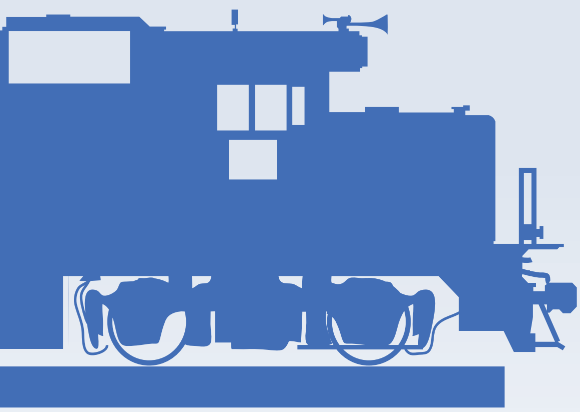

# ASSESSMENT OF CLIMATE IMPACTS AND RISKS ON EXISTING AND PLANNED FEDERAL LAND TRANSPORTATION INFRASTRUCTURE (ROAD AND RAIL)

EXECUTIVE SUMMARY
MINISTRY OF TRANSPORT


Por ordem do
Ministério Federal do Meio Ambiente, Proteção da Natureza e Segurança Nuclear
da República Federal da Alemanha

Por meio da
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PROADAPTA
Adaptação à Mudança do Clima

MINISTRY OF SCIENCE, TECHNOLOGY AND INNOVATION

MINISTRY OF TRANSPORT

BRAZILIAN GOVERNMENT
BRASIL
UNITING AND REBUILDING

**Federative Republic of Brazil**

Luiz Inácio Lula da Silva
**President of the Republic**

José Renan Vasconcelos Calheiros Filho
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Brasília, December 2022.

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# Presentation

*As established in Provisional Measure No. 1,154, of January 1, 2023 and Decree No. 11,360, of January 1, 2023, the former Ministry of Infrastructure, whose name is used here, is called the Ministry of Transport.*

Ordinance No. 05 of January 31, 2020 established the Ministry of Transport's Sustainability Guidelines. There are five guidelines that guide sectoral policies, plans, programs and projects, as well as making it possible to expand the supply of transport infrastructure in a sustainable manner. This administrative document is the main socio-environmental and climate reference for the strategic and political actions of the Ministry and its related entities.

Given that the governments of Brazil and Germany cooperate technically to achieve the commitments made in international climate agreements, the German Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) (*Bundesministerium für Wirtschaft und Klimaschutz - BMWK*) has been supporting the Brazilian government in actions to increase the country's resilience through the International Climate Protection Initiative (*Internationalen Klimaschutzinitiative - IKI*). Implemented by the German Technical Cooperation Agency Deutsche *Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH*, the project "Support for Brazil in Implementing the National Agenda for Adaptation to Climate Change - ProAdapta" aims to foster increased climate resilience in Brazil through the effective implementation of the National Adaptation Agenda for various sectors and thematic areas, including the transport sector.

In this context, a cooperation agreement was established between GIZ and the Ministry of Transport, whose main action is the development of the study "Impacts and risks of climate change in the road and rail sectors". Nicknamed "AdaptaVias" (Abbreviation in Portuguese of Adaptation and Ways - road and rail), the study is in line with Guideline 2 of the Sustainability Guidelines, which aims to "promote the inclusion of climate change issues in transport infrastructure". The aim of the study was to survey and systematize the impacts and risks of climate change on existing and planned federal rail and road transport infrastructure, as a subsidy for the development of adaptation strategies for the sector.

The study was developed by GITEC Brasil Consultoria Socioambiental and GITEC-IGIP GmbH (GITEC) in association with the Transport Engineering Program of the Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE/UFRJ), together with the Steering Committee made up of representatives from the MT, GIZ, the Ministry of Science, Technology and Innovation (MCTI) and the National Institute for Space Research (INPE).

Among the challenges faced during the study was the limited data on climate-related damage and infrastructure characteristics. Due to its great relevance, breadth and innovative nature, it is hoped that the study will be used as a starting point for reviewing and improving the regulatory process in the land transport sector, as well as guiding public policies on the subject, which is so important for the national economy, as these are the main modes of transportation for goods, merchandise and people between the different regions of Brazil.

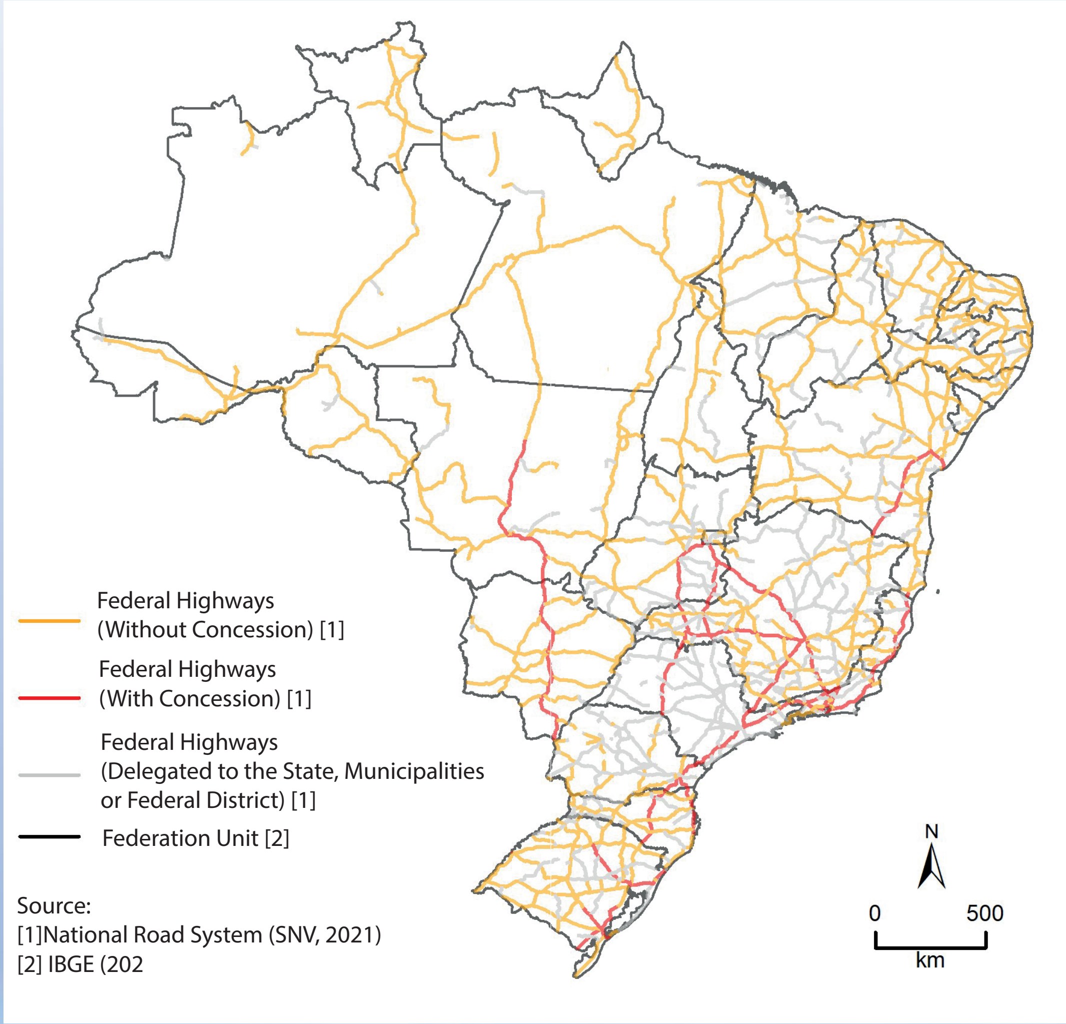

Photo: Ministry of Transport.

## Introduction

Climate change is already a reality and is one of the biggest global challenges of the 21st century, causing loss and damage to society that can no longer be ignored. In addition to rising temperatures, climate change causes changes in rainfall patterns, ranging from droughts to floods and landslides, as well as rising sea levels, an increase in the frequency and intensity of storms and other hazards, which can have direct and indirect impacts on various economic sectors (BRASIL, 2016). Transportation systems are designed on the basis of historical climate patterns that assume stationarity, i.e. constancy. However, there is already robust evidence that climate patterns are changing (IPCC, 2022), which could cause damage to infrastructure and consequently reduce the efficiency of transportation operations. These impacts generate additional costs for maintenance, recovery or reconstruction of any damaged assets, so that certain effects are felt immediately, while others manifest themselves in the medium or long term. In addition to these impacts on the infrastructure itself, the impacts of climate change on the transport sector can directly or indirectly affect people's travel conditions and the distribution of inputs and services, as well as increasing the likelihood of traffic accidents (EVANS *et al.*, 2009).

In Brazil, the transportation sector is highly dependent on road transport, which has a far greater territorial reach than other modes of transport, with a modal split of 68.5% in 2015 (MInfra, 2021). According to the National Department of Transport Infrastructure (DNIT, 2021), the total length of the federal road network, excluding planned routes, is 79,634 km, of which 69,473 km (87%) correspond to paved roads and 10,161 km (13%) correspond to unpaved roads, as shown in Figure 1. It should be noted that 11,476 km of the total length are under federal concession.

**Figure 1** - Federal road network.



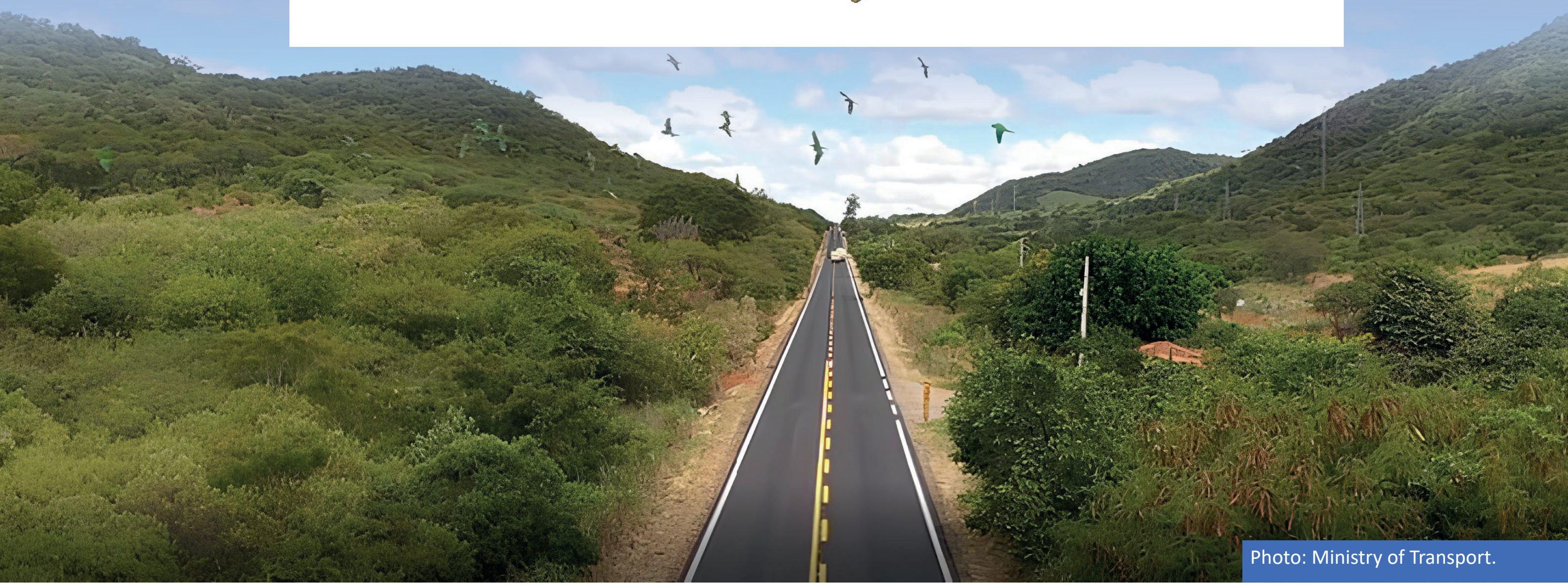
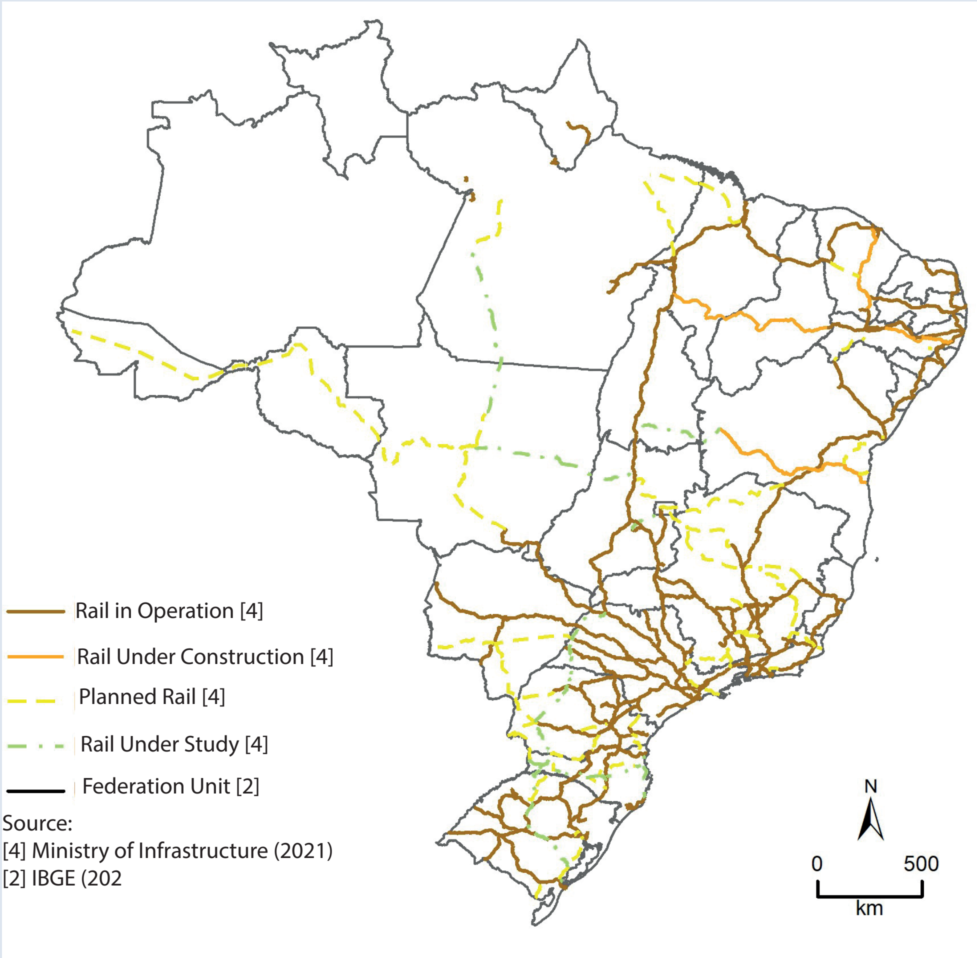



Photo: Ministry of Transport.

The rail transport sector is the second most used in Brazil for cargo transportation, behind road transport, accounting for around 15.1% of the modal split in 2015 (MInfra, 2021). According to the DNIT (2021), the total length of the federal rail network is 30,660 km. The spatial distribution of railroads is concentrated in the South and Southeast, followed by the Northeast. The North has few railroads, which are limited to the states of Tocantins, Amapá and part of Pará. The Midwest region has rail networks in all its states. Figure 2 shows a map of the rail network in operation and under construction in Brazil.

**Figure 2** - Rail network in operation and under construction.




Given the importance of these modes of transport, both for the transportation of people and freight, impacting the country socially and economically, it is vitally important to adapt rail and road transport infrastructure to climate change.

The climate risk of transport infrastructure depends on a variety of factors, including its nature, location, design characteristics and construction practices (RATTANACHOT *et al.*, 2015). Thus, decision-makers responsible for determining when and where infrastructure should be developed or improved are facing a new challenge, which consists of understanding how climate change can affect rail and road transportation and identifying the most critical points (hotspots) (CHINOWSKY & ARNDT, 2012).

Photo: Ministry of Transport.

Faced with the current climate emergency, adaptation measures are needed to reduce risks and minimize impacts, especially on transport infrastructure. There are various adaptation measures that can be divided into structural and non-structural measures, but which depend, for an appropriate technical choice, on a thorough knowledge of climate risks and the factors that influence them (DE ABREU; SANTOS; MONTEIRO, 2022). Thus, the climate risk assessment, or climate risk analysis, is an essential tool for identifying risk factors for the current and future climate, as well as guiding the adaptation measures to be implemented.

In this report, the methodological basis and terminology used were based on the Fifth Assessment Report (AR5) and corroborated in the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (IPCC, 2022), in the methodological documents of AdaptaBrasil-MCTI (MCTI, INPE & RNP, 2022) and in the manual on climate risk assessment by GIZ, EURAC & UNU-EHS (2018).

The Climate Risk Index (CRI), made up of hazard, exposure and vulnerability factors (sensitivity and adaptive capacity), as illustrated in Figure 3, was drawn up based on the following steps:

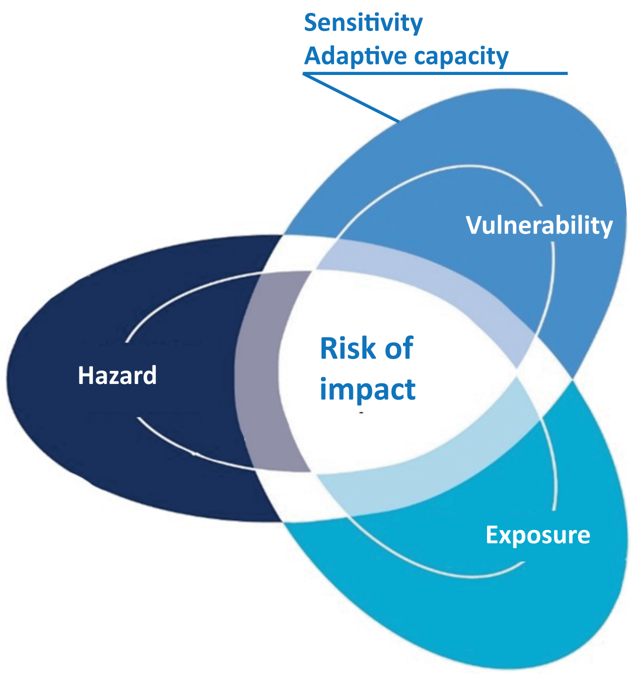
(i) definition of the most relevant impacts;

(ii) selection of indicators;

(iii) data collection; and

(iv) normalizing, weighting and aggregating data on hazard, exposure, adaptive capacity and sensitivity (biophysical and structural).

**Figure 3** - Conceptual framework of climate risk and its components.




**Source: Adapted from IPCC (2022)**

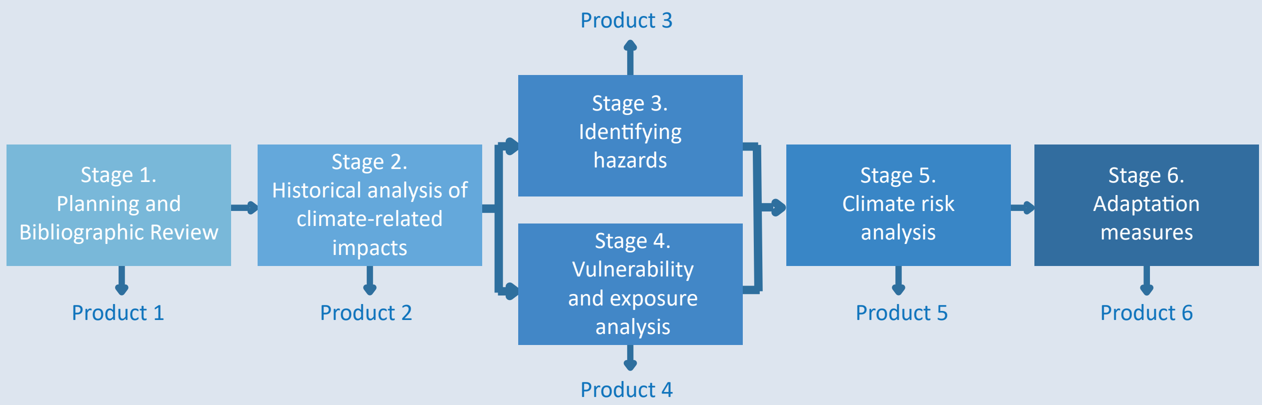
In order to achieve the desired results, in addition to an extensive literature review and technical meetings between the project's stakeholders, workshops were also held to consult and listen to representatives of federal government institutions and concessionaires operating in the Brazilian rail and road transport sector.

The climate risk assessment methodology used and the main results obtained for each mode of transport are presented below, as well as a list of potential adaptation measures.

# Methodology

The study was divided into six major stages, according to the methodological flow shown in Figure 4.

**Figure 4** - Stages and products.




Stage 1, Planning and Bibliographic Review, aimed to survey the methodologies for evaluating, assessing and analyzing climate risk and identify the most appropriate for the context of Brazilian land transport. The stage also included defining the key players for the development of the study.

Stage 2 included a historical analysis of climate-related impacts on Brazil's federal land transport infrastructure, in order to identify the main climate impacts on rail and road transport infrastructure. To do this, data and historical series were analyzed and consultations were held with key players (selected in Stage 1), through meetings, forms and workshops. The stage also included the development of a conceptual model for the different risks through the construction of impact chains.

Next up was the Identification of hazards (Stage 3), which aimed to define the climate indicators for each impact selected and the criteria for drawing up climate change scenarios (e.g. base period, time horizon, greenhouse gas (GHG) emissions scenarios). To weight the climate indicators, the multivariate Maximum Covariance Analysis (MCA) technique was applied, which consists of identifying and highlighting the most significant relationships in the data set used.

Stage 4, vulnerability and exposure analysis, aimed to determine the level of sensitivity and adaptive capacity (vulnerability) and the level of exposure of each type of infrastructure to the different impacts selected in Stage 2, by consulting experts. In this stage, vulnerability and exposure indicators were selected for each impact analyzed, based on existing bibliography and available data (collected in Stage 1). The analysis only considered georeferenced data available for the entire national territory. The main bases used for infrastructure exposure and sensitivity data came from the National Logistics Plan (PNL-2035, MInfra 2021), the National Road System (SNV) and data from the DNIT, the National Land Transport Agency (ANTT) and concessionaires, passed on by the Ministry of Transport. Once the indicators were defined, the raw data was normalized and weighted in participatory workshops and technical meetings.

With the results of stages 3 and 4, i.e. the indicators of hazard, vulnerability and exposure of land transport infrastructure for rail and road, it was possible to prepare a detailed Climate Risk Analysis (Stage 5). The climate risk analysis considered both operational and structural aspects and resulted in Climate Risk Indices (CRI) for rail and road transport modes, as well as an analysis of their impacts.

The CRI was obtained based on the interaction between hazard, exposure and vulnerability, without assigning specific weights to each risk component, according to the methodology applied to calculate impact risk in the energy sector, available on the AdaptaBrasil-MCTI platform (MCTI, INPE & RNP, 2022) and adapted for this study, according to Equation 1:

**Equação 1** - Cálculo de risco de impacto.

$$\text{RISK} = \frac{(\text{HAZARD} + \text{EXPOSURE} + \text{VULNERABILITY})}{3}$$

The normalized values of both the CRI and the components were classified into five classes, as shown in Table 1.

**Table 1** - Index scale.

| Level | Values |
|---|---|
| Very low | < 0,01] |
| Low | 0,01 - 0,24 |
| Medium | 0,25 - 0,49 |
| High | 0,50 - 0,74 |
| Very high | ≥ 0,75 |

In this linear classification, "high" and "very high" risks do not necessarily mean that the level of criticality is high, as this is a relative and not an absolute assessment.

## CONCEPTS:

**Climate risk: potential for consequences (impacts), where something of value can be affected and the outcome is uncertain.**

**Components of climate risk:**

**- Hazard: potential for a climate event to occur that could cause health impacts, damage to property, infrastructure, livelihoods, ecosystems;**

**- Exposure: presence of people, livelihoods, ecosystems and their services, infrastructure or economic and social assets in places that could be adversely affected;**

**- Vulnerability: propensity or predisposition to be adversely affected. Vulnerability is made up of sensitivity and adaptive capacity.**

**Source: IPCC (2022).**

Finally, Stage 6 (Adaptation Measures) aimed to carry out a systematic and comprehensive literature review, both nationally and internationally, on climate change adaptation measures for land transport infrastructure. Adaptation measures were classified into different categories, such as structural/non-structural, phase in the asset cycle and planning level.

Photo: DNIT

# Main Results

In **Stage 1 (Planning and Bibliographic Review)**, the data and information needed to identify impacts on land transport infrastructure resulting from hazards were collected, through historical analyses, considering operational and structural aspects, which formed the basis for the development of **Stage 2.**

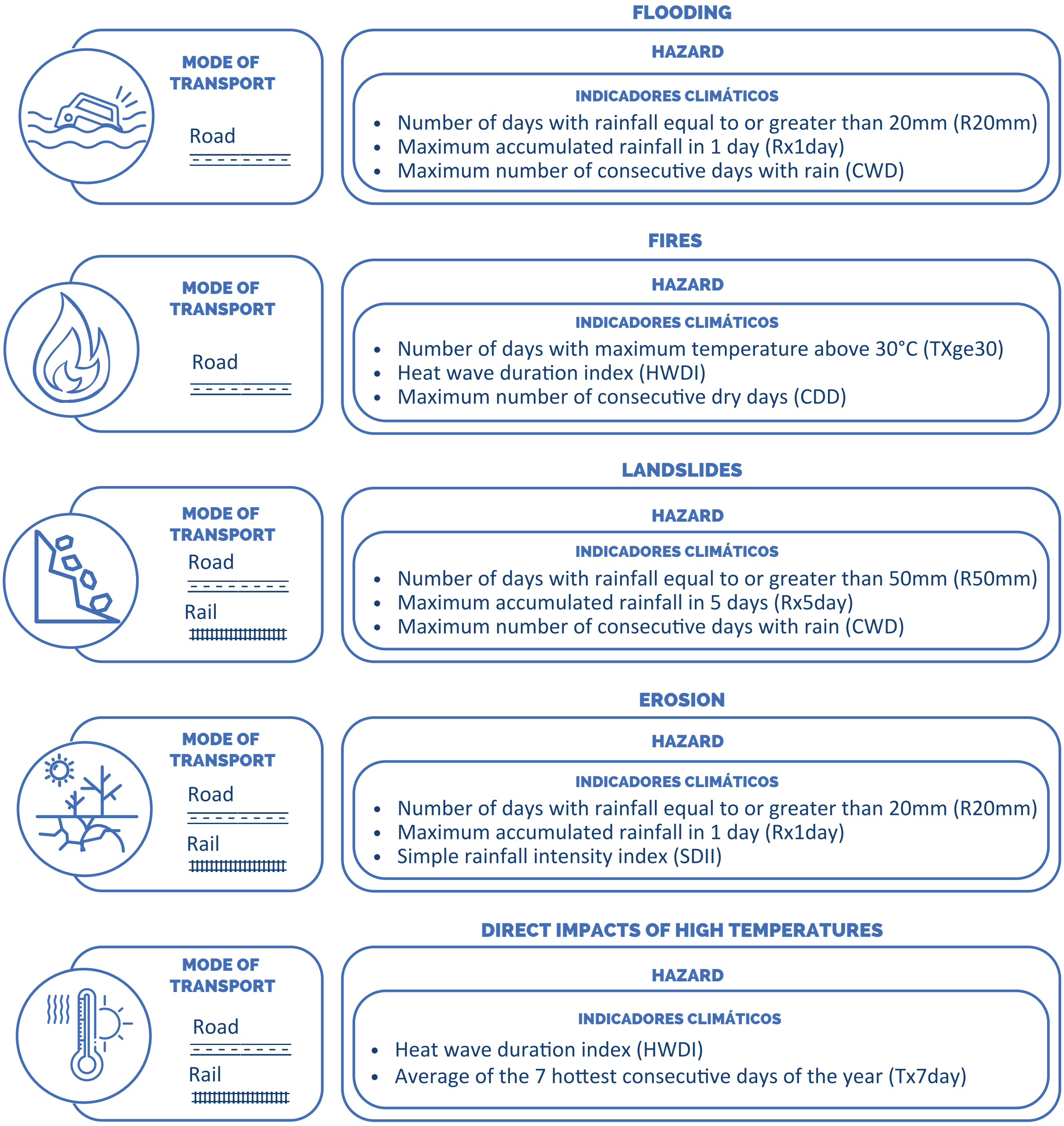
From this survey, through meetings, forms and workshops, 41 institutions were consulted, including federal public bodies and concessionaires, as well as 62 key players to identify the impacts. These impacts were prioritized through a participatory process, resulting in **three climate change impacts common to railroads and highways**, namely: impacts due to landslides, erosion and direct impacts due to high temperatures; and **two climate change impacts unique to highways**, namely: flooding and fires, shown in Figure 5. It should be noted that this study chose to focus mainly on biophysical (intermediate) impacts, rather than impacts on infrastructure, due to the complexity of the interrelationships that require the use of more specific data, which is currently lacking in the Brazilian context. The results were validated and consolidated in workshops together with the Study's Steering Committee, made up of technicians from the MT, MCTI, INPE and GIZ, among other relevant actors.

In **Stage 3**, once the impacts had been defined, the climate indicators that make up the thematic hazard indicators were defined (Figure 5). To select and prioritize the hazard indicators, the following criteria were applied: (i) literature review; (ii) analysis of occurrence versus meteorological data; (iii) trend analyses and (iv) analysis of future change scenarios.

*[1]For more details on the participatory prioritization methodology, see Product 2 of the study "Impacts and risks of climate change in the road and rail sectors".*

Photo: Agência Brasil

**Figure 5** - Climate indicators selected for the prioritized impacts on railroads and roads.




In addition, the criteria for constructing climate change scenarios, shown in Figure 6, were defined in **Stage 3**. The base period or reference period considers the years 1981-2000. The data used to calculate the base period is observational data from the Climate Prediction Center (CPC, CHEN *et al.*, 2008) and the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS, FUNK *et al.*, 2015) for temperature and precipitation indicators, respectively. To calculate climate change scenarios, the Change Factor method (ANANDHI *et al.*, 2011) was used, based on data from historical rounds and GHG emissions scenarios from climate models. The GHG emissions scenarios considered in this study are the intermediate (Shared Socioeconomic Pathways - SSP2-4.5) and high emissions (SSP5-8.5) from projections of 13 global climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6).

**Figure 6** - Criteria for customizing climate information.

**TIME HORIZONS**

**BASE PERIOD**

**1981 - 2000**

Representation of the climate in the 1990s and 2000s, the time of the Basic Guidelines for the Preparation of Road Studies and Projects (DNIT, 2005b), and the Basic Hydrology Manual (DNIT, 2005a).

**SHORT TERM**

**2026 - 2045**

The National Logistics Plan (PNL) deals with the long-term planning of land-based linear infrastructure and presents a vision of the future in the year 2035, the central year of the first time horizon (2026-2045).

**MEDIUM TERM**

**2046 - 2065**

In view of the concession periods, a further time horizon was defined: 2046-2065 (centered on 2055).

**EMISSIONS SCENARIOS**

**INTERMEDIATE: SSP - 4.5 / HIGH EMISSIONS: SSP - 8.5**

The choice of 2 scenarios was based on the need to estimate the uncertainties related to the socio-economic paths that society could adopt.

The choice of an intermediate scenario and a high-emissions scenario was based on the scenarios adopted in the National Plan for Adaptation to Climate Change (Brazil, 2016).

**CLIMATE MODELS**

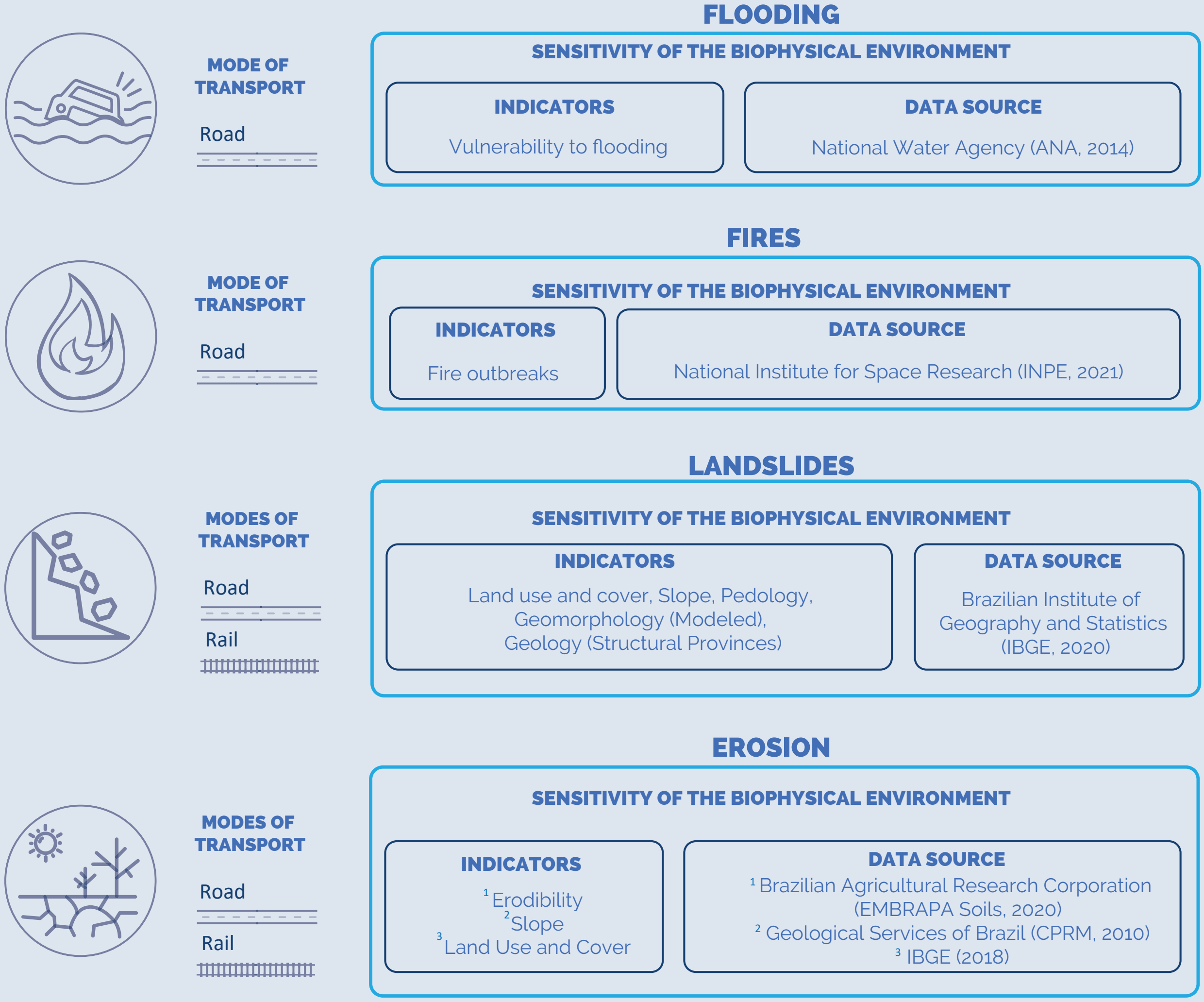
**13 GLOBAL MODELS OF THE COUPLED MODEL INTERCOMPARISON PROJECT PHASE 6 (CMIP6)**

Multi-model approach to estimating uncertainties associated with climate modeling

Based on the available data, **Stage 4** carried out the vulnerability and exposure analysis, where three exposure indicators were surveyed and weighted for the road mode: location of the central axis of the road (Ministry of Transport database); location of the Special Engineering Structure (SES, DNIT database); and Annual Average Daily Traffic Volume (AADT, DNIT database) and two exposure indicators for the rail mode (location of the rail section - Ministry of Transport database and Vehicle Volume - PNL 2035 database).

Vulnerability was made up of sensitivity and adaptive capacity indicators. The sensitivity of the rail infrastructure was made up of the type of gauge (Ministry of Transport database) and the weight of the load (PNL database). Road sensitivity was composed of the Surface Condition Index (SCI) (DNIT database), the type of road (DNIT database) and the weight of the cargo transported (PNL-2035 database). The biophysical sensitivity of both modes of transport varies according to the intermediate impact analyzed (see Figure 7). It is worth highlighting that, in the context of high temperatures, the impact is direct on the infrastructure, i.e. there is no intermediate biophysical impact. As such, there is no indicator of the sensitivity of the biophysical environment for this specific case.

**Figure 7** - Sensitivity indicators of the biophysical environment and raw database used for the prioritized impacts on railroads and roads.




Specifically in relation to adaptive capacity, it was considered that the Environmental Performance Index (IDA), which serves as a parameter to assess the efficiency and quality of environmental management in transport infrastructure projects, was the best indicator to represent this sub-component of vulnerability. However, as the index in question only analyzes concession roads and railroads, it was not considered to have sufficient national coverage to be incorporated into the database.

Figures 8 and 9 illustrate the hierarchical structure of the indicators for rail and road, respectively. The infrastructure exposure and sensitivity indicators used were the same for all impacts within the same mode, with changes to the climate (see Figure 5) and biophysical environment sensitivity (see Figure 7) indicators.

**Figure 8** - Hierarchical structure between the compositions of indicators and climate risk indices for landslides, erosion and high temperatures for railway infrastructure.

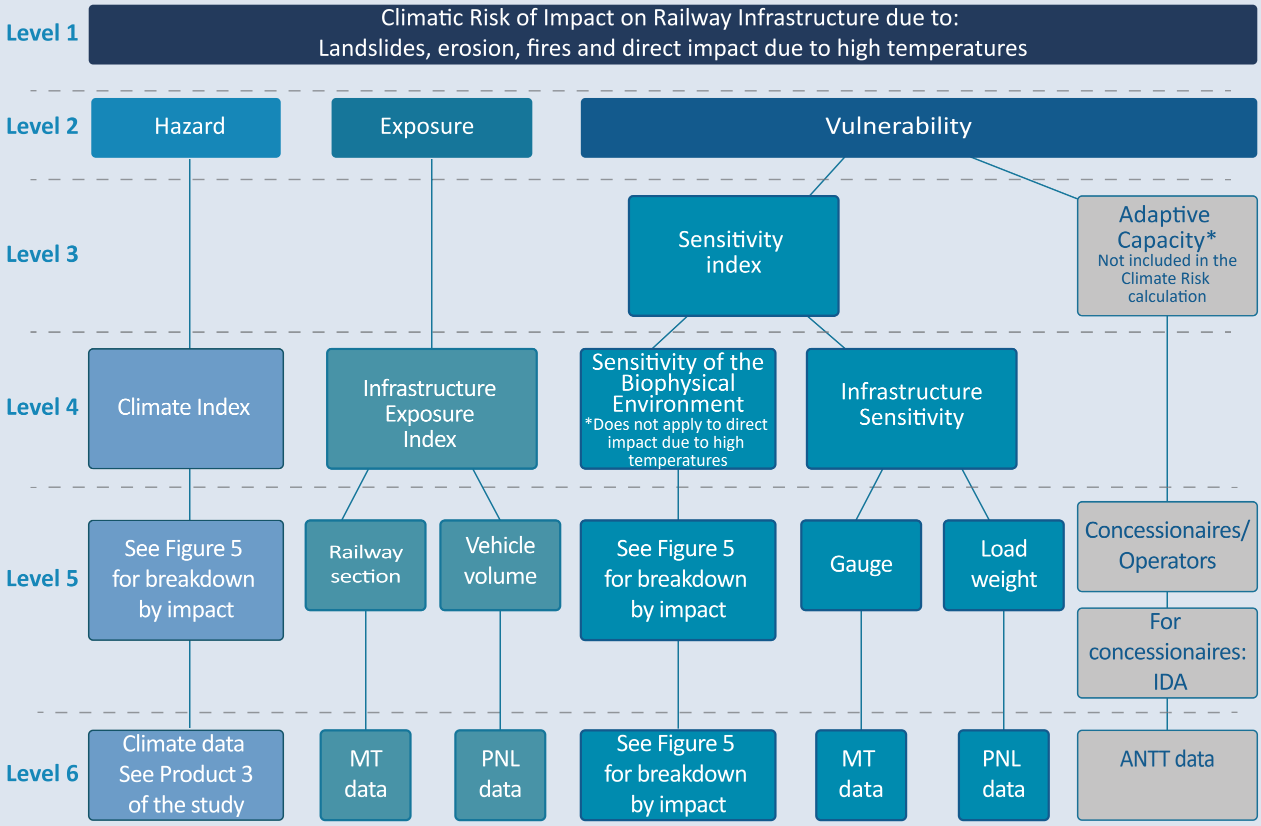
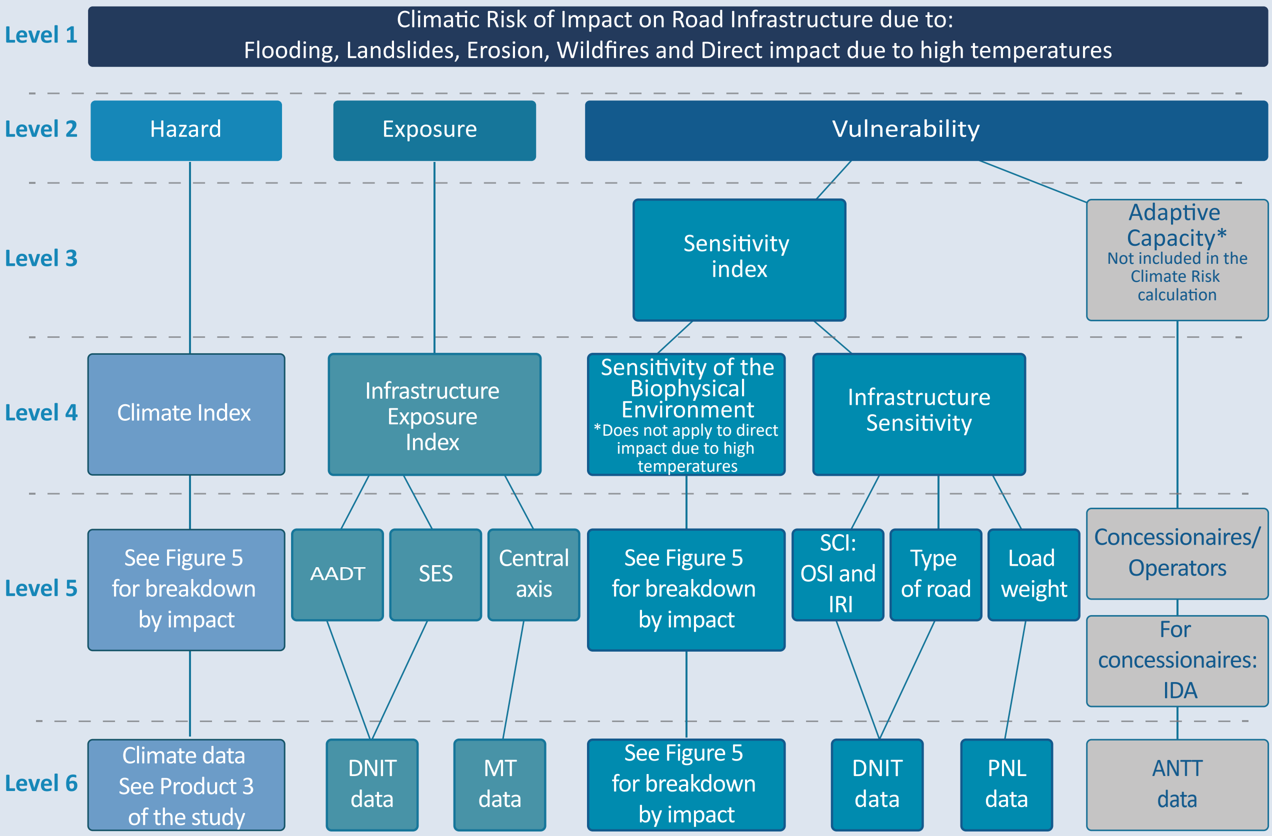



**Figure 9** - Hierarchical structure between the compositions of indicators and climate risk indices for flooding, landslides, erosion, fires and high temperatures for road infrastructure.



In order to understand the maps of the CRI components (Level 1), it is necessary to look at the maps relating to hazard, exposure and vulnerability (Level 2 of the hierarchical structure), since risk is the result of the combination of these components.

It should also be noted that, for the same mode of transport, the hazard maps vary between impacts and between the scenarios and time horizons analyzed, the vulnerability maps only vary from impact to impact, and the sensitivity maps are considered the same for all impacts, scenarios and time horizons.

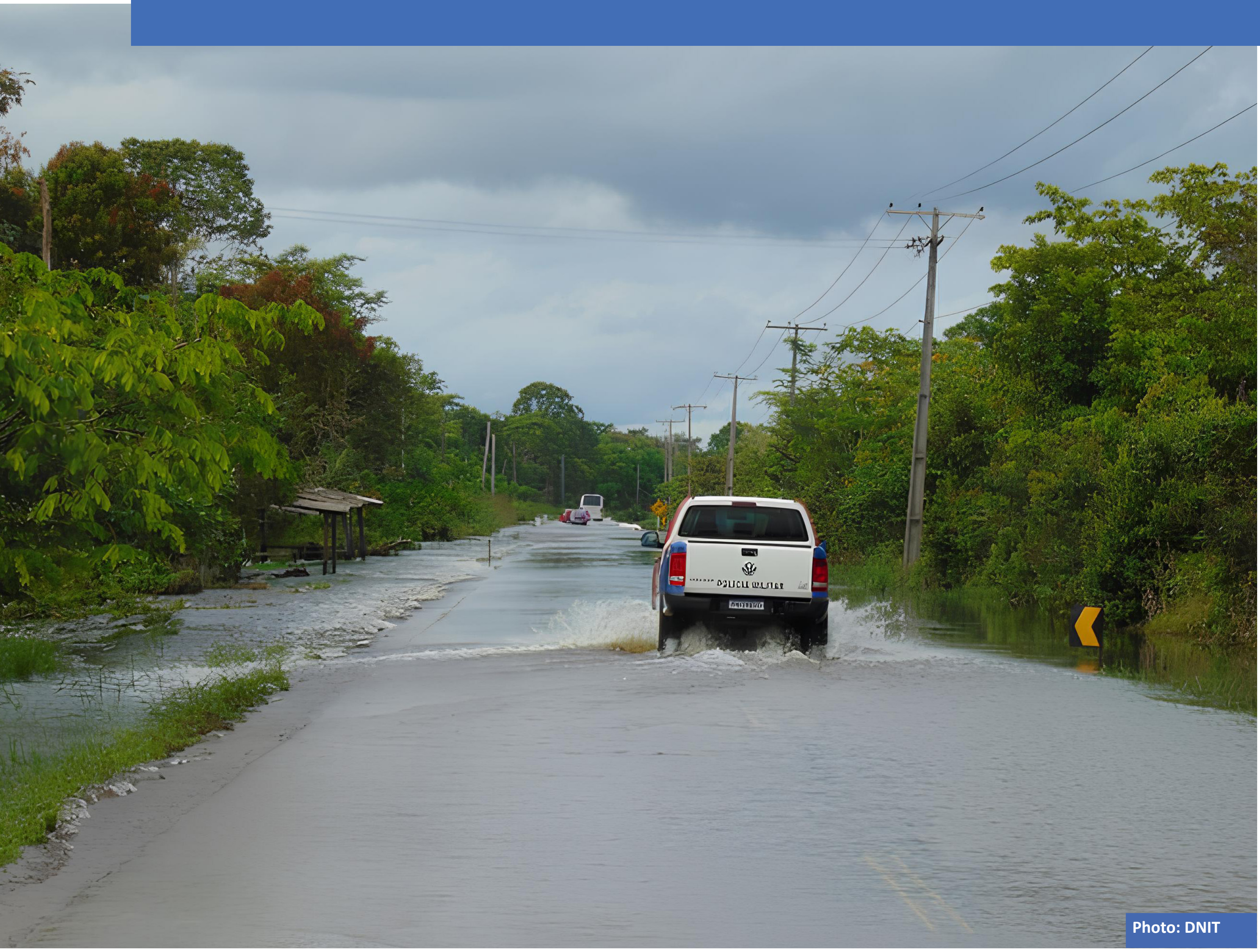


Photo: DNIT

The vulnerability component was only calculated with information on the sensitivity of the biophysical environment and the sensitivity of the infrastructure (Level 3), since the data needed for adaptive capacity was not available or did not exist for the entire rail and road network until the conclusion of this study, so it could not be incorporated into the analysis.

General information about the Brazilian rail and road network is presented below, which helps to understand the results of stages 5 (Climate Risk Analysis) and 6 (Adaptation Measures).

## Railroads and Climate Indices

The aim of this section is to highlight the main results of the climate risk assessment for the biophysical impacts of landslides and erosion and for the direct impacts on railway infrastructure due to high temperatures. It should be noted that the temporal analysis of climate risk is associated with the hazard indicator, given that among the indicators involved in the calculation of the climate risk assessment, only this one was evaluated considering its variation over the period analyzed. In this sense, the exposure and vulnerability indicators were considered as constant variables, taking into account the current conditions of each stretch of railroad. By assessing these indicators as constant variables, it was possible to understand how much a hazard could affect the railroads if no adaptation measures were adopted.

Photo: Divinópolis City Hall/MG

- **Climate Risk Indices (CRI) - Railways**

When considering the impacts related to **landslides**, the CRI of the railway infrastructure for the base period showed a high and very high level in the Southeast Region, with emphasis on:

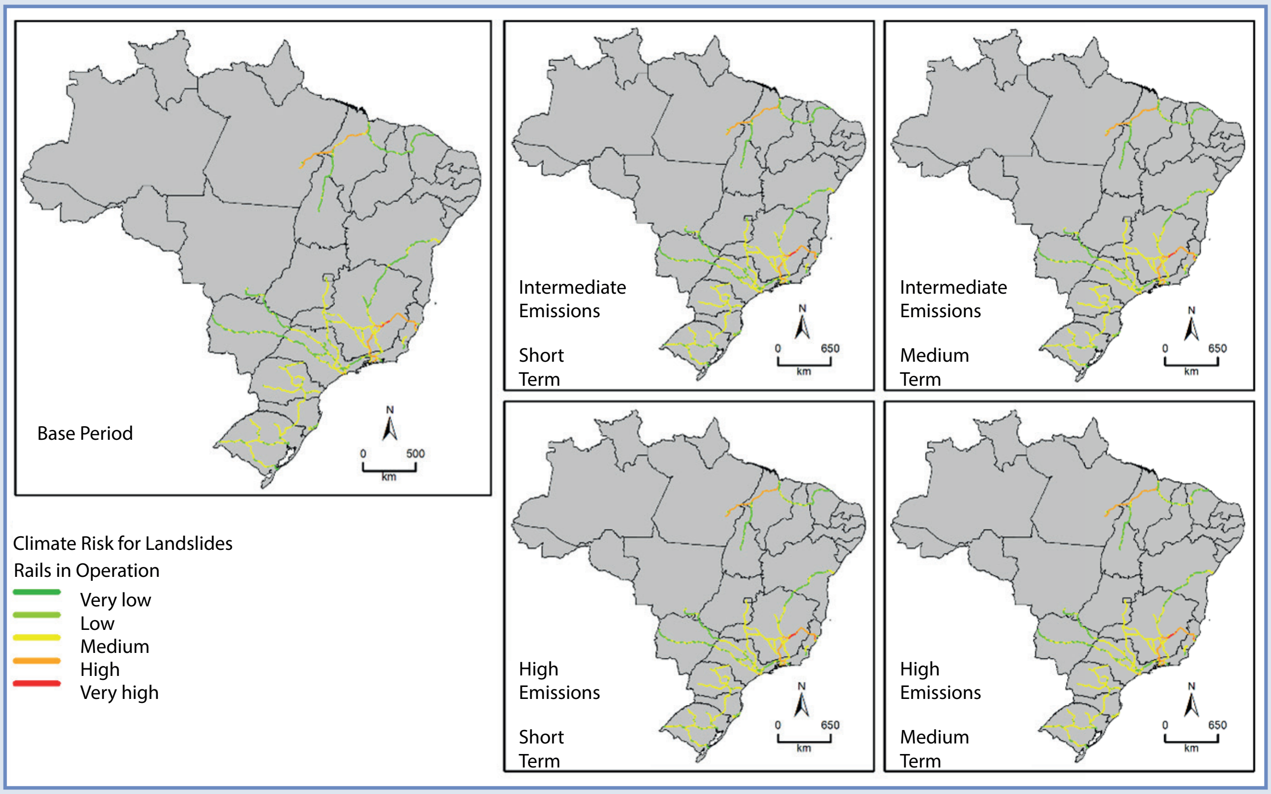
- São Paulo (Estrada de Ferro do Litoral, operated by MRS Logística);
- Minas Gerais/Rio de Janeiro (Minas x Rio Railroad, operated by MRS Logística);
- Espírito Santo/Minas Gerais (Estrada de Ferro Vitória a Minas, operated by Vale S.A); and
- North/Northeast on the Pará-Maranhão axis, more specifically on the Carajás Railroad, operated by Vale S.A.


Photo: TVCI

It should be noted that these CRI results come mainly from the components of **exposure**, highlighting the railroads with the most traffic, especially those railroads associated with the flow of Brazilian mineral production, and **vulnerability**, made up of the sensitivity of the infrastructure, highlighting the regions that carry a greater weight of cargo, and the sensitivity of the biophysical environment to landslides, mainly due to the presence of the Serra do Mar (high slopes). Medium and high levels of erodibility and deeply anthropized land use and cover can be found in this region.

With specific regard to the **hazard**, it can be seen that only stretches of railroad on the coast of São Paulo have a high level. In addition to these, there are stretches with a medium threat level in Rio Grande do Sul and Santa Catarina. This reality can be seen both in the base period and in the future scenarios. In general, there is a pattern of a reduction in the length of railroads at low climate risk of landslides and an increase in such lengths at medium, high or very high risk, as the emissions scenario or time horizon changes. This variation stems from the changes observed in the hazard sub-index and no significant variations were identified between scenarios and horizons, as shown in Figure 10.

**Figure 10** - Risk map of landslide impacts on railroads for the current climate and four future climate change scenarios.



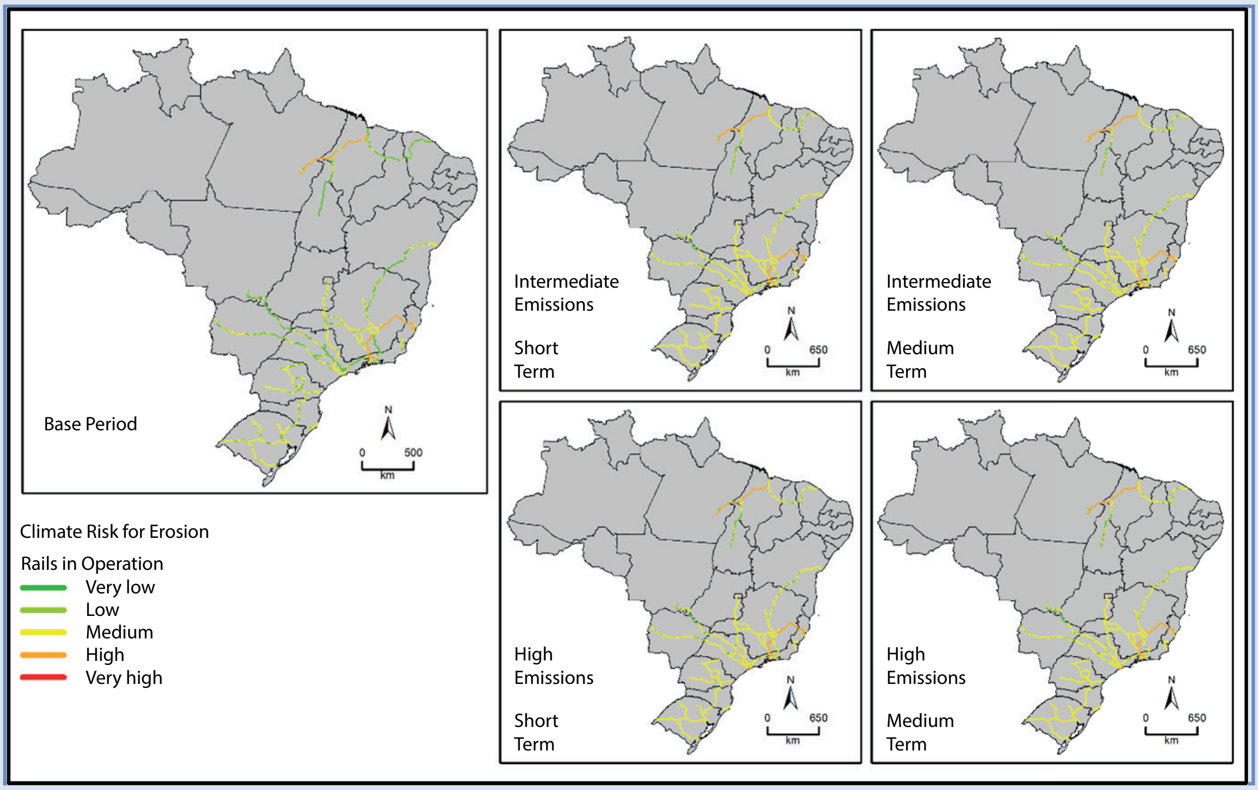

As for impacts due to **erosion**, there is a configuration of stretches with high levels concentrated in:

- Pará/Maranhão (Carajás Railroad, operated by Vale S.A);
- Rio de Janeiro/Minas Gerais (Minas x Rio Railroad, operated by MRS Logística); and
- Espírito Santo/Minas Gerais (Vitória-Minas Railroad, operated by Vale S.A).

Furthermore, as already explained in the considerations regarding landslides, the impact risk components that most influence the calculation of the CRI in relation to erosion are **exposure** and **vulnerability**. The hazard of erosion for the base period was low in almost the entire country (98.2%). In the projections, approximately 60% of the rail network has medium levels of hazards.

It should also be noted that there are few variations in the level of risk between future scenarios, but there is a notable difference between the base period and future scenarios, as can be seen in Figure 11. This is due to variations in the **hazard**, which means that between the base period and the future scenarios, there is a 27% increase in the length of railroad mileage at medium climate risk, which represented 1.4% of the stretches at medium level in the base period, rising, for example, to 59.8% in the high emissions scenario (SSP5-8.5) over a medium-term horizon (2046-2065).

**Figure 11** - Risk map of erosion impacts on railroads for the current climate and four future climate change scenarios.




In an analysis of the **direct impacts of high temperatures** on the Brazilian federal railroad infrastructure, the highest CRI were observed in the Southeast Region, with emphasis on the railroads:

● that connect Minas Gerais to Espírito Santo (Vitória a Minas Railroad, operated by Vale S.A) - including stretches with very high and high levels;

● linking Minas Gerais to Rio de Janeiro (Estrada de Ferro Minas x Rio, operated by MRS Logística) - including stretches with high and medium levels;

● in the North/Northeast, the Pará-Maranhão axis (Estrada de Ferro Carajás, operated by Vale S.A) - including stretches with high and medium levels; and

● in the South, a stretch in Rio Grande do Sul, between Cacequi and Dilermando de Aguiar (Porto Alegre--Uruguaiana Railroad) - including stretches at high and medium level.

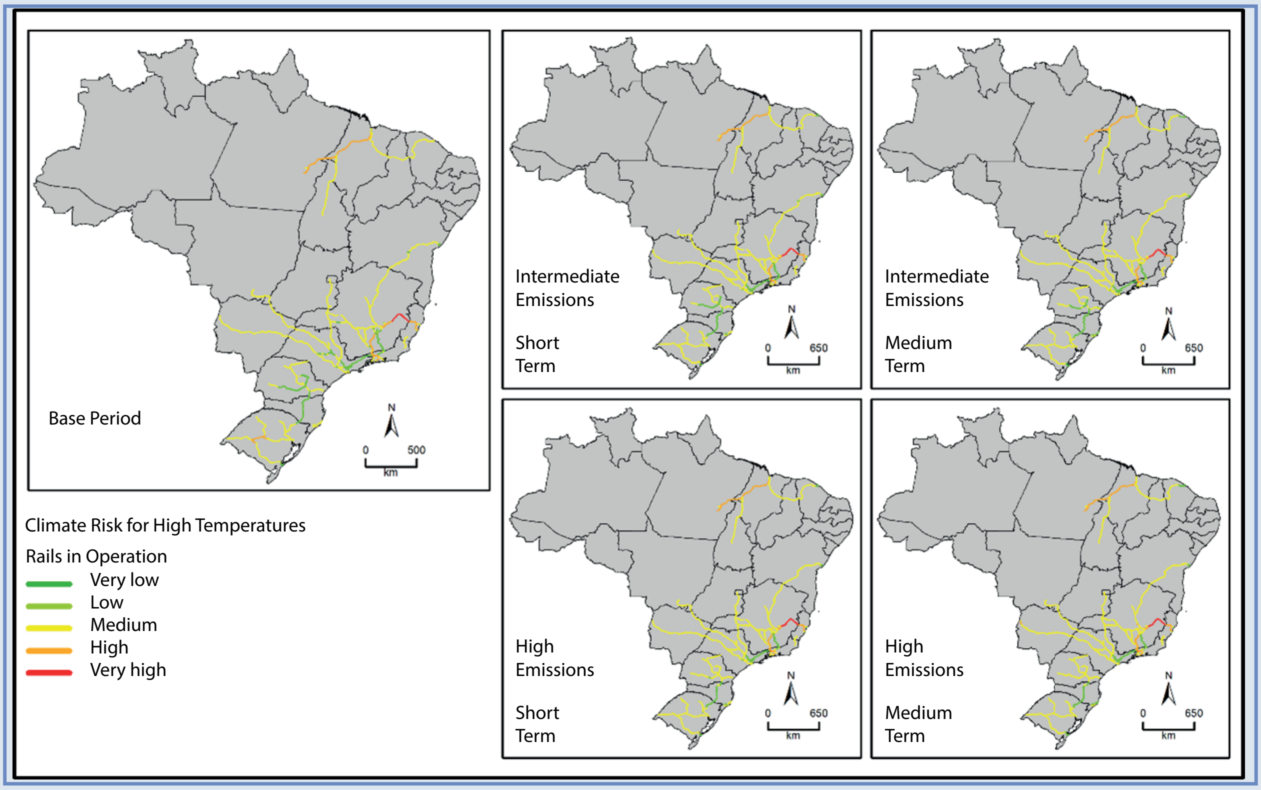
Once again, the significant contribution of the **exposure** and **vulnerability** components in determining the level of the CRI for direct impacts due to high temperatures stands out. It should be noted, however, that unlike the intermediate (or indirect) impacts presented above, as this is a direct impact on infrastructure, sensitivity indicators for the biophysical environment were not taken into account when calculating vulnerability.

Another point worth highlighting is the high level of **hazard** on the railroads located in the state of Rio Grande do Sul, on the stretch between Uruguaiana and Santa Maria (Porto Alegre-Uruguaiana Railway), which meant that this region was included in the areas with the highest CRI in terms of direct impacts due to high temperatures, unlike the other impacts analyzed above.

According to Figure 12, the comparative analysis between the base period and the scenarios and horizons shows that there were reductions in the stretches of railroad under a low level of climate risk as the emissions scenarios increased and/or the time horizons changed (with an increase only in the high emissions scenario, considering a medium-term time horizon), and increases in the areas under medium and very high risk.

It is also worth noting the variations seen in the hazard maps, which represented a sign of an increase in the level of this component of climate risk, especially in the Brazilian Midwest Region, and in some states located in the Southeast and Northeast regions; in the northeast of the state of São Paulo (Noroeste do Brasil railroad), as well as in parts of the states of Minas Gerais and Bahia (Bahia-Minas FCA 116 railroad).

**Figure 12** - Risk map of the impact of high temperatures on railroads for the current climate and four future climate change scenarios.



# Roads and Climate Indices

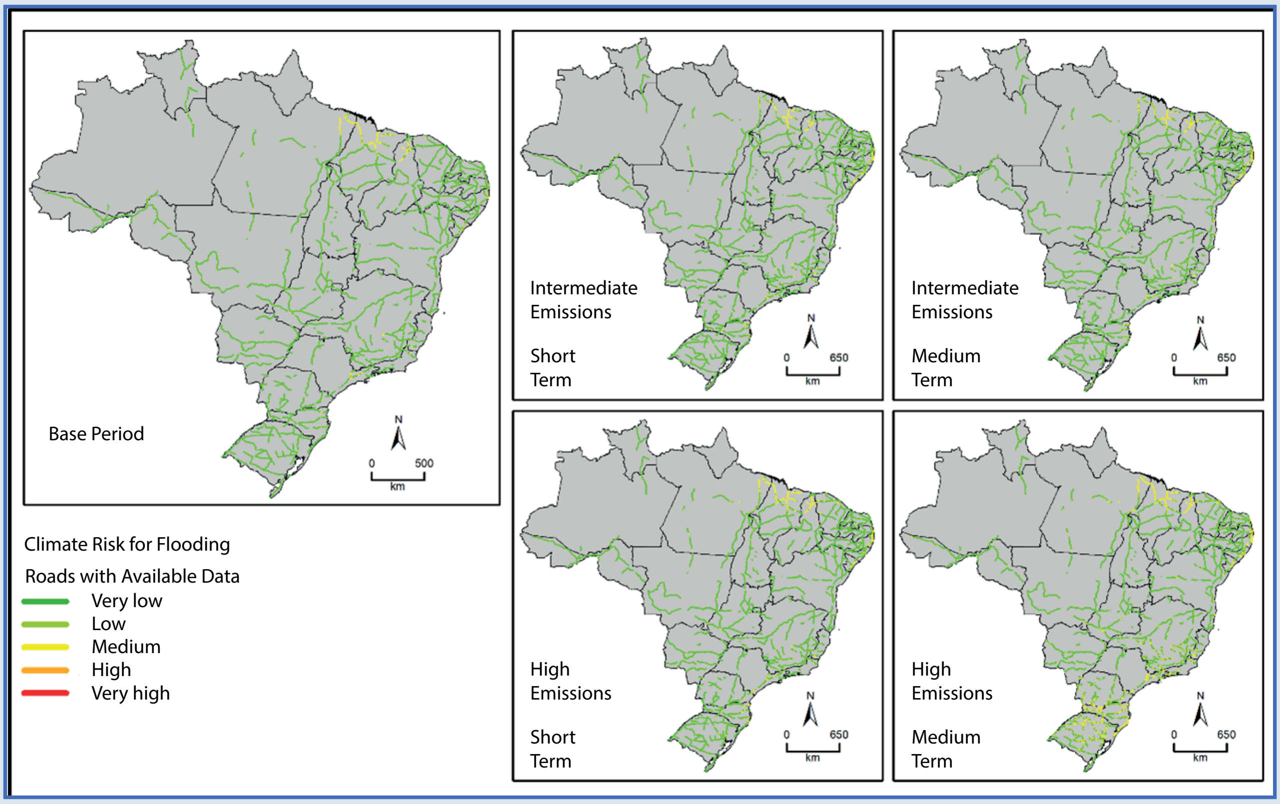
This section seeks to highlight the main results of the climate risk assessment for the biophysical impacts of flooding/flooding, landslides, erosion and burning and for the direct impacts on road infrastructure due to high temperatures. It is worth mentioning that, as was established in the analysis of railroads, the temporal analysis for roads considered variations only in the hazard, with the exposure and vulnerability indicators being kept constant, paying attention to the current conditions of each stretch of road.

### Climate Risk Index (CRI) - Roads

In terms of **flooding** during the base period, all the highways had a very low or low CRI level, with the exception of some stretches in Pará and Maranhão, as well as parts of highways on the coast of the Northeast, which have a medium climate risk level. The low CRI levels come mainly from **exposure**, which implies a high and medium risk of impact only on stretches of the BR-116 and BR-381, due to the high volume of vehicles that pass through them daily, and **vulnerability**, made up of the sensitivity of the infrastructure and the sensitivity of the biophysical environment, which implies a medium and high risk only on stretches of the BR-163, in Pará. All the other highways have low or very low levels for these two components, which has a direct impact on the CRI results. As shown in Figure 13, almost imperceptible variations are found between the base period and the intermediate emissions scenarios in the short and medium term horizons. However, in the high emissions scenario, there is an increase in the number of roads with a medium level of climate risk, especially in the South and Southeast regions. In the high emissions scenario (SSP5-8.5) for the short term (2046-2065), 84.1% of roads remain at a low level. However, there is a sign of an increase in stretches with a medium level, due to the increase in the level of **hazard**.

Photo: DNIT

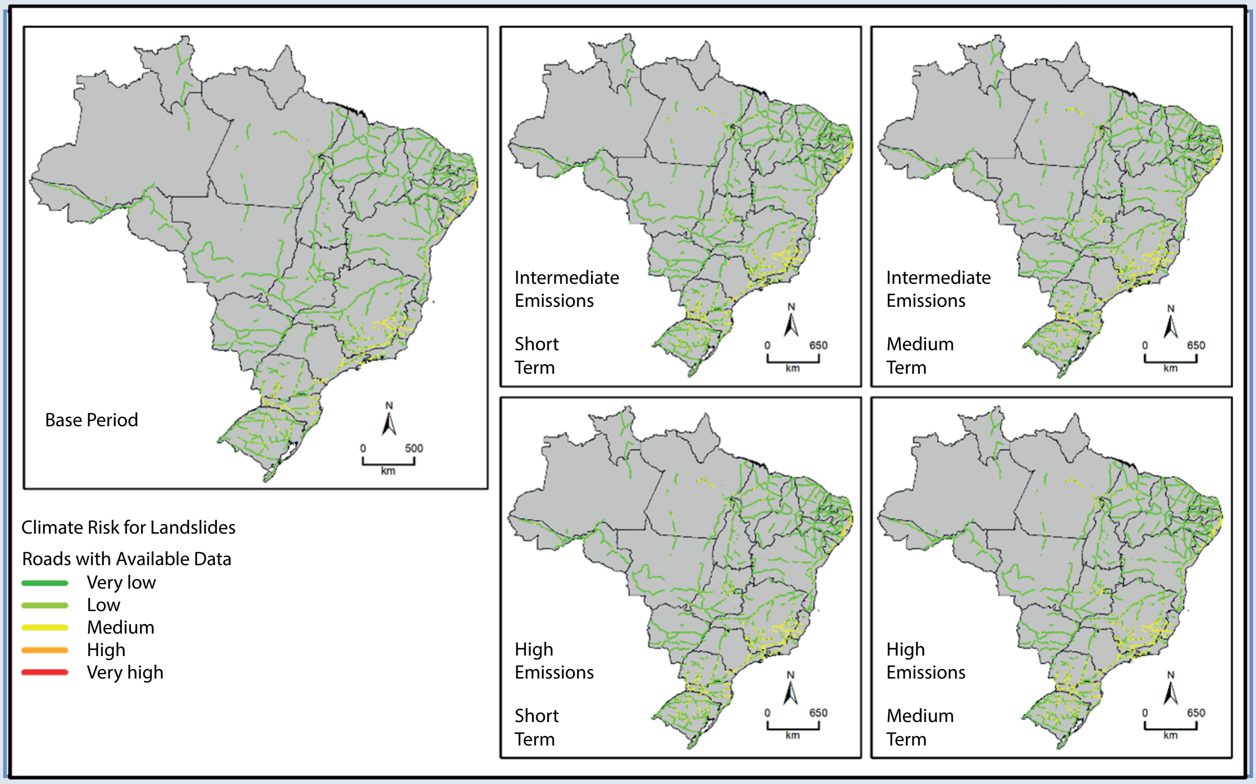
**Figure 13** - Road flood impact risk map for the current climate and four future climate change scenarios.




The roads with the highest levels of CRI (medium level) due to the impact of **landslides**, in all the scenarios and horizons considered in this study, as shown in Figure 14, are located in the South and Southeast regions (Serra do Mar and Serra Geral), as well as coastal roads in the Northeast. In the North, only BR-230 (Altamira-Marabá), in Pará, is in this situation due to its medium hazard level and high **vulnerability** level. It should be noted that the CRI is significantly affected by the vulnerability component, especially with regard to susceptibility to landslides (more rugged terrain, among other factors) in the Southeast and South (Serra do Mar and Serra Geral) and the coast of the states of Pernambuco and Alagoas.

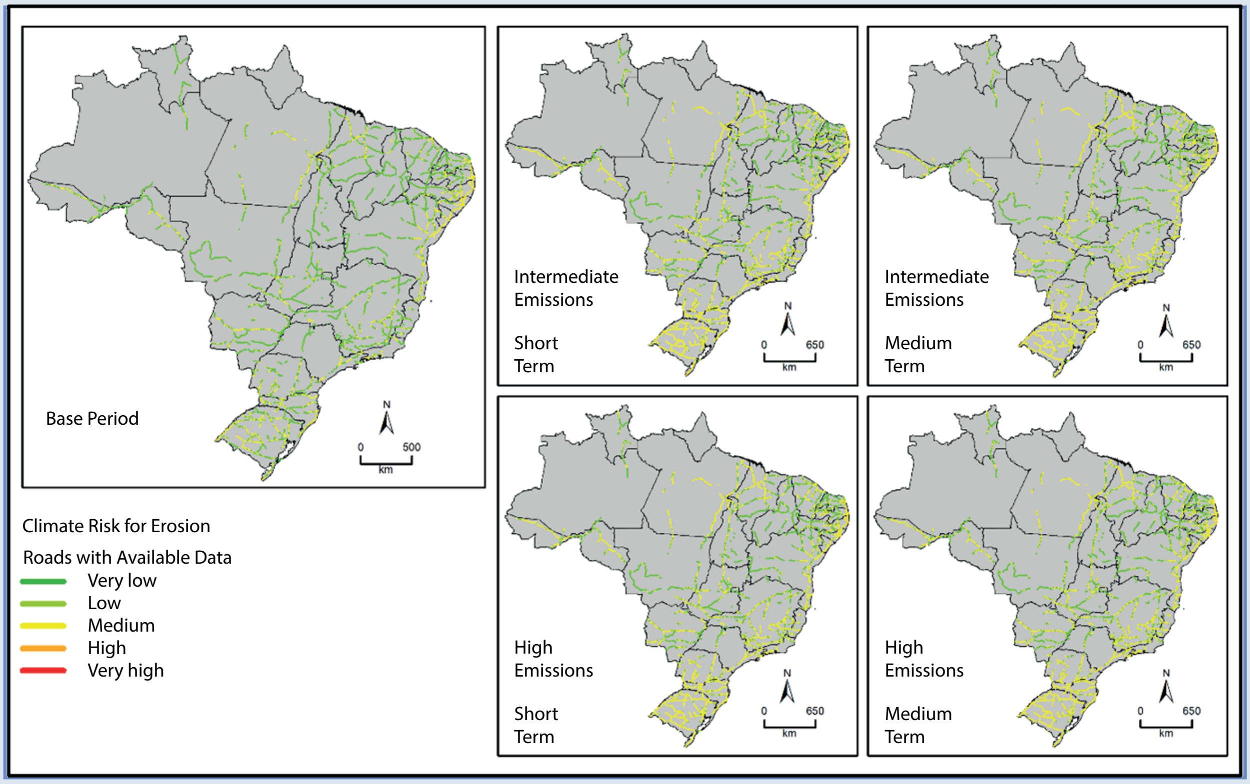
In general, as the emissions scenario or time horizon changes, there is a pattern of a slight reduction in the length of roads at low climatic risk of landslides and an increase in these lengths at medium risk. This variation stems from changes in the **hazard** component. This is due to the increase in medium hazard areas between the base period and the high emissions scenario (SSP5-8.5) for the medium-term horizon (2046-2065) for practically the entire Southern Region and for the states of Minas Gerais, Mato Grosso and Goiás and the coast, which corresponds to BR-101.

**Figure 14** - Road landslide impact risk map for the current climate and four future climate change scenarios.




As for the impact related to **erosion**, which is strongly related to land use, the stretches with the most significant CRI, as shown in Figure 15, are concentrated on the highways in Pará, on highways located in the southern states and on road stretches in the northeastern states, especially on the coast (BR-101), which presents a medium risk of impact on road infrastructure. These results are related to **vulnerability** to erosion, which in almost all the highways has a medium or high level of impact, especially BR-163 in Pará, which stands out for having many stretches with high and very high levels. In addition, an increase in the average climate risk can be observed throughout Brazil, due to the increase in the level of risk of impact of the **hazard**, when comparing the intermediate and high emissions scenarios with the base period. In these scenarios, other stretches of medium CRI can be observed on the coast of the Northeast Region, as well as part of the states of Acre, Rondônia, Pará and Maranhão.

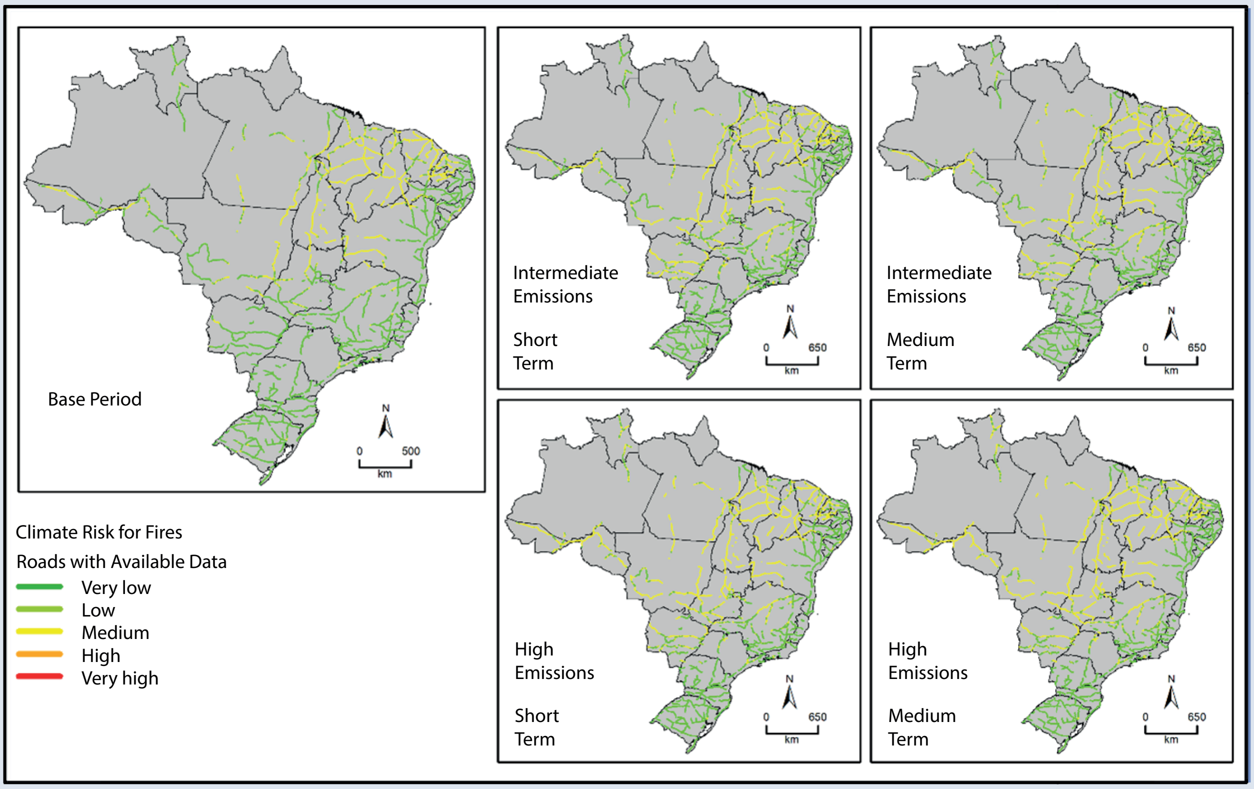
**Figure 15** - Road erosion impact risk map for the current climate and four future climate change scenarios.




The CRI for **fires** for the base period (Figure 16) is low for 68.1% of the Brazilian road network, with 31.9% of the road length at medium risk in the interior of the Brazilian Northeast (Maranhão, Ceará, Rio Grande do Norte and the hinterland of Bahia) and part of the North (Tocantins and Pará). With regard to **vulnerability** to fires, the roads with a very high and/or high hazard level are concentrated in the states of Maranhão, Piauí and Pará. As the scenario for intermediate emissions is modified, the stretches of road under low risk decrease, if the short-term time horizon is considered, progressively reducing for the medium-term time horizon, and for the high emissions scenario, in the short and long term. As a result, stretches under medium risk increase at the same rate.

This increase in medium-risk road sections occurs especially in the Central-West and Northern regions of Brazil, where the impacts of **hazards** increase according to the time horizon and emissions scenarios. In the high emissions scenario (SSP5-8.5) and medium-term scenario (2046-2065), 50.5% of the stretches have a low level of risk and 49.5% have a medium level.

**Figure 16** - Risk map of the impact of road fires for the current climate and four future climate change scenarios.




According to Figure 17, in relation to **direct impacts due to high temperatures**, it can be seen that, unlike the other impacts analyzed, in the base period there is a predominance of stretches with a medium level of risk (63.2%). This is because approximately 60% of the road sections have a high or very high level of hazard in the base period and in the future scenarios. The road sections with the highest risks due to the direct impact of high temperatures are located inland, in all regions of the country. On the other hand, the roads located on the coast are at low risk for all scenarios and time horizons. In the south of the country, the state of Rio Grande do Sul stands out, with its roads at medium risk for all the scenarios considered. With regard to **vulnerability** to high temperatures, which is composed only of the sensitivity of the infrastructure, since there is no sensitivity of the biophysical environment to this impact, the states of Rio Grande do Sul stand out, with a medium hazard level in many stretches, and Pará, with road stretches with a high and very high level.

This result is mainly due to the **hazard** component, which has higher levels of impact risk in the interior of the country, and medium vulnerability, which contributes especially in the South to the highest risk values. It should also be noted that, considering the intermediate emissions scenario (SSP2-4.5), the stretches with a medium level of risk fall to 50.3% in the short term (2026-2045) and rise to 67.4% in the medium term (2046-2065) compared to the base period. For the high-emissions scenario (SSP5-8.5), the stretches with medium risk represent 65.3% in the short term (2026-2045) and 62.6% in the medium term (2046-2065).

**Figure 17** - Risk map of the impact of high temperatures on roads for the current climate and four future climate change scenarios.

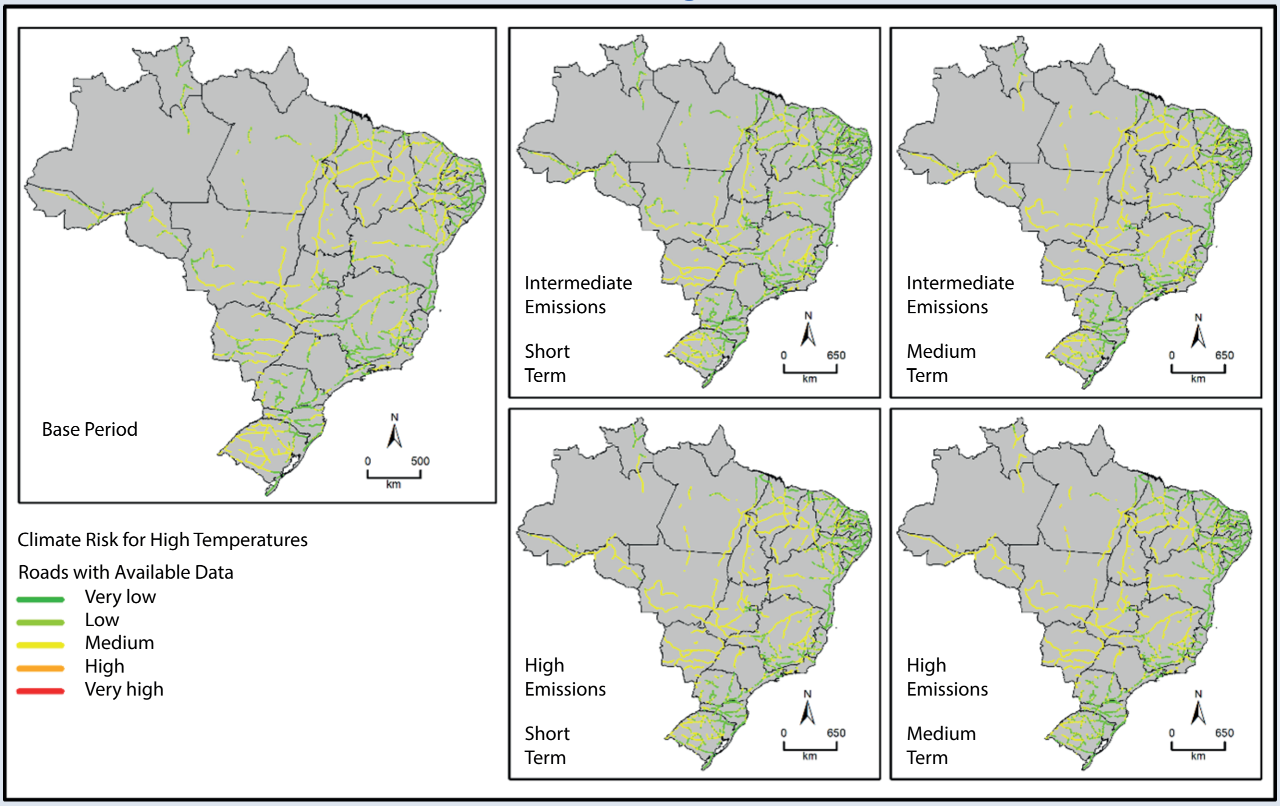



Photo: DNIT

# Adaptation Measures

Adaptation can be defined as "*the process of adjustment in natural or human systems in response to actual or expected climatic stimuli and their effects, which moderates or avoids damage or exploits beneficial opportunities*" (IPCC, 2022). In land transport infrastructure, the aim of adaptation measures is to reduce the vulnerability and exposure of assets in order to keep the transport system operational. Adaptation measures can be either non-structural (soft adaptation) or structural (hard adaptation) (IPCC, 2022). These measures must be linked to current and future planning, risk management, operation and maintenance practices in order to increase the resilience of transport and reduce the impacts of extreme climate events (DE ABREU; SANTOS; MONTEIRO, 2022). Adaptation measures should be compatible and, whenever possible, combined with mitigation strategies to reduce GHG emissions, such as NbS (IPCC, 2022).

The listing of climate change adaptation measures for rail and road land transport infrastructure was based on a systematic and comprehensive literature review at national and international level. A total of 179 adaptation measures were identified, considering the two modes of land transport (rail and road), of which 121 are structural measures and 58 are non-structural measures (Figure 18). Figures 18, 19 and 20 show the number of adaptation measures identified for each type of impact, phase of the asset's life cycle and planning level. This separation between the different adaptation measures was agreed in alignment with the Steering Committee, which separated each adaptation measure by type of impact and hazard, type of measure (structural and non-structural), whether it can be considered an NbS, whether it consists of a GHG emissions mitigation measure, in addition to adaptation, categorizing them by stages of the asset cycle and by planning levels.

**Figure 18** - Adaptation measures by type of impact and structural and non-structural classification.

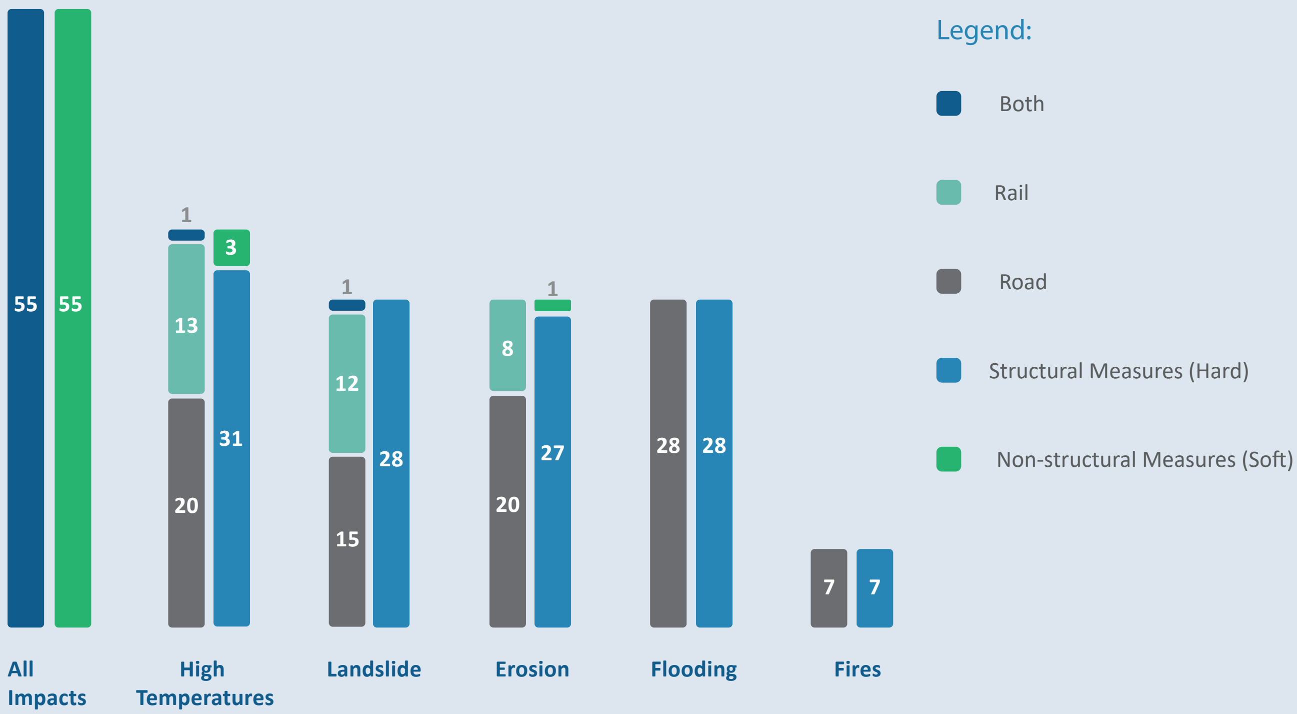


**Figure 19** - Adaptation measures by asset life cycle phase and structural and non-structural classification.

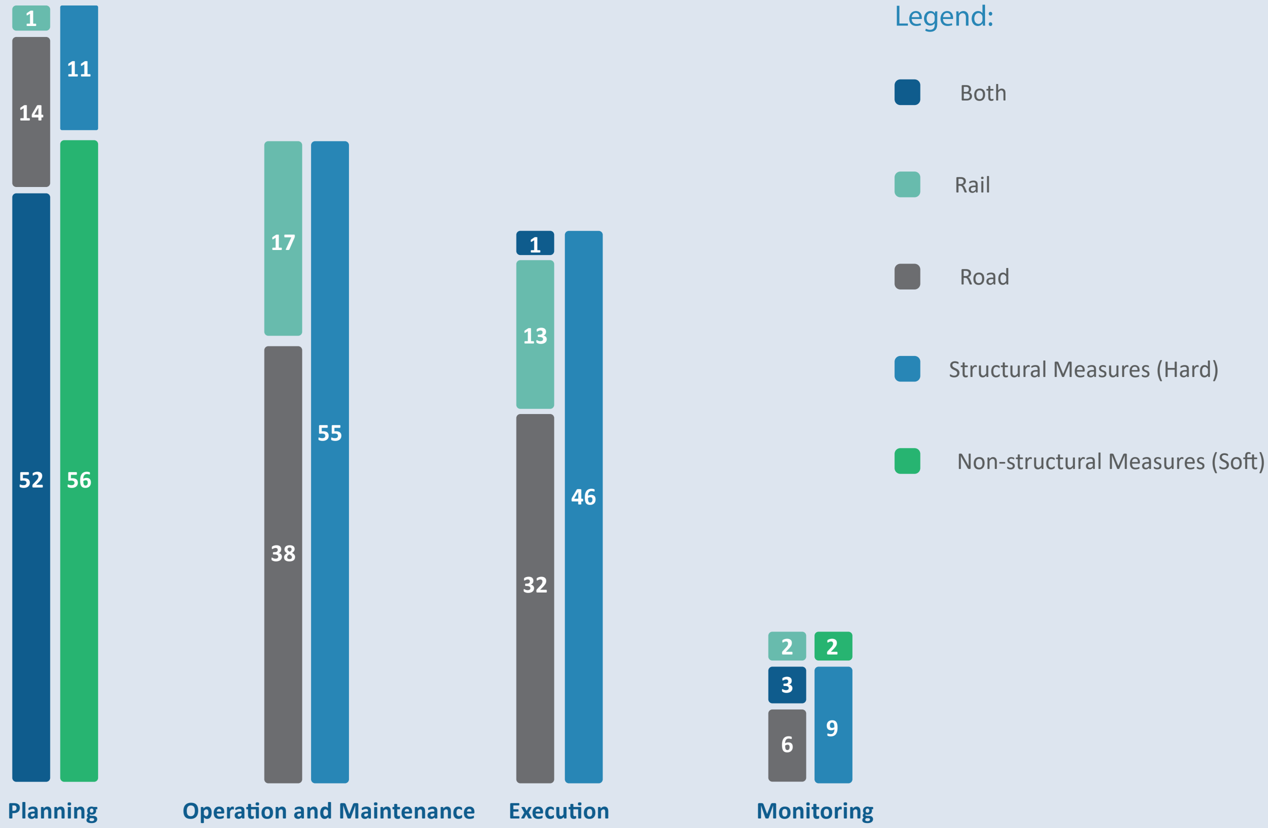
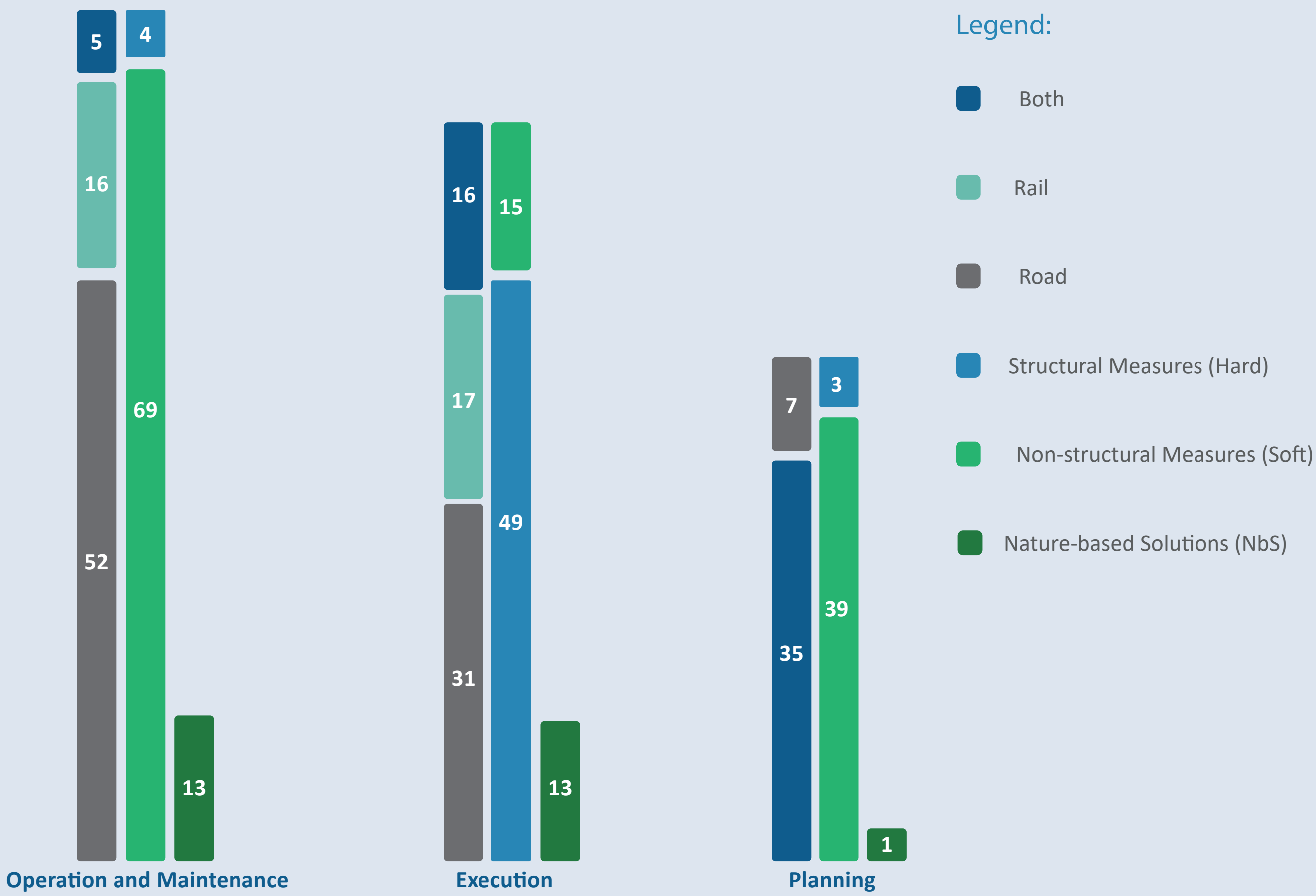



**Figure 20** - Adaptation measures by planning level, structural and non-structural classification and NbS.



Of the 179 adaptation measures listed in the bibliography consulted, 27 relate to the generation of GHG emission mitigation benefits. The vast majority of these measures, which are a combination of adaptation and mitigation, are also considered NbS. Table 2 below shows these figures for rail and road transport.

**Table 2** - Summary of the number of adaptation and mitigation measures, as well as NbS.

| Modes of transportation | Adaptation and Mitigation | Nature-based Solutions (NbS) |
|---|---|---|
| Both | 3 | 4 |
| Road | 10 | 11 |
| Rail | 14 | 16 |
| **Total** | **27** | **31** |

Below are examples of non-structural adaptation measures that address both modes of transport (Table 3) and then specific examples of structural adaptation measures for rail (Table 4) and road (Table 5) separately. For each measure, the phase of the asset's life cycle, its planning level and whether they are also associated with mitigation and NbS are described.

Photo: DNIT

**Table 3 -** Non-structural adaptation measures in the planning phase applicable to rail and road transport modes.

| Non-structural adaptation measures | Level | NbS | Mitigation |
|---|---|---|---|
| Improving integrated spatial planning in relation to road and rail alignments to ensure that adjacent critical ecosystems, which serve as buffers against flooding, erosion, temperature increases, among others, are maintained and protected (e.g. EbS). | Strategic | NbS | Mitigation |
| Evaluation of the possibility of co-benefits and synergies between mitigation and adaptation related to the different alternatives applied to the transport sector (for example, the promotion of rail is more favorable for both adaptation and mitigation). | Strategic | | Mitigation |
| Effective integration of transport with other sectors in the planning and development process through, for example, Strategic Environmental Assessment. | Strategic | | Mitigation |
| Land use planning based on sustainable development, including Sustainable Transport Oriented Development. | Strategic | NbS | |
| Prohibiting the development (construction or expansion) of infrastructure in areas of environmental vulnerability, recognizing the inherent cost of building in risk-prone areas. | Strategic | NbS | |
| Changes to road and rail regulations and asset management policies (in order to promote adaptation). | Strategic | | |
| Systematization of the recording of historical data on damage caused by climatic events, specifying the type of event and the resulting biophysical impact, e.g. the Brazilian Classification and Codification of Disasters (COBRADE) (BRASIL, 2014). | Strategic | | |
| Stakeholder participation, engagement and support - encourage stakeholder involvement in climate adaptation and resilience-building needs. | Strategic | | |
| Systematization of information on the behaviour of strategic transport infrastructure in adverse climate situations, centralizing it in a single database. | Strategic | | |
| Incorporating adaptation clauses into national investment in transport infrastructure. | Strategic | | |

**Table 3 -** Non-structural adaptation measures in the planning phase applicable to rail and road transport modes. (Continued)

| Non-structural adaptation measures | Level | NbS | Mitigation |
|---|---|---|---|
| Promoting greater involvement of the transport sector in climate change adaptation issues, through training and dissemination of information. | Strategic | | |
| Preparing studies and research on the relationship between climate change and the vulnerability of transport infrastructure, with a view to supporting public policies, planning and identifying solutions for the sector. | Strategic | | |
| Strengthening, centralizing and making transparent information on the Monitoring and Maintenance history of transport infrastructure. | Strategic | | |
| Improving risk management by identifying critical infrastructure (hotspots). | Strategic | | |
| Prioritization of corrective works for sites assessed as being most at risk of failure or service interruption. | Strategic | | |
| Establishing ongoing funding mechanisms to support the Adaptation Planning, Coordination, Evaluation and Monitoring structure, with the help of the institutional focal point. | Strategic | | |
| Identifying the need for training in damage assessment, response selection, cost-benefit analysis and the preparation of plans and projects. | Strategic | | |
| Increased resilience in the asset renewal phase. | Strategic | | |
| Increasing the transport sector's capacity to respond to extreme weather events through plans, action protocols and preventive measures. | Strategic | | |
| Systematic analysis of risk reduction combined with the costs associated with implementing adaptation measures. | Strategic | | |

**Table 3 -** Non-structural adaptation measures in the planning phase applicable to rail and road transport modes. (Continued)

| Non-structural adaptation measures | Level | NbS | Mitigation |
|---|---|---|---|
| Encouraging the use of new technologies, such as sustainable drainage systems, which will reduce existing and future flood risks. | Strategic | | |
| Establishing public-private partnerships to implement adaptation and resilience. | Strategic | | |
| Development of an Integrated Contingency Plan, incorporating the transportation system as a whole. | Tactical | | |
| Integration of different types of asset monitoring databases, preferably with some standardization between them. | Tactical | | |
| Development of appropriate monitoring indicators to assess the effectiveness of adaptation measures. | Tactical | | |
| Reviewing the effectiveness of current quantitative data collection procedures for the impacts of extreme weather events and long-term climate change, with the aim of developing a cross-sector reporting mechanism. | Tactical | | |
| Defining roles in generating and identifying the necessary data, specifying data collection instruments, and storing and maintaining them in databases. | Tactical | | |
| Improving weather forecasting capacity and implementing early warning systems. | Tactical | | |
| Carrying out a mid-term review of the statutory adaptation plans for critical infrastructure, with possible contributions from relevant actors. | Tactical | | |
| Improving the production and availability of information on extreme events related to the transportation system. | Operational | | |

**Table 4** - Examples of structural adaptation measures for rail.

| Structural adaptation measures for rail | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Changing the rail installation procedure to increase the temperature limit for thermal expansion. | Planning | Tactical | | |
| Combined erosion prevention (revetments, concrete blocks and wood piles with vegetation; logs, log walls or dead wood; among others). | Execution | Tactical | NbS | Mitigation |
| Biotechnical stabilization to improve grey engineering structures. | Execution | Tactical | NbS | Mitigation |
| Planting “protection forests”. | Execution | Tactical | NbS | Mitigation |
| Re-engineering slopes to change their degree of inclination, improve drainage or provide stabilization. | Execution | Tactical | | |
| Providing redundancy within the system. | Execution | Tactical | | |
| Installation of soft erosion protection (grass, shrubs and trees, coconut or geotextile mats with vegetation, dead plant material). | Execution | Operational | NbS | Mitigation |
| Adequate installation of buttress drains on slopes and renovation of crest drains. | Execution | Operational | | |
| Slope stabilization, including the installation of gabion walls, soil nails and sheet piles. | Execution | Operational | | |
| Drainage improvement, rock bolting/anchoring, rerouting. | Execution | Operational | | |

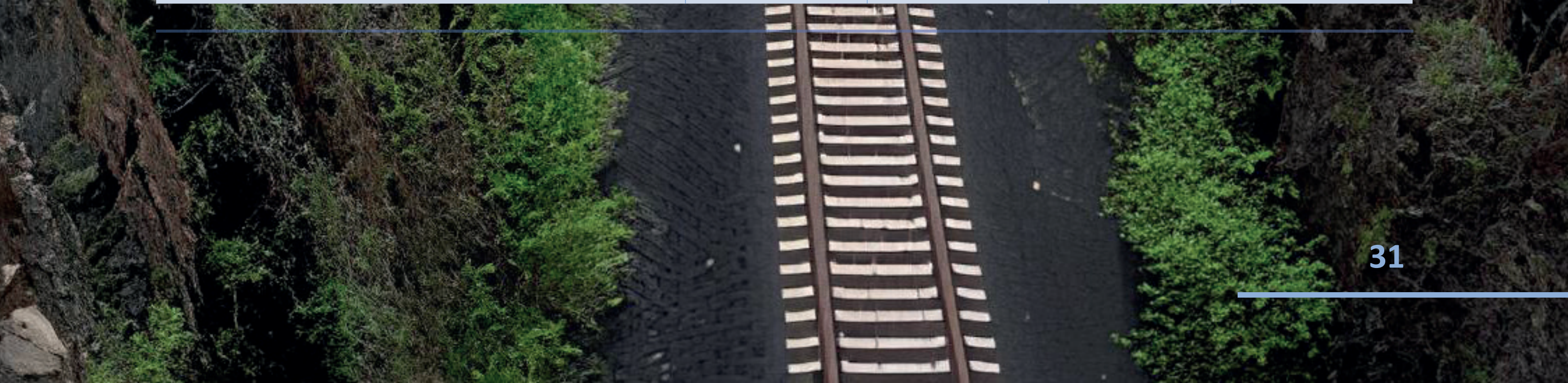


**Table 4** - Examples of structural adaptation measures for rail. (Continued)

| Structural adaptation measures for rail | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Use of moss and lichens for erosion control. | Operation and Maintenance | Tactical | NbS | Mitigation |
| Vegetation management to improve slope stability. | Operation and Maintenance | Tactical | NbS | Mitigation |
| Painting the tracks white in areas of known high risk of thermal expansion in direct sunlight. | Operation and Maintenance | Tactical | | |
| Replacing bridges using heat-resistant materials with lower coefficients of thermal expansion. | Operation and Maintenance | Tactical | | |
| Replacement of articulated rail with continuously welded rail. | Operation and Maintenance | Tactical | | |
| Installing sun protection to mitigate the heat (planting trees or other forms of cover, painting rails, among others). | Operation and Maintenance | Tactical | | |
| Plant cover and root structures to protect against soil erosion. | Operation and Maintenance | Operational | NbS | Mitigation |
| Maintenance and improvement of natural wetlands. | Operation and Maintenance | Operational | NbS | Mitigation |
| Vegetation management along the rail corridor, including selection of suitable vegetation. | Operation and Maintenance | Operational | NbS | Mitigation |
| Installation of hard erosion protection (gravel and stone, concrete blocks, gabions and steel or wooden piles). | Operation and Maintenance | Operational | | |

**Table 4** - Examples of structural adaptation measures for rail. (Continued)

| Structural adaptation measures for rail | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Regular monitoring and maintenance of the track and trackbed. | Operation and Maintenance | Operational | | |
| Replacing rails to repair lateral alignment defects in the buckling zone and realigning rails in adjacent zones. | Operation and Maintenance | Operational | | |
| Purchase, installation and maintenance of the railroad's temperature sensors and related software infrastructure. | Operation and Maintenance | Operational | | |
| Controlled removal of vegetation to prevent forest fires. | Operation and Maintenance | Operational | | |
| Event detection through local monitoring of slopes with sensors. | Monitoring | Tactical | | |
| Digital monitoring to warn when bridge joints become too dense or materials need to be replaced with more heat-resistant ones. | Monitoring | Operational | | |

**Table 5** - Examples of structural adaptation measures for road transport.

| Structural adaptation measures for road transport. | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Improved floodplain management. | Planning | Strategic | NbS | Mitigation |
| Building redundant infrastructure. | Planning | Strategic | | |
| Adapting construction standards to new climatic events. | Planning | Tactical | | |
| Relocation or redesign of critical roads located in flood zones. | Planning | Tactical | | |
| Development and implementation of improved subgrade erosion detection methods. | Planning | Tactical | | |
| Use of new asphalt mixtures - permeable sidewalk- which help to drain standing water more quickly. | Execution | Tactical | | |
| Development of drainage tunnels under major roads and highways to facilitate faster drainage. | Execution | Tactical | | |
| Installation of soft erosion protection (grass, shrubs and trees, coconut or geotextile mats with vegetation, dead plant material). | Execution | Operational | NbS | Mitigation |
| Combined erosion prevention (revetments, concrete blocks and wooden piles with vegetation; logs, log walls or dead wood; among others). | Execution | Operational | NbS | Mitigation |
| Installation of soft protection, which includes natural sedimentation barriers and forests, as well as wetlands, which create a buffer zone. | Execution | Operational | NbS | Mitigation |

**Table 5** - Examples of structural adaptation measures for road transport. (Continued)

| Structural adaptation measures for road transport. | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Implementation of erosion control measures on road verges. | Execution | Operational | | |
| Installation of improved drainage at intersections. | Execution | Operational | | |
| Increased redundancy in electrical systems. | Execution | Operational | | |
| Planting vegetation along roads to reduce the exposure of roads to erosion. | Operation and Maintenance | Tactical | NbS | Mitigation |
| Maintenance/restoration of mangrove areas, which act as energy dissipators in coastal regions, maintaining the coastline. | Operation and Maintenance | Tactical | NbS | Mitigation |
| Adjusting the frequency of inspection and maintenance due to risks. | Operation and Maintenance | Tactical | | |
| Creating accommodations that relate to reducing the severity of damage, such as elevating and modifying infrastructure to reduce the impact of flooding. | Operation and Maintenance | Tactical | | |
| Planting vegetation along roads to reduce the exposure of roads to soil and rock slides. | Operation and Maintenance | Operational | NbS | Mitigation |
| Planting vegetation along roads to reduce the exposure of roads to flooding. | Operation and Maintenance | Operational | NbS | Mitigation |
| Increased cleaning and maintenance of roads and highways and their surroundings. | Operation and Maintenance | Operational | | |

Table 5 - Examples of structural adaptation measures for road transport. (Continued)

| Structural adaptation measures for road transport. | Life cycle | Level | NbS | Mitigation |
|---|---|---|---|---|
| Use of better quality, erosion-resistant materials. | Operation and Maintenance | Operational | | |
| Adjusting the frequency of maintenance and periodic cleaning of the drainage network near roads. | Operation and Maintenance | Operational | | |
| Installation of rigid protection, which provides a barricade against water ingress. | Operation and Maintenance | Operational | | |
| Replacing the damaged asphalt coating with another coating made of more heat-resistant materials. | Operation and Maintenance | Operational | | |
| Increased cooling of the asphalt with water. | Operation and Maintenance | Operational | | |
| Raising and protecting signs and other electrical equipment. | Operation and Maintenance | Operational | | |
| Adjusting the frequency of correction of mill out ruts in the sidewalk. | Operation and Maintenance | Operational | | |
| Improving subgrade monitoring conditions, especially after heavy rains. | Monitoring | Tactical | | |
| Research into new techniques and materials suitable for reduced wear, in order to incorporate this into instruction booklets and technical construction standards. | Monitoring | Operational | | |

# Conclusions and Recommendations

Climate change implies several challenges for the Brazilian land transport sector. The AdaptaVias study assessed the level of climate risk for the main biophysical and direct impacts on rail and road transport infrastructure throughout Brazil. The study aims to support the Ministry of Transport and stakeholders in drawing up strategies to minimize the damage and losses caused by climate change in the transport infrastructure sector.

The results show that the sections of Brazilian railroads with the greatest climate risks due to landslides, erosion and high temperatures, from the base period to the high emissions scenario (SSP5-8.5) and medium term (2046-2065), are located in the Southeast (Vitória-Minas Railway, operated by Vale S.A, and Minas x Rio Railway, operated by MRS Logística) and in the North/Northeast, specifically on the Pará-Maranhão axis (Carajás Railway, operated by Vale S.A). In addition to the direct impact of high temperatures, there is a stretch of railroad located in Rio Grande do Sul, between Cacequi and Dilermando de Aguiar (Porto Alegre--Uruguaiana Railroad).

With regard to the analysis of road transport infrastructure, it can be seen that the distribution of the stretches where climate risk is highest varies between different impacts. With regard to flooding, it can be seen that some stretches in Pará and Maranhão, as well as parts of highways on the coast of the Northeast, have a medium level of climate risk, although even in the high emissions scenario (SSP5-8.5) and medium-term scenario (2046-2065), more than 80% of the road stretches remain at a low level. As for landslides, in all the scenarios and horizons considered, the highest levels of climate risk (medium risk) are located in the South and Southeast (Serra do Mar and Serra Geral), on the coast of the Northeast, and in Pará, in the North. In relation to erosion, the stretches with the highest risk are concentrated on the highways in Pará and in the states of the South and Northeast regions of Brazil, especially on the coast (BR-101), which has a medium level of impact on road infrastructure. The risk of impact due to fires for the base period is medium for 31.9% of the road sections, located mainly in the interior of the Brazilian Northeast and part of the North, and low for 68.1% of the Brazilian territory. Depending on the GHG emissions scenario, road sections at low risk decrease and road sections at medium risk increase. This increase occurs especially in the Center-West and North regions of Brazil. With regard to direct impacts due to high temperatures, it can be seen that, unlike the other impacts analyzed, in the base period there is a predominance of stretches with a medium level (63.2%), located in the interior of the country, spread across all regions, while the roads located on the coast of the country, for all scenarios and time horizons considered, are at low risk of impact.

In view of the climate risks analyzed and the various implications for the transport system, it is essential to implement adaptation measures (such as those described in Chapter 5). As a way of enhancing the effectiveness of adaptation, it is important to promote actions with different approaches in an integrated manner, including both structural ones, which have a more specific application by type of impact (acting on infrastructure design cycles), and non-structural ones, which have a more general application of a governmental, educational and social participation nature (covering institutional and management processes).

It is worth noting that the project has presented some challenges, particularly in terms of the availability of data for the whole of Brazil. The lack of specific data on the infrastructure, year of construction/age of the asset, or the difficulty of accessing Maintenance reports and corrections, makes it difficult to analyze and possibly recommend measures. Another gap is the lack of records of damage associated with the climate and infrastructure characteristics that represent adaptive capacity (e.g. maintenance, contingency plans, insurance). This limited the use of vulnerability indicators that could represent each of the biophysical or direct impacts on infrastructure analyzed. The lack of data recording impacts on roads and railroads made it impossible to validate the results of the climate risk index, which is fundamental in climate risk mapping (DE

SHERBININ *et al.*, 2019) and should be considered in future studies. In this way, it is recommended to systematize and promote the recording of damage and losses caused by climatic events, specifying the type of event according to, for example, the Brazilian Classification and Codification of Disasters (COBRADE, BRAZIL 2012). Another important aspect is that future scenarios should be interpreted with caution. The scenarios are based on a significant set of climate models, but the uncertainties, although they have been quantified, have not been incorporated into the risk maps. In addition, new models are available and it is therefore recommended to update the hazard maps and incorporate the uncertainty estimates into the risk maps.

Another opportunity for future study is to carry out more specific analyses for the stretches with the highest levels of impact risk, already in the base period, or whose risk increases considering the different scenarios and time horizons. Similarly, climate risk evaluations for the transport sector from the perspective of integrated systems, as well as cross-sector economic evaluations, are possibilities for future development that can support the incorporation of adaptation into the formulation of public policies. By focusing on specific railroads and roads, new research can include more robust bases on existing infrastructure, allowing for a more in-depth analysis of risks. This would also allow for the inclusion of adaptive capacity indicators, which were lacking in this study due to the need to represent the entire Brazilian territory, which is continental in size. In addition, more in-depth studies are recommended on the feasibility of implementing adaptation measures based on NbS in the search for climate-resilient development.

It is worth noting that the involvement of representatives of important Brazilian public bodies and private concessionaires, from the development of the impact chains to the assignment of the weights of the indicators used in the climate risk assessment, was of paramount importance in achieving results consistent with the Brazilian reality. In addition, this study brings the issue of climate resilience to the forefront of discussions by national authorities on adaptation measures for Brazil's rail and road transport infrastructure, serving as a basis for the development of public policies related to this issue, as well as supporting regulatory policies.

Photo: Ministry of Transport.

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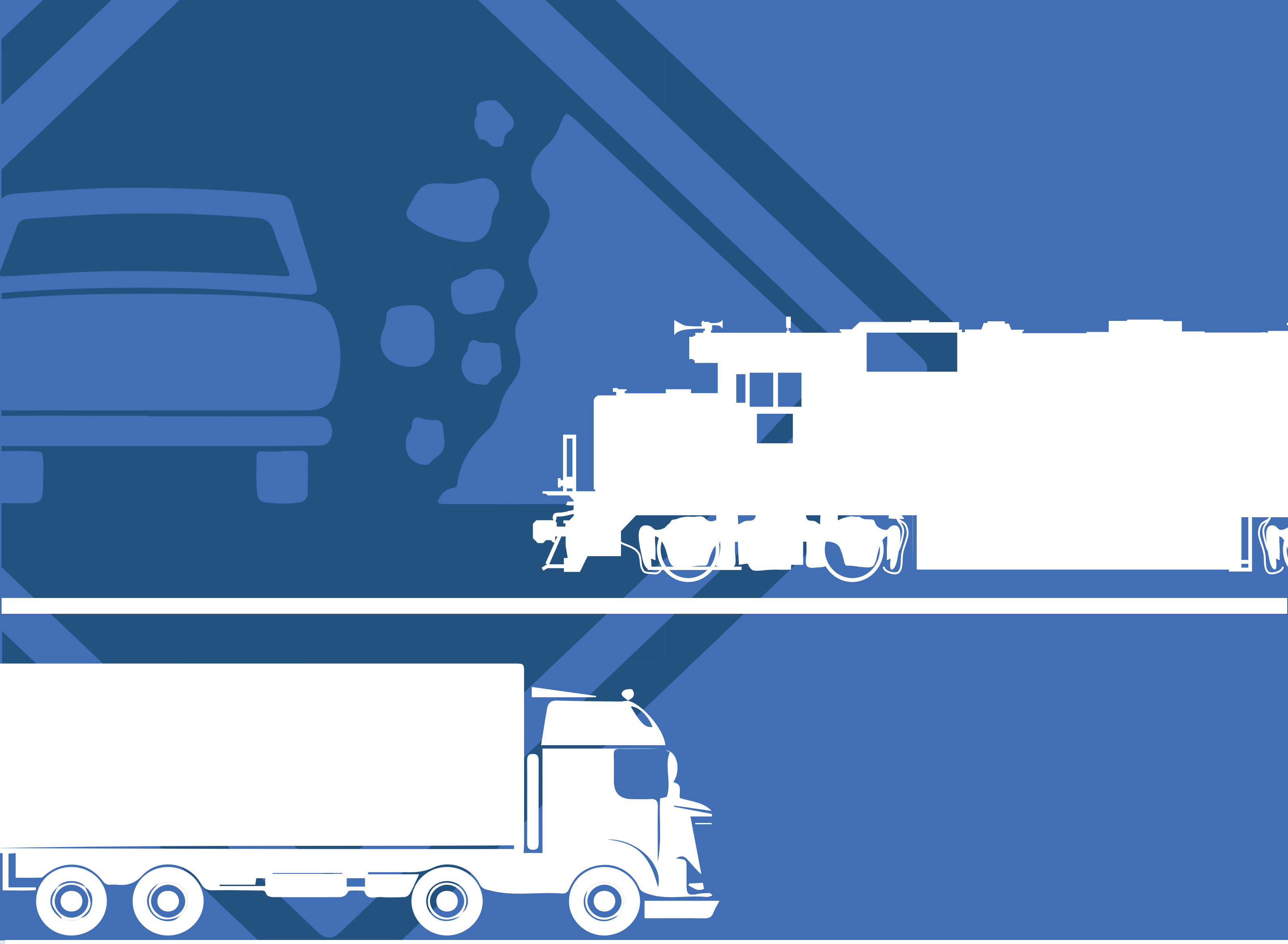


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