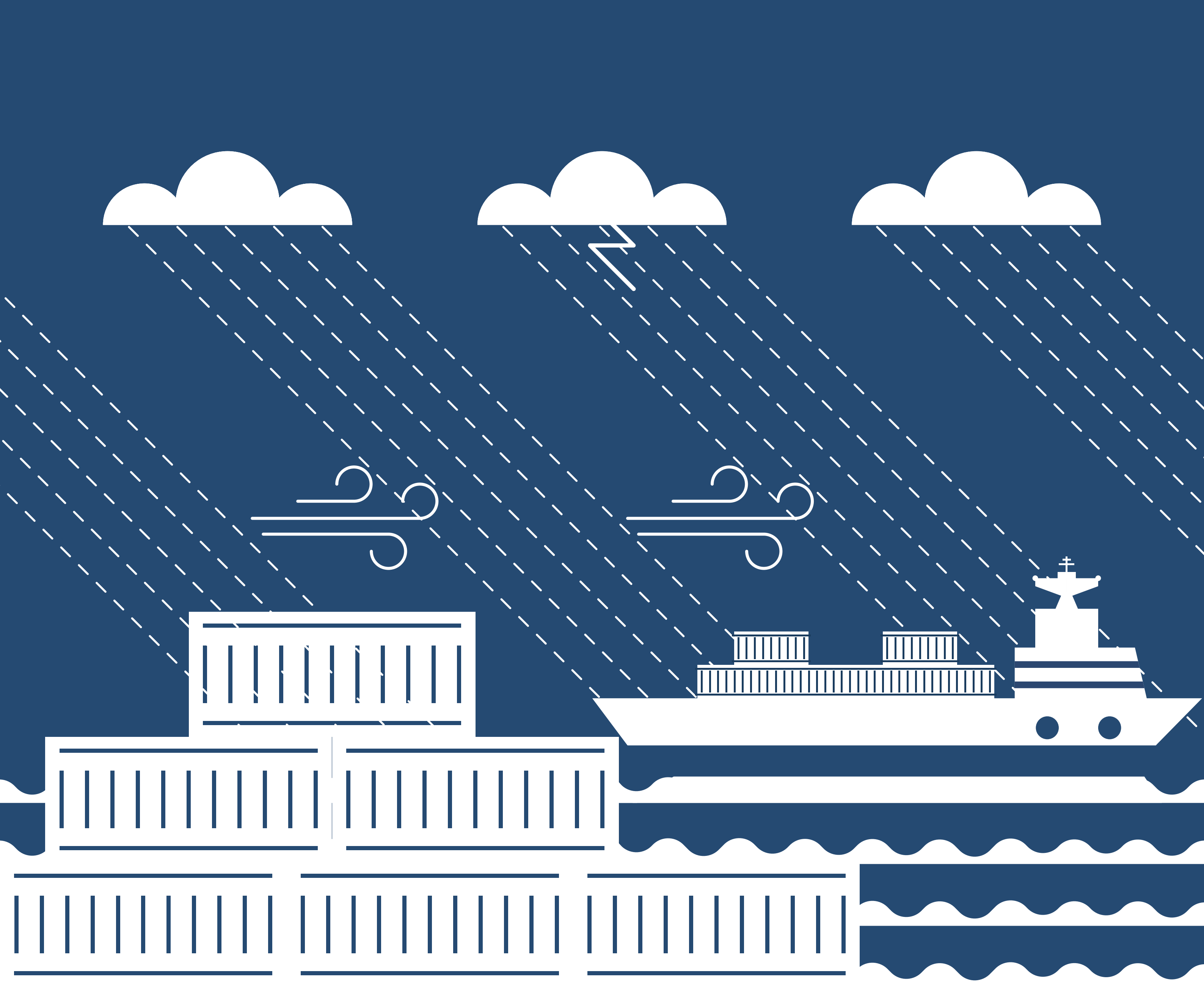

IMPACTS AND RISKS OF CLIMATE CHANGE TO **BRAZILIAN COASTAL PUBLIC PORTS**

Executive Summary

On behalf of:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
of the Federal Republic of Germany

Implemented by:
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PROADAPTA | CSI
Climate Change Adaptation

INPE

ANTAQ
Agência Nacional de Transportes Aquaviários

MINISTÉRIO DO MEIO AMBIENTE

MINISTÉRIO DA INFRAESTRUTURA

MINISTÉRIO DA ECONOMIA

PÁTRIA AMADA BRASIL
BRAZILIAN GOVERNMENT

Federative Republic of Brazil

Jair Bolsonaro
President of the Republic

Tarcísio Gomes de Freitas
Minister of Infrastructure

Brazilian National Waterway Transportation Agency – ANTAQ

Eduardo Nery
General Director

Adalberto Tokarski
Director

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Director

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Elaboration of the document: WayCarbon

This publication was produced by a team of independent consultants under the coordination of the German Cooperation for Sustainable Development, through the projects Enhancing Climate Services for Infrastructure Investments (CSI) and Supporting Brazil in the Implementation of the National Agenda for Adaptation to Climate Change (ProAdapta), with the participation of the BRAZILIAN NATIONAL WATERWAY TRANSPORTATION AGENCY – ANTAQ and the National Institute for Space Research (INPE).

The projects CSI and ProAdapta were agreed in the framework of the German Cooperation for Sustainable Development, through a partnership between the Brazilian Ministry of Environment (MMA) and the Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), within the framework of the International Climate Initiative (IKI) of the Federal Ministry of Environment, Nature Conservation and Nuclear Safety (BMU).

1 :: Presentation

In view of the technical cooperation between the governments of Brazil and Germany to honor the commitments made in international climate agreements, the German Ministry of Environment, Nature Protection and Nuclear Safety (BMU) has been supporting the Brazilian government in actions to increase the country's resilience, through projects aimed at adaptation to climate change.

Among these projects, there is the "Supporting Brazil in the implementation of its National Agenda for Climate Change Adaptation – ProAdapta" which aims to enhance climate resilience in Brazil, through the effective implementation of the Brazilian National Adaptation Plan (NAP).

Implemented by the German Technical Cooperation Agency Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, ProAdapta supports processes of coordination and cooperation among the three spheres of government, economic sectors and civil society.

The Brazilian National Waterway Transportation Agency (ANTAQ) realized that there is the need to consider, in its spectrum of action, the impacts and risks of climate change to Brazilian port terminals in order to guarantee the efficiency and regularity of operations.

For this reason, in January 2020, a Cooperation Agreement was signed between ANTAQ and GIZ for the preparation of the study entitled *"Impacts and Risks of Climate Change to Brazilian Coastal Public Ports"*. The deliverables within the scope of this partnership have the potential to support the implementation of national public policies to improve the resilience of Brazilian ports, by prioritizing actions and investments.

The agreement embraces three well-defined axes: 1) assess the impacts and risks of climate change to the main public coastal ports in Brazil and identify the ports that are under the highest risks; 2) assess the impacts and risks of climate change for three ports selected from the national assessment (axis 1) and elaborate a guideline for climate risks assessments at port scale, and 3) report general recommendations for adaptation measures the port sector and communicate the outcomes of the project.

The study presented here is part of the axis 1. It assesses the impacts and risks of climate change to 21 public coastal ports in Brazil, as well as adaptation options to increase the resilience of port in the face of climate change. This study was carried out by the consultancy company WayCarbon in collaboration with the Brazilian National Institute for Space Research (INPE), which played a fundamental role in the provision of technical support for defining the methodological approach adopted in the climate risk assessment.

In addition to an extensive literature review and technical meetings between the project stakeholders, a series of consultations were held with the representatives of the ports. Unfortunately, knowledge about the impacts of climate change on Brazilian coastal zones, especially on ports, is limited. The lack of monitoring on the impacts caused by weather events is the greatest limitation in understanding the impacts of climate change on Brazilian ports.

Thus, considering the great relevance of this study, it is expected that it can be the starting point for the improvement of the regulation in the port sector, as well as a guidance for the implementation of public policies on adaptation to climate change in Brazil and abroad.

2 :: Introduction

Coping with the consequences of climate change is one of the most complex challenges of this century. The port sector is among the sectors that can directly face the impacts from climate change. Especially because port infrastructure is highly exposed to climatic hazards. Ports are a critical intersection point for global trade, so such negative impacts could result in considerable damages and losses, given that approximately 90% of global trade depends on maritime transport to sustain itself.

In Brazil there are 36 public ports within the competence of the Union, called Organized Ports and governed by Law No. 12,815/2013. In this category, there are ports managed by the Brazilian federal government, through government-controlled private companies called Companhias Docas, or those whose administration has been delegated to cities, states or public consortia. The areas of these ports are delimited by an act of the Federal Executive Branch according to article 15 of the Law No.12.815 of June 2013.

Such public ports are of great importance in transport logistics, constituting a logistical link between the modes of cargo transport, with great relevance in the flow of production to national and international consumer markets, as well as in obtaining input materials for the performance of their economic activities. The port sector has a growing potential to expand its operations, increasing its influence on the national economy.

According to data from the Waterway Statistics Report[1], produced by the ANTAQ (ANTAQ, 2019), about 95% of the country's foreign trade flow, in tons, passes through the port sector[2] and Brazilian ports move, on average, 293 billion Brazilian *reais* annually, which means about 14.2% of the Brazilian Gross domestic product (GDP).

Climate change can cause losses to the sector, influencing the regional economy and global supply chains. This is because port facilities, as they are located in coastal areas, are directly and indirectly affected by extreme weather events, such as intense precipitation, strong winds and storm surges, in addition to an increase in air temperature and sea level rise. These phenomena contribute to an increasing occurrence of floods, coastal erosion and losses of coastal ecosystems (NOBRE; MARENGO, 2017). All of this makes ports susceptible to climate risks, both in terms of disruptions to daily operations and in terms of damage and repairs to infrastructure (BECKER *et al*., 2016; NG *et al*., 2016).

For the port sector, this process is problematic because it can lead to interruption of navigation in port regions (for security reasons) and even to the flooding of terminal yards and nearby areas, such as roads. In addition, these impacts, together, lead to an increase in the costs of maritime complexes and also affect the durability and resistance of port facilities.

In this sense, ports around the world are increasingly looking for the identification and assessment of climate risks that highlight the need to develop adaptation strategies, with the purpose of reducing the financial and operational losses resulting from these impacts.

Large port complexes, such as those in Rotterdam, in the Netherlands, and New York-New Jersey; Los Angeles-Long-Beach; San Francisco and Houston, in the United States, have been studying, over the last decade, the impacts of sea level rise on ports and urban areas. And, in some cases, they are already developing action plans to reduce the impacts of sea level rise.

1. QlikView (antaq.gov.br).

2. Currently China, USA, Argentina and some countries belonging to the European Union are important commercial partners of Brazil.

Therefore, given the relevance of the port sector to the Brazilian economy and the sector's high exposure to climate hazards, adaptation becomes fundamental and urgent to ensure port operations and, consequently, the resilience of the logistic sector. A previous study, the "Brazil 2040" Program of the Secretariat for Strategic Affairs of the Presidency of the Republic (SAE-PR), revealed that port infrastructure is highly exposed to climate hazards and the risks can no longer be ignored.

Adaptation is defined as a process of adjustment of human and natural systems to the current and future effects of climate (IPCC, 2014). In the context of the port sector, adaptation involves implementing actions aimed at reducing vulnerability to climate hazards or identifying opportunities to increase resilience to climate change. Such actions may include technology, changes in engineering, design and maintenance, planning, insurance and improvement of management practices (SCOTT *et al*., 2013).

In this context, this study aimed to identify the impacts and risks of climate change to public ports on the Brazilian coast, and to offer a list of general recommendations for possible adaptation measures to increase the resilience of ports to the undesirable effects on the port operation and infrastructure.

To achieve this objective, the study included, among other aspects: i) an literature review on methods to asses climate risks, with special attention to the port sector; ii) identification of the main impacts (damages and losses) that the Brazilian coastal port sector has suffered due to weather events; iii) analysis of the frequency (increase/decrease) of impacts; iv) identification of climate hazards that affect the Brazilian coastal ports; v) analysis of the frequency (increase / decrease) of climate hazards; vi) assessment of the level of vulnerability (sensitivity and adaptive capacity) and exposure of ports to climate hazards; vii) assessment of the climate risk level (hazard x vulnerability x exposure) of the ports; and viii) assessment of adaptation measures that can be implemented by the port sector.

The climate risk assessment embraces 21 public coastal ports, namely: Angra dos Reis (RJ), Aratu-Candeias (BA), Cabedelo (PB), Fortaleza (CE), Ilhéus (BA), Imbituba (SC), Itaguaí (RJ), Itajaí (SC), Itaqui (MA), Natal (RN), Niterói (RJ), Paranaguá (PR), Recife (PE), Rio Grande (RS), Rio de Janeiro (RJ), Salvador (BA), Santos (SP), São Francisco do Sul (RS), São Sebastião (SP), Suape (PE) and Vitória (ES) – Figure 1

Figure 1: Location of public ports on the Brazilian coast selected for analysis.

Prepared by: WayCarbon, GIZ, ANTAQ (2021).

3 :: Methods

The climate risk assessment for Brazilian public coastal ports was carried out in six major steps.

(1) Review of methods to assess climate risks. It included a literature review of national and international risk analysis methodologies applicable to the port sector, which were compared with the climate risk assessment method proposed by the Intergovernmental Panel on Climate Change (IPCC, 2014), in order to validate the feasibility of the application in the context of Brazilian coastal ports.

(2) Assessment of impacts. It was carried out by administering an electronic questionnaire[3] to the 21 Brazilian public ports analyzed, with the objective of collecting specific information that supported the risk assessment.

(3) Assessment of climate hazards indicators and definition of scenarios and time horizons. It was based on a literature review on climate hazards with the greatest potential to impact ports and on the results obtained through the electronic questionnaire that was administered, in step (2), to the representatives of the public ports under analysis. Then, in a new stage of consultation with the ports covered, the adherence of the results obtained to the reality experienced by the Port Authorities was certified.

3. For further details, see the full report containing the study methodology.

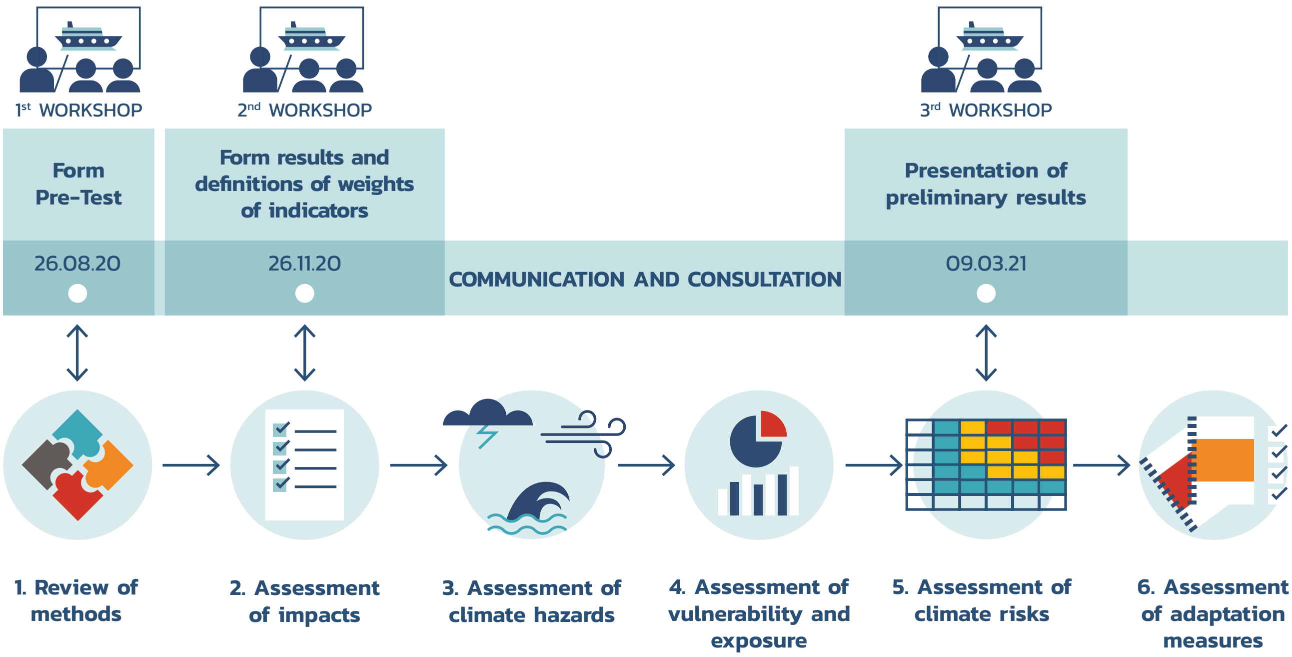
(4) Assessment of vulnerability and exposure. It was based on data available in the literature and on the results of the electronic questionnaire that was administered. In this step, port specialists, appointed by the ports, gave their opinion on the definition of weights applicable to the variables of the vulnerability indicator.

(5) Assessment of climate risks. This step consisted of applying the risk method proposed by the IPCC (2014), validated in step 1. At this stage, a ranking was prepared with the ports classified as having the greatest risk due to the occurrence of thunderstorms, strong winds and sea level rise.

(6) Assessment of adaptation measures. This step was based on the results from the survey conducted with the port authorities and a literature review.

The main steps taken throughout the study are summarized in Figure 2 below.

Figure 2: Sequencing of the steps followed in the study.

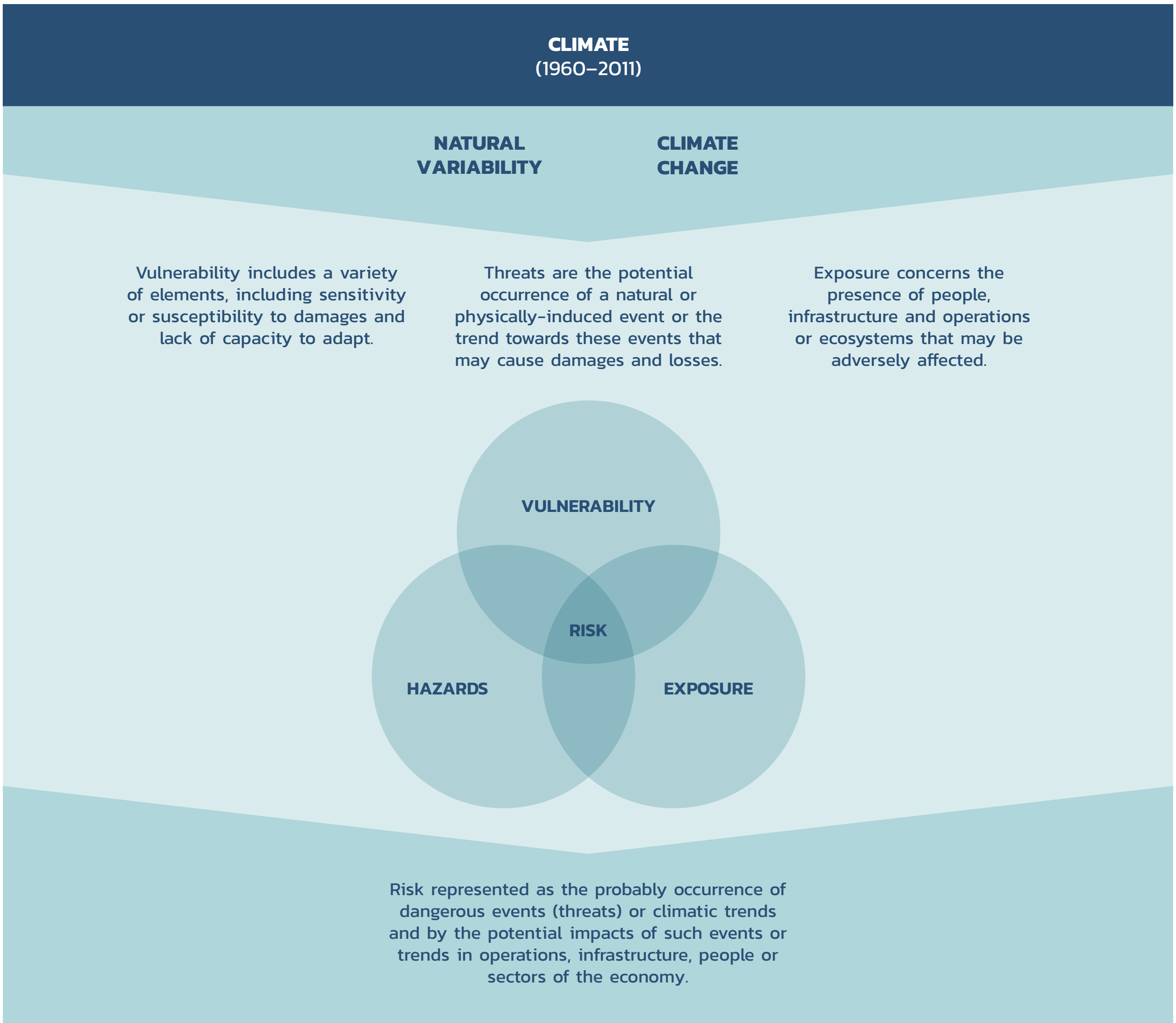


Prepared by: WayCarbon, GIZ and ANTAQ (2021).

3.1 :: Climate Risk Index for Ports

The method used for assessing the climate risks for ports was the climate risk framework of the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014). The IPCC's climate risk framework considers climate risk as a result of the interaction of climate hazards with the exposure of natural, human and economic systems and their characteristics of vulnerability, obtained as a function of the sensitivity or susceptibility to damage and the capacity to adaptation (Figure 3).

Figure 3: Climate Risk Analysis Methodology.



Source: Prepared from IPCC (2014).

Mathematically, the equation used to represent the climate risk index was:

$$R = A \times E \times V$$

Where:
A: Represents the climate hazard considered;
E: Represents the exposure of a given port to the considered hazard;
V: Represents the port's vulnerability to the considered hazard.

$$\check{R} = \frac{\frac{x}{\sigma}}{\text{máx}\left(\frac{x}{\sigma}\right)} \quad [2]$$

After calculating the risk index, the results were standardized, according to Equation 2:

Ř: Standardized risk index;
X: Risk index for each port in each period and scenario analyzed;
σ: Standard deviation of the "x" set.

Thus, the climate risk index can be presented on a scale of values that range from 0 to 1, which are classified as shown in Table 1.

Table 1: Climate Risk Index Scale

RANGE	CLASS
0 ≤ Ř < 0.199	Very Low
0.2 ≤ Ř < 0.399	Low
0.4 ≤ Ř < 0.599	Medium
0.6 ≤ Ř < 0.799	High
0.8 ≤ Ř ≤ 1	Very High

Prepared by: WayCarbon, GIZ and ANTAQ (2021).

4 :: Main Results

(1) Review of methods: it was found that the IPCC's climate risk framework is adequate to the context of Brazilian coastal port and little adjustments were adopted in order to cope with the lack of data available.

(2) Assessment of impacts: based on the responses of the port authorities, it was possible to identify eight[4] climate hazards. Thunderstorms and strong winds are the most prominent hazards affecting the logistical chain, operations and port structures. Several ports reported an increase in the frequency of impacts resulting from thunderstorms and strong winds. Moreover, the survey revealed a gap in the monitoring of weather-related impacts by the ports, which made the assessment of the current impacts of climate change difficult.

(3) Assessments of hazards: the climate hazards selected in this study were thunderstorms, strong winds and sea level rise. The future scenarios were based on the 2030 and 2050 periods and considering the Greenhouse Gas Emissions Scenarios RCP4.5[5] (moderate emissions) and RCP8.5[6] (high emissions). The hazards from thunderstorms, strong winds and sea level rise were selected considering their potential to cause interruptions in the operations and infrastructure damages. Although sea level rise was not pointed out by the ports as a relevant climate hazard, sea level rise was taken into account in this study considering that the literature presents evidence that the rate of sea level rise has been on an upward trend in recent years, with the potential to cause significant impacts on the port sector. Regarding the selected periods and scenarios, these were defined according to the method presented in the AdaptaBrasil[7] platform of the Ministry of Science, Technology and Innovation (MCTI), into which the results of this project will be incorporated, in addition to considering the time horizons included in the port sector's planning instruments.

(4) definition of vulnerability and exposure indicators, it was possible to identify 13 indicators of adaptive capacity to storm and gales and 10 of adaptive capacity to increase in mean sea level,

4. Climate threats analyzed: thunderstorms, strong winds, sea level rise, coastal and river floods, coastal erosion, fog, heat waves.

5. In the RCP4.5 scenario, the concentration of CO^2 equivalent in the atmosphere reaches about 650 ppm by the end of the 21st century and strategies to reduce GHG emissions cause the radiative forces to stabilize at 4.5 W/m² before the year 2100, which represents an increase between 1.8°C and 3,3°C in the global average temperature (INPE, 2021).

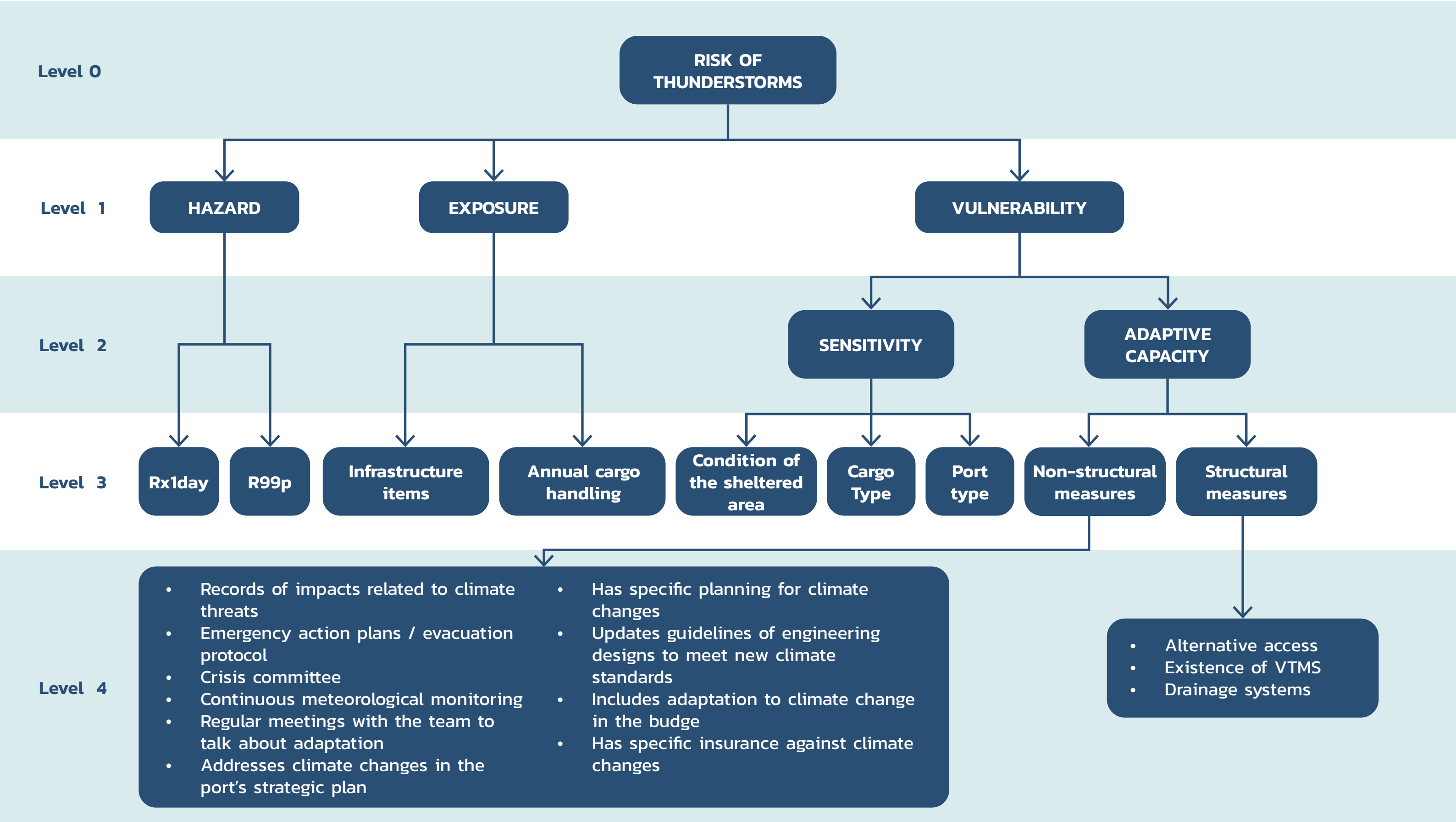
6. RCP8.5 corresponds to a scenario of high concentration of GHG in the atmosphere, in which the equivalent CO^2 exceeds 1000 ppm by the end of the 21st century and, therefore, the radiative forcing will reach 8.5 W/m² by the year 2100, leading to an increase between 3.3°C and 5.9°C in the global average temperature (INPE, 2021).

7. https://adaptabrasil.mcti.gov.br/

based on the results of the administered questionnaire, all referring to the vulnerability dimension. Sensitivity and exposure indicators were identified in the literature, including two (2) for exposure to the three threats analyzed, three (3) for sensitivity to storm and gale threats, and two (2) for sensitivity to mean sea level rise.

(5) Assessment of climate risks: the combination of the climate hazard, exposure and vulnerability indicators resulted in the climate risk index. Figures 4, 5 and 6 illustrate the hierarchical structure of the risk index of thunderstorms, strong winds and sea level rise, respectively. The hierarchical structure follows the model adopted by AdaptaBrasil.

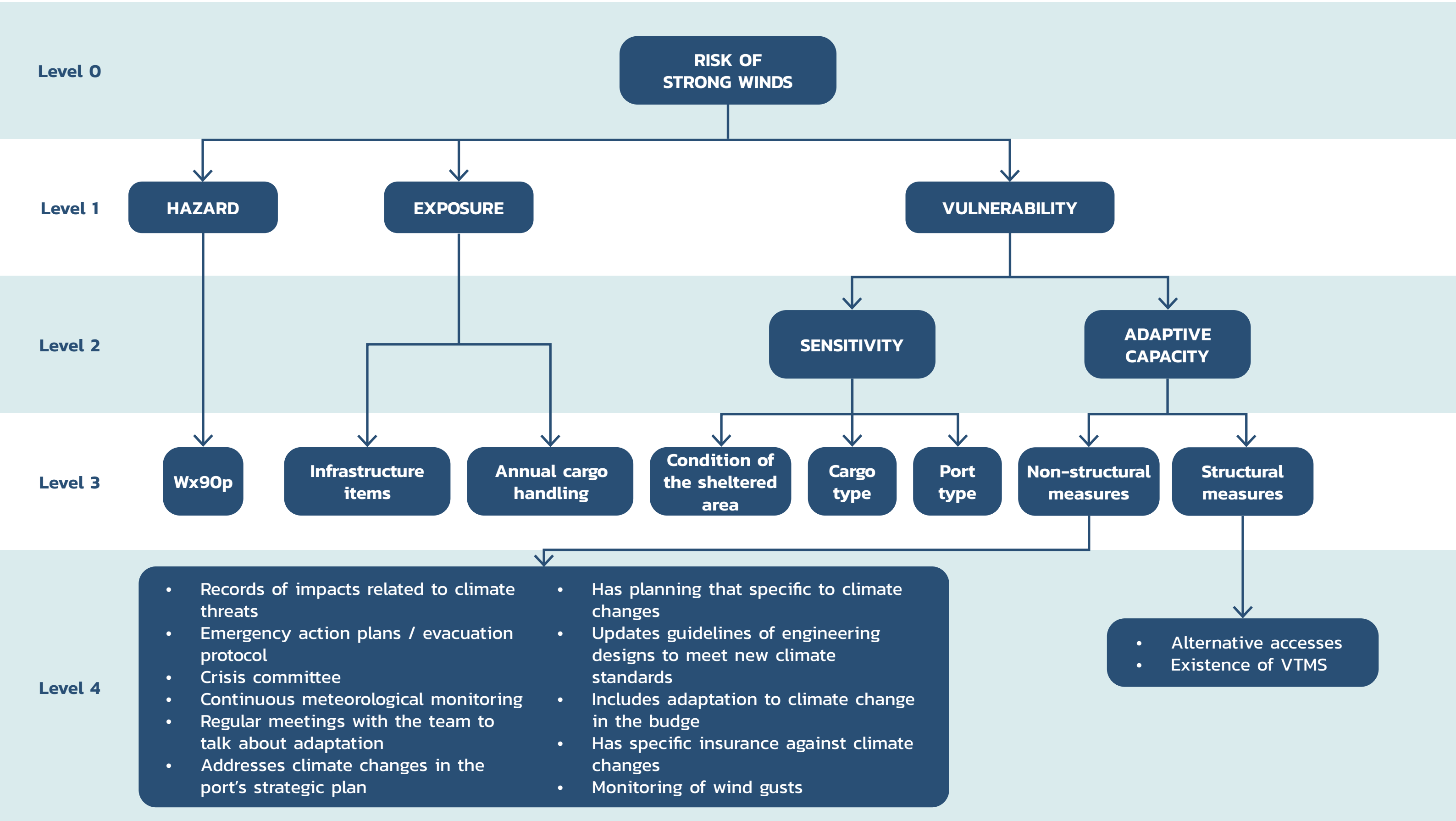
Figure 4: Hierarchical Structure of the Risk Index for Thunderstorms



Prepared by: WayCarbon, GIZ and ANTAQ (2021).

Note: The indicator Rx1day represents the largest annual volume of precipitation in one day, while the R99p represents the percentage of days in the year in which precipitation was above the 99th percentile in relation to the base period (1986–2005). The "type of load" indicator considered for this calculation is related to the vegetable load, since the operation of this type of load is more sensitive to storms.

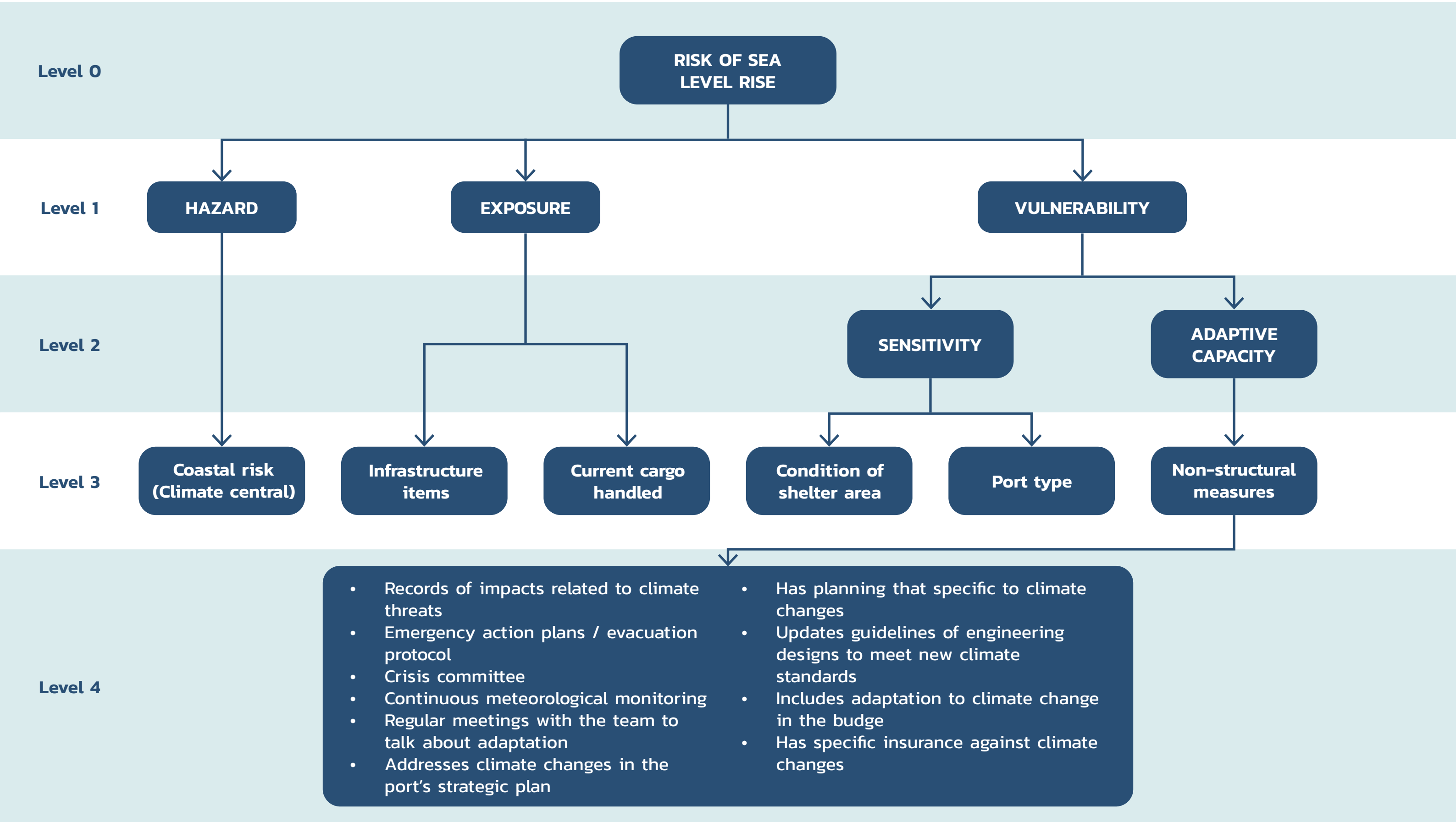
Figure 5: Hierarchical Structure of the Risk Index for Strong Winds.



Prepared by: WayCarbon, GIZ and ANTAQ (2021).

Note: The Wx90p indicator consists of calculating the percentage of days when the maximum wind speed is greater than the 90th percentile. The "type of load" indicator considered for this calculation is related to containerized loads, general cargo and solid bulk, due to the operations' sensitivity to strong winds, as there may be difficulty in handling lifting equipment due to wind speed.

Figure 6: Hierarchical Structure of the Risk Index for Sea Level Rise.



Prepared by: WayCarbon, GIZ and ANTAQ (2021).

Note: The hazard of sea level rise is presented by the presence or absence of coastal risk, which was possible to identify using the Ebba "CoastalDEM" digital elevation model. The condition of the sheltered area indicator represents the structural integrity of the sheltered area, aiming to indicate how much the sheltered area fulfills its function of protecting port operations from winds, sea and waves. The port-type indicator indicates whether the port is artificially or naturally sheltered, given that depending on this type of shelter, ports can be more or less sensitive to the analyzed hazard. In the case of Brazilian ports, these can be: naturally sheltered by an island/bay, naturally sheltered by a river/lake or artificially sheltered.

The climate hazard indicator was calculated in different ways depending on the climate hazard. For thunderstorms and strong winds, indicators were developed based on extreme weather indices. The database used to calculate these indicators considered a set of regional climate models made available by the project entitled *"Coordinated Regional Detalownscaling Experiment"* (CORDEX)[8] forced by global climate models from the Coupled Model Intercomparison Project 5 (CMIP5) for the domain of South America. The preparation of indicators related to these two hazards was monitored and validated by INPE specialists. For the sea level rise indicator, the hazard was estimated from the "CoastalDEM" digital elevation model, in which it was assessed based on whether or not there will be the presence of an inundated area (polygon) at the port. The indices were calculated for the historical period of 1986-2005 and for the 2021-2040 (centered in 2030) and 2041-2060 (centered in 2050) and the scenarios were RCP4.5 and RCP8.5.

The exposure indicator for all analyzed hazards is composed of the intermediate indicators "number of infrastructure items" and "annual cargo handling". The number of infrastructure items was obtained from the master plans of the ports, while the annual cargo handling amount was obtained from ANTAQ's Waterway Statistics.

The vulnerability indicator, made up of the sensitivity and adaptive capacity indicators, was obtained through the survey with the ports and a literature review. The answers to the questionnaire, as mentioned above, supported the development of the adaptive capacity indicator. The literature review was the basis for the choice of intermediate indicators for the sensitivity analysis. The condition of the sheltered area and the type of port were based on the *World Port Index* (WPI) data from the *National Geospatial-Intelligence Agency* (NGA), while the type of cargo, present only for the hazards of storms and gales, was obtained through data from ANTAQ's Waterway Statistics Report.

It should be noted that in climate risk calculations, only the hazard index varies in the future. Exposure and vulnerability indicators were considered as constant variables, taking into account the current conditions of each port. Thus, by evaluating these indicators as constant variables, it was possible to understand how much a climate hazard could affect the ports in the future.

(6) assessment of adaptation measures: fifty-five adaptation measures were identified. From that amount, 21 are structural measures and 34 that are non-structural measures. Structural measures involve engineering works for the correction and/or prevention of disasters, and may also cover the areas of technology, as well as ecosystem-based adaptation (EbA)[9]. Non-structural measures aim to reduce the disaster through administrative management, norms, regulations or programs, covering the areas of design and maintenance, planning, insurance and systems management.

4.1 :: Climate Risk Index for Ports

The results of the **thunderstorm risk index**, described in Table 2, show that 16 (76.2%) ports present constant results throughout the period analyzed. Among these, approximately half remain with a risk rated "high" or "very high" in the current climate. When comparing the observational period with the projected periods, in the RCP 4.5 emission scenario, no port had its risk level significantly changed. It is highlighted that either it increased in the projection to 2030 and 2050 (23.8% of the ports), or it remained constant (76.2%). In the RCP 8.5 emission scenario, only two ports (9.5%) had their risk level increased, one of them had the risk level classified as very "low" going to "medium" in the projected period for 2030 and 2050, and the other had the risk level changed from "medium" to "high" in the projection for 2050. The remaining ports presented no changes in risk level.

8. It is a program sponsored by the World Climate Research Program (WCRP) to develop an enhanced framework for generating regional-scale climate projections for impact assessment and adaptation studies worldwide within the IPCC AR5 timeline.

9. The use of ecosystem management activities to increase resilience and reduce vulnerability.

Regarding the “very high” level of thunderstorm risk, the ports of Aratu-Candeias, Cabedelo and Rio Grande stand out for all scenarios and time-horizons.

For both ports Aratu-Candeias and Cabedelo, the indicators that most contributed to the high risk were “hazard” and “exposure” (Table 2). For the port of Rio Grande, the same result is due to the strong influence of “exposure” and “vulnerability” indicators. The ports of Natal and São Francisco do Sul also draw our attention, because their risk, which was classified as "high", changed to "very high" in the RCP4.5 emissions scenario, for the years 2050 and 2030.

Table 2: Results of climate risk index for thunderstorms

Port	E	V	Obs.		RCP4.5				RCP8.5			
					2030		2050		2030		2050	
			A	Ř	A	Ř	A	Ř	A	Ř	A	Ř
Angra dos Reis	0.5	0.3	0.6	0.283	0.6	0.285	0.6	0.282	0.6	0.277	0.6	0.284
Aratu-Candeias	0.8	0.5	0.8	0.993	0.8	1.000	0.8	0.992	0.8	0.977	0.8	0.977
Cabedelo	0.7	0.6	0.7	0.856	0.7	0.880	0.7	0.882	0.7	0.864	0.7	0.851
Fortaleza	0.7	0.5	0.5	0.509	0.5	0.537	0.5	0.544	0.5	0.536	0.5	0.553
Ilhéus	0.5	0.4	0.6	0.426	0.6	0.426	0.7	0.436	0.6	0.427	0.7	0.429
Imbituba	0.7	0.5	0.6	0.618	0.6	0.638	0.6	0.632	0.6	0.628	0.6	0.637
Itaguaí	0.8	0.3	0.5	0.397	0.5	0.406	0.5	0.401	0.5	0.401	0.5	0.410
Itajaí	0.6	0.3	0.6	0.308	0.6	0.312	0.6	0.308	0.6	0.304	0.6	0.309
Itaqui	0.8	0.3	0.4	0.292	0.4	0.319	0.4	0.333	0.4	0.318	0.5	0.349
Natal	0.7	0.5	0.8	0.792	0.8	0.793	0.8	0.809	0.7	0.788	0.7	0.766
Niterói	0.5	0.3	0.6	0.249	0.6	0.256	0.6	0.250	0.6	0.251	0.6	0.256
Paranaguá	0.9	0.4	0.6	0.661	0.6	0.666	0.6	0.663	0.6	0.658	0.6	0.670
Recife	0.7	0.4	0.8	0.750	0.8	0.779	0.8	0.774	0.8	0.787	0.8	0.767
Rio de Janeiro	0.8	0.3	0.6	0.481	0.6	0.494	0.6	0.483	0.6	0.484	0.6	0.495
Rio Grande	0.9	0.6	0.5	1.000	0.5	0.983	0.5	0.987	0.5	0.998	0.5	0.991
Salvador	0.7	0.3	0.8	0.461	0.8	0.464	0.8	0.462	0.8	0.456	0.8	0.458
Santos	1.0	0.3	0.6	0.627	0.6	0.636	0.6	0.622	0.6	0.620	0.6	0.639
São Francisco do Sul	0.7	0.6	0.6	0.792	0.6	0.801	0.6	0.791	0.6	0.785	0.6	0.798
São Sebastião	0.6	0.5	0.6	0.596	0.6	0.604	0.6	0.591	0.6	0.582	0.6	0.601
SUAPE	0.9	0.2	0.9	0.604	0.9	0.625	0.9	0.622	0.9	0.630	0.9	0.617
Vitória	0.8	0.3	0.6	0.398	0.6	0.400	0.6	0.394	0.6	0.393	0.6	0.394

Very Low	Low	Medium	High	Very High
0 – 0.199	0.2 – 0.399	0.4 – 0.599	0.6 – 0.799	0.8 – 1.000

Source: Data sent by port entities and CORDEX data. **Prepared by:** WayCarbon, GIZ and ANTAQ (2021).

Note: E = Exposure, V = Vulnerability, A = Hazard, Ř = Risk (standardized) and Obs = Observational.

The ranking for the threat of thunderstorms remains practically the same in the observed period and for the scenario RCP 8.5 for the period projected in 2050, as shown in Table 3. The ports of Rio Grande, Aratu-Candeias and Cabedelo were the ports classified with the highest thunderstorm risk in the two periods observed, occupying the first, second and third place, respectively. The ports that underwent changes were: Natal (4th to 6th), São Francisco do Sul (5th to 4th), Recife (6th to 5th), Vitória (16th to 17th), Itaguaí (17th to 16th), Itajaí (18th to 19th) and Itaqui (19th to 18th).

Table 3: Ranking: risk of thunderstorms

Position	Port	Observed	Position	Port	RCP8.5 2050
1°	Rio Grande	1.000	1°	Rio Grande	0.991
2°	Aratu-Candeias	0.993	2°	Aratu-Candeias	0.977
3°	Cabedelo	0.856	3°	Cabedelo	0.851
4°	Natal	0.792	4°	São Francisco do Sul	0.798
5°	São Francisco do Sul	0.792	5°	Recife	0.767
6°	Recife	0.750	6°	Natal	0.766
7°	Paranaguá	0.661	7°	Paranaguá	0.670
8°	Santos	0.627	8°	Santos	0.639
9°	Imbituba	0.618	9°	Imbituba	0.637
10°	SUAPE	0.604	10°	SUAPE	0.617
11°	São Sebastião	0.596	11°	São Sebastião	0.601
12°	Fortaleza	0.509	12°	Fortaleza	0.553
13°	Rio de Janeiro	0.481	13°	Rio de Janeiro	0.495
14°	Salvador	0.461	14°	Salvador	0.458
15°	Ilhéus	0.426	15°	Ilhéus	0.429
16°	Vitória	0.398	16°	Itaguaí	0.410
17°	Itaguaí	0.397	17°	Vitória	0.394
18°	Itajaí	0.308	18°	Itaqui	0.349
19°	Itaqui	0.292	19°	Itajaí	0.309
20°	Angra dos Reis	0.283	20°	Angra dos Reis	0.284
21°	Niterói	0.249	21°	Niterói	0.256

Prepared by: WayCarbon, GIZ e ANTAQ (2021).

The results of the **strong winds risk index**, presented in Table 4, show that 33.3% of the ports already have a risk classified as "high" or "very high". When analyzing this situation in future scenarios, there is a significant increase in risk, which, in the RCP4.5 scenario, represents 57.1% and 66.7% of the ports, for 2030 and 2050, respectively. With respect to the RCP8.5 scenario, the result is even more expressive, reaching "high" or "very high" risk in 76.2% of the ports in the 2050 period. This means that the number of ports with significant risk will more than double in this scenario if adaptation measures are not adopted. Considering the two time-horizons, the level of risk increases for Aratu-Candeias, Cabedelo, Natal, Salvador and Suape, particularly in the RCP 8.5 scenario.

Table 4: Results of climate risk index for strong winds

Port	E	V	Obs.		RCP4.5				RCP8.5			
					2030		2050		2030		2050	
			A	Ř	A	Ř	A	Ř	A	Ř	A	Ř
Angra dos Reis	0.5	0.5	0.6	0.364	0.7	0.397	0.7	0.440	0.7	0.406	0.8	0.449
Aratu-Candeias	0.8	0.4	0.6	0.496	0.7	0.578	0.8	0.599	0.8	0.615	0.9	0.723
Cabedelo	0.7	0.5	0.6	0.445	0.7	0.568	0.8	0.617	0.8	0.604	1.0	0.737
Fortaleza	0.6	0.6	0.6	0.534	0.7	0.638	0.8	0.692	0.7	0.662	0.8	0.754
Ilhéus	0.5	0.7	0.6	0.595	0.7	0.663	0.7	0.703	0.7	0.699	0.8	0.789
Imbituba	0.6	0.8	0.6	0.761	0.6	0.776	0.7	0.804	0.7	0.799	0.7	0.835
Itaguaí	0.7	0.6	0.6	0.618	0.7	0.670	0.7	0.747	0.7	0.696	0.8	0.764
Itajaí	0.6	0.4	0.6	0.334	0.6	0.345	0.7	0.350	0.7	0.351	0.7	0.361
Itaqui	0.8	0.3	0.6	0.426	0.7	0.487	0.8	0.525	0.8	0.536	0.9	0.580
Natal	0.7	0.5	0.6	0.467	0.8	0.607	0.8	0.681	0.8	0.643	1.0	0.802
Niterói	0.4	0.5	0.6	0.324	0.6	0.351	0.7	0.388	0.7	0.369	0.7	0.400
Paranaguá	0.9	0.5	0.6	0.634	0.7	0.686	0.7	0.717	0.7	0.695	0.7	0.741
Recife	0.7	0.7	0.6	0.728	0.7	0.840	0.7	0.873	0.7	0.872	0.8	1.000
Rio de Janeiro	0.8	0.5	0.6	0.581	0.6	0.628	0.7	0.694	0.7	0.660	0.7	0.715
Rio Grande	0.9	0.5	0.6	0.698	0.7	0.721	0.7	0.741	0.7	0.719	0.7	0.737
Salvador	0.7	0.7	0.6	0.676	0.7	0.771	0.7	0.794	0.8	0.813	0.9	0.944
Santos	1.0	0.5	0.6	0.733	0.7	0.777	0.7	0.842	0.7	0.796	0.7	0.857
São Francisco do Sul	0.6	0.6	0.6	0.592	0.7	0.626	0.7	0.638	0.7	0.631	0.7	0.661
São Sebastião	0.6	0.6	0.6	0.532	0.7	0.562	0.7	0.614	0.7	0.582	0.7	0.629
SUAPE	0.9	0.4	0.6	0.494	0.7	0.560	0.7	0.575	0.7	0.579	0.8	0.653
Vitória	0.8	0.3	0.6	0.288	0.7	0.333	0.8	0.377	0.8	0.357	0.8	0.396

Very Low	Low	Medium	High	Very High
0 – 0.199	0.2 – 0.399	0.4 – 0.599	0.6 – 0.799	0.8 – 1.000

Source: Data sent by port entities and CORDEX data. **Prepared by:** WayCarbon, GIZ and ANTAQ (2021).

Note: E = Exposure, V = Vulnerability, A = Hazard, Ř = Risk (standardized) and Obs = Observational.

The ranking of ports (Table 5), in relation to the strong wind risk, shows significant changes from the period observed for the period projected for 2050. Among these, those that occurred for the ports of Rio Grande and Christmas. The port of Rio Grande, which was among the five ports with the highest risk for windstorms in the observed period, was ranked 11th in the 2050 period. The port of Natal, ranked 15th in the observed period, rose to 5th place, having a considerable increase in its risk index of strong winds.

Table 5: Ranking: risk of strong winds

Position	Port	Observed	Position	Port	RCP8.5 2050
1°	Imbituba	0.761	1°	Recife	1.000
2°	Santos	0.733	2°	Salvador	0.944
3°	Recife	0.728	3°	Santos	0.857
4°	Rio Grande	0.698	4°	Imbituba	0.835
5°	Salvador	0.676	5°	Natal	0.802
6°	Paranaguá	0.634	6°	Ilhéus	0.789
7°	Itaguaí	0.618	7°	Itaguaí	0.764
8°	Ilhéus	0.595	8°	Fortaleza	0.754
9°	São Francisco do Sul	0.592	9°	Paranaguá	0.741
10°	Rio de Janeiro	0.581	10°	Cabedelo	0.737
11°	Fortaleza	0.534	11°	Rio Grande	0.737
12°	São Sebastião	0.532	12°	Aratu-Candeias	0.723
13°	Aratu-Candeias	0.496	13°	Rio de Janeiro	0.715
14°	SUAPE	0.494	14°	São Francisco do Sul	0.661
15°	Natal	0.467	15°	SUAPE	0.653
16°	Cabedelo	0.445	16°	São Sebastião	0.629
17°	Itaqui	0.426	17°	Itaqui	0.580
18°	Angra dos Reis	0.364	18°	Angra dos Reis	0.449
19°	Itajaí	0.334	19°	Niterói	0.400
20°	Niterói	0.324	20°	Vitória	0.396
21°	Vitória	0.288	21°	Itajaí	0.361

Prepared by: WayCarbon, GIZ e ANTAQ (2021).

The **sea level rise risk ranking** of the 21 public ports remained unchanged over the time-horizons Eleven port, or 52% (Aratu-Candeias, Paranaguá, Rio Grande, Santos and São Francisco do Sul, Cabedelo, Fortaleza, Imbituba, Itaguaí, Recife and São Sebastião) will have, in 2030, risk of sea level rise classified as “very high” or “high”, with a strong influence from the exposure indicator (Table 6). The null result for the ports of Angra dos Reis, Niterói and Rio de Janeiro comes from the method selected for this study, which did not identify the occurrence of a flood spot in the periods and scenarios analyzed.

Table 6: Results of climate risk index for sea level rise.

Port	E	V	RCP4.5				RCP8.5			
			2030		2050		2030		2050	
			A	Ř	A	Ř	A	Ř	A	Ř
Angra dos Reis	0.5	0.5	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000
Aratu-Candeias	0.8	0.6	1.0	1.000	1.0	1.000	1.0	1.000	1.0	1.000
Cabedelo	0.7	0.5	1.0	0.640	1.0	0.640	1.0	0.640	1.0	0.640
Fortaleza	0.7	0.6	1.0	0.778	1.0	0.778	1.0	0.778	1.0	0.778
Ilhéus	0.5	0.4	1.0	0.499	1.0	0.499	1.0	0.499	1.0	0.499
Imbituba	0.7	0.5	1.0	0.705	1.0	0.705	1.0	0.705	1.0	0.705
Itaguaí	0.7	0.5	1.0	0.731	1.0	0.731	1.0	0.731	1.0	0.731
Itajaí	0.6	0.1	1.0	0.127	1.0	0.127	1.0	0.127	1.0	0.127
Itaqui	0.8	0.3	1.0	0.463	1.0	0.463	1.0	0.463	1.0	0.463
Natal	0.7	0.3	1.0	0.416	1.0	0.416	1.0	0.416	1.0	0.416
Niterói	0.4	0.4	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000
Paranaguá	0.9	0.4	1.0	0.834	1.0	0.834	1.0	0.834	1.0	0.834
Recife	0.7	0.4	1.0	0.637	1.0	0.637	1.0	0.637	1.0	0.637
Rio de Janeiro	0.8	0.4	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000
Rio Grande	0.9	0.5	1.0	0.963	1.0	0.963	1.0	0.963	1.0	0.963
Salvador	0.7	0.3	1.0	0.471	1.0	0.471	1.0	0.471	1.0	0.471
Santos	1.0	0.4	1.0	0.811	1.0	0.811	1.0	0.811	1.0	0.811
São Francisco do Sul	0.7	0.6	1.0	0.805	1.0	0.805	1.0	0.805	1.0	0.805
São Sebastião	0.6	0.6	1.0	0.678	1.0	0.678	1.0	0.678	1.0	0.678
SUAPE	0.9	0.3	1.0	0.573	1.0	0.573	1.0	0.573	1.0	0.573
Vitória	0.8	0.4	1.0	0.595	1.0	0.595	1.0	0.595	1.0	0.595

Very Low	Low	Medium	High	Very high
0 – 0.199	0.2 – 0.399	0.4 – 0.599	0.6 – 0.799	0.8 – 1.000

Source: Data sent by port entities and CORDEX data. **Prepared by:** WayCarbon, GIZ and ANTAQ (2021).

Note: E = Exposure, V = Vulnerability, A = Hazard, Ř = Risk (standardized) and Obs = Observational.

Regarding the ranking of the sea level rise index (Table 7), it is noteworthy that, as there is no data for the period observed, it was not possible to carry out a comparative analysis with the period 2050. However, through the results below, it is possible to identify the ports that will suffer most from the impacts if the sea level rise occurs.

Table 7: Ranking: risk of sea level rise

Position	Port	RCP8.5 2050
1º	Aratu-Candeias	1.000
2º	Rio Grande	0.963
3º	Paranaguá	0.834
4º	Santos	0.811
5º	São Francisco do Sul	0.805
6º	Fortaleza	0.778
7º	Itaguaí	0.731
8º	Imbituba	0.705
9º	São Sebastião	0.678
10º	Cabedelo	0.640
11º	Recife	0.637
12º	Vitória	0.595
13º	SUAPE	0.573
14º	Ilhéus	0.499
15º	Salvador	0.471
16º	Itaqui	0.463
17º	Natal	0.416
18º	Itajaí	0.127
19º	Angra dos Reis	0.000
	Niterói	0.000
	Rio de Janeiro	0.000

Prepared by: WayCarbon, GIZ e ANTAQ (2021).

5 :: Adaptation Measures

Fifty-five adaptation measures were identified, 21 of which were structural and 34 non-structural. The Tables 8 and 9 show the adaptation measures, the respective climate hazards, their classification in relation to the Port Development and Zoning Plan (PDZ) and the percentage of ports that have already adopted the measures, based on information gathered in the survey with the ports. Not all measures that were found in the literature were addressed by the ports, and these cases are identified in the table below as "N/A" (not applicable). It is worth noting the PDZ is a planning instrument for the port sector, in which there is the definition of the actions that the ports will adopt in a short-, medium- and long-term scenario. Thus, by indicating the section of the PDZ in which the adaptation measure fits, we sought to show that these suggested measures are and should be aligned with this important instrument, and can thus be integrated with them.

Table 8: List of structural adaptation measures

Measure	SLR	Thunder storms	Strong Winds	PDZ	% of ports that adopt the measure
Adequacy of structures for new weather patterns	✓	✓	✓	PIP	N/A
Diversification of land connections to the port/ terminal	✓	✓	✓	PIA	N/A
Increase in the shelter infrastructure dimensions	✓	✓		PIP	N/A
Construction of shelter infrastructure	✓	✓		PIP	N/A
Reinforcement of rockfill structures	✓			PIP	N/A
Automation of logistical tasks		✓	✓	MO	N/A
Implementation of VTMS		✓	✓	MO	4,76%
Reinforcement of shelter infrastructure	✓			PIP	N/A
Raising of shelter infrastructure	✓			PIP	N/A
Protection of cargoes against flooding	✓			PIP/PRA	N/A
Inclusion of sea level rise projections in future infrastructure designs	✓			MO	N/A
Adjustment of berth structures at sea level	✓			PIP	N/A
Increase in port elevation quota	✓			PIP	N/A
Expansion of the dredging process	✓			MO	N/A
Improved quality of access to the port/terminal	✓			MO	N/A
Consideration of sea level rise in infrastructure remodeling and replacement inventories	✓			PIP	N/A
Improvement in drainage systems		✓		PIP	N/A
Renovation of infrastructure or equipment vulnerable to flooding		✓		PIP	N/A
Consideration of watershed-level landscape planning and ecosystem-based adaptation options for flood risk reduction		✓		PIP	N/A
Implementation of SuDS		✓		PIP	N/A
Use of automatic wind monitors on ship loaders			✓	MO	N/A

Prepared by: WayCarbon, GIZ, ANTAQ (2021).

Note: SLR = Sea Level Rise; VTMS = *Vessel Traffic Management Information System*; MO = Operational Improvements, PIP = Port Investment Proposition, PIA = Access Investment Proposition, PRA = Area Reorganization Proposition, N/A = Not applicable. The calculation of the percentages of the ports that have the identified measures was done considering the number of ports that stated, in the administered questionnaire, that they had already adopted the measure for at least one of the analyzed hazards.

Table 9: List of non-structural adaptation measures

Measure	SLR	Thunder storms	Strong Winds	PDZ	Current scenario
Provision of emergency plans to drivers	✓	✓	✓	MG	N/A
Review of contingency plans	✓	✓	✓	MG	N/A
Modification in the arrangement of structures in the organized port area	✓	✓	✓	PRA	N/A
Working together with insurance companies	✓	✓	✓	MG	N/A
Purchase of specific insurance against climate change	✓	✓	✓	MG	0%
Creating a network for sharing information	✓	✓	✓	MG	N/A
Holding meetings to discuss adaptation	✓	✓	✓	MG	28,57%
Addressing climate change in the port's strategic plan	✓	✓	✓	MG	28,57%
Adoption of specific planning for climate change	✓	✓	✓	MG	9,52%
Including climate change adaptation in the budget	✓	✓	✓	MG	4,76%
Updating engineering design guidelines to meet new climate standards	✓	✓	✓	MG	14,29%
Record of impacts related to climate hazards (dates, consequences or costs)	✓	✓	✓	MG	4,76%
Adoption of emergency action plans/evacuation protocol	✓	✓	✓	MG	9,52%
Establishment of a crisis committee	✓	✓	✓	MG	9,52%
Implementation of its own continuous meteorological monitoring/Cooperation with other institutions	✓	✓	✓	MO	23,81%
Carrying out operational-capacity assessments	✓	✓		MO	N/A
Change of work schedule during extreme events		✓	✓	MG	N/A
Forming partnerships with local weather stations		✓	✓	MG	N/A
Adoption of good work practices		✓	✓	MG	N/A
Review of critical operational thresholds for cargo handling equipment		✓	✓	MO	N/A
Maintenance Program Review and Adjustment		✓		MG	N/A
Engagement of stakeholders to plan flood management options		✓		MG	N/A
Review of alert systems		✓		MO	N/A
Adjustments to storm-sensitive cargo storage		✓		MO	N/A
Use of exclusive PPE for flooded areas		✓		MG	4,76%
Implementation of warning systems			✓	MO	N/A
Implementation of wind speed prediction system			✓	MO	N/A
Reduction of stacking height of containers			✓	MO	N/A
Review of crane braking and fastening systems			✓	MO	N/A
Review of conveyor belts, lighting systems and general infrastructure			✓	MO	N/A
Equipment maintenance and contingency plan			✓	MG	4,76%
Improvement of management for the prevention of windthunderstorm risks			✓	MG	N/A
Monitoring of wind in the port/operational area			✓	MO	4,76%
Monitoring of wind by lifting equipment			✓	MO	N/A

Prepared by: WayCarbon, GIZ, ANTAQ (2021).

Note: SLR = Sea Level Rise; MG = Management Improvements, MO = Operational Improvements, N/A = Not applicable. The calculation of the percentages of the ports that have the identified measures in place was done considering the number of ports that stated, in the administered questionnaire, that they had already adopted the measure for at least one of the analyzed hazards.

The adoption of adaptation measures in response to climate change by public ports on the Brazilian coast is still in its early stages. In terms of structural adaptation measures, only one port reported that it had implemented the VTMS. Despite being more widespread compared to structural measures, management measures still only exist in a few ports. Among the 13 adaptation measures of this type presented in the questionnaire, only 3 of them have been adopted by more than 20% of the ports (Meetings to discuss adaptation; Approach to climate change in the port's strategic plan; and Implementation of its own continuous meteorological monitoring/Cooperation with other institutions). Note also that no port reported that it had taken out specific insurance against climate change, which is a measure that has the potential to mitigate the financial impacts of these events.

It is also important to emphasize that adaptation to climate change must be considered taking into account the specific characteristics of each context, therefore, generic adaptation actions should not be adopted without an appropriate investigation of the location (McEvoy and Mullet, 2013). In this sense, to implement the actions that are closer to the reality and interest of each port, a process of selection and prioritization of actions is necessary, and that can be done using the list presented.

Among the existing methods to assist in the selection and prioritization process, there is the multi-criteria analysis, considered as an instrument to support the decision-making process. This analysis allows comparing heterogeneous measures by combining different criteria, which can be financial and non-financial in nature(SCOTT *et al.*, 2013):

- **Costs:** refers to the immediate economic costs of the option, and probable ongoing costs, as well as the associated social and environmental costs;
- **Effectiveness:** the adaptation option must achieve the stated objective;
- **Efficiency:** the benefits of the option must outweigh the costs;
- **Equity:** the adaptation option should not negatively affect other areas or people;
- **Priority:** extreme risks must be dealt with urgently;
- **Co-benefits:** adaptation options may be able to benefit from opportunities that provide environmental, social or economic benefits;
- **Poor adaptation:** the options should not block the outcomes, limit future adaptation options, or negatively impact other areas or people.

6 :: Conclusions and Recommendations

The Brazilian port sector is already experiencing the impacts of climate change and, in the future, the situation is expected to worsen. Among the risks analyzed, strong winds were shown to be the most critical ones for future scenarios, considering that 33.3% (7 of 21) of the ports, in the observational scenario, are already classified as facing a "high risk" or “very high risk” for gales, and that may rise to 76.2% (16 of 21) in the RCP 8.5 emission scenario for the year 2050.

As for the thunderstorm risk and sea level rise, the results classified as "high" and "very high" remained unchanged or with little variation between the periods and scenarios analyzed and compared to the observational scenario. Moreover, for the period of 2050 and emission scenario RCP8.5, this result is projected, for both hazards, in 52.4% (11 of 21) of the analyzed ports. In this same period and emission scenario, it is worth noting that the northeast region had the most ports with "very high" or "high" level in the climate risk for storms and thunderstorms, matching the southern region for sea level rise.

Reducing climate risk involves adopting structural and non-structural adaptation measures. However, as seen above, a small portion of the ports adopt measures that make them resilient to the analyzed climate hazards. This fact and the results of the climate risk indices demonstrate that adaptation measures shall be immediately adopted by the port sector, as a way to minimize the possible impacts and damages resulting from thunderstorms, strong winds and rising sea levels.

Note that the involvement of the ports throughout the project, from the selection of climate hazards and the indicators to be used in the exposure and vulnerability analyses to the validation of the preliminary results of the risk analysis, was of paramount importance to obtain results that were consistent with the reality experienced by them. Thus, to ensure an efficient and effective adaptation in the local context, the active involvement of port sector actors, from managers to front-line workers at the port, is recommended.

This study represents a major step towards the inclusion of the theme of climate resilience in the port sector on the agenda of Brazilian public authorities. The results presented have the potential to support the formulation of national public policies on adaptation to climate change in the port sector, in addition to allowing for regulations and inspections more focused on this important topic. As demonstrated throughout this report, the impacts of climate change on port operations are already a reality in Brazil and, if the current conditions remain unchanged, this scenario is likely to get worse. Therefore, based on this relevant diagnosis, concerted actions among governments, port authorities and the regulatory agency are necessary to mitigate the impacts of climate change in Brazilian ports.

From the ranking of ports classified as having the highest risk of storm, strong wind and sea level rise in the period 2050 and in the RCP 8.5 emission scenario, it was possible to observe that some ports remained in the top five for at least two of the hazards analyzed, namely: Aratu-Candeias (thunderstorm – 2nd place and sea level rise – 1st place), Rio Grande (thunderstorm – 1st place and sea level rise – 2nd place), Recife (thunderstorm – 5th place and strong winds – 1st place), Santos (strong winds - 3rd place and sea level rise – 4th place), São Francisco do Sul (thunderstorm – 4th place and sea level rise – 5th place).

In this sense it is worth noting that axis 2 of this project will present customized analyses for three Brazilian ports (Santos, Rio Grande and Aratu-Candeias). These ports were selected from the climate risk rankings presented, in addition to considering the regional characteristics and the prospect of new investments materialized in qualified leases in the Investment Partnership Program – PPI. It is expected that such studies will contribute even more towards increasing the resilience of Brazilian ports to the impacts arising from climate change.

7 :: References

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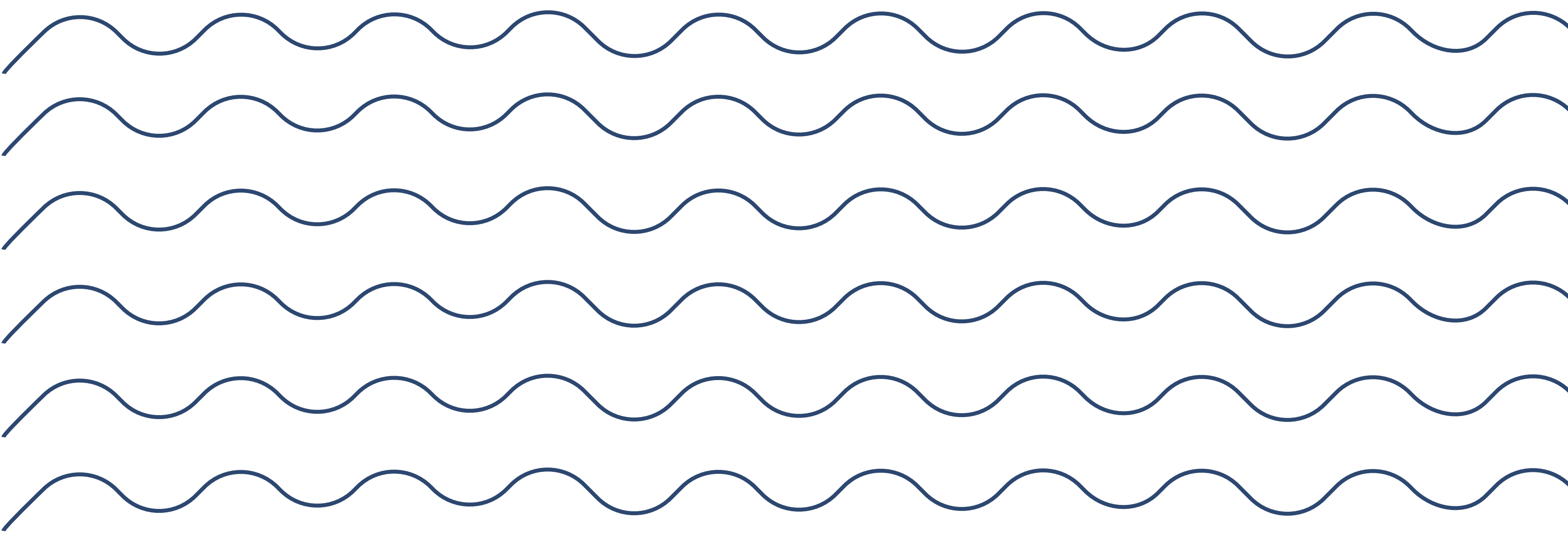

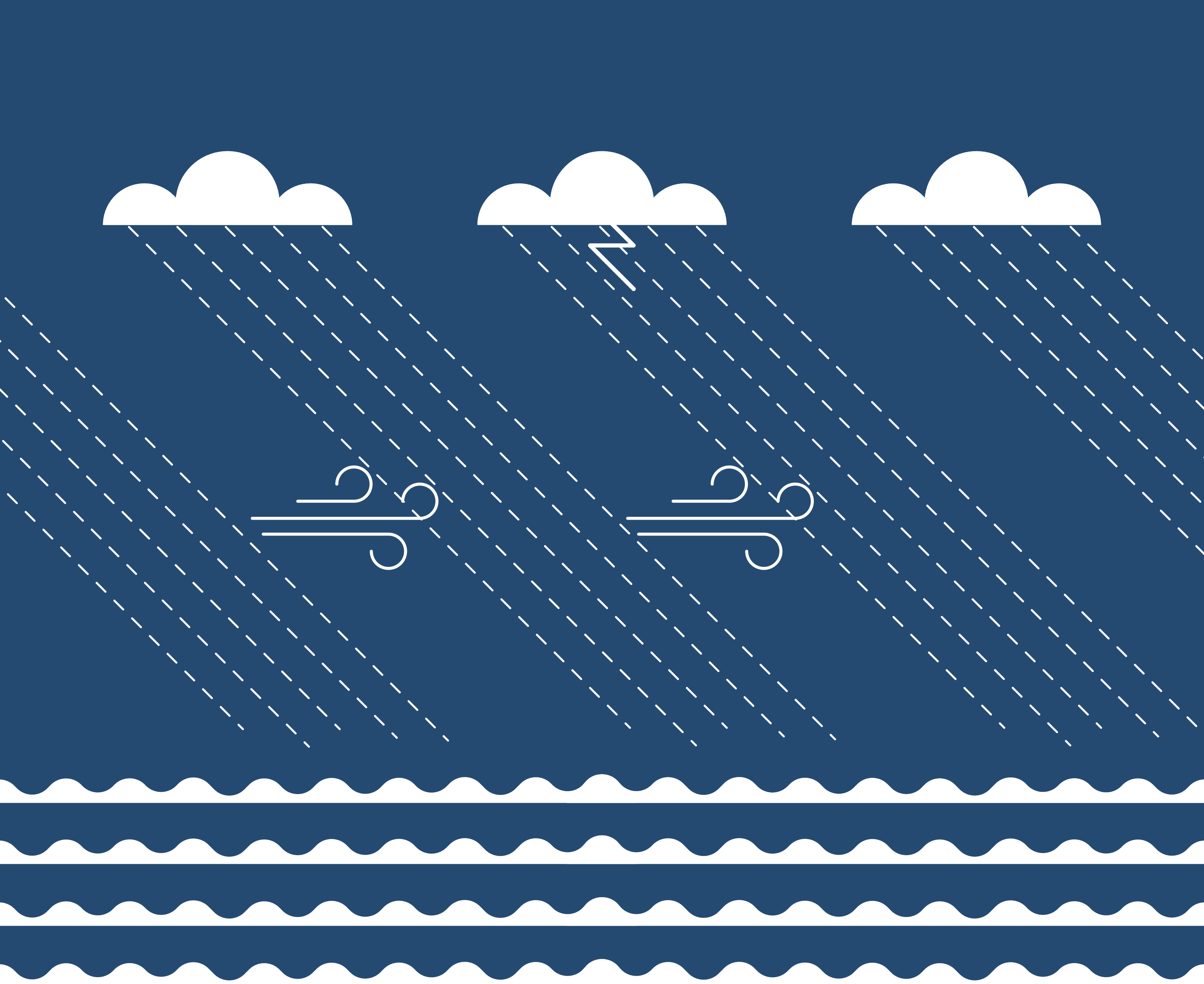

On behalf of:

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Climate Change Adaptation

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