Strategy for Infrastructure

National Adaptation Plan
to Climate Change

6 Strategy for Infrastructure

6.1 Introduction

The term infrastructure encompasses a broad array of sectors, physical and operational integration of which are essential for functioning of a modern economy and society. This strategy covers the Transport, Urban-Mobility and Energy segments, all of which are of strategic importance for Brazil's development and receive substantial investment from the federal government, states, municipalities, and from the private sector. This Strategy was prepared jointly by staff of the Ministries of Transport (MT), of Cities (MCid), and of Mines and Energy (MME) which are the focal points for this strategy.

Transport, for purposes of this Plan, comprises the physical and operational infrastructure of various modalities of transport for moving people and cargo among Brazil's cities and regions, and encompasses federal highways, railways and waterways.

For Urban Mobility, the strategy covers an array of public and private, mass and individual, motorised and non-motorised transport modes used to move people and goods within cities and the physical infrastructure for provision of services, including routes, transfer points and systems.

For the Energy sector, the generation, transmission, and distribution segments are addressed. Energy is a vital input for practically all other economic sectors. In view of the high proportion of energy from renewable sources in Brazil's energy mix, the sector's greenhouse gas emissions are remarkably low by International standards.

Future climate projections indicate that Brazil is likely to be affected by various impacts of climate change, including increased occurrence of extreme events and rising sea levels, which may have numerous effects on all infrastructure segments.

Moreover, as a consequence of strong interdependence among the sectors covered in this Chapter, interruptions or reduced performance of one sector is likely to cause reciprocal and synergistic effects on others. Indeed, climate impacts may simultaneously affect infrastructure elements in more than one of these segments.

The objective of this Strategy is to assess impacts and vulnerabilities associated with climate change, from the standpoints of the Transport, Urban Mobility and Energy sectors and to propose guidelines for addressing them.

There are considerable interdependence among the factors that may affect these sectors, hence the need to adopt joint adaptation and planning approaches. Thus, the strategy proposes guidelines for adaptation, targeted at reducing vulnerabilities within the scope of each sector.

6.2 Transport

6.2.1. Introduction

The legal framework for Brazil's transport infrastructure is provided by the National Traffic System (Law 12379/2011 - SNV[15]) and encompasses the physical and operational infrastructure of different modalities of transport of people and goods, under federal, state and municipal jurisdictions. This strategy on adaptation to climate change for the transport sector focuses on highway, railway and waterway cargo transport in Brazil.

The National Plan for Logistics and Transportation (PNLT) developed by the Ministry of Transport is the main planning document for the transport sector in Brazil and assigns it a permanent management structure, based on a geo-referenced information system. The Plan provides for the main factors of interest to the sector, in terms of both supply and demand, with a view to adjusting the cargo-transport mix so as to stimulate use of the most efficient modalities.

The current Brazilian matrix of regional cargo transportation displays a high concentration of road transport which accounts for approximately 52% of total freight transported. In second place comes railway freight (30%), followed by coastal shipping (8%), inland waterways (5%), and pipelines (5%)[16].

In quantitative terms, the Brazilian road network extends for 1,720,755 km, most of which (78.6%) is unpaved. Paved roads account for 12.3% of the network; and 9.1% is planned but as yet unbuilt. Of Brazil's paved roads, 45.8% are under state jurisdiction; and 36.4% are federal highways.

The national railway network comprises approximately 28,000 km of track. The Brazilian inland waterway system stretches approximately 63,000 km through 12 river basins. Moreover, there are some 21,000 km of navigable waters of which, in 2012, 6,500 km were used by commercial shipping[17].

It can thus be perceived that Brazil has a strong transport matrix, the infrastructure for which is currently undergoing a renewed cycle of expansion and modernization. This underscores the importance of approaching climate aspects that could potentially expose the sector to impacts, both from the operational standpoint and from that of conservation of physical assets.

Within the context of the National Plan for Climate Change, in 2013, the Ministry of Transport published its Sectoral Plan for Transport and Urban Mobility for the Mitigation of Climate Change (PSTM) with

[15] The *National Transportation System* (SNV) comprises the Federal Transport System (SFV) and the transport systems of the states, Federal District and municipalities, including highway, railway and waterway systems.

[16] National Logistics and Transport Plan (2011)

[17] Strategic Waterway Plan (2013)

a view to demonstrating the Brazilian federal government's commitment to preparing for climate change, while maintaining competitiveness and conditions for economic and social-environmental development.

6.2.2. Impacts and vulnerabilities

Cargo transport infrastructure, like that of other sectors, may be affected by higher-temperatures, rainfall and wind-intensity scenarios, capable of causing direct and indirect impacts on the road, railway and waterway transport networks (MACARTHUR, 2013; FGV, 2013). Among such impacts, the most common are floods and landslides, many of which are consequences of extreme weather events (INPE, 2010). Intense rainfall events have caused flooding that seriously disrupts road and railway transport.

Unpaved roads, which account for 78.6% of the Brazilian road network, are highly vulnerable to a variety of climatic factors and especially to intense rainfall, which can lead to the interruption of transport routes (ARNDT; CHINOWSKYT, 2012). Such disruptions may even compromise interconnection between different transport modes, adding to transport costs by requiring additional safety measures or use of alternative routes which, generally, entail longer distances and hence higher costs (UNCTAD, 2009; UNECE & UNCTAD, 2010).

When saturated, the roadbeds of highways become subject to excessive pressures, causing deformation and cracking of asphalt surfaces. Under very intense rainfall conditions, structural changes may occur, causing damage to paved surfaces, increasing maintenance costs and demanding installation of additional structures and adaptations on the road transport system.

Table 10 lists climate variables and potential changes that may impact highway infrastructure, based on studies conducted in different countries.

Table 10. Impacts of extreme events on transport systems

Country	Climate Variable	Expected change	Expected impact of change climate variables
Canada	Temperature	Rise in maximum and minimum temperatures (especially in winter)	Increase in the frequency of freezing cycles – defrosting with deterioration in the pavement
	Rainfall	Increase in intensity and frequency	Increased presence of debris on roads, landslides, flooding and changes in sizing of bridges and culverts
	Sea level	Higher average levels	Flooding and damage to roadways, sidewalks and marine installations located in lowland areas
Holland/ United Kingdom	Rainfall	Higher in winter and lower in summer	Flood risk and associated damage from insufficient drainage capacity
	Sea level	Higher average levels and consequent rise in groundwater levels	Flooding, problems with light materials used on the base layers (EPS-Expanded Polystyrene), contamination by the leaching of ash used in the sub-base
Australia	Temperature	General rise	Changes in climate which, when drier, causes loss of asphalt binding and shortens lifespans of bituminous materials
	Rainfall	Lower intensity and frequency	

Source: Adaptation of *Technical Committee D. 2 Road Pavements* (2012) *apud* Project 2040 (SAE, 2015)

Increased rainfall and flooding events can cause erosion, damaging roadways and metal structures such as bridges. If such structures have older concrete components or lack maintenance, there is increased risk of moisture infiltration and corrosion (SOO HOO & SUMITANI, 2005). Highways may likewise become structurally unstable owing to subsurface erosion, resulting in increased maintenance costs (CNRA, 2009).

Another impact caused directly by increased rainfall or extreme storms, which are likely to occur more frequently, is runoff flooding that exceeds capacity of projected storm drains, overloading current drainage systems (SOO HOO & SUMITANI, 2005).

For terrestrial transport, the main foreseen impacts resulting from heavy rainfall or flooding are (OSWALD, 2009): (1) increased flooding of roadways, low bridges and tunnels; (2) increased frequency and severity of overflows from drainage systems; (3) increased flooding of evacuation routes; (4) delays and stoppages of vehicle traffic; (5) higher incidence of disasters on roads caused by landslides and erosion; (6) washout of bridge abutments and excessive moisture in crevices, causing deterioration of structures and slippage of slabs; (7) destruction highway and bridge signage. All these impacts would result in traffic-flow problems and interruption of journeys.

For inland-waterway navigation, the impacts of extreme rainfall events and increased numbers of days of rainfall could lead to higher water levels increasing the length of high-water seasons, leading to enforced stoppages of service for safety reasons, causing substantial economic impacts (MIDDELKOOP *et al*., 2001; KREKT *et al*., 2011).

By contrast, periods of drought, also foreseen to become more frequent, could cause drops in water levels, increasing the average annual number of days during which inland navigation is hampered or suspended, owing to limitations on waterway carrying capacity (MIDDELKOOP *et al*., 2001). Even if improvements to navigation channels are carried out, they will tend only partially to relieve such problems. Moreover, low water levels oblige vessels to use only part of their potential capacity, thereby considerably increasing costs for this transport mode (KOETSE & RIETVELD, 2007).

Changes in temperature will tend to impact transport infrastructure, such as bridges and railway tracks and to cause deterioration of roads and railways, thus requiring more frequent maintenance (SOO HOO & SUMITANI, 2005). An increase in the number of days with high temperatures raises the risk of premature deterioration of transport infrastructure caused by thermal expansion of bridge joints, increased deformity of paved surfaces and causing changes in periods of construction activity (IPCC, 2007; OSWALD, 2009).

Though materials used in assembly of metal structures permit a certain degree of plasticity allowing for contraction and expansion (MEYER, 2008) nonetheless, uncertainties relating to future climate change could pose threats related to tolerance of the various types of transport infrastructures to greater temperature variations (IPCC, 2007).

For example, on highways, degradation of paved surfaces is directly related to thermal stress, which can cause softening of asphalt layers when temperatures exceed projected limits (LAVIN, 2003). For inland navigation, excessive warming could lead to lower water levels and, consequently, reduced flow levels, caused by evaporation (LEMMEN & WARREN, 2010).

Higher sea-surface temperatures give rise to tropical-storm phenomena, causing strong winds to become more frequent (OSWALD, 2009). Such winds may: (1) reduce the stability of bridge decks, (2) lead to an increase in highway and railway journey interruptions, caused by blockage of lanes and tracks by falling trees and rocks, and (3) increase the probability of highway infrastructure flaws.

As mentioned earlier, variations in seasonal weather conditions, besides causing direct impacts, may have indirect impacts on transport and other economic sectors. For agriculture, problems arising from logistical bottlenecks could be exacerbated by the impacts of climate change on the transport sector, especially on highways (FGV, 2013).

It is likely that, as a consequence of natural disasters, transport costs will rise and that new alternative routes will be sought to carry produce to markets, thus disrupting traditional supply chains (BECKER *et al*., 2012). Increased frequency and intensity of extreme events may also affect the breaching of bottlenecks, by increasing maintenance costs of barges and wagons, thus causing delays and raising costs (IPCC, 2007; POTTER *et al*., 2008; UNCTAD, 2009).

An accumulation impacts on the transport network may result in loss of infrastructure assets, hampering the recovery capacity and resilience of the entire sector, given that transport infrastructure accounts for a substantial national investment.

For cargo transport, adaptation can be regarded as the sector's response to the impacts of foreseen extreme weather events. Brazil's social development and economic growth require constant investment in transport infrastructure. Such investment becomes even more necessary in a context of climate change, to maintain or reduce costs of goods and services, and to enable free circulation of people throughout the country.

Analysis of the adaptive capacity of transport system management to climate change often poses complex questions, since transport infrastructure is dependent upon and interconnected with numerous other systems. Moreover, potential impacts are not limited to a given geographical region, but have repercussions that extend to other transport modes.

However, in view of the need to re-establish or maintain the continuity of cargo-transport links among the various regions despite climate threats, the National Transport System (SNV) and National Transport Logistics Plan (PNLT) propose adaptation strategies, such as selection of an alternative route and switches of transport modality in the event of interruption of stretches of a major highway.

The main objective of the National Plan for Logistics and Transportation is to restore sectoral strategic planning. A geo-referenced database has been set up to enable modelling and assessment of long-term project outcomes.

Such projects encompass expansion of cargo-carrying capacity on strategic routes, filling of gaps in the national highway network, and construction of new sections to enable increases in efficiency, through redirection of cargoes from roads to railways and/or waterways. Furthermore, such logistical integration projects focus on reducing bottlenecks at strategic locations, such as cargo terminals of ports and airports.

The main aim is to promote stability of the Brazilian cargo transport matrix. This goal is linked to the strategy for ensuring capacity of the transport sector to respond to potential damage to infrastructure in areas or regions likely to be affected by extreme weather events, thereby making the system less vulnerable to climate change.

To complement the PNLT and further promote integration with other policy areas, the Ministry of Transport has launched the Strategic Waterway Plan (PHE) with the aim of enhancing waterborne cargo and passenger transport, especially on inland waterways.

6.2.3. Guidelines for adaptation

Some of the strategic issues related to reducing vulnerabilities to climate change in the transport sector are addressed by a strategy for promoting a more stable cargo-transport matrix. This could make the system less vulnerable while, at the same time, ensuring development of intermodal approaches, through improvements in access to port, railway and airport terminals. Such improvements in the flow of goods and passengers would be especially significant during occurrence of critical climate events.

Notwithstanding the attention that planning of the Brazilian transport system has received in recent years, further rationalisation of the transport mix will require institutional measures and significant investment.

There follows a set of guidelines to be adopted by the Transport sector, for addressing emerging needs for adaptation to potential effects of climate change:

1. Promote greater engagement of the transport sector in issues relating to adaptation to climate change, through capacity building and dissemination of information.

2. Take into account, as appropriate, issues relating to adaptation to climate change in institutional plans, programmes and projects of the Transport sector.

3. Prepare studies and research on the relationship between climate change and the vulnerability of transport infrastructures, as inputs for public policies, planning and identification of solutions for the sector, through Ecosystem-based Adaptation (EbA) approaches.

4. Evaluate possible co-benefits and synergies between mitigation and adaptation strategies relating to different alternatives applied to the transport sector.

5. Improve production and availability of information on extreme events relating to the transport system.

6. Increase the capacity of the transport sector to respond to extreme climate events by means of plans, action protocols and preventive measures.

The Ministry of Transport hereby assumes a commitment to assimilate the guidelines for regional public transport established in this NAP, within the scope of the Sectoral Plan for Transport and Urban Mobility for Mitigation and Adaptation to Climate Change (PSTM) as defined deadline setting by the Inter-ministerial Committee for Climate Change (CIM).

6.3 Urban mobility

6.3.1. Introduction

The guidelines of the National Urban Mobility Policy (PNMU) were established by Law 12587 of 3rd January 2012, commonly referred to as the Urban Mobility Law, which defines mobility as: *"the manner in which movement of people and cargo takes place within urban space"*. Such movement is essential for economic and non-economic viability of activities in cities, where roughly 84% of Brazil's population is concentrated (IBGE, 2010).

According to the Mobility Law, the National Urban Mobility System comprises an organized and coordinated range of transport modes, services and infrastructures that enable movement of people and cargo within the territory of a municipality. These include: motorized and non-motorized vehicles; urban passangers transport and cargo services; mass and individual, public and private transport; roads and other public routes; including underground railways; waterways and bicycle lanes; parking lots; terminals; stations and other transport hubs; stops, boarding and disembarking of passengers and cargo; roadway and traffic signage; equipment and installations; traffic control instruments; inspection; collection of fares and fees; and dissemination of information.

Urban mobility in Brazilian cities is subject to disruption arising from adverse weather conditions and climate events such as flooding, temperature variations, etc. (hereinafter referred to as climate impacts). The frequency and severity of such impacts may vary, depending upon projected climatic variations and the characteristics of each locality having potential to generate economic losses and jeopardise the well-being of the population.

Thus, for the urban mobility sector, adaptation is crucial for protecting the intrinsic value of transport infrastructure, ensuring the reliability of mobility systems, the feasibility of economic activities, and safeguarding the quality of life and safety of the population.

The activities of federal, state and municipal bodies on this theme must be aligned with provisions of the Urban Mobility Law. At the federal level, the Ministry of Cities is responsible for overseeing implementation of the instruments foreseen in the PNMU, such as the Urban Mobility Plan, deployment of which is mostly in the hands of local governments.

In consonance with PNMU guidelines, in June 2013, the Ministry of Cities launched the Sectoral Plan for Transport and Urban

Mobility for Mitigation and Adaptation to Climate Change (PSTM) within the context of the National Plan for Climate Change, upcoming review of which is outlined in this NAP.

6.3.2. Impacts and vulnerabilities

The effects of climate change will be unevenly distributed throughout Brazilian territory (see Volume I of the NAP) both in terms of gradual changes in weather patterns and temperature and rainfall levels, and in the behaviour of extreme events, with rising degrees of uncertainty.

Sea levels are expected to rise throughout this century, with effects exacerbated by extreme climate events of increasing intensity, such as storms and strong winds associated with low pressure, neap tides and high waves, posing risks to Brazilian coastal cities, as described on Strategy for Coastal Zones.

Vulnerabilities for urban mobility stem from interaction among various aspects, including weather conditions, degree of exposure, sensitivity, and associated adaptive capacity. The influence of such factors varies in accordance with locality and specific characteristics of each conurbation, and, consequently, the severity of impacts may vary greatly from one area of a city to another.

Exposure is associated with systems and the infrastructure characteristics of the various different transport modes potentially subject to climate impacts, and that may have reflexes in terms of damage to physical assets, reduced performance, or interruption of mass-transit or cargo-carrying capacity. Exposure may also directly or indirectly affect travel choices of the population, with repercussions of a socioeconomic nature.

Within the context of climate-change scenarios foreseen for Brazilian territory, the following climate aspects are likely to have an impact on urban mobility:

Higher average temperatures, heat waves and exacerbated “heat-island” effects;
Increased rainfall and occurrence of extreme events (storms, strong winds), causing flooding, floods, landslides, tree falls, higher groundwater levels, among other consequences;
Rise in average sea levels and high tides, associated with extreme events, sea swells and tidal storms, causing flooding in coastal areas, higher groundwater levels and salt-wedges in estuaries, among other consequences;
Reduced rainfall, lower flow and water levels in water bodies.

The following table illustrates the initial impacts of climate change and their potential effects on urban mobility, and other infrastructures.

Table 11. Potential impacts on infrastructure and urban mobility

<table>
<tr><th>Climate impact</th><th>Potential impacts on Infrastructure</th><th>Potential impacts on Urban Mobility</th></tr>
<tr><td>Rising temperatures, heat waves and aggravation of heat islands</td><td>Deterioration and deformation of paved surfaces and tracks;

Deterioration and deformation of structural elements of bridges, viaducts and culverts;

Fatigue in building materials;

Instability on slopes;

Overheating and overloading in equipment (engine cooling, air conditioning, electrical control systems, signalling and communications).</td><td rowspan="4">Reduced safety and / or performance of transport modes;

Reduced comfort of passengers, pedestrians and cyclists;

Increased travel time;

Blocking of transport routes *;

Restricted logistics for distribution of goods and services;

Increased operational costs (maintenance and replacement of assets);

Reduced participation of mass transport and non-motorized modes.</td></tr>
<tr><td>Increased rainfall and occurrence of extreme events</td><td>Damage to infrastructure owing to flooding on transport routes*, terminals, stations and special artworks;

Corrosion and deterioration of structures;

Instability on slopes, landslides and trees falling;

Damage to equipment and electrical systems (air conditioning, control, signalling and communication systems);

Damage to foundations of transport routes * (base / sub-base etc.);

Overloading in drainage systems;

Reduced of visibility and vehicle traction;

Restricted navigability (headways under bridges etc.).</td></tr>
<tr><td>Rising sea levels</td><td>Damage to infrastructure due to coastal flooding;

Erosion and corrosion of structures and building materials;

Damage to foundations of transport routes (base / sub-base).</td></tr>
<tr><td>Reduced rainfall</td><td>Restricted navigability.</td></tr>
</table>

Source: AUTCC – GIZ and EU Strategy, adapted from SEMOB/MCid.

* the term “ transport routes “ includes highways, railways, subways, waterways, cycle tracks and walking paths

Potential impacts on road and railway infrastructures share some similarities, including those associated with special engineering structures, drainage systems, roadbeds, stability of embankments, among others.

Certain systems have very specific sensitivities to temperature variations, such as propensity of rails to buckle and fatigue, of transmission lines to deform/snap, of paved surfaces to deform, of motors to overheat, etc. Weaknesses of this type may result in greater demand for cooling systems and add to the discomfort of users.

Ground-level systems tend to be more exposed to extreme events. Threats of this type may also degrade and affect access to underground stations and terminals. Moreover, impacts to isolated elements of transport systems tend to have repercussions throughout the network, especially when these lack flexibility, integration, scope, and redundancy capacity. Thus, not only events that shut down entire transport systems, but also those that could lead to reduced operational performance need to be considered.

Rising sea levels could cause devastating flooding of coastal areas, exacerbating sea-water encroachment and overflowing of inland water courses, saltwater intrusion, rusting of infrastructure elements, coastal erosion, etc.

Such climate impacts directly or indirectly affect the movement of people and distribution of goods and services within cities, and raise the probability of accidents. They also generate additional costs for maintenance, recovery and/or refurbishing of damaged or deteriorated assets. Some such damages are immediately visible, whereas others only become apparent in the medium or long term.

The severity of potential impacts in each city varies not only according to climate conditions, but also on biophysical and socio-economic attributes of the site.

In the case of extreme rainfall events, for example, susceptibility to floods, flooding and landslides depends on an array of factors, including: topography (declivity, depressions, and floodplains), presence of water bodies, land use (surface sealing, presence of vegetation), soil types, effectiveness of urban drainage systems, etc.

From a socioeconomic perspective, conditions of mobility (i.e., access to public-transport services, decent roads and sidewalks, etc.) in a given locality or neighbourhood have a direct influence on the magnitude of impacts. In practical terms, heavy rainfall may cause major disruption of mobility services for populations in poorly served areas. In consequence, they may have to walk longer distances in the rain or on inadequate roads, wait longer for transport, or simply be unable to reach their intended destinations.

Such restrictions on mobility may induce, or even require, adoption of alternative forms of transport, new routes, or altered timetables, implying changes in the behaviour of commuters. Choices and reactions to transport stoppages caused by adverse climatic conditions are often conditioned by factors such as schooling levels, income bracket, age group, and characteristics of the intended trip (distance, cost, motive etc.). Thus, different segments of the population will react differently to inconveniences caused by interruption of mobility services. Moreover, disabled people count as a vulnerable group in the context of this NAP, which reinforces the challenge of ensuring universal accessibility to urban mobility services.

Climate-related disruptions of infrastructures in other sectors, including fallen electricity cables, failure in communications and signalling systems, outages of electric-power supply for subway, light rail and tramway systems may also have repercussions on urban mobility. Sectoral policies that address climate-change adaptation in the fields of urban development, sanitation, urban solid wastes and telecommunications are also correlate to those for urban mobility.

Day-to-day experience in Brazilian cities has shown that adaptation is needed not only to address gradual climate changes but, more pressingly, the challenges of intense adverse weather events in the short term, often referred to as extreme events. These need not refer only to catastrophic events, but also to more moderate ones that nonetheless cause great inconvenience to the population.

With respect to extreme events, it is plainly impossible to totally eliminate all their impacts. However, the concept of resilience implies ways in which people and systems can react in order to minimize negative consequences, i.e., the capacity to anticipate, prepare, respond and recover, in adverse situations.

In the mobility sector, adaptive capacity and resilience are closely related concepts, covering an array of conditions necessary for development and implementation of adaptation measures. Such measures encompass institutional arrangements, technology, knowledge and economic management that relate to structures, resources, information analysis, availability of technologies, and the existence of programmes for mitigation and adaptation to climate change and urban-mobility planning. Moreover, the willingness of government, private-sector, academic and civil-society players to work together on this topic is also of fundamental importance for adaptive capacity.

The quality of public-transport systems is also an essential factor for gauging adaptive capacity, and entails aspects relating to coverage, capacity, integration and alternative modes and routes, which enable better management in the event of stoppages or loss of performance of one specific element of a system, minimizing impacts on commuter journeys.

Other examples of adaptive capacity include: (1) availability of technical solutions (drainage and pumping systems, weather-proofing of equipment, enhanced construction methods and maintenance technologies etc.); (2)

cooperation among the sectoral bodies responsible for transport and mass-transit systems, sanitation, and among federal, state and municipal administrations, especially in large metropolitan regions; (3) early-warning systems to promote readiness for extreme weather and public information systems to advise the population on how different transport modes will be affected, offering advice on alternative routes, etc.

The vulnerabilities of the urban mobility sector relate to a combination of current and projected climate impacts, to biophysical and socioeconomic characteristics, to the quality of installed transport infrastructure and systems, and to the commuting patterns of the population. All these factors need to be addressed when assessing current adaptive capacity, remembering that, the greater the adaptive capacity, the lower the vulnerability to impacts.

6.3.3. Guidelines for Adaptation

In view of the rates of population growth prevalent in Brazilian cities, it is important that new infrastructures and urban mobility systems incorporate an adaptation perspective. Adopting such a perspective requires a focus on planning of land-use and settlement patterns, integrated infrastructure projects that take into account climate risks assement, so as to avoid generating new exposures and vulnerabilities. Moreover, adoption of sustainable urban-planning, mixed land-use and density control principles, which minimize distances and/or commuting needs, can help reduce vulnerability of the urban-mobility sector to climate change while, at the same time, reducing greenhouse-gas emissions.

There needs to be a complete overhaul of existing transport infrastructure from an adaptation perspective, targeted at minimizing climate impacts, based not only on maintenance cycles, but also on reassessment and refinement of technical specifications.

In contrast to private automobiles, public mass-transit systems and non-motorized transport help reduce congestion and facilitate commuting. Improvements to mass-transit systems and promotion of non-motorized transport could create synergies between adaptation and climate-change mitigation goals while, at the same time, benefiting the public and the economy as a whole.

Technical solutions that imbue urban-mobility systems with greater resilience and that focus on prevention and minimization of the impacts of extreme events should be considered, with a view to facilitating transport of people and goods and reducing losses and recovery time in the event of stoppages. Efficient implementation of such solutions entails adoption of robust transport systems, prior identification of bottlenecks and prioritization of routes and infrastructures capable of operating even when such events are occurring, thereby providing an alternative to more vulnerable transport modes. Planning of such solutions must take into account rising demand, and be equipped with operational signalling and early-warning systems to orient passengers in the event of emergencies.

Demarcation of green areas, planting of trees, recovery and protection of natural streambeds and of lakeshores, i.e., Ecosystem-based Adaptation (EbA) measures, should serve as the basis for local-level programmes for fostering adaptation and resilience. Invariably, the effectiveness of adaptation strategies depends upon public and private-sector involvement and production of knowledge, both on the national and local levels, and its dissemination to the public. Although Brazil's municipalities are responsible for the planning and management of their local transport systems, the coordination function of the federal government reduces duplication and helps foster synergies, especially in metropolitan regions.

Measures for implementation of climate-change adaptation strategies should not be taken on an *ad hoc* basis, but rather, be intrinsically incorporated into the decision-making processes and policies of the sector, with a view to minimizing inconvenience and economic losses for the population.

There follows a set of adaptation guidelines for the mobility sector:

1. Inter-institutional coordination among government institutions, to harmonize national adaptation plans and policies with local planning and actions, involving private-sector, civil-society and academic players;

2. Consideration of urban-mobility vulnerability studies for preparation of local-level adaptation and resilience programmes, in coordination with relevant sectors;

3. Incorporation of adaptation and resilience to climate change into urban-mobility plans, in coordination with urban land-use planning and in line with Ecosystem-based Adaptation (EbA) principles;

4. Strengthening of mass-transit infrastructure and popularisation of non-motorized individual transport, through facilitation of intermodal integration and flexibility in the system;

5. Stimulus to studies on the need to review technical standards, both for planning and maintenance of urban mobility infrastructure, incorporating an adaptation perspective;

6. Building awareness of climate change and its impacts on mobility, encouraging the population to prepare and contribute toward mitigation and adaptation measures;

7. Disseminate information on urban transit networks;

8. Support innovative projects for reducing carbon emissions and increasing capacities for adaptation to climate change.

6.4 Energy

6.4.1. Introduction

Renewable energy is considered a priority and diversification of sources a fundamental principle of Brazil's energy matrix. A number of mechanisms provided for in legislation are targeted at meeting diversification goals.

Given the importance attributed to renewable energies and their wide distribution throughout Brazilian territory, an assessment of the degree to which climate change may impact such facilities is needed to identify threats and potential means of reducing vulnerabilities.

When assessing vulnerabilities of the energy sector to impacts of climate change, the electric-power sector, broken down into the generation, transmission and distribution segments is the first point of focus in the context of this NAP. This is a complex sector, as it involves energy derived from a variety of sources, including both fossil fuels and renewables.

The main energy source for the National Electricity Grid is hydropower, whereas other renewable and fossil-fuel energy sources complement the system. Thus, the Brazilian eletric power Matrix is characterised by much lower greenhouse-gas emissions than systems of similar size in other countries of the world. An Interconnected Transmission Network links generation facilities installed in a variety of river basins located throughout the country and reserve non-hydraulic generating capacity for use when water shortages affect hydroelectric generating capacity.

Figure 7 shows the composition of the energy sources that feed the Brazilian Electric Power Matrix:

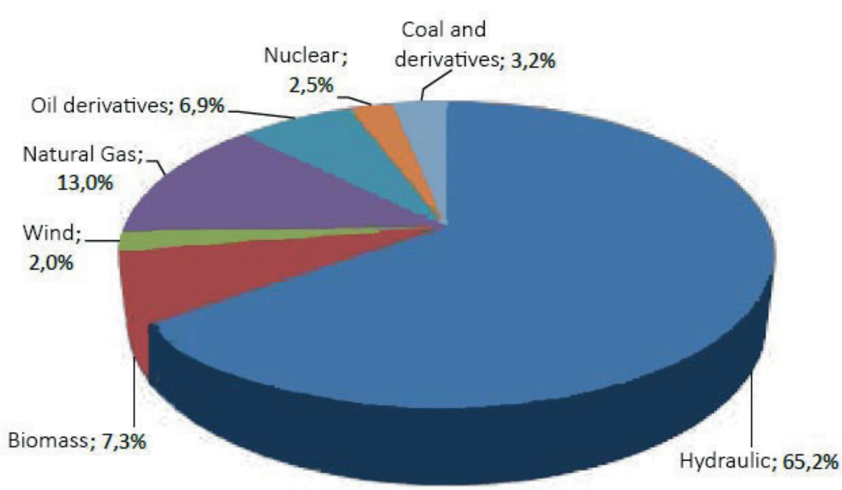

Figure 7. Brazilian Electric Power Matrix
Source: National Energy balance sheet, base year 2014

Hydroelectric power is distributed throughout Brazilian territory. The main reservoirs and hydroelectric power plants for generation are located in the central-south of Brazil. There are, moreover, a number of basins where hydroelectric potential has not yet been exploited, especially near borders in the North region and on rivers in the Amazon Basin.

Brazil also has great potential sources of wind power, mostly concentrated in central and coastal areas of the Northeast, Southeast and South regions. The map in Figure 8 shows the most promising areas for exploitation of Brazil's wind power potential:

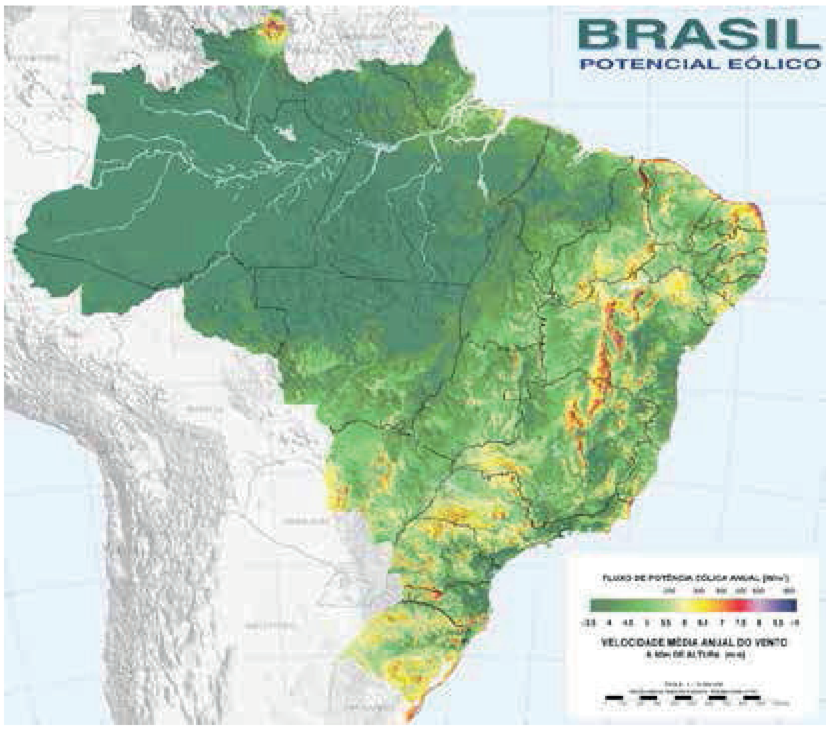

Figure 8. Brazilian Wind Farm Potential
Source: Centre of Research- CEPEL

Biomass provides another significant renewable-energy source for generation of electric power from thermal power plants, fuelled by sugar-cane bagasse, located alongside sugar and ethanol mills. The Southeast and Northeast regions of Brazil have the greatest potential for this form of electricity generation and ethanol production.

Another potential power source for electricity generation is solar power, as currently collected and converted into electricity by photovoltaic arrays, and, in the future, through solar-thermal power plants. Though solar power currently contributes only a small component of Brazil's electricity matrix, this is likely to grow significantly in coming years.

Brazil has high solar radiation potential, fairly evenly distributed throughout the country, as is shown in Figure 9.

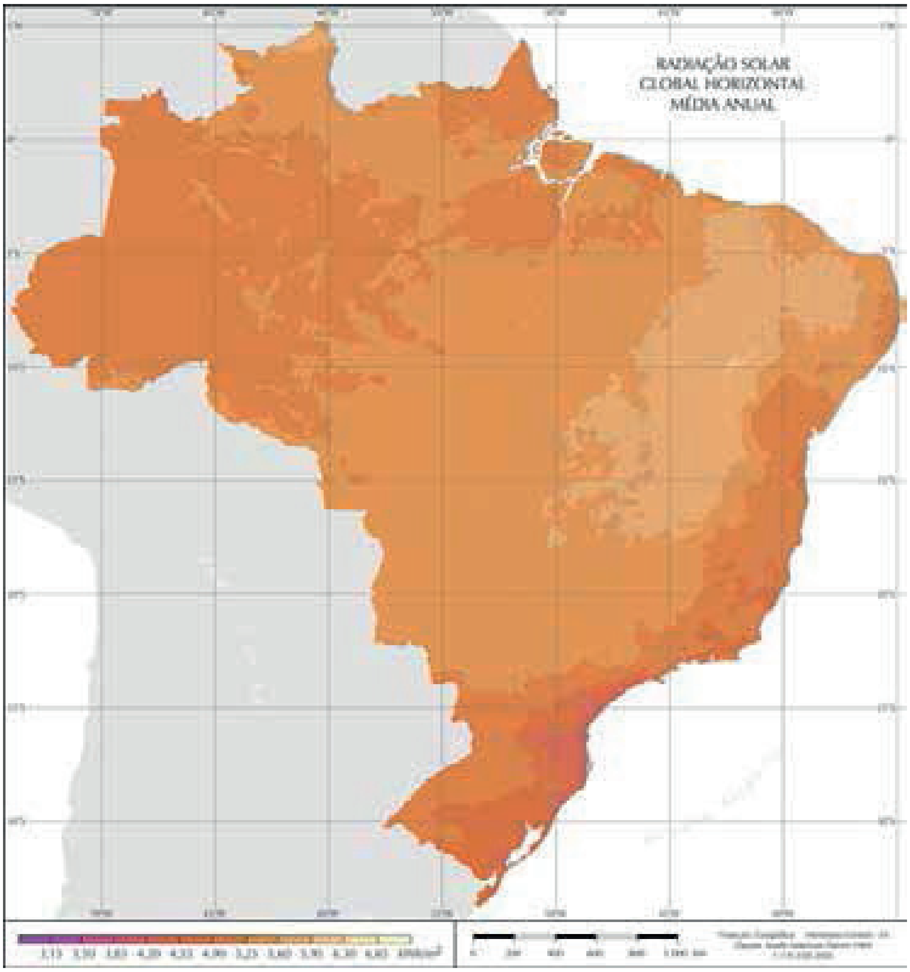

Figure 9. Solar radiation in Brazil
Source: Brazilian Atlas of Solar Energy- INPE/2006

A network of transmission lines interconnects power plants in different river basins, thereby optimising availability of water resources in the various reservoirs throughout the country. Vast quantities of water stored in the reservoirs of hydroelectric power plants serve to regulate downstream flows, storing water for use in periods of low rainfall.

To enhance the effectiveness of this system, a centralised body, the Electric System National Operator (ONS) issues orders[18] for discharges of each plant and for operation of the transmission line network, with a view to optimising supply. Figure 10 shows a diagram of the National Interconnected Transmission System:

[18] *Dispachos* – orders issued by the Electric System National Operator, determining which plants should operate and which should be on standby so as to maintain, permanently, a production volume equal to consumption, taking into account plants of lower cost. In general terms, these orders initiate power generation from the hydroelectric plants and when necessary, generation by the lower-cost thermal plants, provided the plant is in technical conditions and has fuel.

Figure 10- National Interconnected System – NIS

Source: Electric System National Operator – ONS, 2014.

A further component of the electricity system is generation reserve, i.e., large thermal-electric plants powered by fossil fuels that spend much of the time on standby, to fill gaps when hydropower sources are in short supply.

Energy security remains one of the main objectives of an adaptation programme for the electricity sector. In this regard, fossil fuel power plants, notwithstanding their greenhouse-gas emissions, fulfil an important role by ensuring stability to the system.

Moreover, the need for maintenance on hydroelectric power plants also makes necessary an expansion of thermal-generation capacity. However, technological criteria and selection of fuels for such plants must prioritize low greenhouse-gas emissions and seek to strike a balance between mitigation and adaptation.

Thus, an assessment of the vulnerabilities of the electrical sector should extend beyond a focus on individual river basins and contemplate the network as a whole, taking into account the array of energy sources, operation of the system, and its reserve-capacity structures.

6.4.2. Impacts and vulnerabilities

There is a consensus among the scientific community that climate change is taking place and that it is highly likely that Brazil, like the rest of the world, will suffer ever more impacts in the next few decades. Regardless of the accuracy of these predictions and doubts as to which scenario will prevail, it is probable that electric-power generation will in some way be affected.

Of the climate parameters most likely to affect the sector, higher average temperatures that increase evapotranspiration of lakes and water courses and changes in rainfall patterns are of greatest concern. Rainfall, in conjunction with evapotranspiration, affects the calculation of the water balance, which is an important conditioning factor for maintenance of river flows.

Other weather parameters also influence electricity production, including cloud cover that reflects solar irradiation, and changes in wind regimes that have a direct effect on generation from wind turbines.

When considering the effects of climate change on electricity generation, other anthropogenic factors also merit consideration. Surface Characteristics and settlement patterns, for example, may interfere in regional wind dynamics. Consumptive[19] uses of river flows, for urban water supply and irrigation, can reduce water availability. In some cases, the effects of these anthropogenic variables overlap with climate issues.

When assessing potential threats to the electrical system in a context of climate change, it is repercussions on the capacity of the National Interconnected Power System to ensure regular supplies of electric power that are of greatest concern. Only by adopting this focus is it possible to make an informed assessment of the vulnerabilities of the system and to determine possible adaptation actions.

Aspects relating to demand for energy brought on by climate change (e.g., increased use of air-conditioning in response to higher temperatures) should be considered when addressing issues of energy availability. On the other hand, greater energy efficiency brought on by technological developments should also influence energy consumption. There follows a list of such aspects as they relate to the electrical system:

[19] Consumptive uses of water refer to uses that abstract water from its natural courses, decreasing spatial and temporal availability. For example: watering livestock, irrigation, public water supply, industrial processing etc.

Impact of the introduction of new technologies, for example, electric vehicles and energy-efficiency policies;
Impact of future consumption patterns in residential and commercial buildings (dwellings and smart buildings);
Penetration of new technologies, such as intelligent networks and ultra-high-voltage transmission lines;
Greater penetration of distributed generation from different sources, for example, photovoltaic arrays on rooftops;
Self-production of electricity by large consumers, using renewable and fossil-fuel sources, such as cogeneration using natural gas.

Adaptation strategies for the electricity sector must also take into account issues relating to environmental legislation for protection and restoration of natural resources (fauna, flora and physical environment). Reducing environmental impacts, through adoption of Ecosystem-based Adaptation (EbA) strategies is an important step toward building resilience.

Such strategies include electricity generation by hydroeletric power plants of various sizes, wind farms, local and distributed solar-power generation, and thermal power plants that use sugarcane biomass as a feedstock. Such systems are subject both to changes in average climate parameters and to extreme events, the latter being the phenomena most likely to cause outages of transmission and distribution systems.

Assessment of the impact of changes in weather patterns entails evaluation of the vulnerabilities of the energy power system to such changes. In the case of hydroelectric power plants with large reservoirs, for example, the characteristics of such reservoirs may mitigate the effects of river-flow variations and, in turn, their electricity-generation capacity. Such characteristics affect not only operational capacity of the power plant, but also regularization of downstream flow levels.

On the other hand, run-of-river plants and plants with small reservoirs lack storage capacity and are thus more exposed to climate variability. This implies that a balance needs to be struck between ensuring continuity of electricity-generation services and the sensitivity of generating systems to climate-change impacts.

In order fully to appreciate the vulnerability to impacts of climate change of the infrastructure of the electrical system as a whole, a synergistic approach is needed. Some regions of Brazil are likely to suffer increases in rainfall, temperature, winds, and solar radiation, whereas others will probably experience declines.

The National Interconnected System enables offsetting of many such effects by shifting and matching available supply to areas of greatest demand. Such offsetting provides the electrical system with intrinsic adaptation capacity that, to some extent, compensates for certain vulnerabilities. Notwithstanding the flexibility that such offsetting provides, Brazil's national energy policy must continue to pursue its goals of ensuring energy security and lowering costs for consumers. Other examples of the adaptation capacity of the sector are:

- A robust transmission system with ramifications to all the regions of the country, interconnecting power plants and load centres in different river basins, with transmission of large blocks of energy over thousands of kilometres, with high reliability;

- A centralised management agency (ONS) that dispatches power throughout the nation;

- A diversified electricity mix with electric power derived from a variety of sources. Seasonal differences in the conditions for energy generation from different sources create complementarities, e.g., generation from wind farms and thermal biomass plants tends to be most productive in months when river flows are lowest. Figure 11 shows typical monthly variations in energy production from different sources over the year.

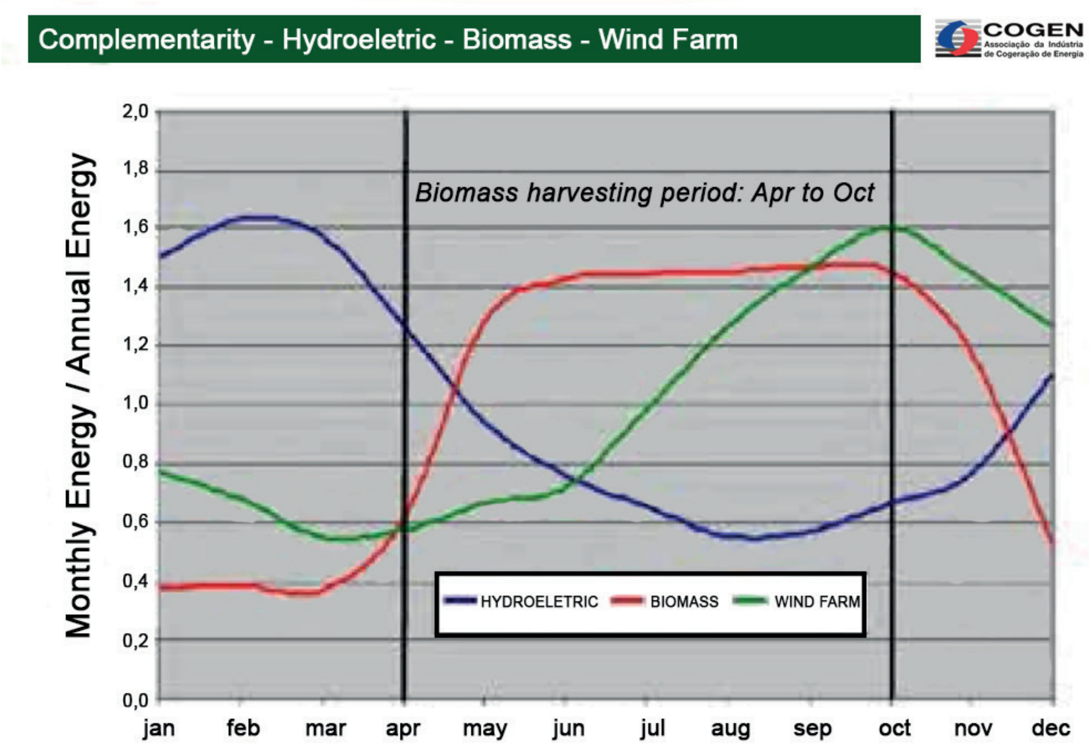

Figure 11- Typical Monthly Variation of energy generation from Hydro, Biomass and Wind sources
Source: Electric System National Operator – ONS

• Reserve generation capacity that can be brought on line to ensure stability of the system.

Certain impacts of climate change may, in effect, strengthen the resilience of the electricity generation system. This could be the case if:

• Climate change accentuates differences in seasonal rainfall patterns of river basins of the Central-South and those of the North region of Brazil. Should this occur, with adequate storage capacity, more intense rainfall in one region could, to some extent, offset lower rainfall in other regions;

• Likewise, offsetting of electricity produced from different sources could occur if climate change favours generation from a particular source in one region, this could offset generation shortfalls in another region.

In the light of these inherent characteristics of the electrical system, an accurate analysis of the real vulnerabilities that it is likely to face can be made, and adaptation measures to mitigate such vulnerabilities and increase resilience can be proposed.

Though in view of their complexity, any quantitative analyses of the vulnerabilities of the electricity sector must entail a great variety of studies, it is nonetheless possible to identify certain isolated climate-change impacts on specific systems, without dwelling upon their synergistic effects on the electrical system as a whole.

Projections from the wide range of climate models present great variability of results for different regions of Brazil, without conclusive quantitative convergence. This shows that caution should be exercised when examining projected impacts suggested by climate modelling, without underestimating them.

An approach to this theme using modelling scenarios for analysis of impacts on different sectors is therefore recommended. Among the array of potential future scenarios, some possible threats to the energy sector can be identified. The following notes, based on studies by the Brazilian Research Network on Global Climate Change (*Rede Clima/*MCTI) and the Secretariat of Strategic Affairs of the Presidency of the Republic (SAE, 2015) focus on qualitative aspects, i.e., impact trends presented in these studies:

• Based on the Water Balance (WB)[20] concept, i.e., the relationship between rainfall and evapotranspiration, which has repercussions on river-flow rates, the value for this indicator applied to river basins presents different behaviours in different parts of Brazil. A declining WB is observed in basins located more in the North (the Amazon Basin) Northeast and East Atlantic. For basins in the South and Southeast, which include the Paraná and Uruguay river basins, the WB will tend to rise during this century. Basins located within the transition regions between these extremes are likely to have a stable WB, i.e., close to zero;

[20] Positive WB: Trend of increasing water availability. Negative WB: Trend of reduced water availability. Zero WB: No influence on water availability.

- A trend toward higher wind velocities is predicted for certain specific areas of the Northeast and South, coinciding with good potential for wind-power generation. Regions where wind speeds are forecast to decrease include some areas of the Amazon and of the Central-West.

- Forecasts for solar radiation indicate that usable sunlight for electricity generation in the North region is likely to remain high. By contrast, in the South, increased cloud cover is likely to result in a decrease in solar radiation. In overall terms, the studies indicate that Brazil has a considerable number of areas suitable for solar-power generation, mostly located in its North, Northeast and Central-West regions.

- For generation from biomass, particularly sugar-cane bagasse, studies show that higher temperatures will reduce the risk of frost in the South, Southeast and south-western areas of the country. This is likely to have a beneficial effect for sugar-cane production and hence energy generation from biomass, as climate restrictions on tropical crops become more relaxed;

- Climatic model projections indicate an intensification of the occurrence of extreme events. Such events may affect infrastructure for electric-power generation, transmission and distribution.

- The vulnerabilities identified should be regarded as merely indicative, and specific actions targeted at minimising their effects on the electricity sector cannot be overly reliant upon them. Further studies with higher degrees of quantification are needed to clarify uncertainties in several areas.

6.4.3. Guidelines for Adaptation

In view of complexities revealed in vulnerability studies on the electricity sector, adaptation actions need to be meticulously assessed and to meet with a solid consensus among bodies that comprise the National Energy Policy Council.

Sectoral policies are formulated within a framework organised to ensure effective fulfilment of goals. Within this framework, the Ministry of Mines and Energy chairs the National Energy Policy Council (an inter-ministerial body that advises the President of the Republic on energy-related policies and guidelines). The Brazilian Electricity Regulatory Agency (ANEEL) and its state-level counterparts is responsible for supervision and regulation of the sector. Other participants in this framework are the Electric System National Operator (ONS), the Brazilian Electric Energy Trading Chamber (CCEE), the Energy Research Company (EPE), and the Electricity Sector Monitoring Committee (CMSE). The Electrical Energy Research Center (CEPEL) is one of the bodies that foster technical and scientific development of the sector. Finally, energy services are provided by various companies that comprise the Eletrobras System[21], state and municipal-level electricity-generation and distribution companies, and the transmission companies.

[21] Centrais Elétricas Brasileiras S.A.

To stimulate debate, and hence consolidation of adaptation concepts that are compatible with objectives of the energy sector, guidelines are needed to ensure attainment of adaptation goals on the part of both private and public stakeholders.

Moreover, the proposed guidelines should orient technology-transfer programmes and capacity-building initiatives for the electricity sector through direct exchanges with other countries, or multilaterally through the United Nations Framework Convention. There follows a list of proposed guidelines for the electricity sector:

1. Promote a greater engagement of electricity-sector institutions in themes relating to adaptation, with a view to adapting institutional policies to new climatic parameters, when appropriate;

2. Deepen impact studies on specific areas of interest to the electricity sector in relation to climate-change trends;

3. Conduct studies on climate-change risks assessment to energy-sector infrastructures, with a view to improving management of activities, focusing on contingency planning for extreme events;

4. Evaluate potential co-benefits and synergies between mitigation and adaptation, relating to various alternatives applicable to the energy sector;

5. Assess, when relevant, interactions between adaptive measures for water, energy, land use and biodiversity, as a means for understanding and managing such interactions;

6. Conduct studies to define and improve planning tools, with a view to adapting parameters in response to scientifically verified climate change impacts.

The guidelines proposed in this Chapter seek to foster electricity-sector planning in the light of climate-change projections and to provide energy-policy guidance in the quest for greater resilience, while abiding by principles of security of supplies, environmental sustainability and moderate tariffs.