# Chapter 9
# Climate-Proof Urban Transport Planning: Opportunities and Challenges in Developing Cities

**Urda Eichhorst, Daniel Bongardt, and Montserrat Miramontes**

**Abstract** Transport plays an important role in all human activities, especially in urban areas where most economic and social activities involve the movement of persons or goods. 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, transportation systems may be unable to recover from such events, resulting in exponential damages. In order to deal with climate change, transport systems must be designed to cater for the mobility demand of all urban populations under changing climatic conditions and to minimise transport-related greenhouse gas emissions. In many cities, decision-makers are not prepared to address these needs at the planning and design stages of urban development. As many urban areas in developing countries are still undergoing rapid development, the time to build climate-proof urban systems is now. This paper gives an overview of the expected impacts of climate change on urban passenger transport as well as possible adaptation measures. It further discusses how to integrate climate proofing into urban transport planning and policy implementation, emphasising the importance of cross-departmental cooperation. Seven steps towards developing an adaptation strategy for urban transport and how they integrate into the main steps of transport planning are presented.

**Keywords** Adaptation • Climate change • Developing cities • Urban transport

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## 9.1 Introduction

Transport is linked to all aspects of urban life: leisure, education, business and industry. Nevertheless, little attention has been paid to the vulnerabilities of urban transport systems to climate change. Ensuring a resilient urban transport system is, however, necessary to avoid frequent disruptions of urban life and associated social and economic costs. As current weather impacts on transport are expected to become more frequent and more extreme in the future, adaptive measures must be taken. 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 of urban passenger transport[1] in developing cities. It further provides orientation on how to integrate climate proofing into urban transport planning and policy implementation. The paper is based on Eichhorst (2009), 'Adapting Urban Transport to Climate Change,' a module of GTZ's sourcebook for decision makers in developing cities (see www.sutp.org).

## 9.2 Developing Cities and Climate Change

Cities are both a major source of greenhouse gas emissions and subject to the impacts of climate change. With high population and infrastructure density, as well as concentrated economic and social activities, cities are particularly vulnerable. The expected impacts of climate change on cities include increased temperature and heat waves, more frequent droughts, sea-level rise, more extreme rainfall events and more intensive and frequent storms (Dawson 2007; IPCC 2007).

Many climate impacts are worsened in cities due to certain aspects inherent to urban development. For example, urban infrastructure hinders the natural drain of water, which increases the risk of flood events. Moreover, urban activities such as transport, air conditioning and industrial processes have direct impacts on the climate and air quality because of the emissions related to their energy use, including heat exhaust.

Urban areas in many developing countries are characterized by chaotic and discontinuous spatial patterns, as well as unorganized and fast development processes (Barros 2004). These characteristics often have negative impacts on mobility and transport in developing cities. Due to rapid urbanisation rates in developing countries, transport systems often operate at capacity, providing little buffer for unexpected impacts. Informal settlements further increase the vulnerability of developing cities. Significant numbers of urban populations live on flood plains or

[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.

otherwise perilous areas with low quality or no transport infrastructure at all. At the same time, many developing cities are already heavily exposed to extreme weather impacts such as tropical storms, heavy flooding and heat waves, all of which are expected to get worse under climate change.

In certain parts of developing cities, where only rudimentary transport infrastructure exists, adaptation will actually require building resilient infrastructure in the first place. Developments that increase the vulnerability of cities by ignoring climate change implications, such as settlements in flood plains, must be avoided. As many urban areas in developing countries are still undergoing rapid development, the time to build climate-proof urban systems is now.

## 9.3 Likely Impacts on Urban Transport and Potential Adaptation Measures

Due to the interconnectivity of urban transport infrastructure, impacts on a single element can often lead to a domino effect, causing disruptions larger than the initial climate impact itself. For instance, the interruption of urban transport due to flooding can lead to indirect economic losses as people miss work and goods are left undistributed. Cascading effects can also lead to human suffering or death; critical services like hospitals may become inaccessible due to flooded or disrupted access routes. Adverse effects can be particularly large when poorly connected areas are completely cut-off, central transportation hubs are affected, or the transport system is working close to its capacity. This has implications for enhanced disaster risk strategies and evacuation plans, which rely heavily on reliable transport systems and are needed in addition to adaptation measures.

The climatic impacts on transport can be classified into three categories: impacts on transport infrastructure, impacts on vehicles and operations, and impacts on mobility behaviour.

### *9.3.1 Transport Infrastructure*

Transport infrastructure in cities generally includes roads, rails and waterways. While the first two are similar in many respects, waterways need to be analyzed separately. In this paper, only the first two types of transport infrastructure are presented in detail. For information on waterways please refer to Eichhorst (2009).

Table 9.1 gives a detailed overview of the relevant climate impacts on road and rail infrastructure, as well as possible adaptation measures. Road infrastructure in this paper is used as a collective term for roads, bicycle lanes and walkways.

In summary, impacts on road and rail infrastructure and the resulting restrictions in their use can cause congestion, accidents and disruption of mobility services.

**Table 9.1** Summary of key climate change impacts and adaptation responses for road and rail infrastructure (Cochran 2009; Eddowes et al. 2003; ODPM 2004; Savonis et al. 2008; Wooler 2004; Woolston undated)

| Relevant climate impacts | Impacts on road and rail infrastructure | Possible adaptation measures |
|---|---|---|
| Increased temperature and more heat waves | Deformations of roads, slowing down or disrupting transport; melting of asphalt/dark surfaces | Planting roadside vegetation to decrease the exposure of roads to heat |
| | Increased asphalt rutting due to material constraints under severe exposure 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 | New design standards may be needed to withstand higher temperatures |
| | Bridge structural material degradation | Increased maintenance |
| | Buckling of rails and rail track movement because of thermal expansion leads to slowing or disruption of transport | Adapted maintenance procedures, such as rail stressing in the USA |
| | | New design standards may be needed for rails to withstand higher temperatures |
| | | 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 |

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**Table 9.1** (continued)

| Relevant climate impacts | Impacts on road and rail infrastructure | Possible adaptation measures |
|---|---|---|
| | | 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) |
| 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 infrastructure (risk mapping) |
| | Road foundation degradation due to increased variation in wet/dry spells and a decrease in available moisture | Avoid new developments in high-risk areas |
| | 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 | Monitoring of soil conditions of existing roads |
| | | Increased cleaning and maintenance of roadways |
| | | 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 infrastructure and flooding of underground/subterranean tunnels in coastal cities | Create vulnerability maps to identify areas most at risk |
| | Degradation of the roadway surface and base layers from salt penetration | 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), pumping of underground systems |
| | | 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 |

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**Table 9.1** (continued)

| Relevant climate impacts | Impacts on road and rail 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 | 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 |
| | Flooding of infrastructure and subterranean tunnels, especially where drainage is inadequate | Audit drains regularly |
| | Infrastructure damages and decrease of structural integrity due to erosion, landslides and increasing soil moistures levels. | 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 |
| | 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 |

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**Table 9.1** (continued)

| Relevant climate impacts | Impacts on road and rail infrastructure | Possible adaptation measures |
|---|---|---|
| | 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 |
| More extreme rainfall events and flooding | Increased weathering of infrastructures | Use more durable material, such as more corrosion resistant material |
| | 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 | Enhance condition monitoring of earthworks, bridges, etc. especially after heavy rains, flooding (or storms) |
| | Subgrade material underneath rails may be degraded more rapidly, loosing strength and bearing capacity | 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 | Adapted technology standards |
| More intensive and frequent storms | Damage to stations/infrastructure fabric, bridges, flyovers, electrified tracks with overhead cables, train platforms street lighting, signs and service stations | Assess if currently used design standards can withstand more frequent and intense storms |
| | Risk of inundation by the sea during high winds, especially in combination with high tides and sea level rise | 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 | Improve weather forecasting for better predictability of storms, leading to better preparation and potentially less damages (early warning systems, disaster risk management) |

(continued)

**Table 9.1** (continued)

| Relevant climate impacts | Impacts on road and rail infrastructure | Possible adaptation measures |
|---|---|---|
| | Disruptions and consequent safety and socioeconomic impacts | Emergency planning and evacuation routes omitting high-risk areas |
| | Leaf fall may be concentrated, decreasing rail security/adhesion | Wind fences for open rail infrastructure |
| | Increased occurrence of lightning strikes to rail signalling or electronic systems | For overhead lines: circuit breaker protection |
| | Lightning strikes disrupting electronic signalling systems, e.g. axle counters electromagnetic compatibility of railways | Adapt design standard for signalling equipment |

This can seriously affect evacuation in the case of extreme weather events. The main adaptation measures, then, include:

- more resilient design standards and materials for infrastructure construction;
- improved drainage systems;
- regular maintenance of all infrastructure;
- urban planning that avoids high risk areas;
- minimising the need for road/rail infrastructure through compact urban planning; and providing sufficient redundancy to allow for alternative ways of passage when obstruction occurs

## *9.3.2 Vehicles and Operations*

Public and private vehicles and their services need to be adapted in order to function reliably under climate change. Adaptation of public transport and informal paratransit are especially important because they are the only motorised mobility options for large parts of developing city populations. Moreover, it is important for public transport services to remain attractive for those who can afford private motorised mobility in order to avoid modal shift towards more emission-intensive transport.

Table 9.2 gives an overview of relevant climate impacts on vehicles and operations, as well as their corresponding adaptation measures.

The vulnerability of the transit system to climate impacts should ideally be considered in the planning phase. Planning for public transport must also be closely integrated with planning for road infrastructure in order to design an efficient and resilient system. Moreover, it is important to consider that public transport plays a key role in disaster risk management and evacuation planning. The consequences of failing to properly integrate public transport services into evacuation plans was bitterly demonstrated during Hurricane Katrina in August 2005.

**Table 9.2** Summary of key climate change impacts and adaptation responses for vehicles and operations (ODPM 2004; Transportation Research Board 2008; Wooler 2004; Woolston undated)

| 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 | Sufficiently large opening windows |
| | Driver discomfort and exhaustion can lead to heightened accident levels | Tinted windows to shade off the sun |
| | May lead to shifts from public to air-conditioned private transport if resources allow or to air-conditioned taxis | White painted roofs |
| | Use of more costly and more energy-intensive air conditioning systems | 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<br>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 | Manage speed limits in bad weather conditions, *e.g.* reduce the running speed of trains |

(continued)

**Table 9.2** (continued)

| Relevant climate impacts | Impact on vehicles or driving conditions | Possible adaptation measures |
|---|---|---|
| | Flooding of the public transport fleet, causing economic damages | 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 | Driver training |
| | Overturning of vehicles or trains | 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 |

Residents of New Orleans without access to a cars were left behind with little relief or guidance from public authorities (Litman 2006; Renne 2005).

### 9.3.3 Mobility Behaviour

Changes in behavior can be expected during adverse weather events. Empirical studies point to slower traffic speeds during rainfall events that lead to delays and disruptions, the most severe impacts occurring during peak hours and on already congested routes (Koetse and Rietveld 2009). This is particularly relevant for many large cities already suffering from traffic congestion.

Adverse weather can also lead to less walking and cycling trips, at least beyond a certain trip length. This can encourage a shift to motorised transport (where those modes are available and affordable) and 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 are expected to be rather low. This underlines the importance of dense urban design, which can reduce travel demand and exposure to adverse weather impacts. In regions where hot weather reduces the attractiveness of cycling and walking, green and blue spaces offer a multi-purpose solution. Lakes and rivers, for instance, can have a cooling effect on the urban microclimate and improve infiltration (countering floods). Trees planted alongside walkways and bicycle lanes can also provide shade while improving the micro-climate, increasing attractiveness and acting as a minor carbon sink.

## 9.4 Taking Action on Adaptation

Providing information and raising awareness of the need to start adaptation today are important to improve the capacity and the acceptance of both decision-makers and society. Since the adaptation of urban passenger transport cannot be limited to simple technical fixes, it requires the behavioural change of transport users and a shift of thinking in planning approaches. Convincing municipal government officials across departments of the relevance of adaptation is a prerequisite for any successful adaptation strategy. In many cases, this will require training key personnel and identifying so-called ‘adaptation champions’ who will push the adaptation agenda within their departments.

City governments need to consider the effects of climate change in relation to particular departmental responsibilities (e.g., rail, roads or housing) but must also work across departments in order to develop an effective and integrated strategy. A balance should be found between providing access to mobility for all, increasing resilience and limiting greenhouse gas emissions.

Different groups of actors are in a position to act on distinct aspects of mobility. Transport planners, then, should interact with each, including, e.g., spatial or city planners, climate change experts, flood and disaster risk managers, transport providers, vehicle suppliers and civil society.

Climate change considerations must be integrated into the general transport system design, new transport developments, as well as maintenance activities of existing transport networks and emergency planning (Fig. 9.1).

Three basic approaches to adaptation can be identified: retreat (or avoid), protect, or accommodate.

Whereas *retreating* from areas at high risk from climate hazard may be a measure of last resort, in a planning context, retreat means *avoiding* development in these areas in the first place. This may also be the cheapest option (Fig. 9.2).

*Protection* can include both hard measures (e.g., sea walls or drainage) and soft measures (e.g., parks for cooling and infiltration, or the protection of mangroves to buffer storm surges). Whereas protection measures are often ‘external’ solutions,

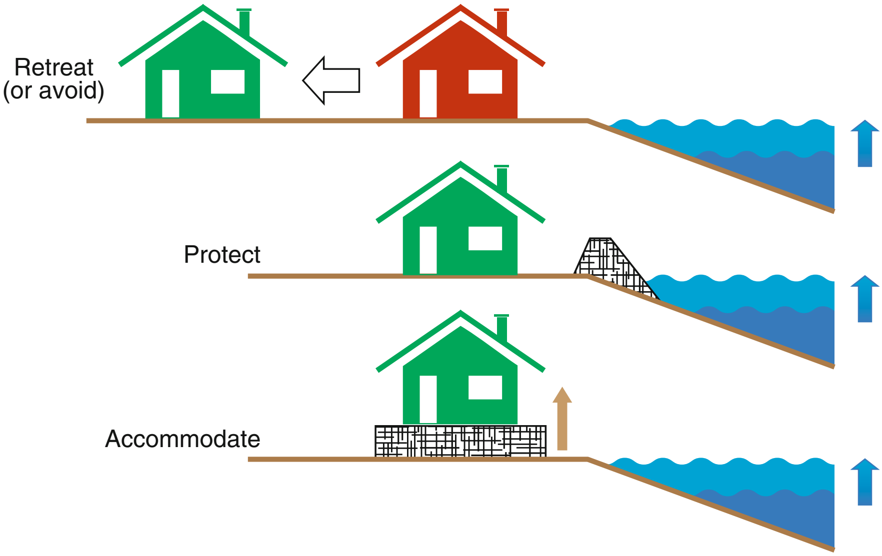


**Fig. 9.1** Three fundamental approaches to adaptation (Eichhorst 2009)

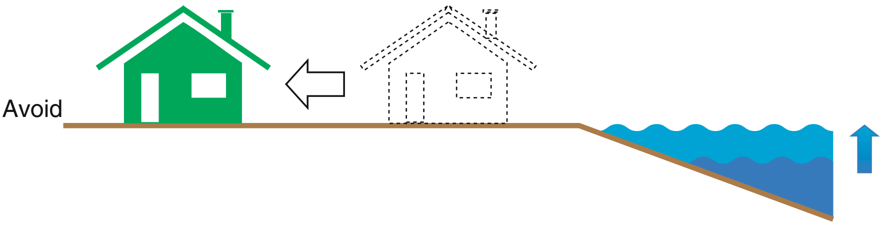


**Fig. 9.2** Avoiding high risk areas for new developments (Eichhorst 2009)

*accommodation* means adapting the transport system or infrastructure itself. Accommodation also includes both hard measures (mostly infrastructure and vehicles) and soft measures (e.g., emergency bus routes).

### *9.4.1 A Framework for Climate-Proofing Transport*

Transport planning and operations need to take current and future climatic changes into account. This means that new tools need to be integrated into transport planning. In particular, the assumptions built into models for long-term transport planning have to be revisited and potentially adjusted.

Climate change adds to the dynamics of urbanisation and increases the uncertainty involved in decision-making. 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. Studies have shown that we now know enough to develop plausible scenarios (Dessai et al. 2009; ECA 2009) in order to make informed decisions, which can significantly reduce vulnerability.

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

Largely based on the approach developed by the UK Climate Impacts Programme (UKCIP), seven important steps can be recognized for developing an integrated adaptation strategy for urban transport development. Figure 9.3 illustrates the process steps 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, mobility concepts in urban areas, comprehensive transport master plans, as well as ex-post climate proofing of existing transport networks and infrastructure (for details on each of the process steps please refer to Eichhorst 2009).

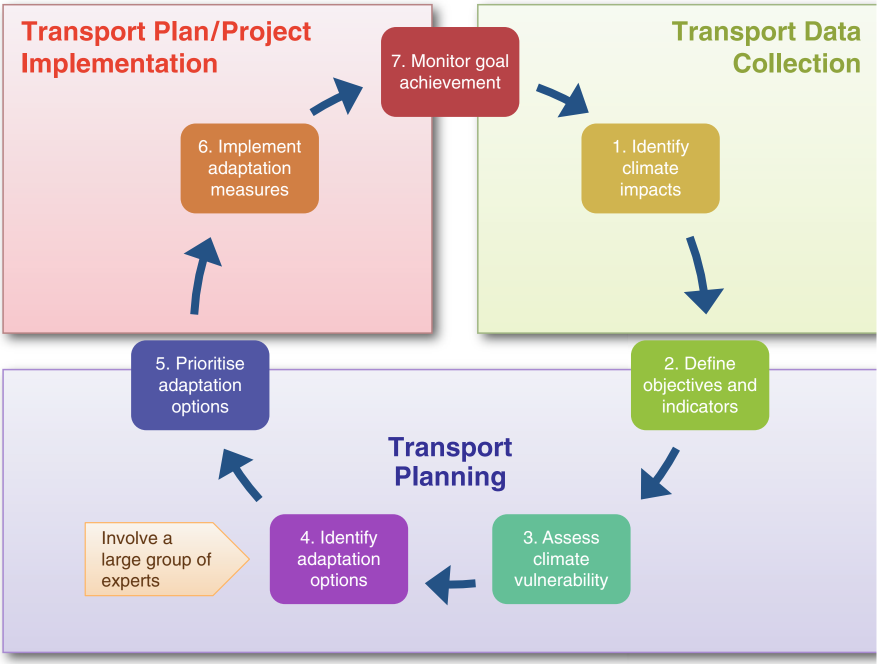


**Fig. 9.3** A framework for developing an adaptation strategy for urban transport development (Eichhorst 2009)

## 9.5 Conclusions and Outlook

In many developing cities, the impacts of extreme weather events on urban transport systems have already been severe. This was seen, for example, in the September 2009 flooding of Manila, when the city's major thoroughfares were rendered impassable by flash floods. This event illustrates the importance of developing more resilient sustainable urban transport systems, especially as impacts are expected to worsen. To be truly sustainable, the transport system must work for all, including the urban poor. This will require addressing current deficiencies in informal settlements.

If vulnerabilities of the urban system within developing cities are to be minimised, adaptation of urban transport must be addressed in the larger context of transport needs. Further work is needed on clearly defining realistic steps towards achieving climate-proof, pro-poor and affordable urban transportation systems in developing cities. For instance, more specific design standards suitable for developing countries are needed.

Adaptation and mitigation measures should be pursued in parallel as 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. Adaptation to climate change in the transport sector has to be seen in the framework of climate proof urban design. This means that the transport sector should be made both resilient *and* as low-carbon as possible. Only if both aspects are tackled can the risks of climate change be minimised.

Significant synergy potential between adaptation and mitigation measures can be identified in compact and transit oriented city planning. These include: minimising travel demand, reducing transport infrastructure and transport emissions, using green spaces and rivers for cooling, infiltration and higher attractiveness, and the development of climate proof design standards for infrastructure. Still, more research is needed to better understand synergies and trade-offs between adaptation and mitigation measures in transport.

There is an urgent need to allocate financial resources to adaptation planning and implementation at the city level. This may be achieved through tapping local, national and international finance sources. Ultimately, each city must identify the specific adaptation needs of its constituency. Local knowledge will help to make better projections and risk assessments possible. 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 with transport planning.

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