fees, play an important role to incentives shifts to more sustainable transport options.

> How to implement TDM is discussed in detail in the GTZ training document *Transport Demand Management.* Modal shift for NMT is discussed in the GTZ *Sourcebook* Module 3d: *Preserving and Expanding the Role of Non-motorised Transport.* Both are available at http://www.sutp.org.

3. ***Improve vehicle technologies and fuels:*** The third strategic pillar is the improvement of transport efficiency. This includes measures concerning vehicle technology as well as the carbon content of fuels.

> How to tackle land-use is discussed in more detail in the GTZ *Sourcebook* Module 4a: *Clean Fuels and Vehicle Technologies*, available at http://www.sutp.org.

Synergies between adaptation and mitigation are located especially within the first two pillars, transport avoidance and modal shift. Although vehicle technology could combine efficiency and resilience improvements, here trade-offs are most likely, in particular concerning air-conditioning requirements that lead to increased transport emissions.

The future risks of climate events will likely encourage more implementation of "Smart Growth" measures, which reduce the need for the number of trips and the length of trips. These measures include Transit-Oriented Development (TOD), urban densification, and mixed-use development. Likewise, trip replacement strategies will also be a greater priority.

These measures include improved Information Communications Technologies (ICT), such as internet connectivity, which allow informational and economic activity to take place without the need for extensive travel. Reducing transport demand through intelligent city planning and the provision of a well functioning public transport system and transport demand management also means less exposure of infrastructure and travellers to climate impacts.

To avoid increasing heat island effects, dense city planning needs to be balanced through the use of green spaces and rivers and lakes, providing cooling and infiltration, improving the urban climate and air quality, as well as overall quality of living. These green and blue spaces also offer the possibility for relaxing and leisure in the city; thereby indirect effects on transport demand by city dwellers escaping from uncomfortable and hot city centres through travelling to remote leisure places may be minimised.

Modal Shift towards (or preserving existing shares of) public and non-motorised transport can both profit from adaptation measures and help adapting to climate change. Greening of roads, for example, helps adapting to warmer temperatures by creating a cooling effect. In combination with the provision of bike lanes and walkways, it can also make non-motorised transport more attractive.

Providing a reliable and comfortable public transport system can minimise shifts to private motorised transport as soon as it becomes affordable. At the same time, public transport needs less space and built infrastructure than motorised individual transport, which reduces adaptation costs for roads.

Especially Bus Rapid Transit (BRT) systems proved to be efficient and inexpensive public transport systems; with the performance of modern rail-based transit systems but at a fraction of the cost. With regard to adaptation, BRT is potentially more flexible than tram or metro systems due to the use of more redundant road infrastructure.

Please refer to the GTZ *BRT Planning Guide* (GTZ, 2007b).

A further important synergy between a high modal share of public transport and adaptation concerns disaster evacuation, which becomes increasingly important with climate change. In particular in developing cities, where access to private mobility remains limited, a well-performing and dense public transport network can ensure efficient evacuation for the whole population.

To maintain the attractiveness of public transport under changing climatic conditions and preserve the existing modal share, adaptation is indispensable. Here, some trade-offs are unavoidable, such as an increasing demand for air-conditioned vehicles, offsetting some of the emission reductions of more efficient vehicles. Nevertheless, private cars would also create additional emissions due to air conditioning. To mitigate the effects of air-conditioning, CO_2-based systems should be preferred to HFC-based systems as far or as soon as they are available[5]. Still, when new public vehicles are purchased; improvements regarding vehicle efficiency and resilience can be tackled at once.

[5] HFC-based systems emit F-gases (ozone-depleting substances), which have a much higher global warming potential than CO_2. Overall about 5 % of transport greenhouse gas emissions are related to F-gases. These gases are mainly emitted due to vehicle air conditioning.

Figure 21
Congestion in Bangkok, Thailand.
Photo by Thirayoot Limanond, 2006, GTZ Photo DVD

Table 5: Synergies between adaptation and mitigation

Strategic approach	Main opportunity for synergies	Mitigation	Adaptation
Avoid/Reduce	■ Sound land-use planning for compact and transit oriented cities with sufficient green spaces ■ Combined with climate-proofed design standards for infrastructure	■ Short distances reduce land conversion, travel demand and related emissions ■ Reliable and high-quality public transport, walking and cycling infrastructure maintains low-carbon modes	■ Parks and green roads provide cooling ■ Short distances reduce the total infrastructure requiring adaptation ■ Short distances favour walking & cycling ■ Resilient infrastructure
Shift/Maintain	■ High quality public transport (in combination with transport demand management measures) ■ Combined with climate-proofed design standards for vehicles and contingency planning ■ High quality pedestrian and bicycle infrastructure ■ Transportation Demand Management (TDM) measures that provide the disincentives to private motorised vehicle use	■ High-quality public transport attracts more customers and reduces car trips ■ Less road space is needed ■ Less CO_2 emissions per passenger kilometre	■ High-quality public transport (*e.g.* include air-conditioning) is necessary to maintain mobility of those without access to a car ■ Reliable public transport is vital for disaster management/ evacuation
Improve	■ Procurement of efficient and resilient vehicles ■ Vehicle standards	■ Energy efficient vehicles reduce the carbon emissions per kilometre	■ Resilient vehicles are necessary to maintain mode share (reliable and comfortable public transit) ■ As far as possible, air conditioning should not be based on HFC but CO_2 (lower warming potential)

Concluding remarks

Currently, information about the local effects of climate change remains limited. Nevertheless, general trends can already be identified and improved information can be expected in the future as efforts to downscale climate models continue. In the end, each city has to identify the specific risks related to its area. Local knowledge will help to make better projections and risk assessments by learning from current impacts.

In many developing cities, the impacts of extreme weather events on urban transport systems can already be severe as experienced in the recent flooding of Manila in September 2009. This illustrates the importance of developing more resilient sustainable urban transport systems, especially as impacts are expected to get worse. To be truly sustainable, the transport system must work for all, also including the urban poor and the disabled. This will require addressing current deficiencies.

Adaptation of urban transport in developing cities must hence be seen in the larger context of addressing transport needs as a whole, if vulnerabilities of the urban system are to be minimised. Further work is needed on clearly defining realistic steps towards achieving a climate-proof, pro-poor and affordable urban transportation system in developing cities. For instance, more specific design standards that are suitable for developing countries are needed.

At the moment, only few case studies exist on adaptation in the transport sector and related costs, as the focus in urban transport remains on mitigation of greenhouse gas emissions. Development of good-practice case studies for adaptation in urban transport and exchange of existing experiences with planning for and management of extreme weather events in developing cities should be encouraged. More efforts are also needed in integrating disaster risk management more closely into transport planning for a warmer world.

The decision-making tools and check lists of this module are a first step towards realising the integration of adaptation into transport projects and planning procedures. As a new area of action much further work is needed, especially in monitoring weather impacts on transport and developing tools that are particularly designed to, plan and manage the integration of adaptation and mitigation in urban transport. In the end, adaptation of urban transport in developing cities requires a process of social learning, to which this paper can hopefully contribute.

Figure 22
Natural cooling: Cycling under trees at a carfree day in Jakarta, Indonesia.
Photo by Judiza Radjni Zahir, 2008, GTZ

References

- **ADB – Asian Development Bank, ed. (2005):** Climate Proofing: A Risk-based Approach to Adaptation – Summary for Policy and Decision Makers. Pacific Studies Series. Asian Development Bank, Philippines.
- **Adger, N.W., Lorenzoni, I., O'Brien, K.L. (2009):** Adaptation now. In: Adger, N.W., Lorenzoni, I., O'Brien, K.L., eds. Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, Cambridge, UK.
- **Adger, N.W. and Vincent, K. (2005):** Uncertainty in adaptive capacity (IPCC special issue on describing uncertainties in climate change to support analysis of risk and options), *C. R. Geoscience*, 337: 339-410.
- **Ayers, J. (2009):** International Funding to Support Urban Adaptation to Climate Change. In: Bicknell, J., Dodman, D., Satterthwaite, D., eds., Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges. Earthscan, London, United Kingdom.
- **Changnon, S.A. (1996):** Effects of summer precipitation on urban transportation. *Climatic Change*, 32: 481–494.
- **Chung, E., Ohtani, O., Warita, H., Kuwahara, M., Morita, H. (2005):** Effect of rain on travel demand and traffic accidents. In: Proceedings of the 8th International IEEE Conference on Intelligent Transportation Systems, Vienna.
- **CIESIN (Center for International Earth Science Information Network):** Low Elevation Coastal Zone (LECZ) Urban-Rural Estimates, Global Rural-Urban Mapping Project (GRUMP), Alpha Version. Socioeconomic Data and Applications Center (SEDAC), Columbia University, Palisades, New York, United States of America. Available online: http://sedac.ciesin.columbia.edu/gpw/lecz (accessed 20.08.2009).
- **Cochran, I. (2009):** Climate Change Vulnerabilities and Adaptation Possibilities for Transport Infrastructures in France. Climate Report Issue No. 18. Available online: http://www.caissedesdepots.fr/fileadmin/PDF/finance_carbone/etudes_climat/09-09_climate_report_n18_transport_infrastructures_in_france.pdf (accessed 21.09.2009)
- **C4S, ed. (2008):** Developing a Transport Strategy for Climate Change Adaptation. SDRN / Dft Event Report 7th December 2007, Church House Conference Centre, SW1P 3NZ, London.
- **Dawson, R. (2007):** Re-engineering cities: a framework for adaptation to global change. *Philosophical Transactions of the Royal Society A*, 365: 3085-3098.
- **Dessai, S., Hulme, M., Lempert, R., Pielke Jr, R. (2009):** Climate prediction: a limit to adaptation? In: Adger, N.W., Lorenzoni, I., O'Brien, K.L., eds. Adapting to Climate Change: Thresholds, Values, Governance. Cambridge University Press, Cambridge, UK.
- **Dreier, P. (2006):** Katrina and power in America, *Urban Affairs Review*, 41, 4: 528-549.
- **Eca – Economics of Climate Adaptation Working Group, ed. (2009):** Shaping climate-resilient development – a framework for decision-making. Available online: http://www.swissre.com/resources/387fd3804f928069929e92b3151d9332-ECA_Shaping_Climate_Resilent_Development.pdf (accessed 17.09.2009).
- **Eddowes, M.J., Waller, D., Taylor, P., Briggs, B., Meade, T., Ferguson, I. (2003):** Railway Safety Implications of Weather, Climate and Climate Change: Final Report. Commissioned by the Rail Safety and Standards Board. Available online: http://www.rssb.co.uk/pdf/reports/research/Safety%20implications%20of%20weather,%20climate%20and%20climate%20change.pdf (accessed 01.09.2009).
- **Frankhauser, S. (2009):** The range of global estimates. In: Parry M., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Sattherwaite, D., Tiffin, R., Wheeler, T. (2009): Assessing the costs of adaptation to climate change: A review of the UNFCCC and other recent estimates. International Institute for Environment and Development and Grantham Institute for Climate Change at Imperial College, London, United Kingdom. Available online: http://www.iied.org/pubs/pdfs/11501IIED.pdf (accessed 29.10.2009).
- **GEF (Global Environmental Facility), ed. (2009):** Financing Adaptation Action. Global Environmental Facility. Available online: http://thegef.org/uploadedFiles/Publications/adaptation-actions.pdf (accessed 22.11.2009).
- **Goudie, A. (1990):** The Human Impact on the Natural Environment. Basil Blackwell, Oxford, United Kingdom.
- **Greater London Authority, ed. (2005):** Climate Change and London's Transport Systems. Summary Report. Greater London Authority, London, United Kingdom. Available online: http://www.london.gov.uk/lccp/publications/transport.jsp (accessed 20.09.2009).

- — **(2008):** The London Climate Change Adaptation Strategy. Summary draft report. Greater London Authority, London, United Kingdom. Available online: http://www.london.gov.uk/mayor/publications/2008/docs/climate-change-adapt-strat-summary.pdf (accessed 20.09.2009).
- **Grenzeback, L. R. and Lukmann, A. T. (2007):** Case Study of the Transportation Sector's Response to and Recovery from Hurricanes Katrina and Rita. Available online: http://onlinepubs.trb.org/onlinepubs/sr/sr290Grenzenback Lukmann.pdf (accessed 10.08.2009).
- **Heath, T. (2001):** Revitalizing cities: attitudes toward city-centre living in the United Kingdom. *Journal of Planning Education and Research,* 20: 464-475.
- **Huq, S. and Satterthwaite, D. (2008):** Climate change and cities. *id21 insights,* 71, January 2008: 1-2. Available online: http://www.id21.org/insights/index.html (accessed 07.08.2009).
- **Parry, M.L., O.F. Canziani, J.P. Palutikof and Co-authors (2007):** Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 23-78.
- **IEA, ed. (2008):** CO_2 Emissions from fuel combustion. IEA, Paris, France.
- **IPCC, ed. (2007):** Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team: Pachauri, R.K. and Reisinger, A., eds., IPCC, Geneva, Switzerland.
- — **(2001) Climate Change 2001:** Mitigation. IPCC, Geneva, 2001.
- **Jacob, K.H., Gornitz, V., Rosenzweig, C. (2007):** Vulnerability of the New York City metropolitan area to coastal hazards, including sea-level rise: inferences for urban coastal risk management and adaptation policies. In: McFadden, L., Nicholls, R., Penning-Rowsell, E., eds., *Managing Coastal Vulnerability.* Elsevier Publishing, Oxford, United Kingdom.
- **Julca, A., Kozul-Wright, R., Vos, R. (2009):** Multidimensional Climate Threats Require New Approaches and More Resources for Adaptation Challenge. *UN-DESA Policy Brief No. 20.* Available online: http://www.un.org/esa/policy/policybriefs/policybrief20.pdf (accessed 03.09.2009)
- **Kamel, N., Leon, D.-M., Wachs, M. (1996):** Transportation Decision Making Under Disaster Conditions. Institute of Transportation Studies, University of California, Los Angeles, United States of America. Cited in Dewar, J. and Wachs, M. (undated): Transportation Planning, Climate Change, and Decision Making Under Uncertainty. Available online: http://onlinepubs.trb.org/onlinepubs/sr/sr290Dewar-Wachs.pdf (accessed 10.09.2009)
- **Kelly, P.M. Kelly and Adger, N.W. (2000):** Theory and practice in assessing vulnerability to climate change and facilitating adaptation, *Climatic Change*, 47: 325–352.
- **Klein, R.J.T., S. Huq, F. Denton, T.E. Downing, R.G. Richels, J.B. Robinson, F.L. Toth, 2007:** Inter-relationships between adaptation and mitigation. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 745-777.
- **Litman, T. (2006):** Lessons from Katrina and Rita: What Major Disasters Can Teach Transportation Planners. Available online: http://www.vtpi.org/katrina.pdf (accessed 20.09.2009).
- **McEvoy, D., Lindley, S., Handley, J. (2006):** Adaptation and mitigation in urban areas: synergies and conflicts. *Municipal Engineer*, 159: 185-191.
- **Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J. and Allen, M. R. (2009):** Greenhouse-gas emission targets for limiting global warming to 2 °C. *Nature* 458, 7242: 1158-1163.
- **MunichRe, ed. (2004):** Megacities – Megarisks: Trends and challenges for insurance and risk management. MunichRe, Munich, Germany. Available online: http://www.preventionweb.net/files/646_10363.pdf (accessed 13.08.2009).
- **Murray, A.T. and Grubesic, T.H., eds. (2007):** Critical Infrastructure – Reliability and Vulnerability. Springer, Heidelberg, Germany.
- **Newman, P. and Kenworthy, J. (1999):** Sustainability and cities: overcoming automobile dependence. Island Press, Washington, DC, United States.

- **Nicholls, R.J., Hoozermans, F.M.J., Marchand, M. (1999):** Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, 9: 69-87.
- **ODPM (Office of the Deputy Prime Minister), ed. (2004):** The Planning Response to Climate Change: Advice on Better Practice. ODPM, London, UK. Available online: http://www.communities.gov.uk/documents/planningandbuilding/pdf/147597.pdf (accessed 16.08.2009).
- **Rahmstorf, S. (2007):** A semi-empirical approach to projecting future sea-level rise. *Science* 315, 5810: 368–370. Available online: http://www.pik-potsdam.de/%7Estefan/Publications/Nature/rahmstorf_science_2007.pdf (accessed 21.09.2009)
- **Renne, J. (2005):** Car-less in the Eye of Katrina. *Planetizen*, 6 September 2005. Available online: http://www.planetizen.com/node/17255 (accessed 20.09.2009).
- **Roberts, D. (2009):** Thinking Globally, Acting Locally: Institutionalizing Climate Change at the Local Government Level in Durban, South Africa. In: Bicknell, J., Dodman, D., Satterthwaite, D., eds., Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges. Earthscan, London, United Kingdom.
- **— (2008):** Durban adapts to climate change. *id21 insights,* 71, January 2008: 1-2. Available online: http://www.id21.org/insights/index.html (accessed 07.08.2009).
- **Satterthwaite, D., Huq, S., Reid, H., Pelling, M., Romero Lankao, P. (2009):** Adapting to Climate Change in Urban Areas: The Possibilities and Constraints in Low- and Middle-Income Nations. In: Bicknell, J., Dodman, D., Satterthwaite, D., eds., Adapting Cities to Climate Change: Understanding and Addressing the Development Challenges. Earthscan, London, United Kingdom.
- **Savonis, M. J., V.R. Burkett, and J.R. Potter, eds. (2008):** Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. Department of Transportation, Washington, DC, USA. Available online: http://www.climatescience.gov/Library/sap/sap4-7/final-report/sap4-7-final-all.pdf (accessed 29.09.2009).
- **Stern, N. (2007):** The Economics of Climate Change [The Stern Report]. Cambridge University Press, Cambridge, United Kingdom.
- **Tompkins, E.L. and Adger, N.W. (2003):** Defining response capacity to enhance climate change policy. *Tyndall Centre Working Paper No. 39*. Available online: http://www.tyndall.ac.uk/publications/working_papers/wp39.pdf (accessed 15.09.2009)
- **Transportation Research Board (2008):** Potential Impacts of Climate Change on U.S. Transportation. *Transportation Research Board Special Report 290*. Washington, DC, USA. Available online: http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf (accessed 1.10.2009)
- **UNFCCC (United Nations Framework Convention on Climate Change), ed. (2008):** Compendium on methods and tools to evaluate impacts of, and vulnerability and adaptation to, climate change. Available online: http://unfccc.int/files/adaptation/nairobi_workprogramme/compendium_on_methods_tools/application/pdf/20080307_compendium_m_t_complete.pdf (accessed 15.09.2009).
- **— (2007):** Climate Change: Impacts, Vulnerabilities, and Adaptation in Developing Countries. United Nations Framework Convention on Climate Change Secretariat. Bonn, Germany.
- **Willows, R. and Connell, R., eds. (2003):** Climate adaptation: Risk, uncertainty and decision-making. UKCIP Technical Report. Available online: http://www.ukcip.org.uk/images/stories/Pub_pdfs/Risk.pdf (accessed 15.09.2009).
- **Wooler, S. (undated):** The Changing Climate: Impact on the Department for Transport. Available online: http://www.dft.gov.uk/pgr/scienceresearch/key/thechangingclimateitsimpacto1909 (accessed 28.08.2009).
- **Woolston, H. (undated):** Climate Change Adaptation for London's Transport System. Available online: http://sdrnadmin.rechord.com/wp-content/uploads/cc_adaptation.pdf (accessed 15.09.2009).
- **World Bank, ed. (2006):** Clean Energy and Development: Towards an Investment Framework. World Bank, Washington DC, United States of America. Cited in World Bank, ed. (2007): The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates – The Global Report of the Economics of Adaptation to Climate Change Study. Consultation Draft. Available online: http://siteresources.worldbank.org/INTCC/Resources/EACCReport0928Final.pdf (05.10.2009).

Annex
Checklists for Chapter 4.2

ANNEX: Checklists for Section 4.2

Checklist 1: Assess climate risk and vulnerability (Step 3)

This checklist is a simplified and adapted version of the key questions identified for risk assessment in the UKCIP Technical report on Climate adaptation: Risk, uncertainty and decision-making (Willows and Connell, 2003).

1. **What is the lifetime of your decision (e.g. road construction)?**
   - ➔ This will inform the choice of climate scenarios to be used in future analysis, and how they are interpreted.

2. **What tools should be used to analyse climate change risks in decision-making? Do these reflect the scale of the problem, its complexity and data availability?**

3. **Could other tools be adopted which would allow more explicit consideration of climate change risk, including estimates of probability, analyses of uncertainties and the significance of key assumptions?**

4. **What are the most important climate hazards in your geographic region and city area - today and in the future? And which climate variables are likely to have an impact on the transport development plan/project?**
   - ➔ Does information on past variability in climate or past extremes of weather indicate potential vulnerability to climate change?

5. **How might future changes in these climate variables affect your decision (e.g. road construction) and ability to meet your decision criteria?**
   - ➔ Different climate change scenarios should be compared, *e.g.* different degrees of sea level rise
   - ➔ Are certain climate variables likely to be of greater significance than others?
   - ➔ Comparison with cities, which already experience expected climate conditions may also be helpful to identify potential risks

6. **Can the level of uncertainty regarding forecasts of particular climatic hazards, or their associated impacts be determined?**

7. **What other (non-climate) factors could also be relevant in relation to meeting your criteria?**

These questions could be answered by filling in a table like the one presented below:

Climate impacts	Level of uncertainty of climate impacts	Impact on transport intervention		Which parts of the city would be most affected?	Which user groups would be most affected?	How does this affect my operational criteria or indicators?	Other factors that could affect criteria or indicators?
		❍ likely					
		❍ unlikely					
		❍ likely					
		❍ unlikely					

Based on this first overview try to answer the following question:

8. **What are the most important consequences? Which are the key climate hazards? How are the consequences dependent on the level of climate change?**

Risk assessments, including estimates of probability, will be contingent on the particular scenario or scenarios upon which they are based.

Checklist 2: Involve different groups of actors in adaptation planning (Step 4)

Public authorities *in charge of providing resilient infrastructure, vehicle requirements/design standards*				
a.	Transport planners	❍ Yes	❍ No	❍ n/a
b.	Urban planners	❍ Yes	❍ No	❍ n/a
c.	Construction and housing department	❍ Yes	❍ No	❍ n/a
d.	Environment agencies	❍ Yes	❍ No	❍ n/a
e.	Disaster or flood risk managers	❍ Yes	❍ No	❍ n/a
f.	Public procurement authorities	❍ Yes	❍ No	❍ n/a
g.	Other:	❍ Yes	❍ No	❍ n/a

Business representatives				
h.	Transport service providers (providing suitable systems and vehicles for public transport)	❍ Yes	❍ No	❍ n/a
i.	Car manufactures (vehicle configurations or accessories, such as air conditioning)	❍ Yes	❍ No	❍ n/a

Users and consumers (Cyclists or pedestrians, Public transport users, Car Drivers)				
j.	Women	❍ Yes	❍ No	❍ n/a
k.	Disabled	❍ Yes	❍ No	❍ n/a
l.	Elderly people	❍ Yes	❍ No	❍ n/a
m.	Children	❍ Yes	❍ No	❍ n/a
n.	Others	❍ Yes	❍ No	❍ n/a

CHECKLIST 3: Adaptation measures for road infrastructure, bike lanes, walkways (Step 4)

(based on Chapter 3.1.1., Table 1)

1 Increased temperature and more heat waves

Impacts:
Deformations of roads, melting of asphalt/dark surfaces, asphalt rutting and bridge degradation

Y = YES N = NO n/a = not applicable

Planting roadside vegetation to decrease the exposure of roads to heat	Y	
	N	
	n/a	

Sources and Explanations:

Reduce overall exposure and provide cooling through green and blue infrastructure, such as parks and lakes, but also road-side trees or other shading	Y	
	N	
	n/a	

Sources and Explanations:

Proper design/construction, overlay with more rut-resistant asphalt or more use of concrete	Y	
	N	
	n/a	

Sources and Explanations:

Revise design standards to withstand higher temperatures	Y	
	N	
	n/a	

Sources and Explanations:

Increased maintenance, milling out ruts	Y	
	N	
	n/a	

Sources and Explanations:

2 More frequent droughts (and less soil moisture)

Impacts:
More landslides and subsidence, road degradation and safety hazards

Y = YES N = NO n/a = not applicable

Assess the likeliness of impacts on road infrastructure (risk mapping)	Y	
	N	
	n/a	

Sources and Explanations:

Avoid new developments in high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

Monitor soil conditions of existing roads	Y	
	N	
	n/a	

Sources and Explanations:

Increase cleaning and maintenance of roadways	Y	
	N	
	n/a	

Sources and Explanations:

3 Sea level rise and coastal erosion

Impacts:
Risk of inundation of road infrastructure and flooding and degradation of the roadway surface

Y = YES N = NO n/a = not applicable

Create vulnerability maps to identify areas most at risk	Y	
	N	
	n/a	

Sources and Explanations:

Restrict developments in high-risk areas, e.g. along the shoreline; zoning	Y	
	N	
	n/a	

Sources and Explanations:

Enhance protective measures, such as sea walls, protection of coastal wetlands (as buffers)	Y	
	N	
	n/a	

Sources and Explanations:

Managed retreat, possibly including abandoning of certain transport infrastructure in the mid to long term	Y	
	N	
	n/a	

Sources and Explanations:

Build more redundancy into the system	Y	
	N	
	n/a	

Sources and Explanations:

Design and material changes towards more corrosion-resilient materials	Y	
	N	
	n/a	

Sources and Explanations:

Improved drainage, pumping of underpasses and elevated roads	Y	
	N	
	n/a	

Sources and Explanations:

4 More extreme rainfall events and flooding

Impacts:
Flooding of roadways and subterranean tunnels, road damages and decrease of structural integrity, undermining and washing off of bridges, washed away roads, degradation of sub-grade material, increased weathering of infrastructures

Y = YES N = NO n/a = not applicable

Improve drainage infrastructure to be able to deal with more intense rainfall events, increasing capacity of drainage infrastructure to deal with increased run-off, include tunnels under large roads to facilitate speedy drainage	Y	
	N	
	n/a	

Sources and Explanations:

Audit drains regularly	Y	
	N	
	n/a	

Sources and Explanations:

Enhanced pumping	Y	
	N	
	n/a	

Sources and Explanations:

Create flood maps to identify most vulnerable areas, where infrastructure needs to be protected/improved/avoided in the future and assess alternative routes	Y	
	N	
	n/a	

Sources and Explanations:

Make flood-risk assessments a requirement for all new developments	Y	
	N	
	n/a	

Sources and Explanations:

Improve flood plain management/coastal management and protective infrastructure, improve inner-city green spaces and flood protection	Y	
	N	
	n/a	

Sources and Explanations:

Early warning systems and evacuation planning for intense rainfall events and floods	Y	
	N	
	n/a	

Sources and Explanations:

Enhance foundations	Y	
	N	
	n/a	

Sources and Explanations:

Build all-weather roads	Y	
	N	
	n/a	

Sources and Explanations:

Enhance condition monitoring of subgrade material especially after heavy rains, flooding	Y	
	N	
	n/a	

Sources and Explanations:

Use more durable material, such as more corrosion resistant material	Y	
	N	
	n/a	

Sources and Explanations:

Regular maintenance of roads and flood protection	Y	
	N	
	n/a	

Sources and Explanations:

5 More intensive and frequent storms

Impacts:
Damage to infrastructure fabric, bridges, flyovers, street lighting and signs, as well to vehicles, risk of inundation by the sea

Y = YES N = NO n/a = not applicable

Assess if currently used design standards can withstand more frequent and intense storms	Y	
	N	
	n/a	

Sources and Explanations:

Adapt design standards for new bridges, flyovers, buildings etc to expected increases of wind speeds and heavy rains	Y	
	N	
	n/a	

Sources and Explanations:

Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages	Y	
	N	
	n/a	

Sources and Explanations:

Emergency planning and evacuation routes omitting high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

CHECKLIST 4: Adaptation Measures for Rail-based (Public) Transport (Step 4)

(based on Chapter 3.1.2., Table 2)

1 Increased temperature and more heat waves

Impacts:
Buckling of rails and rail tracks, increased temperatures in underground networks (and trains)

Y = YES N = NO n/a = not applicable

Adapted maintenance procedures, such as rail stressing in the USA	Y	
	N	
	n/a	

Sources and Explanations:

Inspect and repair tracks, track sensors, and signals	Y	
	N	
	n/a	

Sources and Explanations:

New design standards/other material use to withstand higher temperatures	Y	
	N	
	n/a	

Sources and Explanations:

Improve systems to warn and update dispatch centres, crews, and stations	Y	
	N	
	n/a	

Sources and Explanations:

Distribute advisories, warnings, and updates regarding the weather situation and track conditions	Y	
	N	
	n/a	

Sources and Explanations:

Management procedures to impose differentiated speed limits	Y	
	N	
	n/a	

Sources and Explanations:

Better (and flexible) cooling systems or air conditioning for underground networks, vehicles (trains) and metro stations	Y	
	N	
	n/a	

Sources and Explanations:

Temperature monitoring for underground infrastructures	Y	
	N	
	n/a	

Sources and Explanations:

Hot weather contingency plans	Y	
	N	
	n/a	

Sources and Explanations:

Design standard for power supply to meet anticipated demand within the life of the system (especially higher demands due to increased air conditioning needs in trains)	Y	
	N	
	n/a	

Sources and Explanations:

2 More frequent droughts (and less soil moisture)

Impacts:
More land slides and subsidence

Y = YES N = NO n/a = not applicable

Assess the likeliness of impacts on rail infrastructure (risk mapping)	Y	
	N	
	n/a	

Sources and Explanations:

Monitoring of high risk tracks and regular maintenance	Y	
	N	
	n/a	

Sources and Explanations:

Avoid new rail lines in high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

3 Sea level rise and coastal erosion

Impacts:
Risk of inundation of rail infrastructure and flooding and flooding of underground tunnels

Y = YES N = NO n/a = not applicable

Create vulnerability maps to identify areas most at risk	Y	
	N	
	n/a	

Sources and Explanations:

Restrict developments in high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

Integrate transport planning with coastal zone management	Y	
	N	
	n/a	

Sources and Explanations:

Enhance protective measures, such as sea walls, protection of coastal wetlands (as buffers), pumping of underground systems	Y	
	N	
	n/a	

Sources and Explanations:

Managed retreat, possibly including abandoning of certain transport infrastructure in the mid to long term	Y	
	N	
	n/a	

Sources and Explanations:

4 More extreme rainfall events and flooding

Impacts:
Increases in flooding of rail lines and underground tunnels, railbed damages and decrease of structural integrity, flooding of underground tunnels, instability of earthworks, degradation of subgrade material, failure of track circuits with subsequent disruptions, increased weathering of infrastructures

Y = YES N = NO n/a = not applicable

Improve or build drainage infrastructure to be able to deal with more intense rainfall events, increasing capacity of drainage infrastructure to deal with increased run-off	Y	
	N	
	n/a	

Sources and Explanations:

Audit drains regularly	Y	
	N	
	n/a	

Sources and Explanations:

Create flood maps to identify most vulnerable areas at high risk of flooding, where infrastructure needs to be protected / improved / avoided in the future and assess alternative routes	Y	
	N	
	n/a	

Sources and Explanations:

Make flood-risk assessments a requirement for all new developments	Y	
	N	
	n/a	

Sources and Explanations:

Restrict developments in high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

Improve flood plain management/coastal management and protective infrastructure	Y	
	N	
	n/a	

Sources and Explanations:

Passenger evacuation plans for underground systems	Y	
	N	
	n/a	

Sources and Explanations:

Enhanced pumping	Y	
	N	
	n/a	

Sources and Explanations:

Enhance condition monitoring of earthworks, bridges etc especially after heavy rains, flooding (or storms)	Y	
	N	
	n/a	

Sources and Explanations:

Improved maintenance	Y	
	N	
	n/a	

Sources and Explanations:

Use more durable material, such as more corrosion resistant material	Y	
	N	
	n/a	

Sources and Explanations:

5 More intensive and frequent storms

Impacts:

Damage to stations/infrastructure, risk of inundation by the sea, obstruction of roads or rails, decreasing rail security/adhesion, increased occurrence of lightning strikes to rail signaling, lightning strikes disrupting electronic signalling

Y = YES N = NO n/a = not applicable

Assess if currently used design standards can withstand more frequent and intense storms	Y	
	N	
	n/a	

Sources and Explanations:

Adapt design standards for bridges, flyovers, stations etc to expected increases of wind speeds and heavy rains	Y	
	N	
	n/a	

Sources and Explanations:

Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management)	Y	
	N	
	n/a	

Sources and Explanations:

Wind fences for open rail infrastructure	Y	
	N	
	n/a	

Sources and Explanations:

For overhead lines: circuit breaker protection	Y	
	N	
	n/a	

Sources and Explanations:

Adapt design standard for signalling equipment	Y	
	N	
	n/a	

Sources and Explanations:

Emergency planning	Y	
	N	
	n/a	

Sources and Explanations:

CHECKLIST 5: Adaptation Measures for Waterways (Step 4)

(based on Chapter 3.1.3, Table 3)

1 Increased temperature and more heat waves

Impacts:
Increased aquatic vegetation growth could lead to clogging

Y = YES N = NO n/a = not applicable

Intensify maintenance of relevant waterways	Y	
	N	
	n/a	

Sources and Explanations:

2 More frequent droughts (and less soil moisture)

Impacts:
Decreased water availability in waterways could restrict their use and lead to more use of road networks

Y = YES N = NO n/a = not applicable

Assess the likeliness of constraints on urban waterway usage and plan for alternatives	Y	
	N	
	n/a	

Sources and Explanations:

Changes to navigation	Y	
	N	
	n/a	

Sources and Explanations:

Assess the viability of flow augmentation	Y	
	N	
	n/a	

Sources and Explanations:

3 Sea level rise and coastal erosion

Impacts:
Port facilities and coastal waterways could become unusable

Y = YES N = NO n/a = not applicable

Enhance flood defences such as sea walls, protection of coastal wetlands (as buffers)	Y	
	N	
	n/a	

Sources and Explanations:

Managed retreat, possibly including abandoning of certain infrastructure in the mid to long term; integration with coastal zone management	Y	
	N	
	n/a	

Sources and Explanations:

4 More extreme rainfall events and flooding

Impacts:
Reduced clearance under waterway bridges, reduced navigability of rivers and channels, Increase in silt deposits

Y = YES N = NO n/a = not applicable

Plan for usage of alternative transport modes	Y	
	N	
	n/a	

Sources and Explanations:

Incorporate higher levels of flooding into future bridge design	Y	
	N	
	n/a	

Sources and Explanations:

Increased dredging of silt	Y	
	N	
	n/a	

Sources and Explanations:

5 More intensive and frequent storms

Impacts:
Storm damage on waterways, obstruction of rivers and channels

Y = YES N = NO n/a = not applicable

Increase structural monitoring and maintenance	Y	
	N	
	n/a	

Sources and Explanations:

Contingency planning	Y	
	N	
	n/a	

Sources and Explanations:

CHECKLIST 6: Adaptation Measures for Vehicles and Operations (Step 4)

(based on Chapter 3.2, Table 4)

1 Increased temperature and more heat waves

Impacts:
Passenger and driver discomfort and heat exhaustion, heightened accident levels, shifts from public to air-conditioned private transport, more energy-intensive air conditioning systems, wearing off or melting of tires, overheating of equipment

Y = YES N = NO n/a = not applicable

Sufficiently large opening windows in busses	Y	
	N	
	n/a	

Sources and Explanations:

Tinted windows to shade off the sun	Y	
	N	
	n/a	

Sources and Explanations:

White painted roofs for public transit vehicles	Y	
	N	
	n/a	

Sources and Explanations:

Improved thermal insulation and cooling systems	Y	
	N	
	n/a	

Sources and Explanations:

Air conditioning, ideally using systems without F-gases (if available and affordable)	Y	
	N	
	n/a	

Sources and Explanations:

For overhead buses: design standard for power supply to meet anticipated demand within the life of the system (especially higher demands due to increased air conditioning) and withstand higher wind speeds	Y	
	N	
	n/a	

Sources and Explanations:

For underground rail: develop hot weather contingency plans	Y	
	N	
	n/a	

Sources and Explanations:

Include new design standards in public procurement requirements of the public transport fleet	Y	
	N	
	n/a	

Sources and Explanations:

New design standards to withstand higher temperatures (e.g. to avoid overheating of equipment or melting of tires)	Y	
	N	
	n/a	

Sources and Explanations:

2 More extreme rainfall events and flooding

Impacts:
Difficult driving conditions with implications for safety, performance and operation, flooding of the public transport fleet

Y = YES   N = NO   n/a = not applicable

Manage speed limits in bad weather conditions, e.g. reduce the running speed of trains	Y	
	N	
	n/a	

Sources and Explanations:

Drivers of public transport vehicles should be appropriately trained for extreme weather conditions, such as heavy rains, hail and wind	Y	
	N	
	n/a	

Sources and Explanations:

Planning for emergency routes	Y	
	N	
	n/a	

Sources and Explanations:

Early warning systems to evacuate high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

Flood insurance	Y	
	N	
	n/a	

Sources and Explanations:

3 More intensive and frequent storms

Impacts:
Difficult driving conditions or impossibility to drive, as well as derailments or collisions leading to disruptions and consequent safety and socio-economic impacts, overturning of vehicles or trains

Y = YES N = NO n/a = not applicable

Driver training	Y	
	N	
	n/a	

Sources and Explanations:

Speed restrictions	Y	
	N	
	n/a	

Sources and Explanations:

Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management)	Y	
	N	
	n/a	

Sources and Explanations:

Emergency planning and identification of evacuation routes omitting high-risk areas	Y	
	N	
	n/a	

Sources and Explanations:

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

– German Technical Cooperation –

P. O. Box 5180
65726 ESCHBORN / GERMANY
T +49-6196-79-1357
F +49-6196-79-801357
E transport@gtz.de
I http://www.gtz.de