IRENA
International Renewable Energy Agency

THE ENERGY SECTOR OF PANAMA

CLIMATE CHANGE ADAPTATION CHALLENGES

ISBN: 978-92-9260-610-7

Citation: IRENA (2024), *The energy sector of Panama: Climate change adaptation challenges*, International Renewable Energy Agency, Abu Dhabi.

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Acknowledgements

This report was developed under the guidance of Gürbüz Gonül (Director, Country Engagement and Partnerships, IRENA) and Binu Parthan.

The document was authored by José Torón, Camilo Ramírez (IRENA) and Fernando Anaya (Consultant).

Valuable inputs and comments were offered by IRENA experts, Rebecca Bisangwa, Ines Jacob, Paul Komor, Sultan Mollov and Gayathri Nair. The report benefited from the participation and contribution of representatives from Panama's Institutions, the National Energy Secretariat (SNE) and the Ministry of the Environment.

Publication and editorial support were provided by Francis Field, Stephanie Clarke and Manuela Stefanides. The report was copy-edited by Fayre Makeig, with graphic design provided by PhoenixDesignAid.

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1. INTRODUCTION

Energy infrastructure development in Panama, as in the rest of Latin America, was conceived under assumptions of climate stability, anticipating minimal or even no changes in climate behaviour over the long term. However, in the past decade, Panama's climate patterns have changed significantly (Ministerio de Ambiente Panama, 2021). It is important to assess the potential impact of these changes on existing and planned energy infrastructure, among other aspects. Without measures to increase the energy sector's resilience to climate change,[1] infrastructure for energy production and transport will be left vulnerable to climatic phenomena—at high economic and social costs to the country. To take one example, rising temperatures could decrease the efficiency of thermal conversion in Panama. Also, extreme droughts could decrease water availability, impacting the plants' cooling and operating systems and causing interruptions in power supply. Changes in hydrological patterns and extreme rainfall could also affect hydropower generation (WEC, 2014), which represents a high share of Panama's energy matrix and is therefore essential to guarantee the country's electricity supply. While a decrease in precipitation and an increase in temperature would hamper generation capacity or make generation irregular, extreme rainfall events would bring floods that jeopardise the infrastructure and operation of hydroelectric plants. At the same time, energy infrastructure in coastal areas would be at high risk of rising sea levels (Ebinger and Vergara, 2011), which could cause damage and interruptions in energy generation, and reception and distribution operations.

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[1] *Resilient infrastructure is infrastructure that, having suffered a natural or anthropogenic failure event, is capable of sustaining a minimum level of service and recovering its original performance within a reasonable time frame and cost (Weikert, 2021).*

Climate change also has a significant impact on the road infrastructure used to transport fuels, making their distribution inefficient and less safe. This infrastructure is particularly susceptible to the effects of climate change, including sea level rise and increased precipitation and flooding. In coastal areas, sea level rise and increased severity of storms can trigger storm surges and more frequent flooding, damaging land-based communication routes, such as roads and bridges. In inland areas, heavy rains can result in flooding and landslides, causing damage to infrastructure (EPA, 2022), and potentially disrupting the distribution of essential fuels by road. This may in turn limit fuel availability at service stations and other distribution points.

In the context of climate change and the energy infrastructure in Panama, accounting for climate resilience in the design and implementation of energy infrastructure investments would not only help mitigate the impacts of climate change, but also complement the cost-effectiveness and quality of energy services. Several studies have shown that investing in resilient infrastructure is a cost-effective and robust option: for every dollar invested, it is possible to save up to six dollars in future asset losses (WEC, 2014; World Bank, 2019; UNCTAD, 2020; Weikert, 2021). Therefore, long-term decisions on energy infrastructure must prioritise climate resilience (Hallegatte *et al.*, 2019). This report identifies key steps to help mitigate potential damages to Panama's energy infrastructure and increase its resilience. Measures are identified based on an assessment of climate risk, as well as the implications of long-term changes in precipitation and temperature.

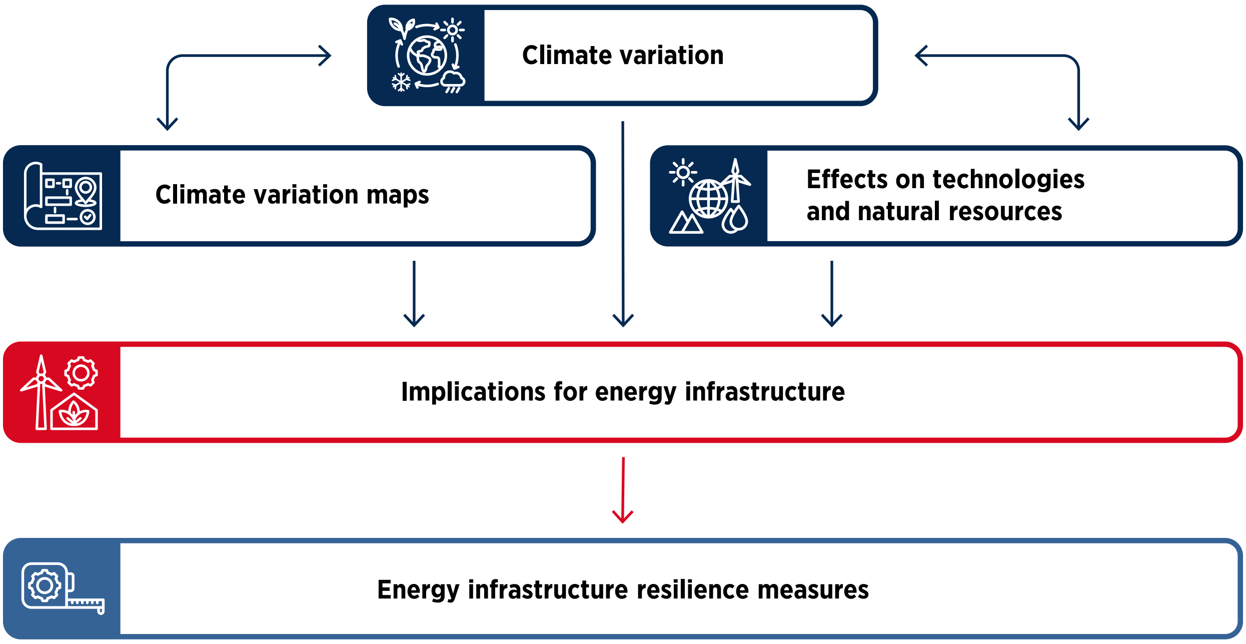
2. METHODOLOGY

Two methodologies were applied in parallel to identify energy resilience measures. The methodology detailed under “Methodology part 1” takes as the main inputs data on temperature and precipitation variations provided by the Ministry of Environment of Panama. The other methodology, detailed under “Methodology part 2”, uses data from the World Bank’s modelling of the occurrence of extreme climate hazards. Except for sea level rise, the results obtained from the analysis were treated independently, but both methodologies converge in the section on climate resilience measures. Each methodology is detailed below.

2.1 METHODOLOGY PART 1: ANALYSIS OF CHANGES IN CLIMATE VARIABLES

This methodology used historical and current records of temperature, precipitation and sea level rise variations compiled by Panama’s Ministry of Environment to construct projections of potential variations up to 2050 and 2070, for the ministry’s update of climate change scenarios for Panama. This information was used to generate section III on the implications of variations in precipitation and temperature for energy infrastructure. Sea level rise was integrated into the hazard analysis, given that its variation is considered to represent a threat that can directly impact the integrity of infrastructure. Figure 1 outlines the methodological sequence used to analyse changes in the variables monitored by the Ministry of Environment.

Figure 1 Methodological sequence 1 – electrical infrastructure



Climate variation maps

The magnitude of changes in Panama was calculated using the "map algebra" tool of the geographic information system (GIS). The calculation utilised the baseline data and the Shared Socio-economic Pathway (SSP) 1-2.6 and SSP5-8.5 scenarios projected for the years 2050 and 2070 provided by the Ministry of Environment. The reference maps were generated first, followed by the estimation of variations using the precipitation and temperature maps for the projected scenarios for 2050 and 2070.

Following this procedure, output values representing the magnitude of changes in the climate variables are obtained. It is important to note that negative values indicate a decrease in the magnitude of the variables, whereas positive values indicate an increase.

Obtaining exchange values

ArcGIS software was used for the procedure to obtain the values of changes in precipitation and maximum temperature that will affect the energy infrastructure under analysis. The software was used as follows:

> For the electricity generation infrastructure (hydro, solar and wind), the GIS tool "extraction" was used. A specific command was used to extract the projected precipitation and maximum temperature values for the different scenarios; the geographic location of individual generation infrastructure was used as the reference. This resulted in the generation of output tables showing the name of the generation infrastructure and the value of change for the variable analysed.

For transmission infrastructure, a different approach was taken to obtain temperature change information. The digital temperature maps were reclassified and transformed into vector format using the GIS "conversion" tool. From this conversion, an intercept was made between the vector temperature maps for the different scenarios and projections and the distribution map of the transmission networks. This resulted in cross-referenced tables that provided the average values of temperature change for each transmission line section.

Infrastructure implications

The impact of changes in the magnitude of average annual rainfall and maximum temperature on the installed energy infrastructure in Panama was assessed. To assess the associated impacts, electricity generation plants based on thermal, hydroelectric, solar and wind power technology, as well as the transmission infrastructure, were considered. Estimates consider the projected decline in operating efficiency of the generation and transmission systems towards 2050 and 2070, as well as the installed capacity and the volume of energy generation that could be compromised under various scenarios of analysis.

For hydroelectric generation, the impact of reduced rainfall was assessed in relation to the reduction in flows feeding the country's hydroelectric power plant basins. The reduction in flows to the hydroelectric basins was estimated based on the magnitude of rainfall decrease (millimetres [mm]), the contributing area of each basin (square kilometres [km^2]) and assuming an average run-off coefficient of 60%, according to the United Nations Educational, Scientific and Cultural Organization (UNESCO, 2008).

Subsequently, the volume of energy and the installed capacity[2] compromised for hydroelectric power plants was estimated for the years 2050 and 2070 for each analysed scenario based on the inflow resulting from the decline in precipitation and assuming an average inflow power ratio of 15.49 gigawatt hours [GWh]/year/cubic metres/second [m^3/s].[3]

To assess the impacts on solar and wind generation, the expected temperature increase for individual plants was determined and its effect on the operational efficiency of the generation systems was estimated. This estimate was used to calculate the reduction in the operating efficiency of the solar and wind power plants. The conversion factors for individual technologies were considered and the decrease in power generation capacity due to temperature increase was estimated.[4] For solar power plants, a 0.5% reduction in transmission efficiency per degree Celsius rise in temperature was considered (Dwivedi *et al.*, 2020), while for wind generation, an efficiency factor of $1.64x10^{-3}$% per degree Celsius (/°C) was assumed (Rodríguez *et al.*, 2020).

A similar procedure was followed to assess the impact on the transmission infrastructure. The effect of the temperature increase on transmission lines was analysed, considering their load carrying capacity and the possible reduction in operational efficiency. This made it possible to identify the areas of the transmission infrastructure that could be affected and to quantify the impact on electricity transmission capacity under the different climate scenarios analysed. Specifically, a 1.2% reduction in electricity transmission capacity on average for each degree Celsius rise in temperature was assumed, considering conductor operating temperatures between 50% and 100% (Castellanos, 2014).

These estimates made it possible to assess the impact of changes in precipitation and maximum temperatures on the electricity infrastructure and to determine the installed capacity and transmission capacity that could be affected under the different climate scenarios considered.

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[2] *Assuming an average capacity factor of 60%.*

[3] *Estimated based on the water balances for Panama's main reservoirs – Boyano, Fortura and Changuinola (IMHPA, 2024).*

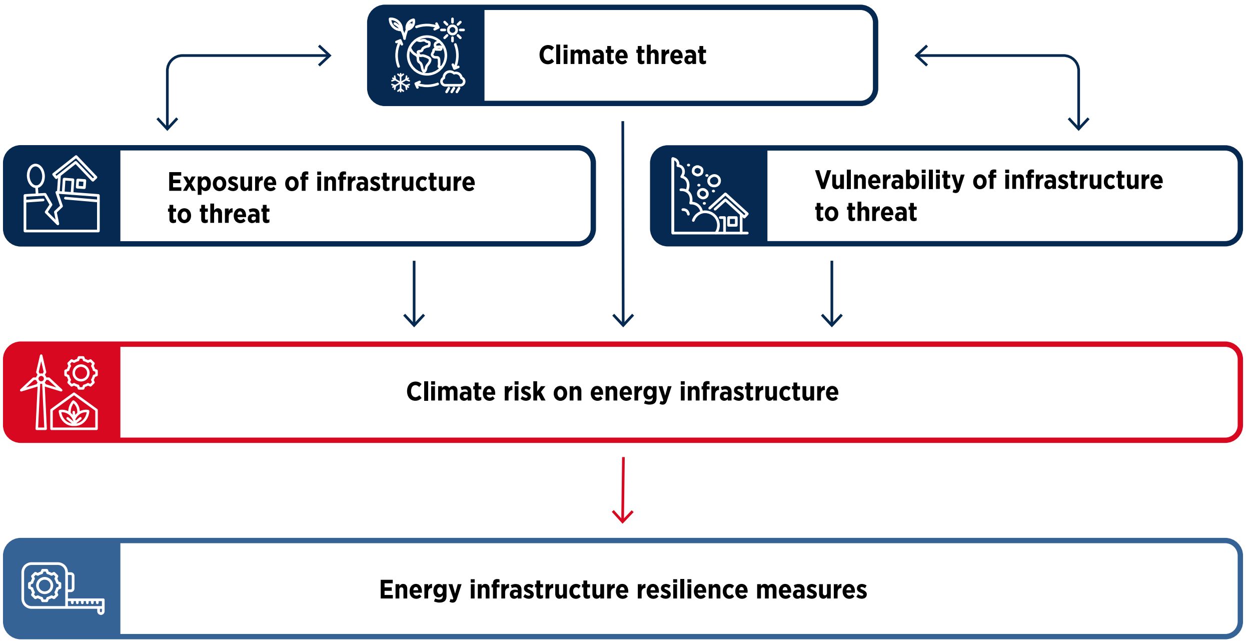
[4] *An average capacity factor of 20% for solar photovoltaic generation and 35% for wind generation was assumed.*

2.2 METHODOLOGY PART 2: ANALYSIS OF INFRASTRUCTURE AT RISK FROM EXTREME WEATHER EVENTS

The methodology used to identify resilience-building adaptation measures for Panama's energy infrastructure begins with a climate risk assessment.[5] The process involves assessing existing electricity generation and transmission infrastructure,[6] as well as the infrastructure planned for the next ten years (ETESA, 2022), along with fuel terminal ports and roads providing access to the main power generation centres.

Risk is assessed by considering climate hazard, exposure and vulnerability, as outlined in the methodology of the Intergovernmental Panel on Climate Change (IPCC, 2014). This approach makes it possible to identify areas of greatest risk and, consequently, to develop adaptation measures focused on mitigating potential damages and making Panama's energy infrastructure more resilient to the impacts of climate change. Figure 2 outlines the methodological sequence used to achieve the proposed objective.

Figure 2 Methodological sequence 2 – electrical infrastructure



Climate threat

The climate risk assessment considers the dangers posed to a system by the manifestation of extreme weather events (Lopez and Montoya, 2019). The spatial occurrence potential of flooding events triggered by rainfall, droughts, extreme heat and sea level rise was assessed based on the World Bank modelling described below and geostatistical interpolation obtained from the ArcGIS programme (ArcMap 10.8),[7] projected to the year 2050 and 2070.

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[5] *Linked to slow progress events, such as temperature changes, changes in precipitation patterns (drought, heavy rains), sea level rise, among others, which should be considered while structuring new public and private investment projects, as well as in adaptation measures.*

[6] *Substations.*

[7] *Characterisation linked to the frequency or intensity of the weather events analysed is excluded.*

The assumptions and information sources used for the climate hazard analysis are summarised below:

- **Input data.** Data to determine the threat of floods, droughts and extreme heat were obtained from the World Bank's Climate Change Knowledge Portal (World Bank, 2024a). Specifically, province-level data were used for average climate projections under the sixth version of the IPCC's Common Information Management Protocol (PCMDI, 2019), and under the multiple ensemble climate projection model.[8] For these projections, the World Bank proposes five scenarios representing possible social and economic development pathways (SSP). The SSP1-1.9 scenario is the most optimistic and envisages a vision of the climate response that could reflect the Paris Agreement target. The SSP1-2.6 scenario suggests a transition to sustainability with a drastic reduction in global emissions and achieving carbon neutrality after 2050. On the other hand, SSP2-4.5 represents an intermediate scenario, in which emissions are maintained at current levels but begin to decline towards mid-century, without reaching zero by 2100. SSP3-7.0 describes a future in which countries become increasingly competitive, leading to a significant increase in emissions, which double by 2100 from today. By contrast, SSP5-8.5 is based on intensified exploitation of conventional fuel resources and represents a future in which greenhouse gas emissions increase significantly (World Bank, 2024a).

  The intermediate scenario (SSP2-4.5)[9] was selected as the basis for the study, since it is aligned with the countries' current CO_2 emission reduction commitments. To assess the impacts of climate change, three climate variables were used: (1) cumulative precipitation on very wet days (mm),[10] which is related to the occurrence of floods; (2) maximum number of consecutive dry days,[11] which is associated with drought events; and (3) average number of days on which the maximum temperature exceeds 35°C, which reflects the occurrence of extreme heat spells. Finally, to analyse the threat of sea level rise, cartographic information in digital format provided by the National Environmental Information System (SINIA) of the Panamanian Ministry of the Environment (SINIA, 2020) was accessed. Specifically, the analysis used the map of coastal flooding resulting from extreme events in 2050 (50-year return period and scenario SSP2-4.5[12]).

- **Threat mapping.** Flood hazard maps for rainfall, drought and extreme heat were generated using GIS.[13] Point data for province-level climatic variables obtained from the World Bank (described in the previous section) were used to construct[14] alongside geostatistical interpolation methods to obtain hazard maps or digital surfaces for the country[15] These digital surfaces were edited and catalogued on a threat scale ranging from high to low, represented by colour palettes appropriate to each case (maps).

Exposure of energy infrastructure to the climate threat

For the purposes of this report, exposure is defined as the presence of infrastructure and/or economic, social or cultural assets in areas that could be adversely affected by a climate hazard (UNDRR, 2022).

The level of exposure was assessed by analysing the geographical location of given infrastructure (georeferencing[16]) in relation to the previously mapped climatic hazards. The data and mapping results are described below:

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[8] *It projects the change in climate variables over time as an average of different models (CANESM5, CNRM-ESM2-1, GFDL_ESM4, MRI-ESM2 and UKESM1-0-II).*

[9] *90th percentile.*

[10] *Exceeding the 95th percentile of daily precipitation intensity.*

[11] *No significant rainfall (<1 mm).*

[12] *95th percentile.*

[13] *The base cartography (boundaries, hydrography, water bodies) was obtained from the STRI GIS Data Portal of the Republic of Panama (https://stridata-si.opendata.arcgis.com).*

[14] *Images are represented in regular pixels (cells), containing a value in a matrix of rows and columns.*

[15] *Interpolation predicts values for the cells of a digital image from a limited number of input (sample) data points.*

[16] *Use of geographic co-ordinates to assign a spatial location to cartographic entities.*

- **Input data.** The input data for the analysis include a list of installed hydro, thermoelectric, solar and wind generation plants, as well as transmission lines and substations, and their geographic locations (co-ordinates), obtained from the SIG-SNE Portal of the Republic of Panama (SNE, 2023). Information on planned generation infrastructure was extracted from the Plan de Expansión del Sistema Interconectado Nacional 2020-2034 (ETESA, 2022). Information related to fuel terminal ports (hydrocarbon and liquefied natural gas) was obtained from the website of the Panama Maritime Authority (AMP, 2023), while information on the distribution of road infrastructure (roadway) was acquired from the STRI GIS Panama Portal (STRI, 2023). Annexes 1 and 2 contain additional information on installed and planned infrastructure, respectively, which has been included in the analysis.

- **Exposure mapping.** Georeferenced infrastructure data were entered into GIS software, and made it possible to create individual layers (maps) according to infrastructure type. These layers were then overlaid on the previously edited hazard maps,[17] and an exposure level (high, moderate or low) was assigned based on the hazard recorded at the location of each specific asset considered.

Vulnerability

Vulnerability refers to the degree to which a system is susceptible to being affected by climate change and coping with its adverse effects (Paz *et al.*, 2019b). Vulnerability depends on the robustness, sensitivity and adaptive capacity of infrastructure (ADB, 2013). Specifically, vulnerability analysis was conducted with a focus on infrastructure's sensitivity (its susceptibility to damage) due to its exposure to a climate hazard. The sensitivity assessment approach was qualitative and based on the experience of various international studies (Nicolas *et al.*, 2019; Paz *et al.*, 2019; OLADE, 2016; ADB, 2012). Table 1 presents a qualitative assessment of the sensitivity of the infrastructure analysed according to the type of climate hazard.

Table 1 Sensitivity of infrastructure to climate hazards

INFRASTRUCTURE	FLOODING DUE TO RAINFALL	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
Onshore wind	Not significant	Not significant	Not significant	Not significant
Solar photovoltaic	Not significant	Not significant	Low	Low
Hydroelectric	High	High	Moderate	Not significant
Thermal*	High	Not significant	Low	Not significant
Hydrocarbon terminal ports	High	Not significant	Low	High
Transmission and distribution lines	Low	Not significant	High	Not significant
Transmission substations	High	Not significant	Moderate	Not significant
Road	High	Not significant	Not significant	High

Based on: Hallegatte *et al.* (2019); Lopez & Montoya (2019); OLADE (2016); and ADB (2013).
Note: *Simple- and combined-cycle steam and gas turbines, cogeneration plants, among others.

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[17] *The extended scale of threat (digital image) initially obtained was disaggregated by means of a three-level reclassification (high, moderate and low). A percentage cut-off for maximum and minimum threat values (dominant share of the data) at the province level was applied. In this way, threat maps with clearly defined limits were obtained, which allowed for visualising and assigning an exposure level for the infrastructure and its location in each province.*

Climate risk to energy infrastructure

The previously rated qualitative levels of threat (T), exposure (E) and sensitivity (S) were quantitatively assessed as follows: high = 3, moderate = 2 and low = 1; R = risk:

$$R = T \times E \times S$$

Finally, the risk was classified according to the levels set out in Table 2.

Table 2 Climate risk classification categories

VALUE AT RISK	RISK CLASSIFICATION	IMPACT LEVEL
>9	High	This classification indicates that the potential impacts of climate-related events are severe, suggesting a high likelihood of significant adverse effects. This level typically triggers immediate response measures.
>3 and ≤9	Moderate	In this range, impacts are noticeable. This level requires careful monitoring and preparation to mitigate potential impacts.
≤3	Low	This classification indicates minimal potential adverse effects due to climate-related events, suggesting that the situation is generally stable but should still be monitored for unexpected changes.

Adaptation measures

Adaptation measures refer to actions that promote adjustments to systems in response to actual or expected climate changes or their effects, to eventually mitigate damage or capitalise on beneficial opportunities (ADB, 2013). Measures to mitigate climate vulnerability and risk are identified based on a thorough understanding of the advantages and disadvantages of the identified adaptation measures, in terms of effectiveness, robustness, flexibility and sustainability, among others (Ministerio de Ambiente Panamá, 2022). Within this context, resilience strategies for infrastructure encompass both non-structural management approaches and structural measures. Recommendations consider the impact of climate risk variables on the operability and physical integrity of energy infrastructure, and include both engineering and non-engineering measures.[18] A brief description of the adverse or positive changes linked to each hazard was created. The theoretical analysis of the electricity system, based on historical average data, offers a snapshot of how various hazards affect the generation, transmission and distribution of electricity at one moment in time. By not modelling real-time responses, this approach excludes the possibility of identifying dynamic operational vulnerabilities during seasonal and hourly operation. Further analysis is thus required, in particular of the operational modelling of the infrastructure. It would also offer an accurate assessment of investment alternatives linked to the degree of probability and severity of climate risks that may affect each activity of the electricity industry. This accurate assessment must also consider, among other aspects, the composition of the load dispatch curve and the hourly and seasonal variations in electricity demand in the country.

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[18] *Referring to reduced performance, shutdown of the activity and plant closure, among others.*

3. ENERGY INFRASTRUCTURE

This section provides an overview of Panama's current and planned infrastructure for the generation, transmission and distribution of electricity, as well as to aid the supply of fuels to the electricity industry, including fuel terminal ports and roads.

3.1 GENERATION

As of the first semester of 2023, Panama had an installed electricity generation capacity of 3 988.48 megawatts (MW) connected to the National Interconnected System (SIN).[19] Of this, 46.25% (1 844.7 MW) corresponds to hydroelectric generation, 33.59% (1 339.65 MW) to thermal generation, 8.42% (336 MW) to wind farms and 11.74% (468.13 MW) to solar photovoltaic generation. Panama's total gross generation in the first half of 2023 was 7 169.84 GWh, including the SIN, total production from auto generators and from isolated systems. Figure 3 shows the percentage distribution by type of technology.

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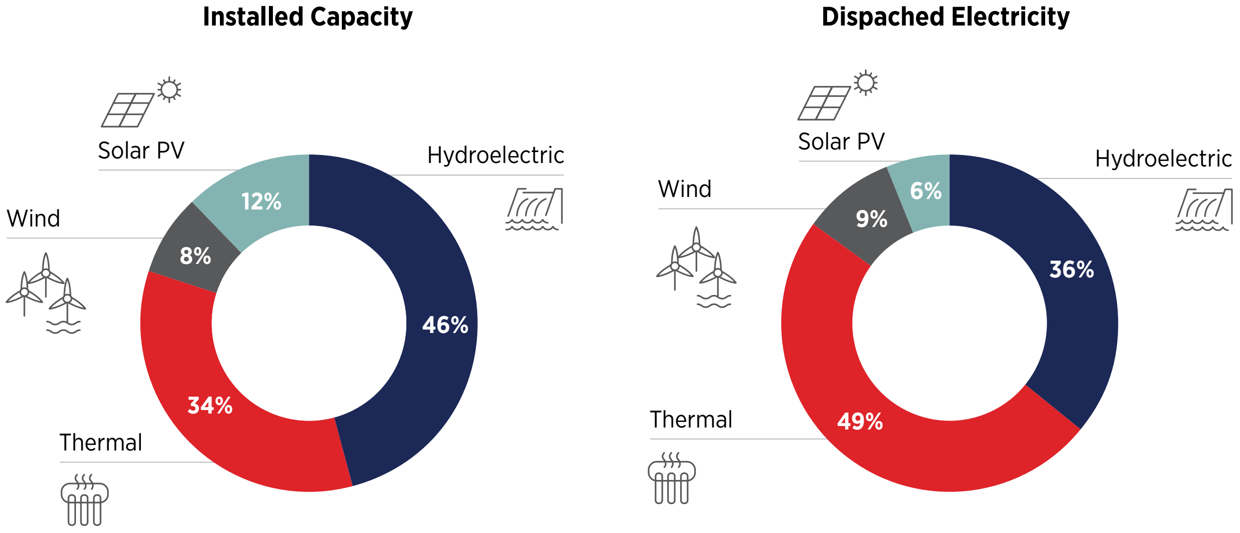
[19] *According to the regulator's statistics on power supply to 2023 (Autoridad Nacional de los Servicios Públicos).*

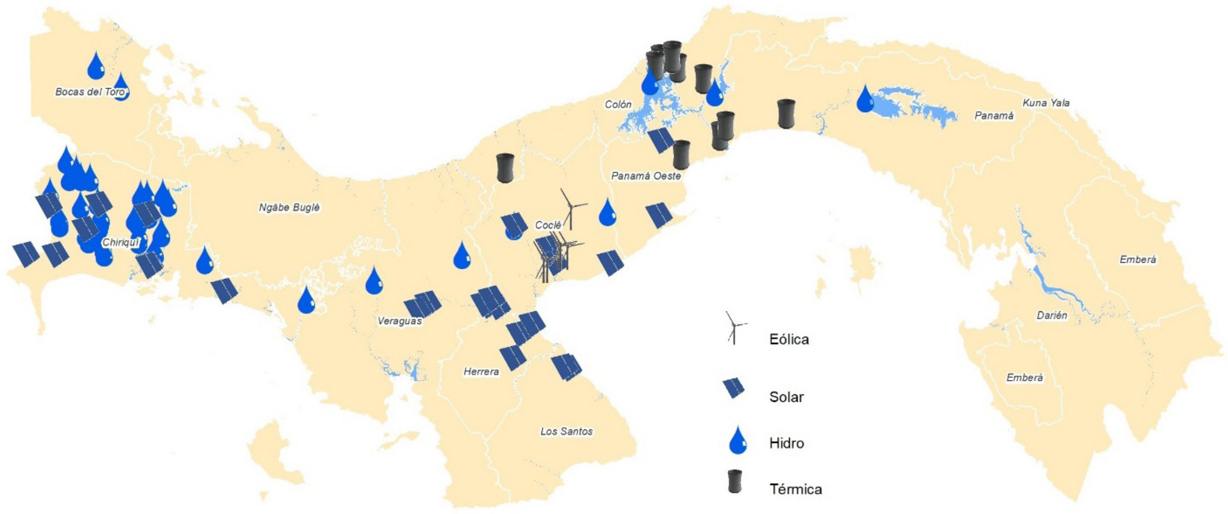
Figure 3 Capacity distribution by technology



Based on: CND statistics (CND, 2023).
Note: PV = photovoltaic.

Hydroelectric generation in Panama is based on 47 power plants, of which approximately 75% started commercial operation between 2010 and 2021. The remaining 19% of plants have an average age of 15 years, while 6% are close to 50 years old. Thermal generation consists of 14 plants, of which 50% are on average 20 years old, 26% are less than 10 years old and the remaining 24% are more than 40 years old. Solar generation entails 41 plants, which were progressively installed from 2015, while wind generation entails seven plants, which became operational from 2018, and are no more than 5 years old. Figure 4 shows the spatial distribution of the georeferenced generation plants.

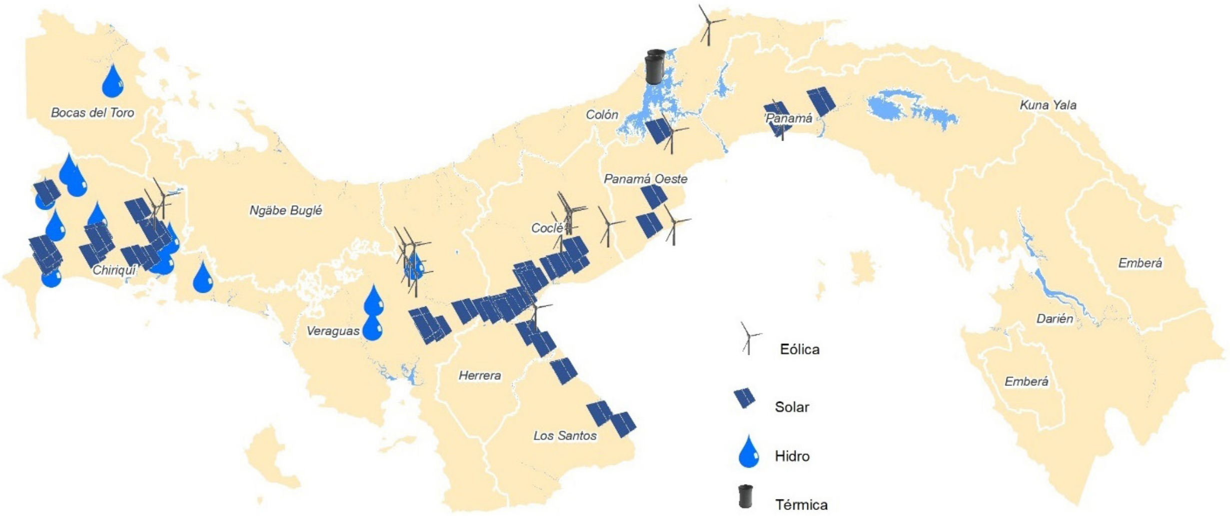
Figure 4 Distribution of power generation plants



Based on: STRI (2023).
Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Panama has projected the introduction of 99 new power plants for the period 2020-2034. These plants will be integrated into the SIN and 67% of them will be solar, 16% wind, 15% hydro and 2% licensed thermoelectric power. In total, the new infrastructure is estimated to add an additional installed capacity of 3 686 MW. Thermal generation would account for 30.6% of the new capacity, followed by solar with 29.7%, wind with 29.6% and hydro with 10.1%. The spatial distribution of the planned infrastructure is shown in Figure 5.

Figure 5 Distribution of planned power generation plants



Based on: Expansion Plan of the National Interconnected System 2020-2034 (ETESA, 2022).

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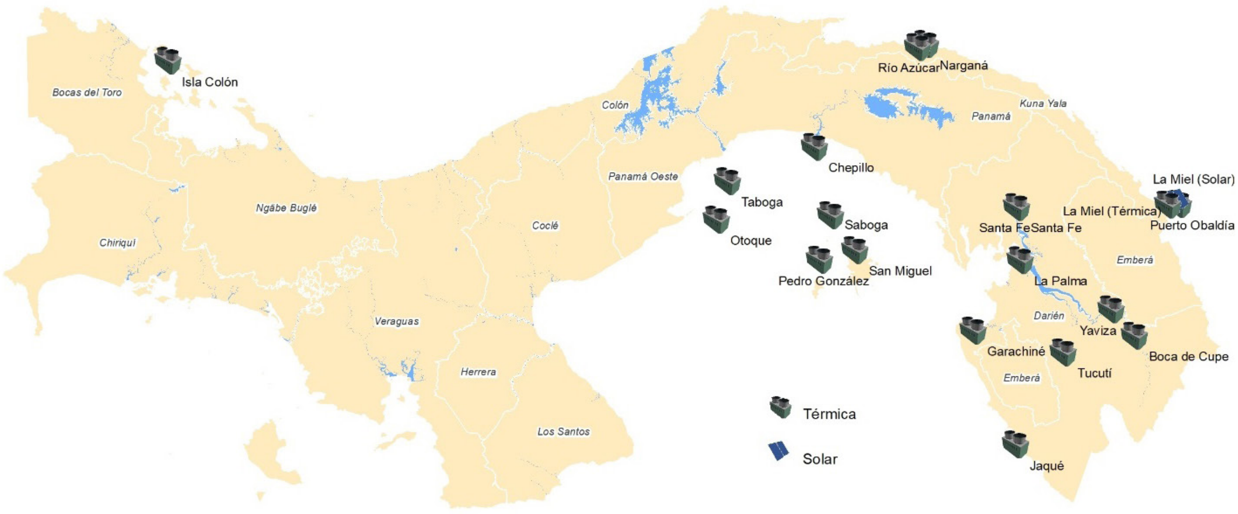
It is also important to mention that Panama has 22 isolated generation systems with an installed capacity of 46.5 MW, of which 94.5% utilise thermal generation technologies. Figure 6 shows the locations of these isolated generation plants.

Figure 6 Distribution of isolated electricity generation systems



Based on: STRI (2023), Isolated electricity generation systems.

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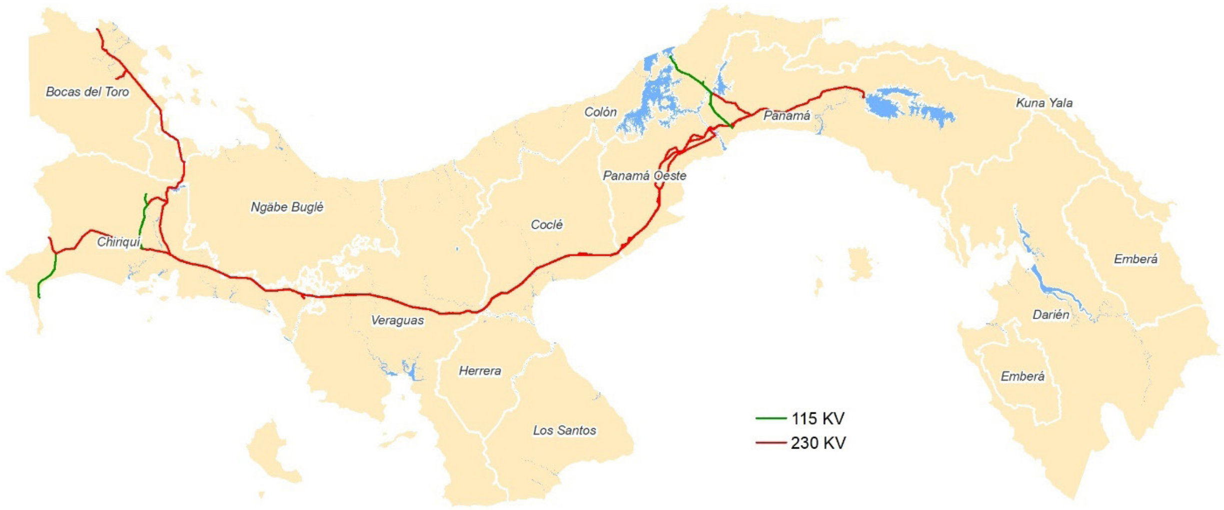
3.2 TRANSMISSION

Panama's electricity transmission system includes a set of 230 kilovolt (kV) and 115 kV high-voltage lines, substations, transformers and other elements necessary to transmit electricity through the SIN to different delivery points. Among the 230 kV lines, the total length of double circuit is 2 712.95 kilometres (km), and of single circuit lines, 94.58 km. For the 115 kV lines, the total length of double circuit is 267.80 km, and of single circuit, 39.90 km (ETESA, 2020). Figure 7 shows the distribution of electricity transmission lines.

Figure 7 Power transmission lines



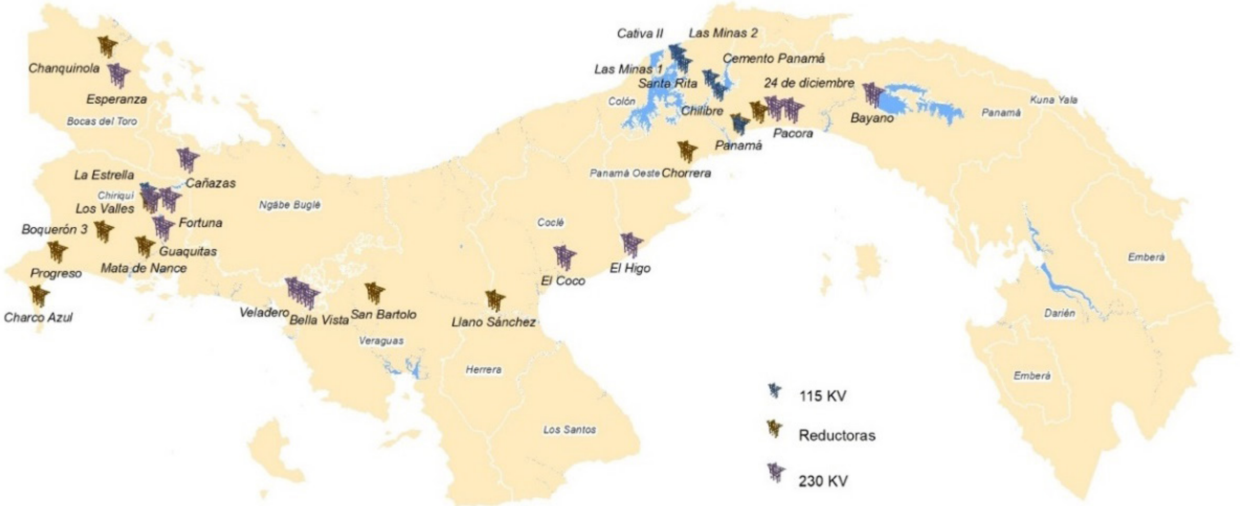
Based on: Data from STRI (2023), Transmission lines.

Note: KV = kilovolt.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

The transmission system includes 31 transmission substations, of which eight are 115 kV switchgear, twelve are 230 kV switchgear and the remaining eleven are step-down stations. The distribution of these substations is shown in Figure 8.

Figure 8 Distribution of transmission substations



Based on: Data from STRI (2023), Transmission substations.

Note: KV = kilovolt.

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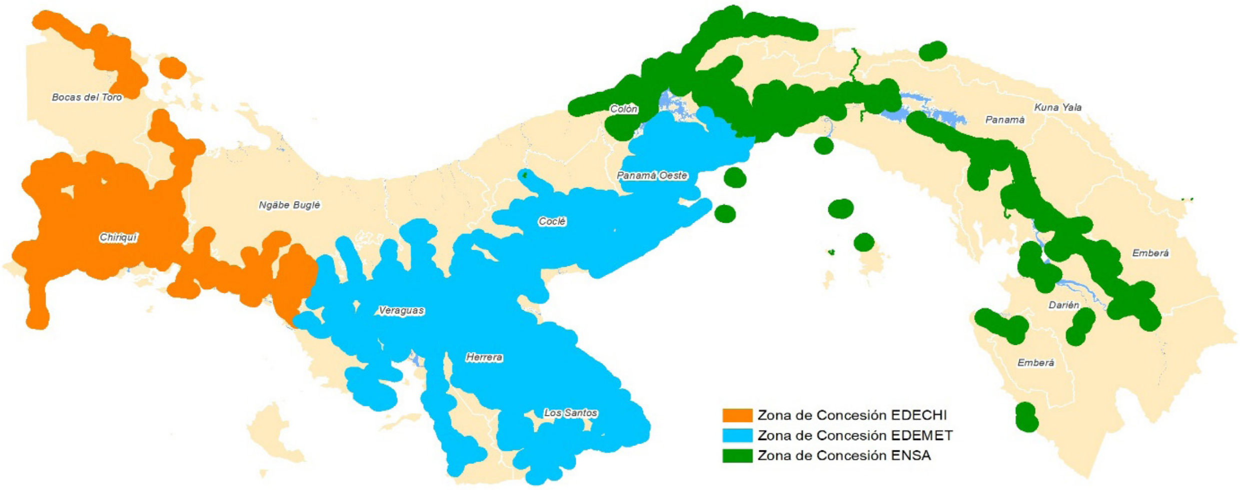
3.3 DISTRIBUTION

Three companies are responsible for electricity distribution in Panama: Empresa de Distribución Eléctrica Metro Oeste, S.A. (EDEMET), Empresa de Distribución Eléctrica Chiriquí, S.A. (EDECHI) and ENSA (formerly Elektra Noreste, S.A.). Together, the concession areas cover 41% of the country's surface area, corresponding to 31 077 km^2. EDEMET covers 64% of this area, while EDECHI covers 30% and the remaining 6% belongs to ENSA, as shown in Figure 9.

Figure 9 Concession areas of the electricity distribution network



Based on: Data from STRI (2023), Electrical distributor concessions.

Note: EDECHI = Empresa de Distribución Eléctrica Chiriquí, S.A.; EDEMET = Empresa de Distribución Eléctrica Metro Oeste, S.A.; ENSA = formerly Elektra Noreste, S.A.

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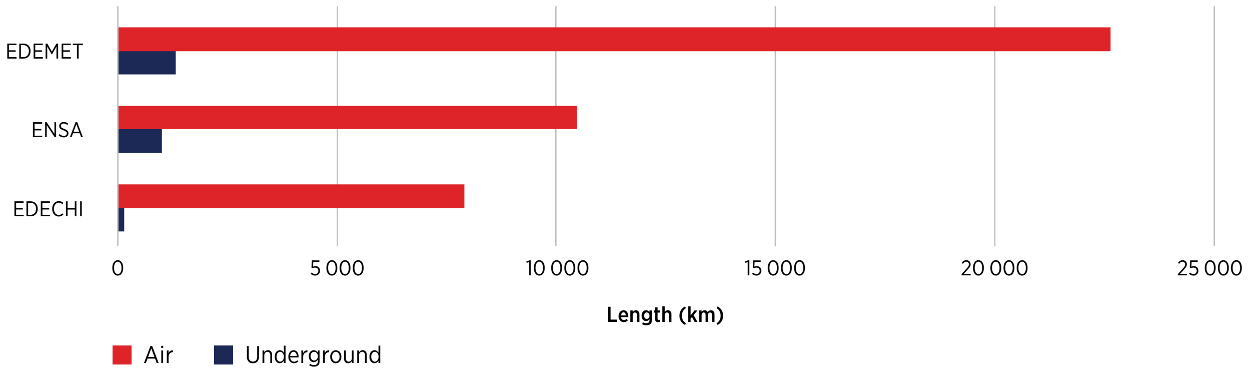
EDEMET's concession area is framed within the provinces of Veraguas, Coclé, Herrera, Los Santos, the province of Panama west of the Panama Canal and the western part of Panama City. EDECHI covers the provinces of Chiriquí and Bocas del Toro, and ENSA covers the provinces of Darién, Colón and part of the province of Panama east of the Canal (except the western part of Panama City, the Comarca Kuna Yala and the islands of the Gulf of Panama).

In 2019, the total length of the distribution networks for the public service was 44 315.64 km, 54% corresponding to EDEMET, 27% to ENSA and the remaining 19% to EDECHI. Figure 10 shows the breakdown of distribution line length by distribution company.

Figure 10 Length of distribution lines, 2019



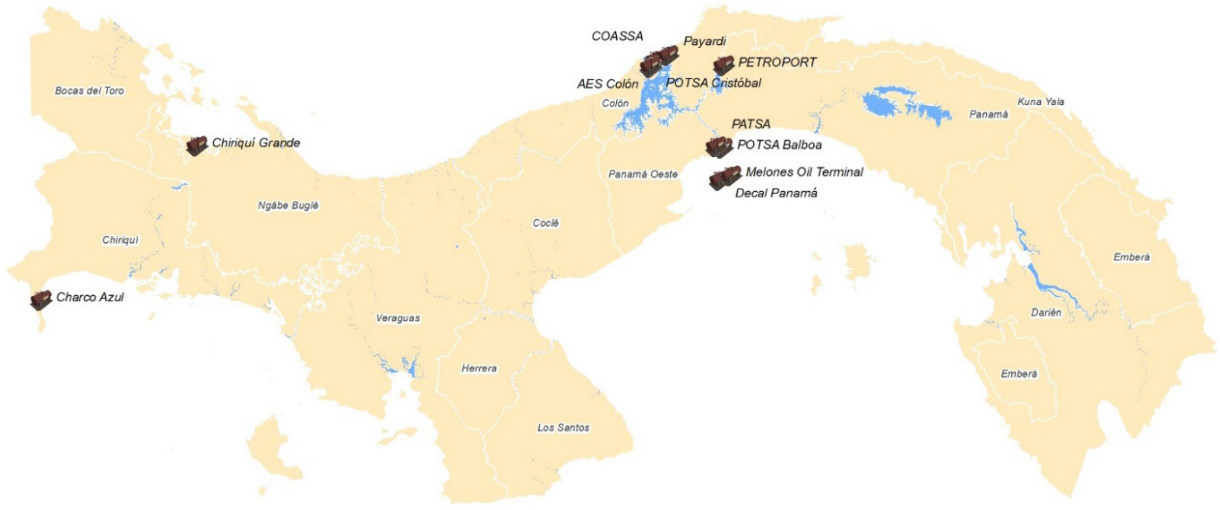
Source: ASEP (2019).

Note: EDECHI = Empresa de Distribución Eléctrica Chiriquí, S.A.; EDEMET = Empresa de Distribución Eléctrica Metro Oeste, S.A.; ENSA = formerly Elektra Noreste, S.A.; km = kilometre.

3.4 CONVENTIONAL FUEL DISTRIBUTION TERMINALS

Panama has ten terminals providing hydrocarbon supply, storage and transfer services, in addition to a liquefied natural gas storage and supply terminal (AES Colón). Six of these terminals are located on the Atlantic side, between the provinces of Colón and Chiriquí Grande. The remaining five terminals are located towards the Pacific side, between the provinces of Panama and Chiriqui, as shown in Figure 11.

Figure 11 Fuel distribution terminals



Based on: Data from AMP (2023).

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Table 3 presents the terminals' operating capacity and when they started operations.

Table 3 Characteristics of hydrocarbon terminals

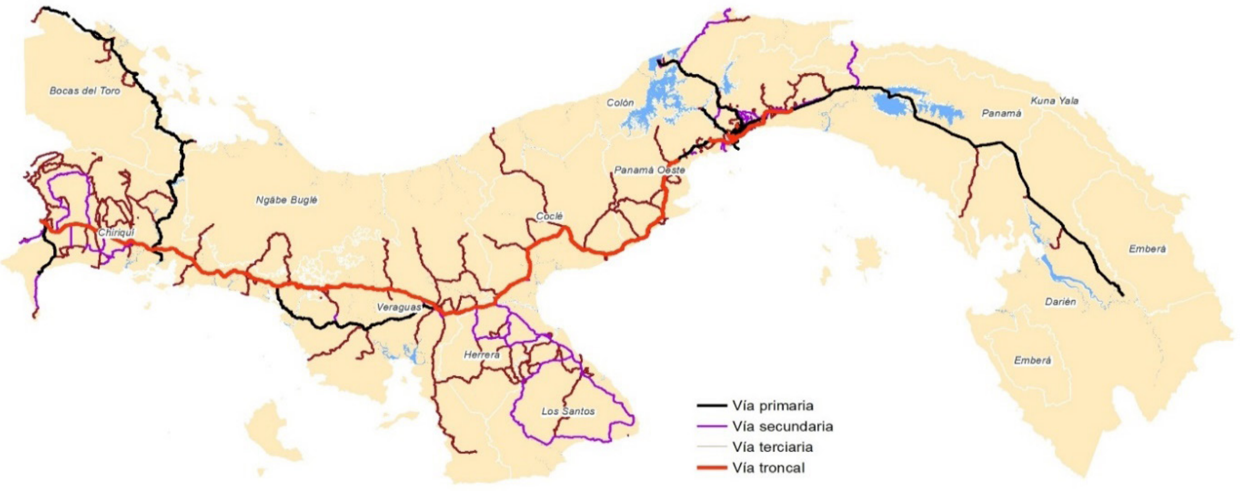
TERMINAL	CAPACITY	START OF OPERATIONS
AES Colón (LNG)	180 000 m^3	2018
Colon Oil and Services (COASSA)	121 685 t	
Decal Panama	356 500 t	2003
Melones Oil Terminal	2.1 million barrels	2013
Panama Oil Terminal (POTSA) – Balboa		2011
Panama Oil Terminal (POTSA) – Cristóbal		2011
Payardi Terminal Company (Chevron)	50 000 t	2015
Petroamérica Terminal (PATSA)	1.5 million barrels	2003
PETROPORT		1996
Charco Azul Petroterminal		1979
Chiriquí Grande Petroterminal		1979

Source: AMP (2023).

3.5 ACCESS ROUTES TO ENERGY INFRASTRUCTURE

Panama's energy infrastructure includes an extensive network of access roads, which cover 5 230 km and connect different energy assets and fuel terminal ports across the country. The network includes trunk roads (16%), primary roads (19%), secondary roads (17%) and tertiary roads (48%). The distribution of these routes is shown in Figure 12.

Figure 12 Access routes to Panama's energy infrastructure



Based on: Data from STRI (2023).

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In Panama, domestic fuel is mainly transported via road, supported by a network of private companies operating at the national, regional or transnational level. These companies play a crucial role in supplying the resource to fuel stations located across the country (LCA, 2022).

4. RATIONALE FOR QUANTIFYING THE IMPACT OF EXTREME WEATHER EVENTS ON THE ENERGY SECTOR

Extreme weather events, such as floods, droughts and extreme heat, have significant impacts on the energy sector. These impacts cause interruptions and imbalances in electricity generation, which can lead to a drop in electricity production capacity and the suspension of services. They also inflict damage on energy infrastructure, such as electricity transmission and distribution networks, as well as infrastructure for extracting, producing, storing and distributing conventional fuels, such as refineries and pipelines. Increased energy demand is observed during heat waves, which can put pressure on energy infrastructure and cause supply issues and trigger energy price surges. For example, changes in the availability of energy resources, such as drought-triggered river flow reductions, affect low-cost electricity generation from hydropower plants, which has to be compensated by other rapid response technologies, or by costlier emergency backup infrastructure, such as diesel- or gas-fired thermoelectric barges.

Quantifying these impacts and their effects on operations and energy supply requires a detailed analysis of the adverse effects of climate risk in the energy sector. This analysis requires modelling based on a set of data that is not always available or easy to generate. For example, information is required on seasonal operating data, the physical resilience of existing infrastructure (which depends on design variables and materials used), primary energy storage capacity and inventory management, the operations management plan, the existence of contingency plans, companies' response capacity, and the analysis of alternatives to access alternative routes and resources to cope with climate contingencies.

This section presents a qualitative overview of the potential impacts on energy infrastructure of four types of weather events: extreme rainfall floods, droughts, heat waves and sea level rise.

4.1 EXTREME RAINFALL AND FLOODS

Extreme flood events can trigger multiple failures in electrical infrastructure; for example, they can open protective devices and damage grid infrastructure – in possibly irreparable ways – resulting in power supply interruptions. Floods can have a significant impact on power generation plants, given that water can infiltrate the facilities and damage electrical equipment, control systems and generators. This can interrupt power generation and affect power supply in the affected areas. There is also a possibility of a decline in power generation capacity at hydropower plants, since floods can reduce the usable load between inflow and outflow levels, which in turn leads to a reduction in power production. Floods can also cause damage to power transmission lines and substations, leading to supply interruptions at the regional and even national level.

In Peru, heavy rains triggered by Cyclone Yaku in March 2023 were reported to have severely damaged energy infrastructure. The rains caused widespread flooding in different regions of Peru, resulting in 106 massive outages affecting more than 150 000 users (OSINERGMIN, 2023). Heavy rains have also damaged hydroelectric power plants in Peru. In 2017, heavy rainfall led to outages at power plants due to sediment build-up in rivers, damage to water channels and landslides that blocked the access roads to the power plants, hindering the transport of personnel, and impeding repair and maintenance (ENEL, 2017).

In Honduras, the passage of Tropical Storm Eta and Hurricane Iota triggered failures in the generation, transmission and distribution systems, directly affecting more than 600 000 customers. The storm was estimated to have cost the electricity sector approximately Honduran lempira (HNL) 262 million (c. USD 11 million), of which 41.8% corresponded to damages, 55.8% to losses and 2.4% to additional costs. The most affected assets were the El Níspero hydroelectric plant, with damages to its access road infrastructure, and the San Pedro Sula Sur substation, combining for an estimated HNL 23 million in damages (c. USD 1 million). Overall losses were estimated at HNL 146 million (c. USD 6 million), reflecting the value of the services that could not be sold. Additional costs were estimated at HNL 6 million (c. USD 0.25 million); these were associated with the mobilisation of personnel to restore the transmission network (BID-CEPAL, 2021).

Storms can also affect wind farms. They can cause power outages and lead to costly repairs or replacements, for example, of detached, broken or deformed turbine blades. Strong winds associated with storms can also cause structural damage to support towers, such as deformation or collapse. One example of storm damage to wind farms occurred during the passage of Hurricane Maria in 2017, which severely affected several Caribbean countries, including Puerto Rico and the Dominican Republic. Hurricane Maria caused severe damage to Puerto Rico's wind farms. Damage to wind turbines was reported, especially to the blades, which were torn off or were severely deformed by the wind's force. Support towers were also damaged in some cases. This damage interrupted wind power generation and left many communities without access to this renewable energy source. The recovery and repair of wind farms in Puerto Rico required significant time and resources. An emblematic case was the Punta Lima Wind Farm, where all 13 wind turbines were destroyed by Hurricane Maria, representing a USD 50 million loss for the operator and affecting nearly 9 000 households (López, 2018).

Extreme weather events can also damage transmission and distribution towers, which experience intense pressure especially from storms and intense wind. Wind at sufficient speed and strength can cause partial or total collapse of towers, disrupting electricity transmission and distribution. Wind can also knock down trees and objects with its force, potentially causing structural damage or breakage of lines when these objects fall on the towers. On the other hand, flooding erodes the ground around the towers, potentially damaging their foundations and stability. Also, erosion caused by sea level rise and storms can jeopardise the stability of both transmission and distribution towers, mainly due to corrosion.

4.2 DROUGHTS

Droughts may severely affect the electricity industry. Water scarcity may reduce thermal power plants' operational efficiency and force a decrease in their production by jeopardising the continuity of their cooling processes. Scarcity also reduces hydropower generation and may increase generation costs. During periods of drought, water levels in reservoirs and rivers decrease, which reduces hydropower generation capacity. Hydropower generation capacity relies directly on the turbined flows, the height of the hydro source and system efficiency.

A decrease in the availability of hydropower may compel generating companies to turn to more expensive generation sources, such as thermal or natural gas plants, increasing electricity generation costs. Also, reduction in hydropower generation can create imbalances in the electricity grid and put pressure on transmission capacity. Transporting power from areas with generation to drought-affected areas may require increased load on transmission lines, potentially affecting their efficiency and leading to congestion issues on the grid.

During prolonged drought, water levels in reservoirs and rivers may reach critical levels, posing a threat to maintaining a steady supply of energy. This can raise concerns about the security of power supply and lead to blackouts or power rationing.

One example was the 2001 drought in Central America, which hampered hydropower generation in all countries of the region by adversely affecting the availability of water stored in dams for generating electricity. It became necessary to resort to power generation in geothermal and thermal plants, as well as to importing energy, mainly of a thermal origin, from countries with surplus capacity. Although this prevented electricity rationing and the adverse impact on productive activities, it did result in an increase in the average cost of energy given these plants' higher unit cost. The increase in the cost of energy was passed on to consumers (CEPAL-CCAD, 2022).

In Panama, this drought also affected the main hydroelectric plants, since the reservoirs of the Fortuna and Bayano plants had been at low levels since the end of 2000. To meet the demand, generation at the thermoelectric plants and imports from Costa Rica had to be increased. Also, hydroelectric generation in the Canal Basin was not possible for much of the year since reservoir levels were low; thermal sources were therefore used. The 2001 drought generated losses of approximately USD 13 million linked to increased generation and operating costs (CEPAL-CCAD, 2022). These additional costs represented a significant burden for the country and affected the stability of the energy sector.

Droughts also have a negative impact on navigation channels. An example of this is the challenge posed by droughts to the Panama Canal Authority. In 2015, Panama's government declared a state of emergency due to a severe drought that reduced water levels in both Lake Alajuela and Lake Gatun, which are critical for shipping through the canal (Rodríguez, 2015). Coping with the drought's repercussions required reducing the draft of vessels and their carrying capacity, and this had a significant economic impact on canal operations and international trade.

4.3 HEAT WAVES

Heat waves have several effects on electricity infrastructure that deserve consideration. They can trigger an increase in energy demand, overload the distribution network, reduce the efficiency of generation plants, increase the risk of fires and generate cooling issues in the electricity infrastructure.

During a heat wave, high temperatures can persist for days or even weeks. Given that more than 60% of the electricity demand is allocated to cooling needs, peak demand rises in terms of both magnitude and duration. This can affect electricity supply, especially in areas with limited generation capacity (Ke *et al.*, 2016). For example, in early 2022, a heat wave in Argentina put excess strain on electricity grids, causing widespread blackouts and leaving 700 000 people in the capital without electricity (Cappucci, 2022).

In addition, high ambient temperatures reduce the thermal capacity of transmission lines, putting more strain on the power grid and increasing the risk of power failures or outages. Studies in the United States (Bartos *et al.*, 2016) indicate that by mid-century (2040-2060), rising air temperatures may reduce the average summer transmission capacity by 1.9% to 5.8% compared with the 1990-2010 baseline period. At the same time, per capita peak loads may increase 2-15% on average due to the increase in air temperature. Another study in the United States shows that a 1°C increase in ambient temperature can reduce the lifetime of a transformer by four years, or 10% (Gao *et al.*, 2017).

Regarding power generation plants, high temperatures can reduce their efficiency. This may result in lower electricity production or the need to reduce plant load to avoid excessive heating and possible damage to equipment. Power plants, especially thermal and nuclear power plants, require cooling systems to keep their operations within safe limits. During heat waves, the water used for cooling, such as rivers and reservoirs, can decline in level and warm up to high temperatures, affecting the efficiency of cooling systems and limiting the generation capacity of plants. The warming of groundwater used in cooling thermal power plants represents a vulnerability to the energy matrix of countries with gas-fired thermal power plants and nuclear power plants. In 2018, heat waves in several European countries forced nuclear plants in Finland, France, Germany, Sweden and Switzerland to reduce their power generation by up to 10% due to the warming of the natural water sources that cool these plants' reactors. In several locations, water temperature exceeded 23°C, three degrees above the safe operating temperature (NEI, 2018).

On the other hand, temperatures and dry conditions during heat waves exacerbate the risk of forest fires, which can damage electricity infrastructure such as transmission towers, distribution lines and substations, leading to power outages. In Chile during the summer of 2017, an extreme heat wave fuelled forest fires, which spread mainly across the regions of O'Higgins, Maule and Biobío, lasting more than 15 days and affecting an area of 467 000 hectares (Cordero *et al.*, 2024). The electricity infrastructure sustained severe damage, including the partial or total destruction of transmission towers and distribution lines. A similar fire occurred in early 2023, causing damage to some 33 km of medium- and low-voltage lines and nine distribution substations (Durante, 2023).

Heat waves also have an impact on the operation of solar panels; negative effects may include decreased efficiency, degradation of materials and reduced lifetime. The efficiency of converting solar radiation into electricity decreases with the increase in temperature, because exposure of the materials used in solar panels to elevated temperatures can dampen their ability to convert sunlight into electricity (Dubey *et al.*, 2013).

Regarding wind power generation, temperature increases influence the performance of wind turbines. The power output of wind turbines varies in direct proportion to the air density, which is directly dependent on the temperature; therefore, an increase in air temperature decreases the density and consequently the generation potential. Studies indicate that the air density ratio can decrease by an average of 0.35% for each degree Celsius increase in temperature (Ulazia *et al.*, 2019). These density reductions associated with increasing ambient temperature usually lead to power losses and a decline in wind farm performance. However, studies indicate that yield losses under climate change scenarios may not be significant in the long term. Estimates made as part of these studies indicate that every 1°C temperature rise could lead to a 1.64×10^{-3}% reduction of wind farm yield (Rodríguez *et al.*, 2020).

4.4 SEA LEVEL RISE

Rising mean sea level poses considerable challenges for seaports, especially due to the potential effects of temporary and permanent flooding. These coastal floods can severely damage port infrastructure, including piers, fuel storage terminals, logistics platforms, maritime transport and even the electricity generation and transmission infrastructure (UNCTAD, 2020). Given Panama's geographical context and its reliance on maritime transport for fuel imports, it is possible that a coastal flood could affect fuel storage terminals and fuel import ports, potentially causing fuel supply disruptions and fuel shortages. The resulting shortages may increase the demand for alternative fuels, driving up prices and electricity generation costs. Also, fuel supply shortages can lead to reductions in electricity generation capacity. Power plants relying on specific fuels may face outages or even suspend operation due to fuel shortages. This can result in power outages and affect the stability of electricity supply in the affected regions.

Also, if power generation plants, substations or other grid-related infrastructure are in low-lying coastal areas, then they may be at risk of flooding and damage, which would affect power generation and supply. This infrastructure risk situation is aggravated when considering the occurrence of possible tropical storms, which may expand the areas of temporary flooding. Studies indicate that, in a scenario of rising sea levels and the additional threat of intense storms or hurricanes, flood-prone coastal areas could double in several countries in the region, for example, Belize, Costa Rica, Honduras, Panama and Venezuela, and this would generate significant impacts on infrastructure, including roads and railways (CEPAL-Universidad de Cantabria, 2012).

An example of the impact of extreme events associated with coastal flooding is offered by Hurricane Sandy, which hit the US east coast in 2012. Of the economic damage it wrought, 13% was due to sea level rise (Strauss *et al.*, 2021). During the hurricane, coastal flooding severely damaged the electrical infrastructure and fuel supplies. Fuel import and storage terminals in the coastal areas were affected, disrupting fuel delivery to power plants. Also, oil refineries and pipelines were damaged, further affecting fuel supply. The lack of fuel supply, due to flooding and damage to the electricity infrastructure, led to widespread power outages in several areas. It is estimated that approximately 8.5 million customers lost electricity supply during Sandy, and some faced outages lasting days and even weeks (FEMA, 2013).

5. ESTIMATING EXPOSURE TO CLIMATE RISK

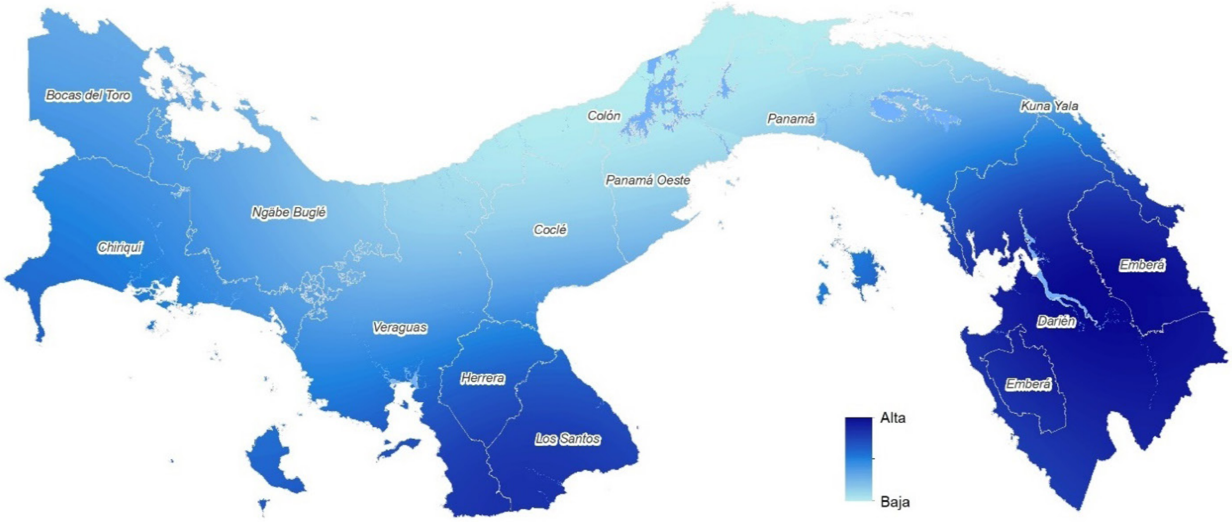
The objective of this section is to present the results of the climate hazard assessment for Panama, which include the spatial distribution of events such as extreme rainfall–triggered floods, droughts, extreme heat and sea level rise in coastal areas. The exposure of energy infrastructure to these events is also described and a climate risk assessment for the infrastructure is presented.

5.1 CLIMATE HAZARD

Extreme rainfall flooding

The results for the 2050 horizon indicate that the provinces of Darién, Emberá, Los Santos, Herrera, southern Veraguas, western Chiriquí and eastern Panama are under a high threat of the occurrence of flood events due to extreme precipitation, as shown in Figure 13.

Figure 13 Flood threat from extreme rainfall, 2050



Based on: World Bank projections (CMIP6) (World Bank, 2024b).

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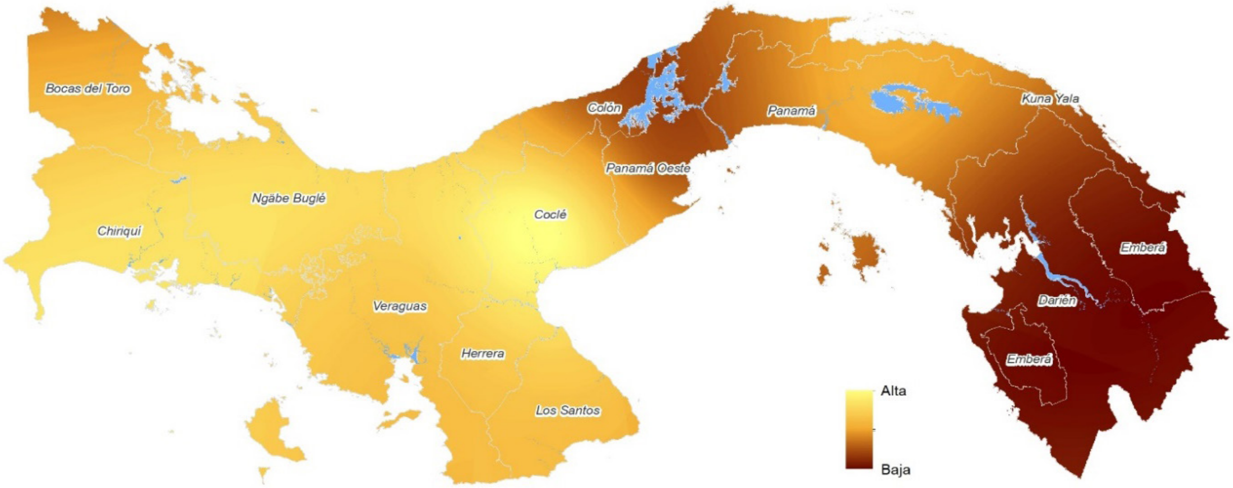
In the provinces identified as high threat, flood events triggered by intense rainfall have been frequent. The watersheds with a very high occurrence of and susceptibility to flooding are Rios between the Caimito and Juan Díaz, with 381 events; Río Juan Díaz and between Río Juan Díaz and Pacora, with 199 events; and Río Caimito, with 176 events. Records collected over 1920-2017 reveal flood frequency ranging from moderate to high for these provinces (Ministerio de Ambiente Panamá, 2019; Ministerio de Economía y Finanzas, 2023).

By 2070, the flood hazard would progress to high for the province of Coclé, whereas for Chiriquí, it would decrease, becoming intermediate to low. For the remaining provinces, the flood hazard would maintain the same distribution as observed for 2050.

Drought

The threat of droughts with a projection to 2050 shows a dominant distribution trend towards the centre-west of the country; the highest level of threat is concentrated in the province of Coclé, followed by Chiriquí, Ngäbe Buglé, Veraguas, Herrera and Los Santos, as shown in Figure 14.

Figure 14 Drought threat, 2050



Based on: World Bank projections (CMIP6) (World Bank, 2024b).

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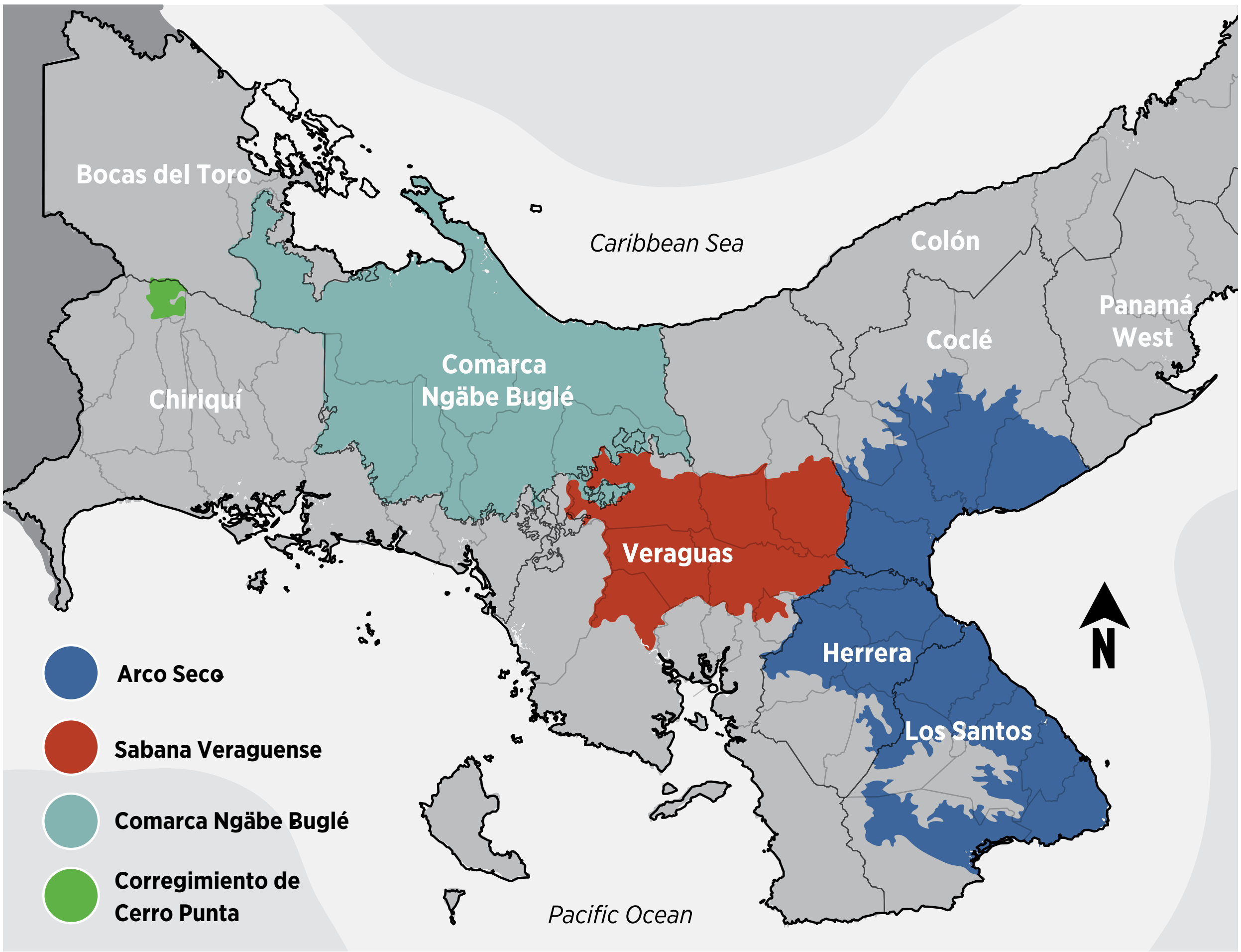
The geographic distribution of the drought threat correlates with the current location of degraded and drought-susceptible areas in Panama, particularly in the region known as the Arco Seco. This correlation is visualised in Figure 15, which shows the spatial coincidence between high drought threat and the presence of drylands.

Figure 15 Dry and degraded land in Panama



Source: (Ministerio de Ambiente Panamá, 2019).

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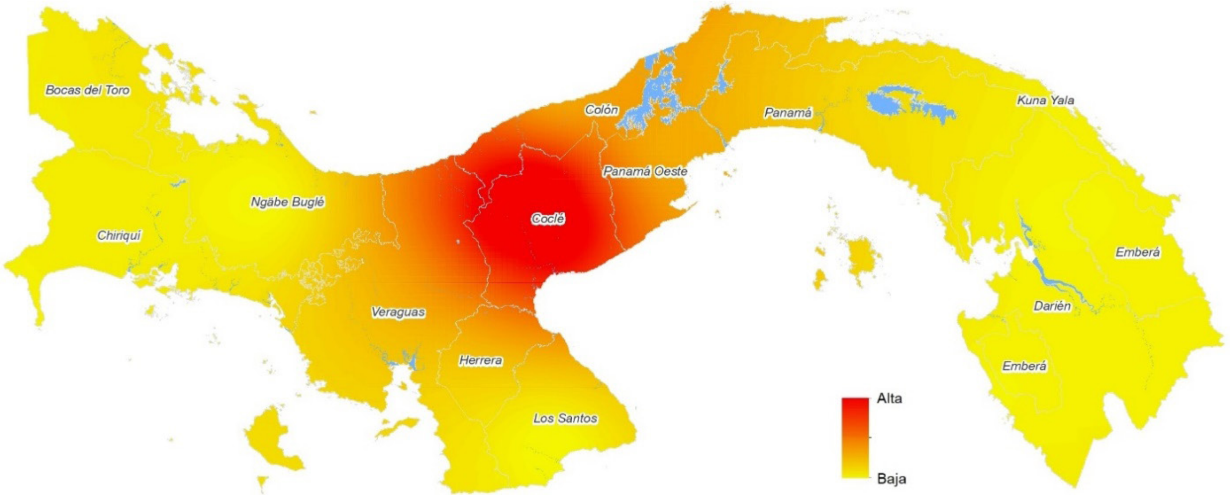
The assessment for the 2070 horizon shows no increase in the distribution of drought hazard levels compared with the levels observed for 2050. Instead, threat levels are expected to decrease at an intermediate scale in the provinces of Ngäbe Buglé, Veraguas, Herrera and Los Santos.

Extreme heat[20]

The results obtained predict a significant increase in the occurrence of extreme heat by 2050 in some areas of Panama. The highest concentration of this hazard is expected in the central zone, mainly affecting the provinces of Coclé, Panamá Oeste, the western part of Colón and the northwest of Veraguas. Figure 16 shows the spatial distribution of this hazard in greater detail.

Figure 16 Threat of extreme heat, 2050



Based on: World Bank projections (CMIP6) (World Bank, 2024b).

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By 2070, the extreme heat hazard level is expected to increase from intermediate to high for the province of Ngäbe Buglé. Across the remaining provinces, the hazard level is expected to maintain the same distribution as observed in 2050.

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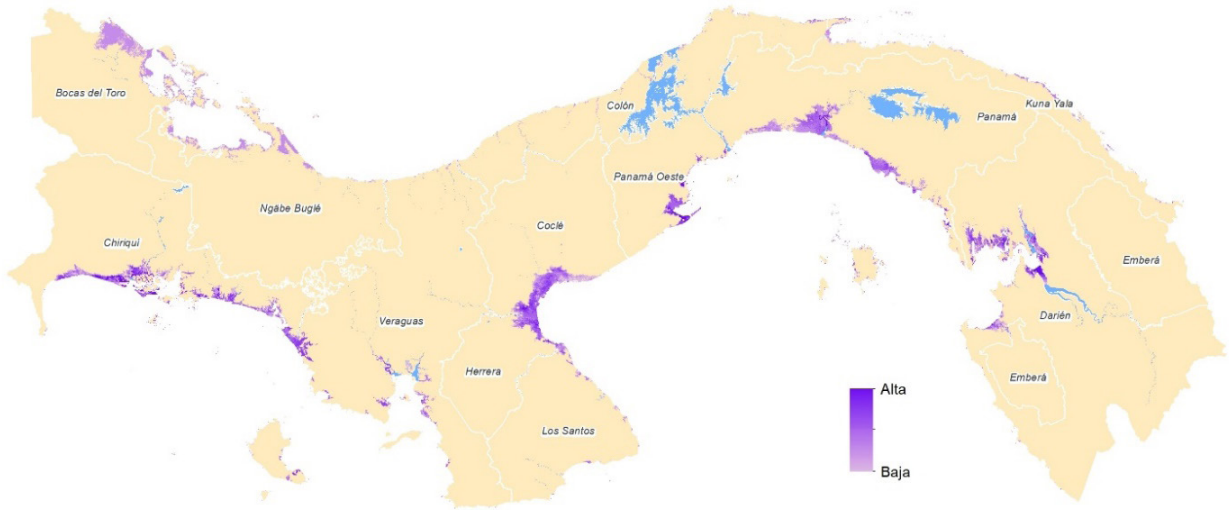
[20] *Ambient temperature exceeding 35°C (95°F).*

Sea level rise

By 2050, sea level rise is expected to present high levels of threat along the Pacific coasts, especially in the provinces of Coclé, Panamá, Panamá Oeste, Chiriquí and Veraguas. According to the selected climate scenario, approximately 2 790 km^2 of the coastal territory will be affected by this phenomenon; 17% of the coastal territory will be under a high level of threat, 21% under an intermediate level and 62% under a low level of threat. Figure 17 shows the distribution and threat levels due to sea level rise for the year 2050.

Figure 17 Threat due to sea level rise, 2050



Based on: Data from the Ministry of Environment and SINIA (SINIA, 2020).

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In particular, the extreme conditions considered are concentrated along the Pacific coast of Panama, specifically in the following points: the surroundings of the city of La Palma and the mouth of the Sambú river, between Garachiné and Taimati, in the Province of Darién; the mangrove area in the district of Chimán, east of Panama City, between the Chico and Chepo rivers, in the Province of Panamá; the bay of Chame, in the Province of Panamá Oeste; the bay of Parita, located in the district of Aguadulce, in the Province of Coclé; the mangroves around the Vidal River, in the Province of Veraguas; and practically the entire coastal area of the Province of Chiriquí, with the exception of the district of Barú (IH Cantabria, n.d.).

On the other hand, along the Caribbean coast, flooding is observed mainly on the coast of Bocas del Toro, including the mangrove area both north and south of this archipelago, and in El Porvenir, in Kuna Yala. Flooding is also recorded in some coastal regions north of the city of Colón, in the Province of Colón (IH Cantabria, n.d.).

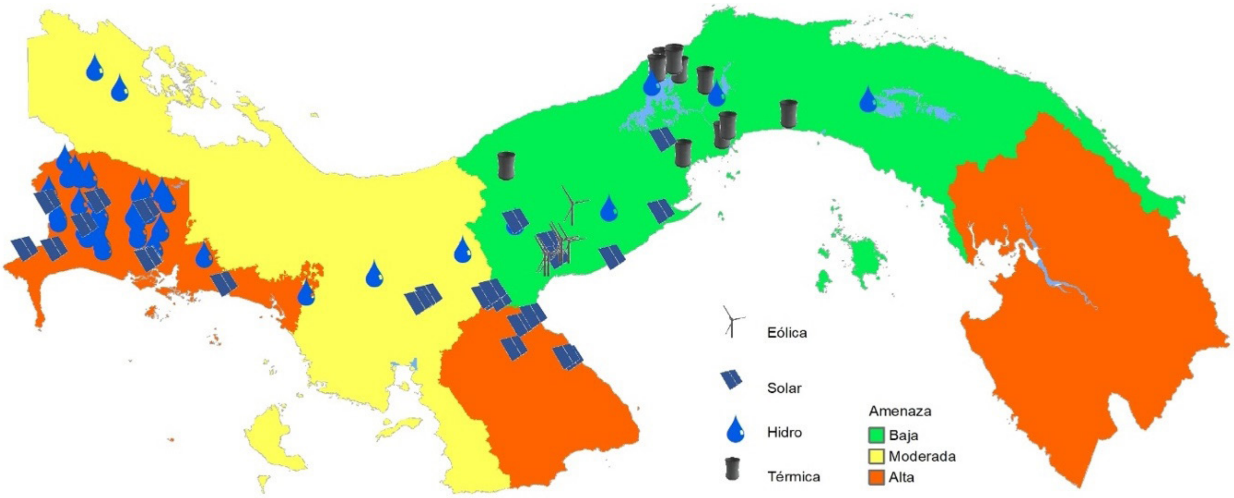
5.2 EXPOSURE OF INFRASTRUCTURE TO CLIMATE HAZARDS

Below are the results broken down by type of infrastructure and type of hazard, taking into account the provincial boundaries of the country.[21] It is important to highlight that the cartographic information shown reflects the spatial location of the infrastructure analysed according to each hazard. In the case of generation and transmission infrastructure, exposure to the threat of sea level rise is not shown, because the spatial distribution of the latter does not represent a threat to this infrastructure, both existing and planned.

Exposure of generation infrastructure to the threat of flooding from extreme rainfall events

Of the total number of hydroelectric plants in operation (47), 80.8% are exposed to a high threat of flooding due to extreme rainfall in 2050, mainly concentrated in the province of Chiriquí. Meanwhile, 39% of the solar infrastructure is exposed to a high threat (16 plants), 31.7% to a moderate threat (13 plants) and 29.3% to a low threat (12 plants). Figure 18 shows the exposure of generation infrastructure in relation to flood hazard levels.

Figure 18 Exposure of energy infrastructure to flooding, 2050



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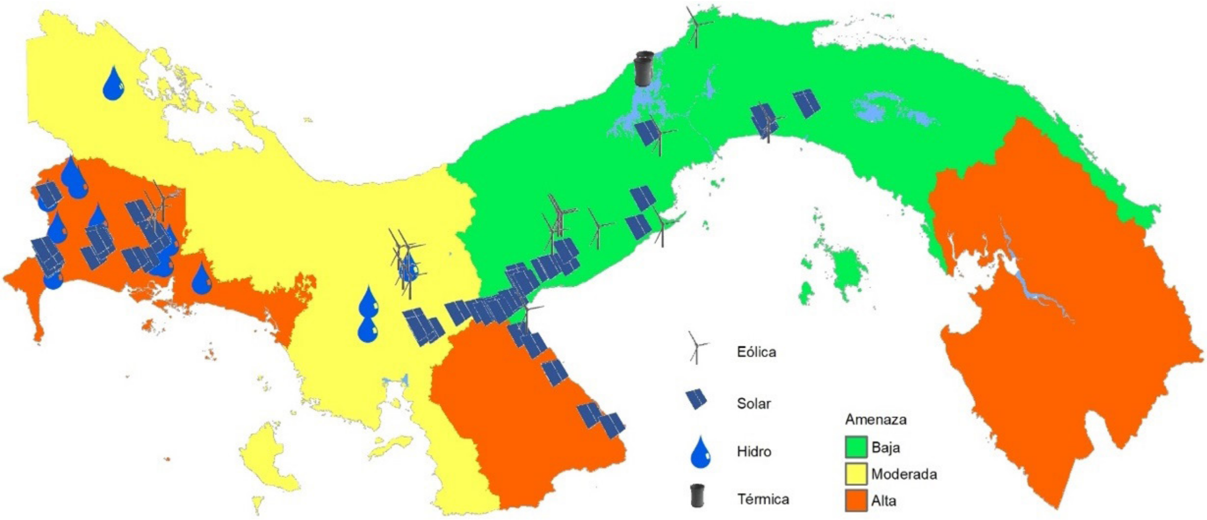
[21] *Annexes 3 and 4 detail the exposure levels of installed and planned infrastructure, respectively.*

Regarding the planned generation infrastructure, 66.6% (10 plants) of the hydroelectric plants would be exposed to a high threat of flooding from extreme rainfall by 2050, while the remaining 33.4% (5 plants) would be in a moderate-threat area. As for the 66 projected solar plants, 45.5% would be in high-hazard areas and 9% in moderate-hazard areas. In the case of the wind power plants, two (12.5%) would be in a high flood hazard zone and four (31.3%) would be in a moderate hazard zone. Figure 19 shows the exposure of planned generation infrastructure in relation to flood hazard levels.

Figure 19 Exposure of planned energy infrastructure to flooding, 2050



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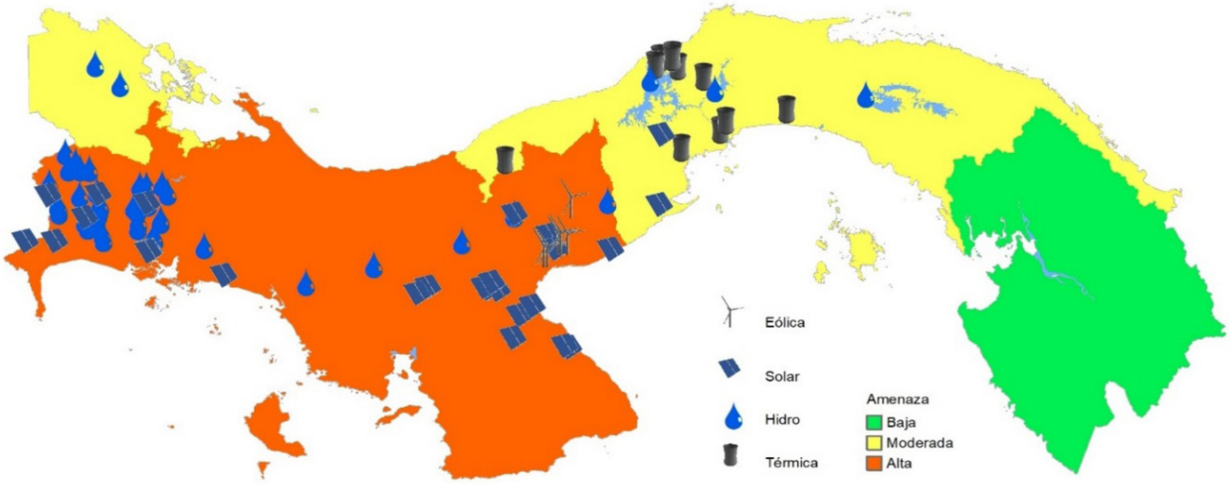
Exposure of generation infrastructure to the threat of drought

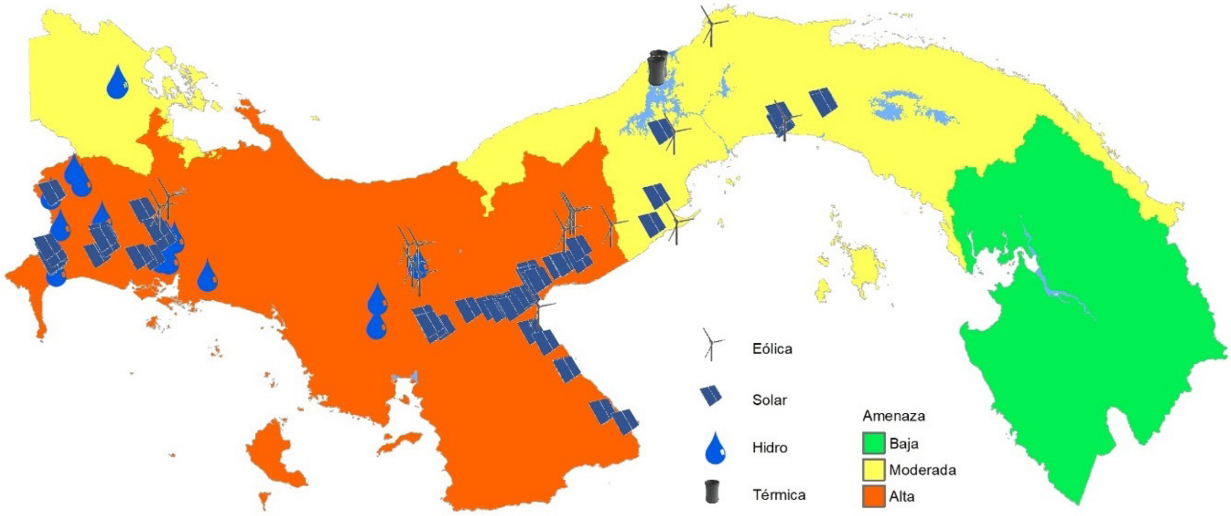
The current generation infrastructure also faces significant drought risks in 2050. Of the 47 installed hydropower plants, 89.4% (42) are exposed to a high threat, while wind infrastructure is located entirely in areas of high exposure. As for photovoltaic generation, 17 plants (41.4%) are located in areas of high exposure to drought. However, these systems present a low vulnerability to this threat, due to their minimal water consumption for electricity production. On the other hand, thermal power plants are exposed to a moderate threat in their entirety, as shown in Figure 20.

Figure 20 Exposure of the installed generation infrastructure to drought, 2050



Planned generation infrastructure shows similar drought threat exposure as above. Thermal generation infrastructure will be located in areas of moderate threat, while the largest proportion (>80%) of the projected hydro, solar and wind generation infrastructure will be exposed to high threat, as detailed in Figure 21.

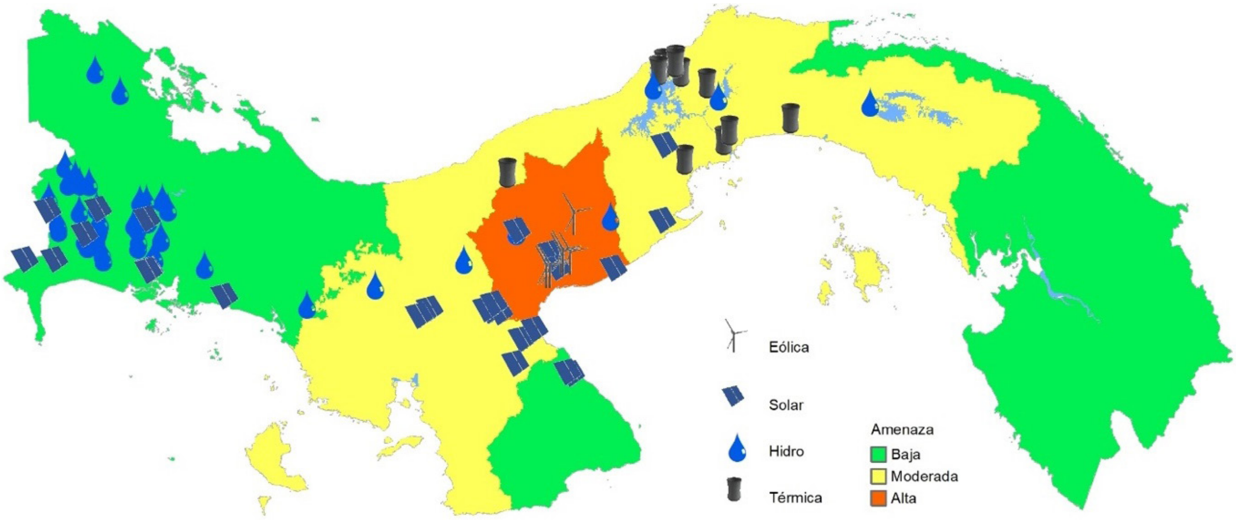
Figure 21 Exposure of planned generation infrastructure to drought, 2050



Generation infrastructure exposure to extreme heat threat

With the exception of wind power plants, a low proportion of the installed generation infrastructure faces a high threat of extreme heat in 2050. However, 100% of thermal plants and 44% of solar plants (18 in total) are exposed to a moderate threat, as shown in Figure 22.

Figure 22 Exposure of installed generation infrastructure to extreme heat, 2050



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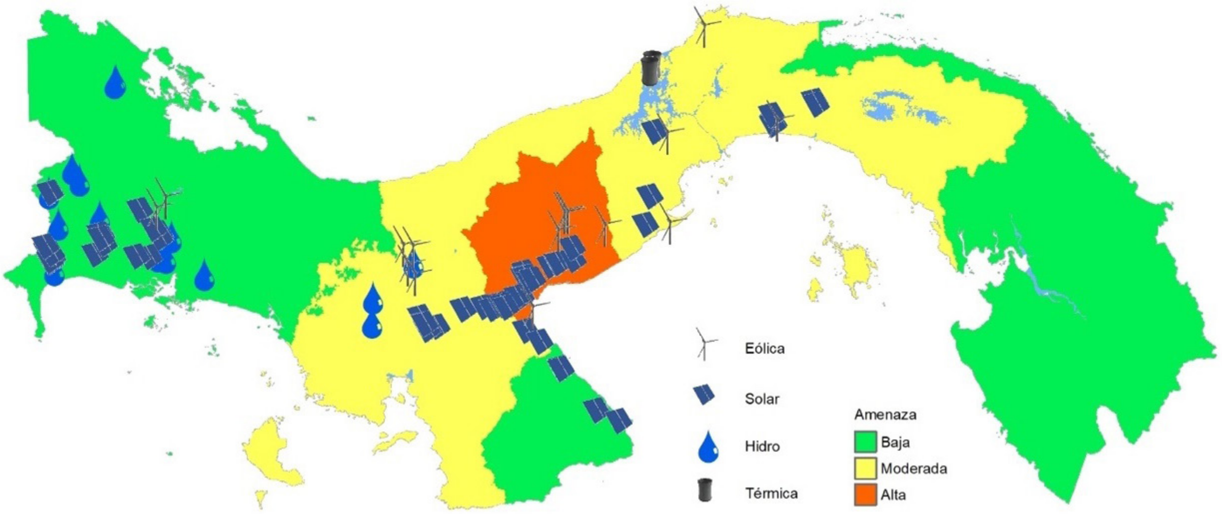
With regard to the infrastructure to be built, about 50% (33) of the planned solar generation plants and 88% (14) of the planned wind generation plants will be located in areas of moderate to high threat, as shown in Figure 23.

Figure 23 Exposure of planned generation infrastructure to extreme heat, 2050



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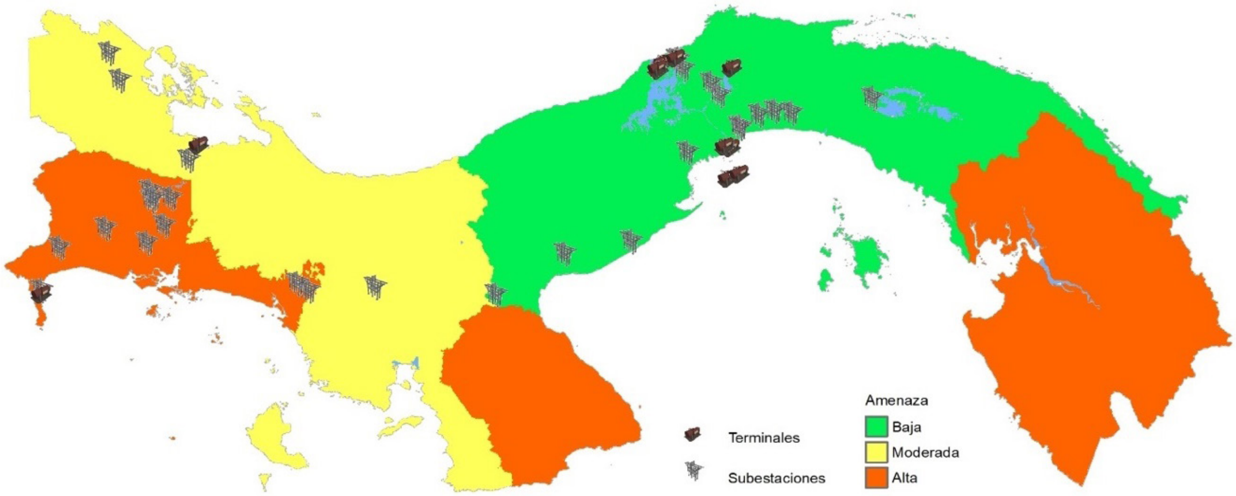
Exposure of hydrocarbon substations and terminals to extreme rainfall flooding

The province of Chiriquí has 14 substations (45% of the total) that are highly exposed to the threat of flooding due to extreme rainfall in 2050. In addition, 2 of the 11 hydrocarbon terminal ports are located in areas of moderate and high exposure, as illustrated in Figure 24.

Figure 24 Exposure of hydrocarbon substations and terminals to flooding, 2050



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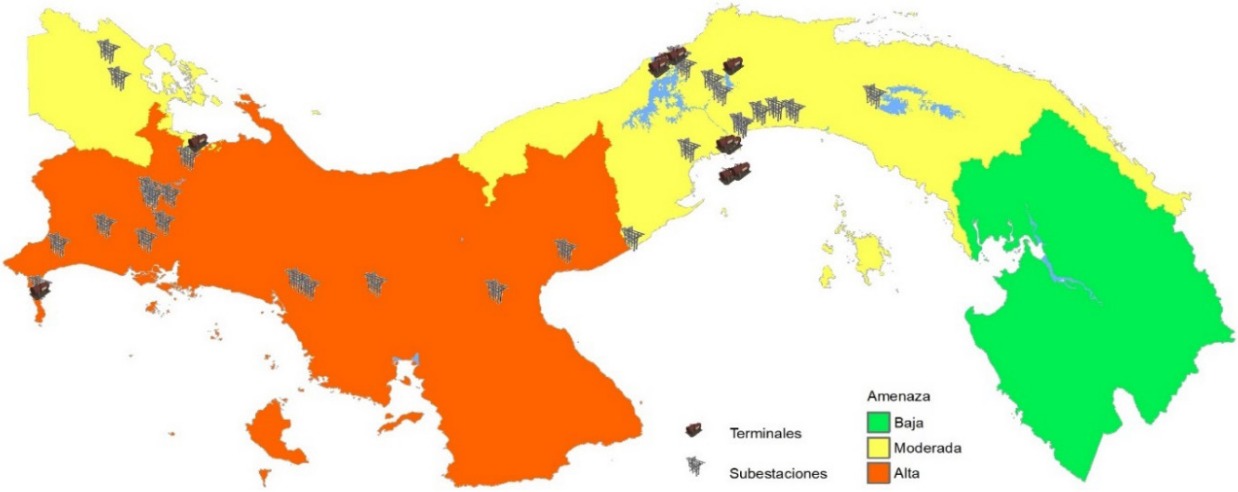
Exposure of hydrocarbon substations and terminal ports to the threat of drought

Of the total number of substations (31), 45% are exposed to a high threat of drought in 2050, while the remaining percentage is located in areas of moderate threat. Meanwhile, 90% of the fuel terminal ports (10) are exposed to a moderate threat of drought and the remaining 10% (1) to a high threat (Figure 25).

Figure 25 Exposure of hydrocarbon substations and terminals to drought, 2050



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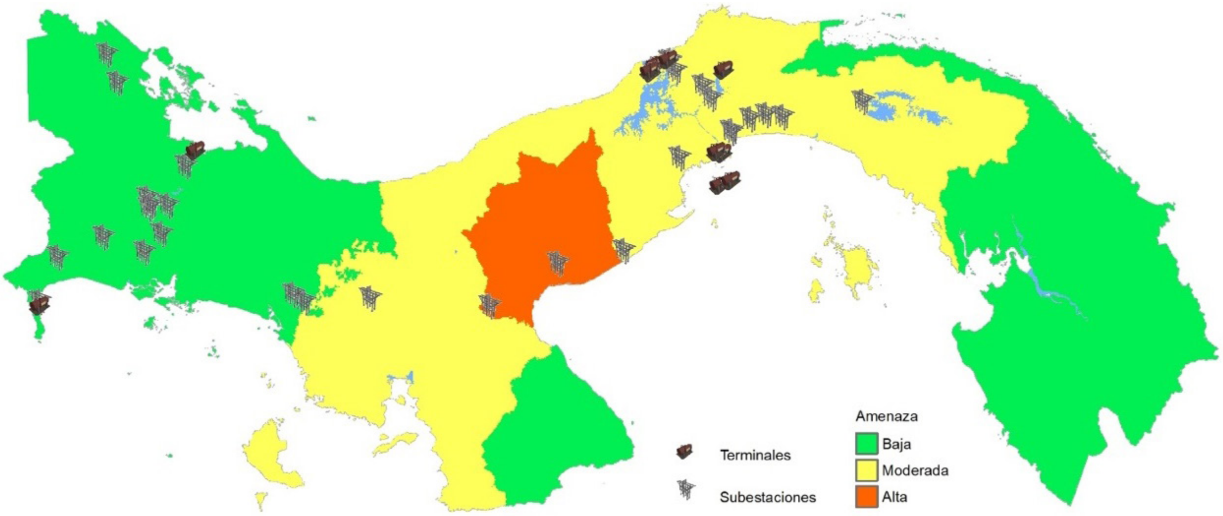
Exposure of hydrocarbon substations and terminals to the threat of extreme heat

The exposure of hydrocarbon substations and terminals to the threat of extreme heat in 2050 is low. Only 6% of substations are in areas of high exposure, while 45% (14) are in areas of moderate exposure. As for hydrocarbon terminal ports, 82% (9) will be exposed to moderate threat, as indicated in Figure 26.

Figure 26 Exposure of hydrocarbon substations and terminals to extreme heat, 2050



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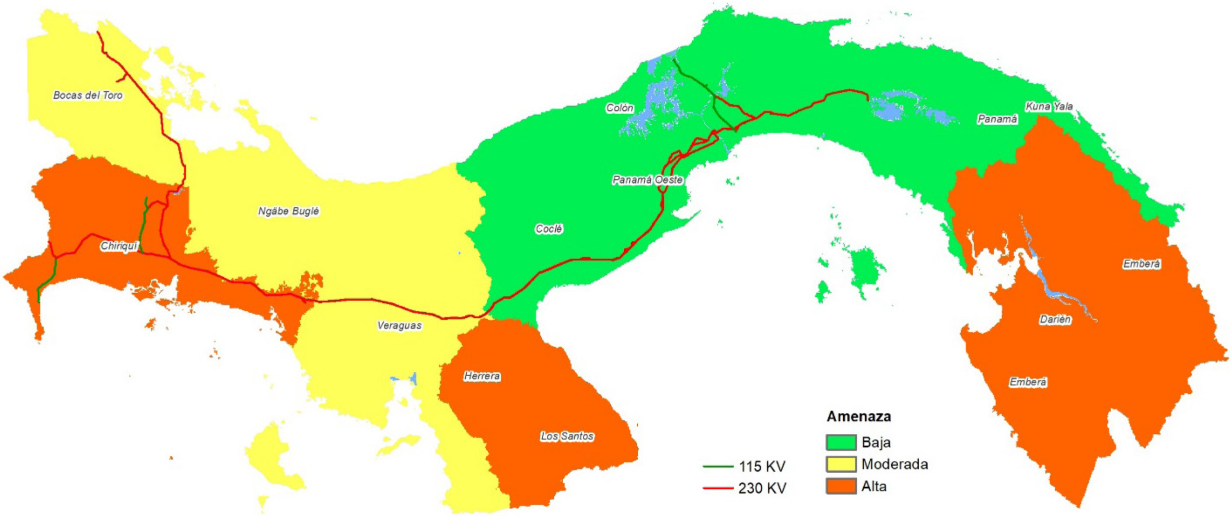
Exposure of transmission lines to the threat of extreme rainfall flooding

It is estimated that the supporting infrastructure of about 670 km of transmission lines will be exposed to a high threat of flooding caused by extreme rainfall, particularly in the province of Chiriquí. In addition, about 808 km of transmission lines will face a moderate threat of flooding, concentrated in the provinces of Bocas del Toro, Veraguas and Ngäbe Buglé, as shown in Figure 27.

Figure 27 Exposure of transmission infrastructure to flooding from extreme rainfall, 2050

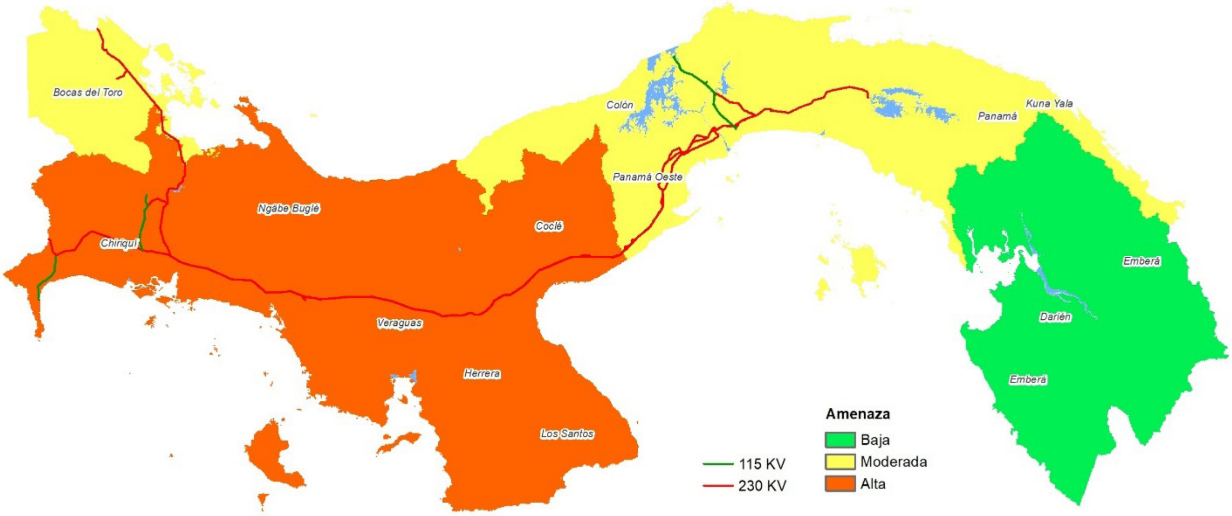


Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Exposure of transmission lines to drought

Some 1814 km of transmission lines passing through the provinces of Coclé, Veraguas and Chiriquí would be affected by the threat of drought. In addition, it is estimated that approximately 1300 km of lines, located in the provinces of Colon, Panama, Panama Oeste and Bocas del Toro, are exposed to a moderate threat, as shown in Figure 28.

Figure 28 Transmission infrastructure exposure to drought, 2050



Note: KV = kilovolt.

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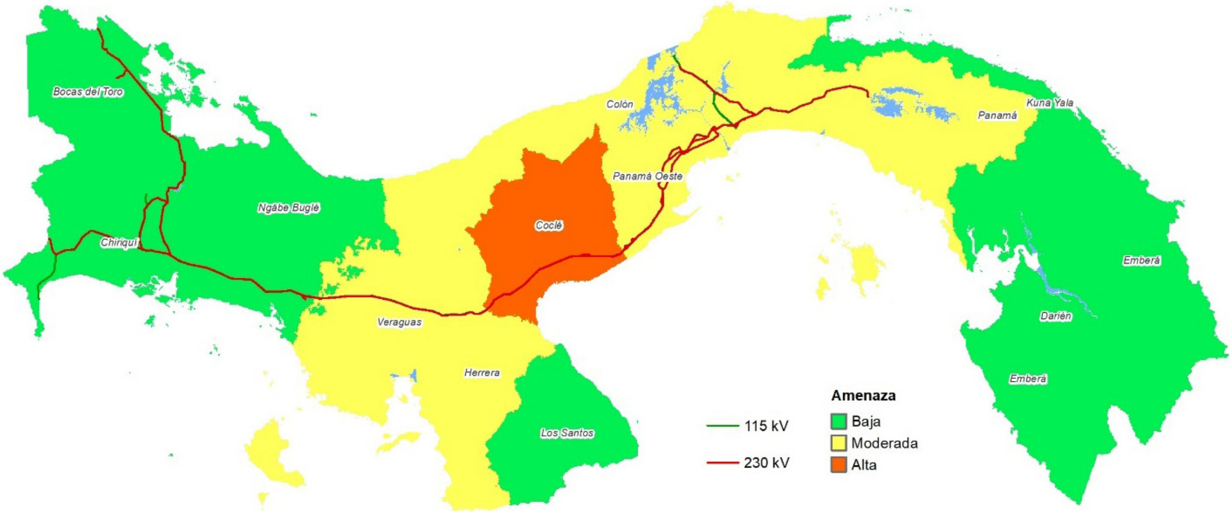
Exposure of transmission lines to extreme heat

Approximately 55% of the transmission lines, equivalent to 1 700 km, will face a moderate threat due to extreme heat events until 2050. Another 30% of this infrastructure (923 km), in the western region, would be exposed to low threat, while the remaining 15% (497 km), most of it in the province of Coclé, would be under high threat. Figure 29 shows the exposure of the transmission infrastructure to the risk of extreme heat.

Figure 29 Exposure of transmission infrastructure to extreme heat, 2050



Note: KV = kilovolt.

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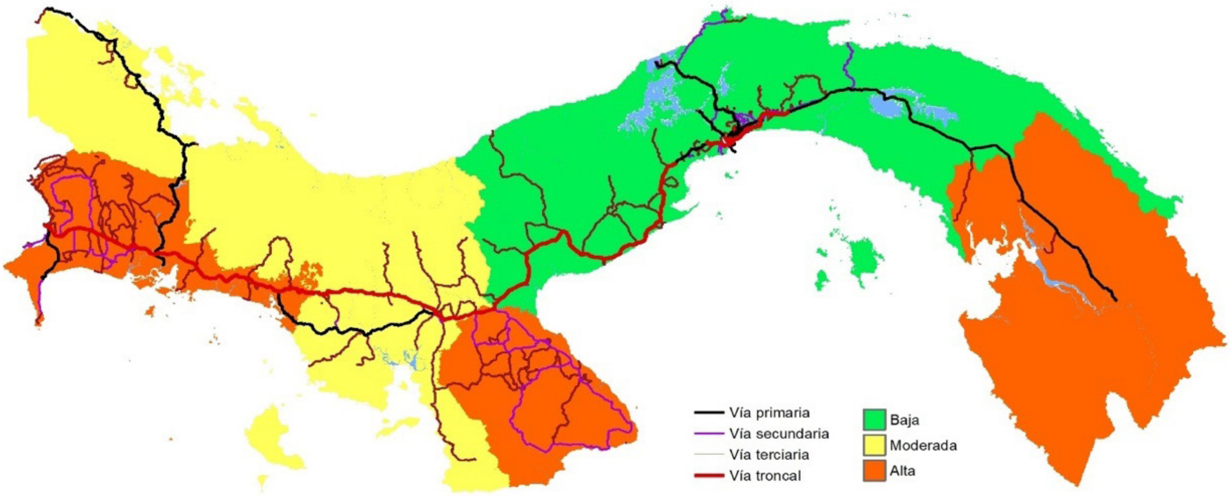
Exposure of road infrastructure to the threat of flooding from extreme rainfall events

The roads that provide access to energy infrastructure (5 230 km in total) have differing levels of exposure to the threat of flooding from extreme rainfall in 2050. Of the 41% (2 155 km) with high exposure, tertiary roads represent 52.4% (1 128 km), secondary roads 25.7% (553 km), primary roads 11% (238 km) and trunk roads 10.9% (236 km). Meanwhile, 994 km of roads (19% of the total) have moderate exposure. Figure 30 shows the exposure of road infrastructure to flood hazards.

Figure 30 Exposure of road infrastructure to extreme rainfall flooding, 2050



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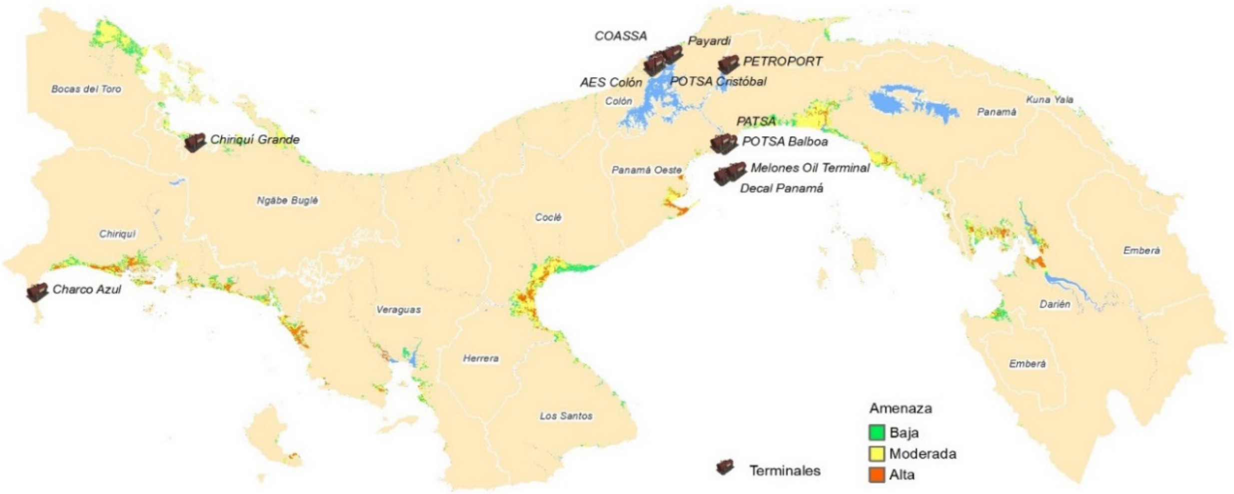
Exposure of oil terminals to the threat of sea level rise

The terminals Decal Panama and Melones Oil Terminal have a high exposure to sea level rise, while COASSA, POTSA Balboa, PATSA, Charco Azul and Chiriqui Grande are moderately exposed. The remaining terminals (POTSA Cristobal, Payardi, PETROPORT and AES Colon) are not exposed to this threat, as shown in Figure 31.

Figure 31 Exposure of hydrocarbon terminal ports to sea level rise, 2050



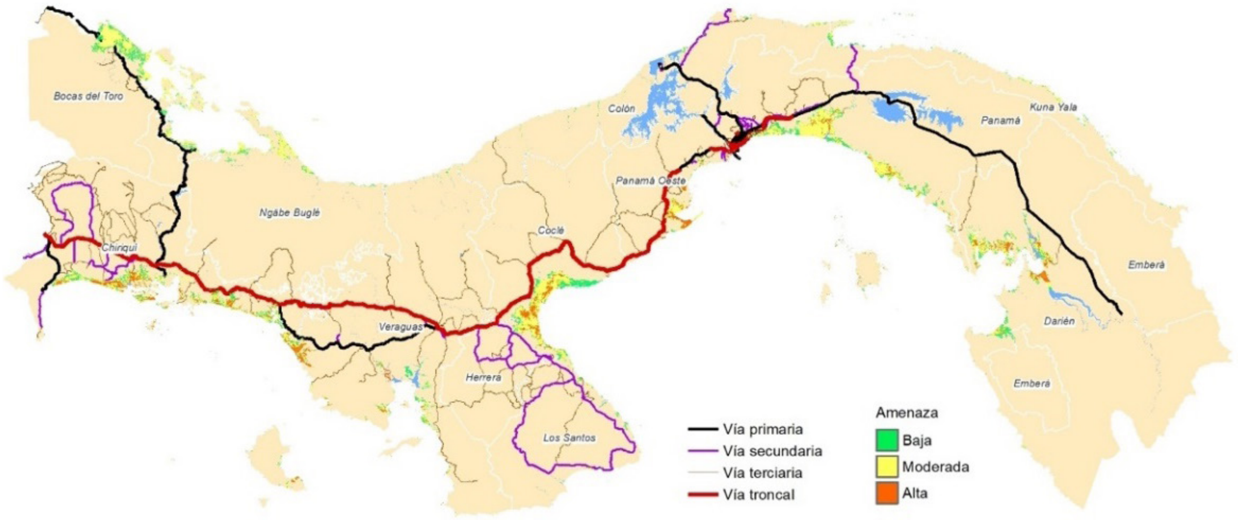
Based on: Data from the Ministry of Environment.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Exposure of road infrastructure to the threat of sea level rise

Road infrastructure is moderately exposed to the threat of sea level rise, accounting for about 39% of the total (2 065 km). Of this figure, 60% corresponds to tertiary roads (1 244 km), 24% to primary roads (492 km) and 16% to trunk roads (328 km). On the other hand, no road infrastructure has been identified that is exposed to a high threat due to sea level rise. To visualise this exposure, see Figure 32.

Figure 32 Roadway exposure to the threat of sea level rise, 2050



Based on: Data from the Ministry of Environment.

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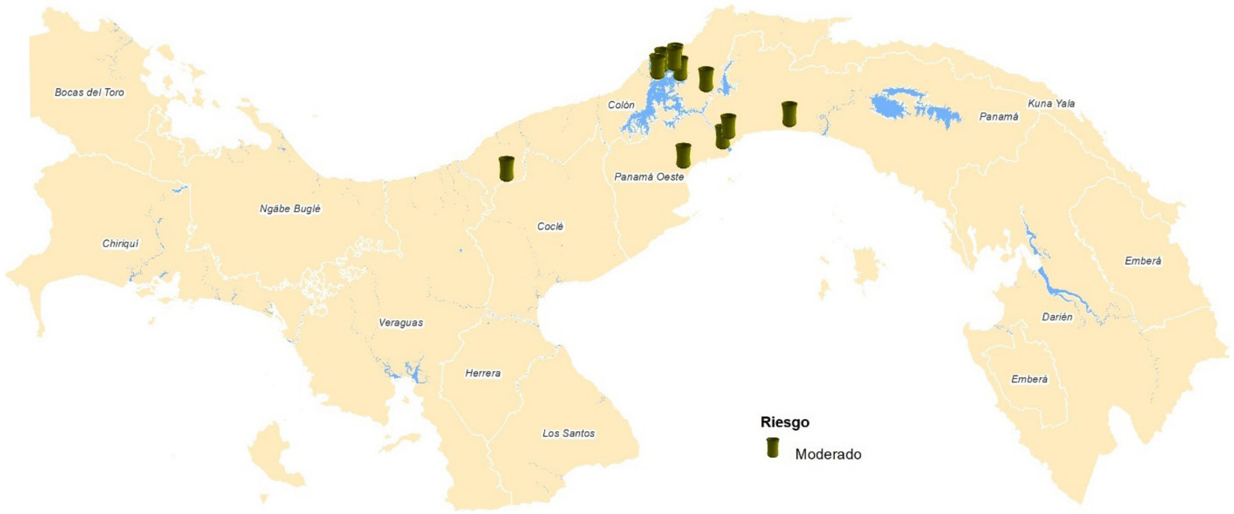
5.3 INFRASTRUCTURE UNDER CLIMATE RISK

Thermoelectric plants

Thermoelectric generation infrastructure, both installed and planned, is expected to face a moderate risk of being affected by extreme heat events by 2050. Regarding the risk of flooding due to extreme rainfall and droughts, this infrastructure is expected to have a low risk of damage. Furthermore, according to the scenario analysed, it is not expected to be exposed to the risk associated with sea level rise. Figure 33 illustrates the risk levels of thermoelectric infrastructure with respect to extreme heat.

Figure 33 Thermoelectric power plants installed under extreme heat risk, 2050

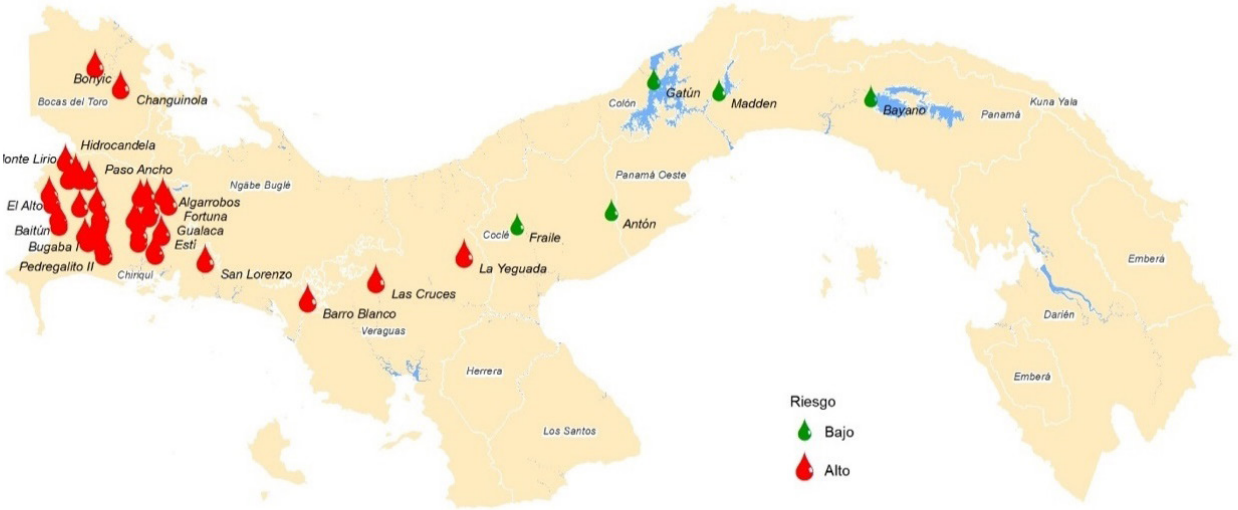


Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Hydroelectric plants

By 2050, it is estimated that approximately 89% of the installed hydroelectric infrastructure, consisting of 42 plants, will be at high risk of flooding due to extreme rainfall. Of these plants, 38 are located in the province of Chiriquí. In addition, all planned hydropower infrastructure will be at risk of flooding. Figure 34 shows the level of risk and the location of installed hydropower infrastructure.

Figure 34 Installed hydropower plants under risk of flooding from extreme rainfall, 2050



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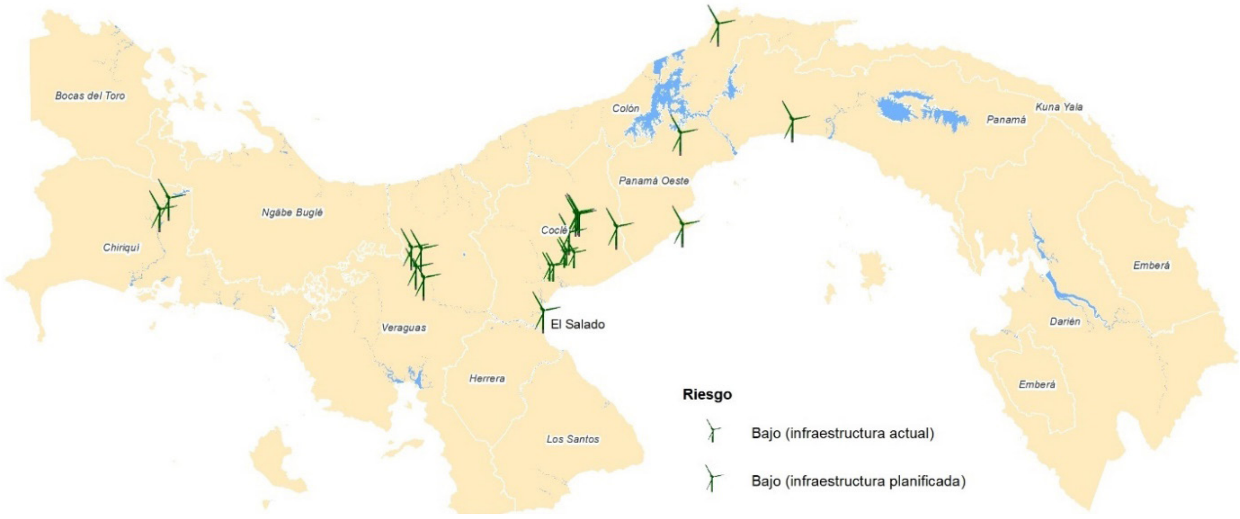
Wind farms

Both existing and planned wind infrastructure is expected to have a low risk of being affected by extreme heat events until 2050. Furthermore, in terms of sea level rise, only the El Salado wind farm, located in the south of Coclé province, is expected to be exposed to a low risk of flooding due to extreme events by 2050. Figure 35 shows the extreme heat risk levels for installed and planned infrastructure.

Figure 35 Installed wind power plants under extreme heat risk, 2050



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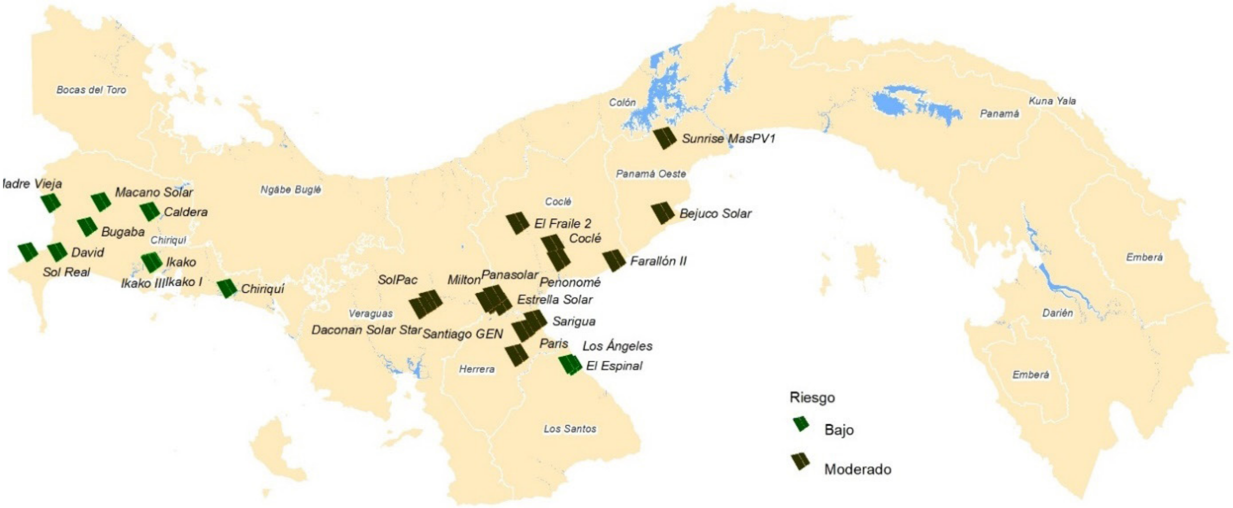
Solar power generation plants

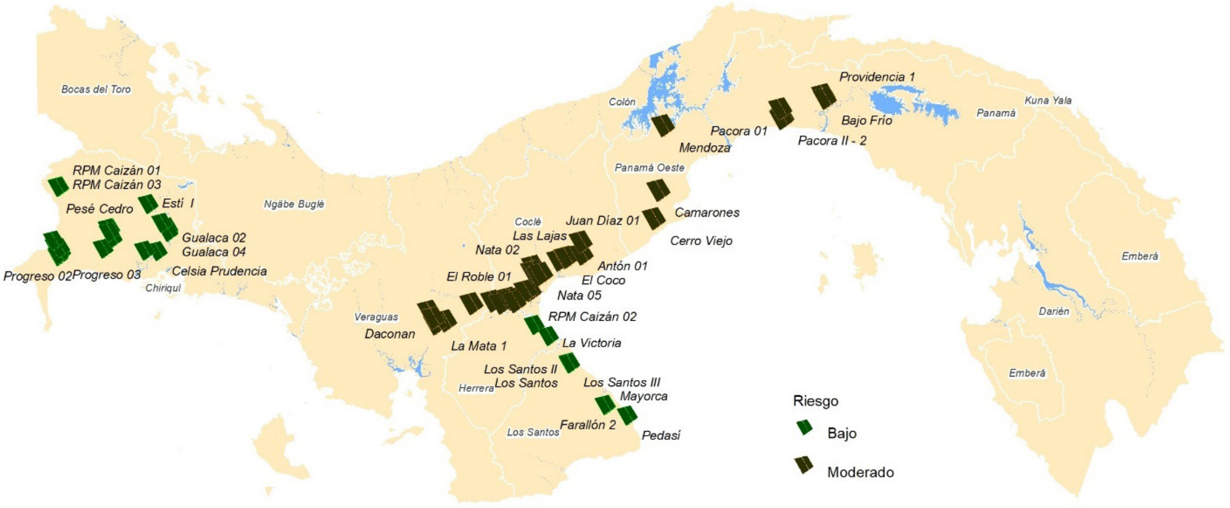
Solar infrastructure, both installed and planned, is at moderate risk of being affected by extreme heat events in 2050. Within the risk category, the first group, comprising 28 plants, represents 68% of the total, while the second group, comprising 33 plants, corresponds to 50%. Figures 36 and 37 illustrate the predicted extreme heat risk levels for installed and planned infrastructure up to 2050.

Figure 36 Installed solar power plants under extreme heat risk, 2050



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 37 Planned solar power plants under extreme heat risk, 2050



Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Electricity transmission networks

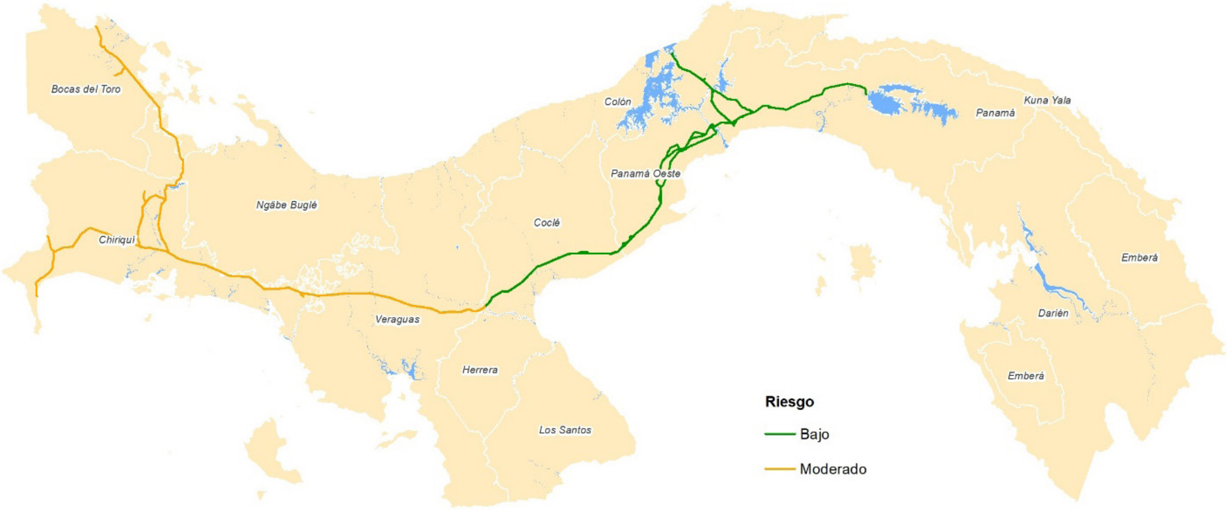
Transmission infrastructure will face a considerable risk of being affected by extreme heat by 2050. It is estimated that 70% of the transmission lines, corresponding to 2 200 km, will be at high risk of being affected, specifically in the provinces of Colón, Panamá, Panamá Oeste, Coclé, Colón and Veraguas, as shown in Figure 38.

Figure 38 Existing transmission lines under extreme heat risk, 2050

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

In addition, transmission lines will also be exposed to the risk of flooding due to the extreme rainfall expected by 2050. It is estimated that approximately 1 478 km of transmission lines will be at moderate risk of being affected by flooding, especially in the provinces of Chiriquí, Bocas del Toro, Veraguas and Ngäbe Buglé, as shown in Figure 39.

Figure 39 Existing transmission lines under risk of flooding from extreme rainfall, 2050



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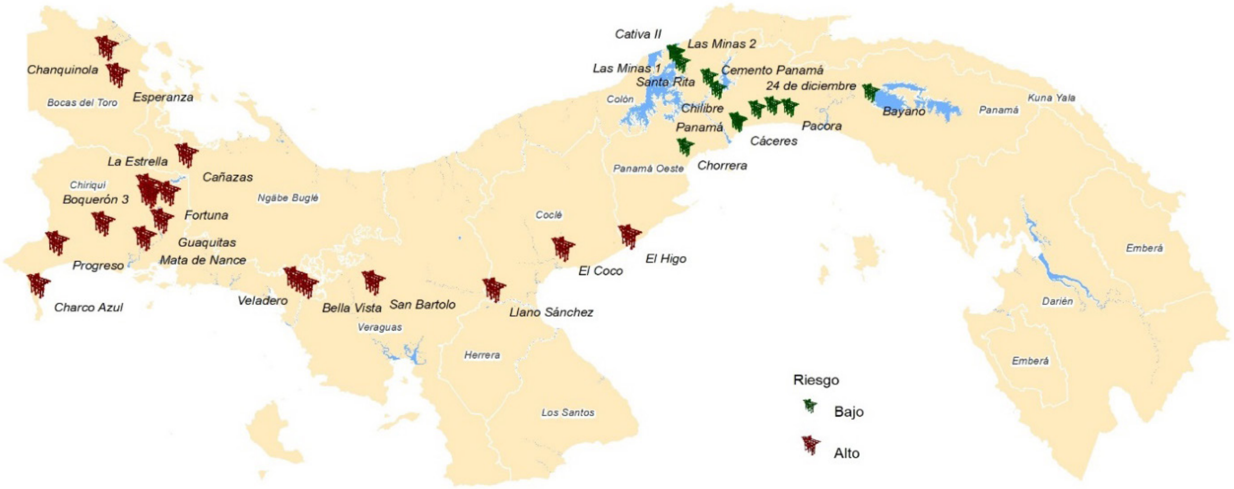
Substations

By the year 2050, it is estimated that most of the substations in the province of Chiriqui will be at high risk of adverse effects from external flooding events. Specifically, it is expected that 18 of the substations, or 58%, will be exposed to this risk. This is illustrated in Figure 40.

Figure 40 Substations at risk of flooding due to extreme rainfall, 2050



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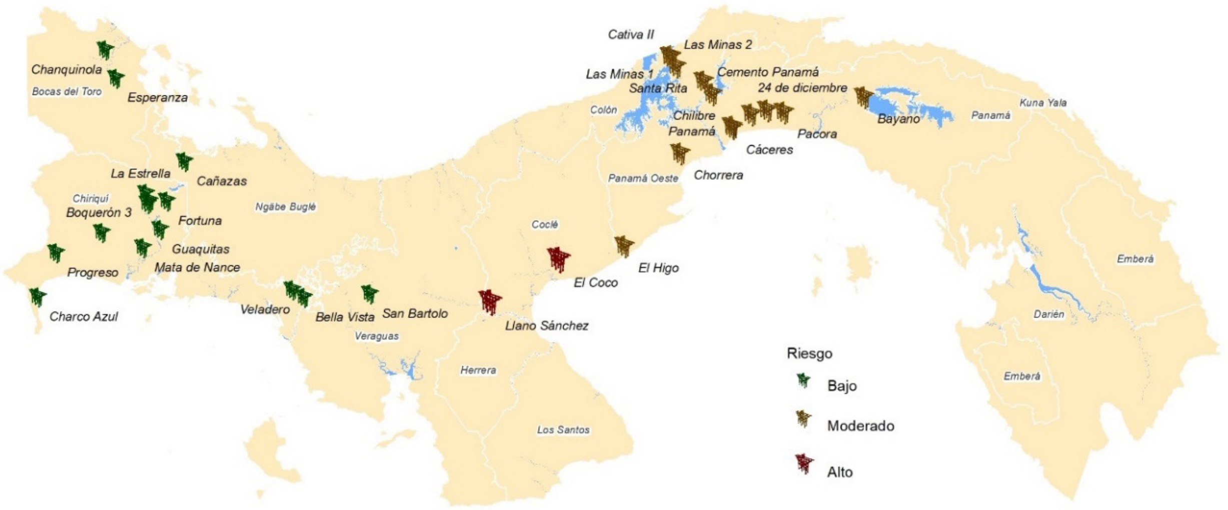
With regard to the risk of extreme heat, projections indicate that by 2050, only two substations would be at high risk of suffering the adverse effects of extreme heat. In contrast, 45% of the substations would be at moderate risk, most of them being located in the west of the province of Panama and in the central area of the province of Colon, as shown in Figure 41.

Figure 41 Substations under extreme heat risk, 2050



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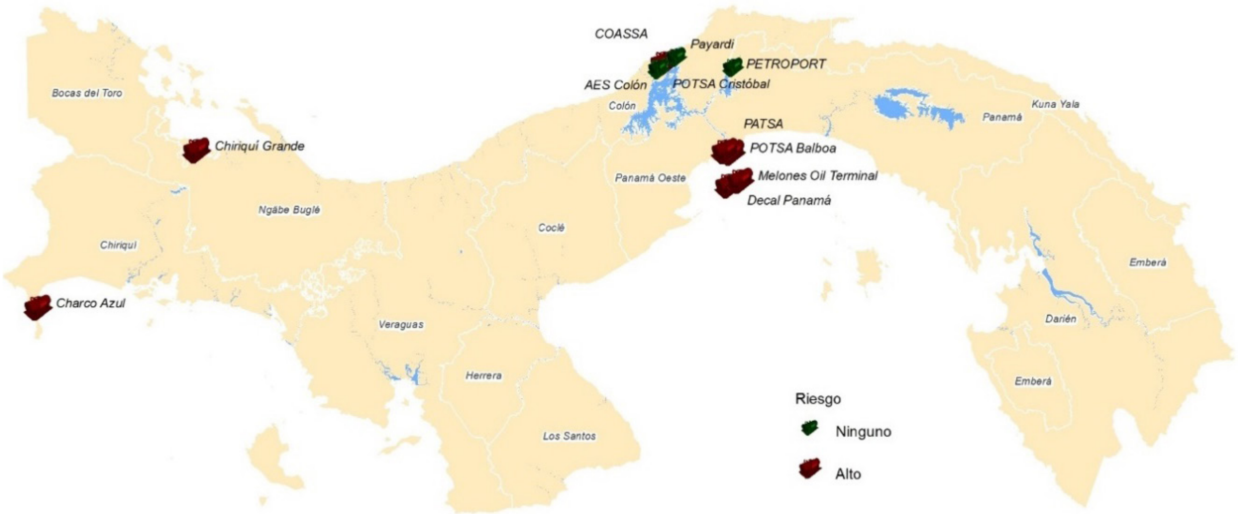
Hydrocarbon terminal ports

The projection of sea level rise to the year 2050 poses a high risk for most of the hydrocarbon terminal ports, specifically 64% of them. Among the ports that would be at risk are COASSA, Decal Panama, Melones Oil Terminal, POTSA Balboa, PATSA, Charco Azul and Chiriqui Grande, as can be seen in Figure 42. These terminals are essential to guarantee the country's energy security.

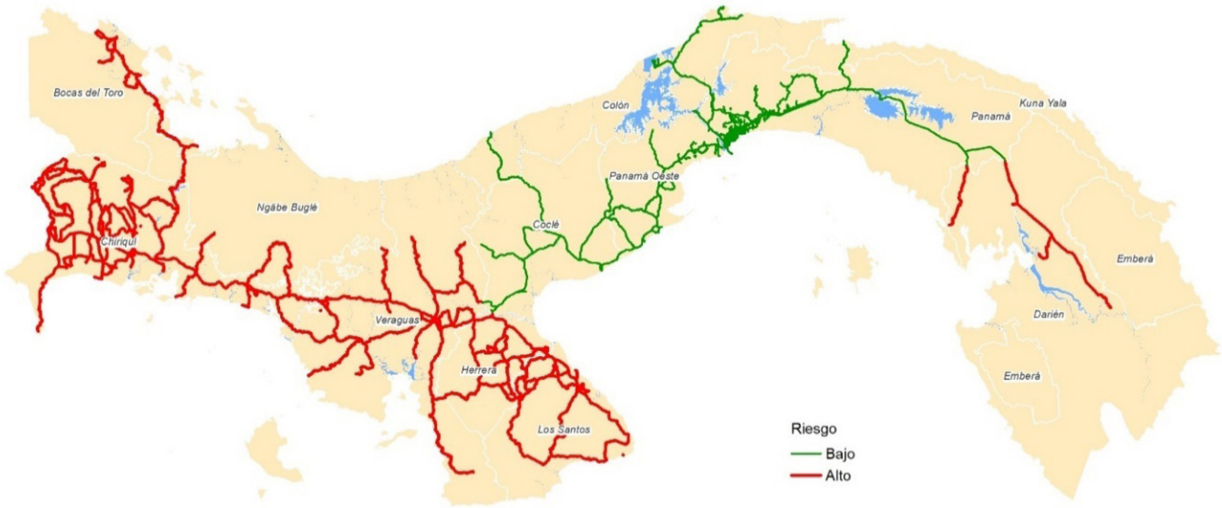
Figure 42 Hydrocarbon terminal ports at risk of sea level rise, 2050



Road infrastructure for access to energy infrastructure

The road infrastructure that provides access to Panama's energy infrastructure faces a considerable risk of extreme flooding by 2050. Specifically, it is estimated that 60% of the roadway, corresponding to 3 149 km, will be at high risk of being affected, mainly in the south-western part of the country, as shown in Figure 43. These findings pose significant challenges for the country's energy sector particularly for the supply chain of conventional fuels, which primarily relies on road transportation.

Figure 43 Road infrastructure at risk of flooding from extreme rainfall events, 2050



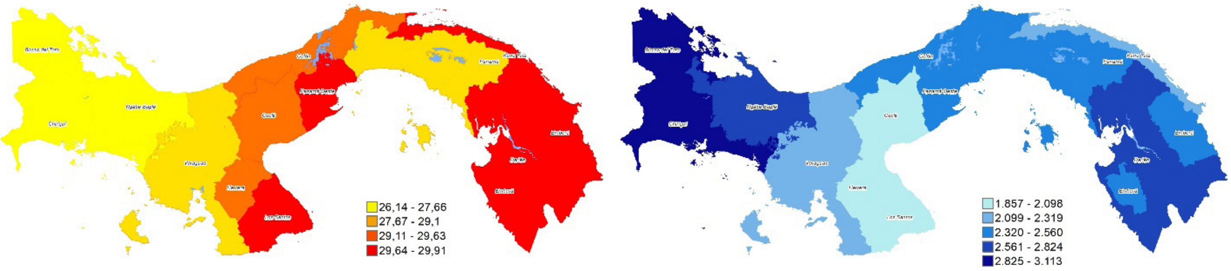
6. IMPLICATIONS OF CHANGES IN RAINFALL AND TEMPERATURE ON ELECTRICITY GENERATION IN PANAMA

This section presents the results of the analysis on how changes in precipitation and maximum temperature affect the efficiency of Panama's current power generation and transmission infrastructure. As mentioned in the methodology section, projections up to 2050 and 2070 were used, based on the Shared Socio-economic Pathway (SSP)1-2.6 and SSP5-8.5 scenarios, provided in digital format by the Panamanian Ministry of Environment.

The analysis begins by showing the magnitude of changes in precipitation and temperature. Then, it describes how these changes affect system efficiency, focusing on the installed capacity and the volume of power generation that could be compromised in the scenarios analysed.

Maps showing the distribution of the reference precipitation and maximum temperature variables at the provincial level are presented in Figure 44. These maps help compare the projected changes in the scenarios analysed.

Figure 44 Precipitation and maximum reference temperature at the provincial level, 1991-2020



Based on: Raster layers provided by the Ministry of Environment Panama.

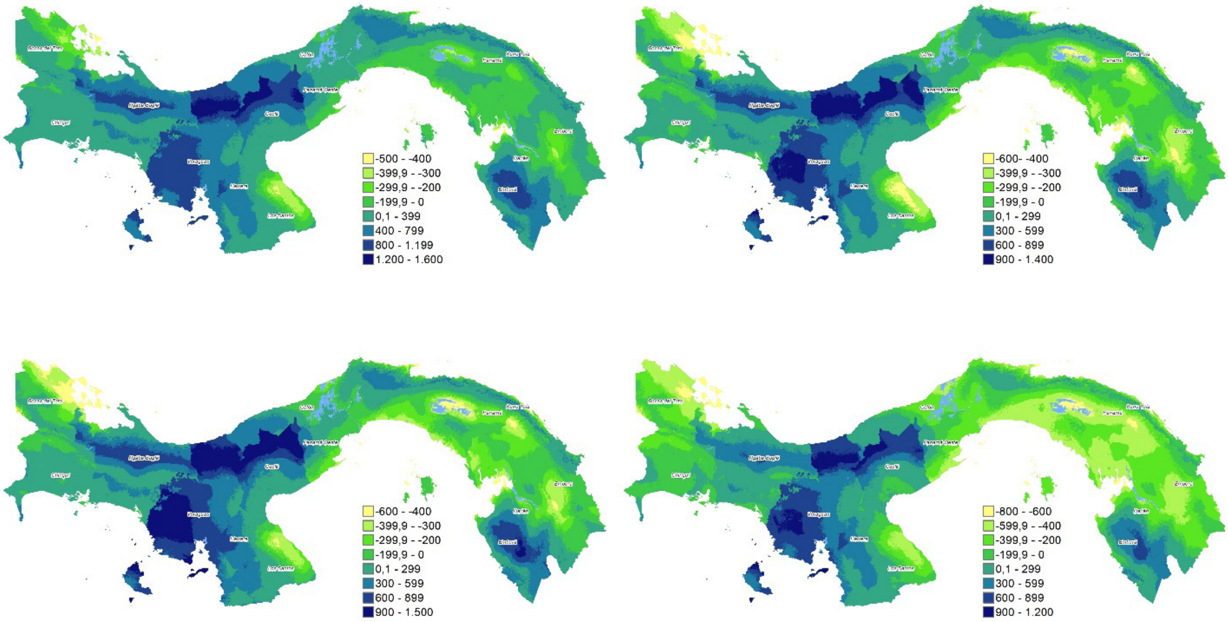
Note: mm = millimetre.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

6.1 PRECIPITATION AND TEMPERATURE CHANGES

The results reveal that by 2050, under the SSP1-2.6 scenario, precipitation could decline by 500 mm, particularly in the provinces of Los Santos, Bocas del Toro, eastern Panama and parts of Darién and Emberá. By 2070, under the same scenario, an increase in the magnitude of the reduction is observed, reaching 600 mm and expanding the affected area. A similar pattern is evident in the SSP5-8.5 scenario, as precipitation declines by as much as 600 mm and 800 mm as of 2050 and 2070, respectively. Figure 45 shows the changes in precipitation across the scenarios analysed.

Figure 45 Estimated average changes in precipitation with respect to the reference scenario



Based on: Data from the Ministry of Environment.

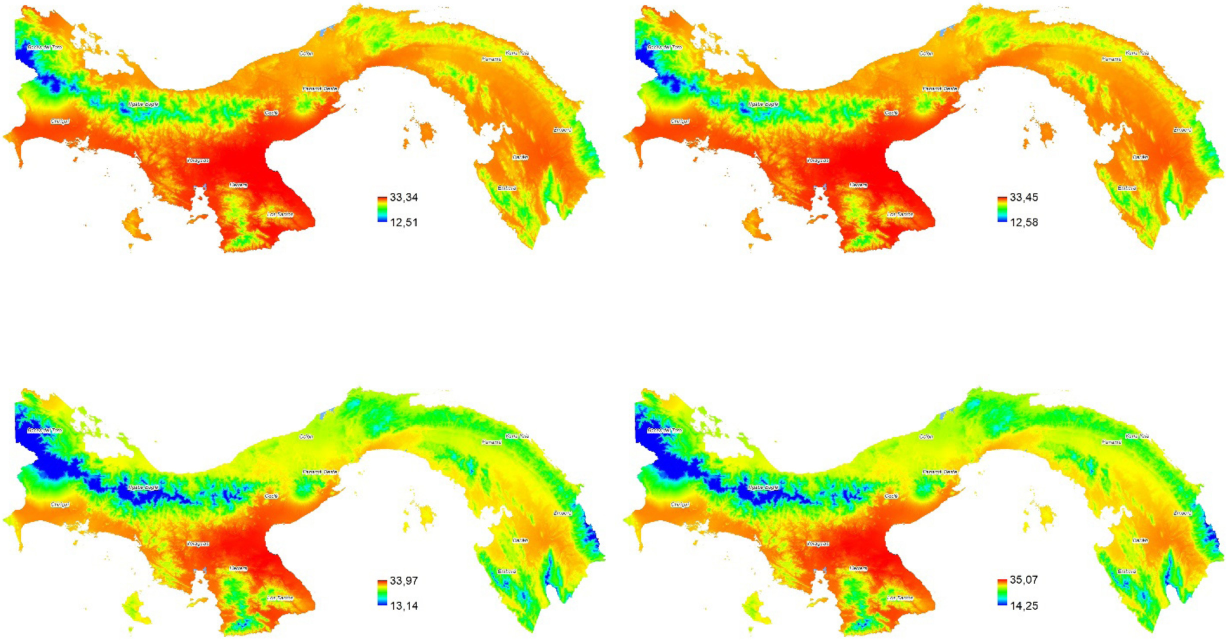
Note: SSP = Shared Socio-economic Pathway.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

In terms of maximum temperature, increases of up to 6°C are projected in the SSP1-2.6 scenario for the years 2050 and 2070. These temperature increases will be most significant (>3°C) in the western Pacific coastal areas, specifically in the provinces of Coclé, Herrera, Veraguas and Chiriquí. On the Caribbean coast, the largest increases are expected north of Ngäbe Buglé and Bocas del Toro. The rest of the country will experience an average maximum temperature increase of around 1.5°C.

In the SSP5-8.5 scenario, maximum temperature increases intensify, reaching between 6°C and 7°C by 2050 and 2070, respectively. Under this scenario, the country's temperatures will average between 3°C and 3.5°C, following a similar spatial pattern to that observed in the previous scenario. Figures 46 and 47 illustrate the maximum temperatures and temperature changes under the scenarios analysed.

Figure 46 Maximum temperature for scenarios SSP1-2.6 and SSP5-8.5 and projection to 2050 and 2070

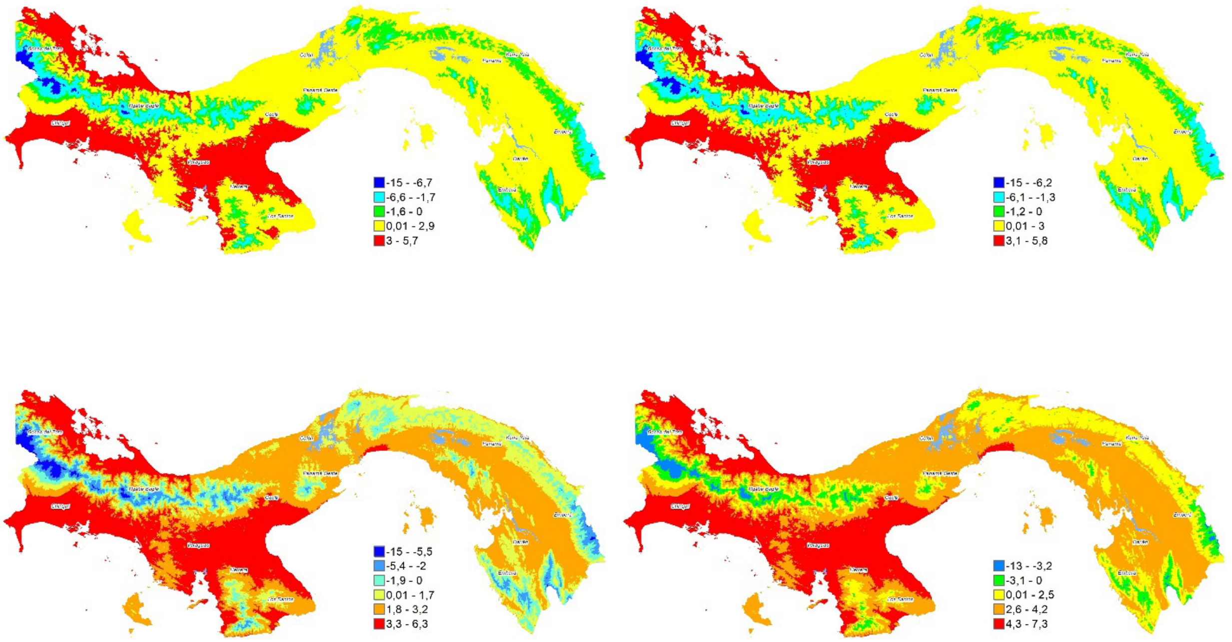


Based on: Raster layers provided by the Ministry of Environment Panama.

Note: SSP = Shared Socio-economic Pathway.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Figure 47 Estimated average changes of maximum temperature with respect to the reference scenario



Based on: Data from the Ministry of Environment.

Note: SSP = Shared Socio-economic Pathway.

Disclaimer: This map is provided for illustration purposes only. Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

The results obtained reflect significant changes in precipitation patterns and maximum temperatures. The digital map visualisation provides a geo-referenced visualisation of how climatic conditions in Panama could change, highlighting both increases and decreases in these variables. This information, while important for the analysis of the evolution of climatic conditions, has limitations when predicting the occurrence of climatic phenomena that cause damage to energy infrastructure and therefore needs to be complemented with modelling to improve policy decision making and infrastructure planning.

6.2 IMPACTS ON THE ELECTRICITY INFRASTRUCTURE

Hydropower infrastructure

Under the SSP1-2.6 scenario, a decrease in precipitation affects five hydropower plants, compromising their generation capacity by about 12.4 MW and power generation by 181 GWh by 2050. The volume of energy that would no longer be produced would be equivalent to 8.2% of the gross generation registered for hydroelectric power plants in Panama in 2022 (2 213.9 GWh). These plants are Bajo del Totuma, Bayano, Bonyic, Changuinola and Hidrocandela. When projecting the scenario to the year 2070, it is estimated that the compromised generation capacity will increase to 28 MW, leaving about 408 GWh/year unproduced. Under this scenario, the plants would be La Fortuna, La Estrella, Los Valles, Monte Lirio, Pando, Paso Ancho and Pedregalito II.

In the context of the SSP5-8.5 scenario, it is projected that by 2050, a total of 11 hydropower plants will experience a compromised capacity of 30.8 MW, with an estimated reduction in electricity generation of 450 GWh. Projecting the scenario to 2070, the compromised capacity would double to about 61.2 MW, equivalent to about 893 GWh/year that would no longer be produced. This volume of compromised energy in 2070 would represent about 40% of the gross generation registered for hydroelectric power plants in Panama in 2022 (2 213.9 GWh). Under this scenario, a total of 35 plants would be affected.

Table 4 breaks down the impact of the change in precipitation on flows and installed capacity for the different scenarios analysed.

Table 4 Impact of rainfall change on installed hydropower generation capacity

	SCENARIO SSP1-2.6								**SCENARIO SSP5-8.5**							
	CHANGE IN PRECIPITATION (mm)		**CHANGE IN INFLUENT FLOW (m^3/s)**		**COMPROMISED CAPACITY (MW)**		**COMPROMISED ENERGY (GWh/year)**		**CHANGE IN PRECIPITATION (mm)**		**CHANGE IN INFLUENT FLOW (m^3/s)**		**COMPROMISED CAPACITY (MW)**		**COMPROMISED ENERGY (GWh/year)**	
NAME	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
Algarrobos	227	60	0.074	0.020	0.00	0.00	0	0	81	-88	0.027	-0.029	0.00	0.03	0	0
Baitún	409	233	5.059	2.883	0.00	0.00	0	0	252	91	3.118	1.130	0.00	0.00	0	0
Bajo del Totuma	-35	-181	-0.021	-0.109	0.02	0.12	0	2	-180	-346	-0.109	-0.209	0.12	0.22	2	3
Bajo Mina	214	50	2.064	0.482	0.00	0.00	0	0	61	-98	0.592	-0.945	0.00	1.00	0	15
Barro Blanco	195	45	2.462	0.567	0.00	0.00	0	0	148	9	1.864	0.109	0.00	0.00	0	0
Bayano	-68	-192	-4.741	-13.36	5.03	14.18	73	207	-226	-451	-15.67	-31.32	16.62	33.23	243	485
Bonyic	-191	-347	-0.493	-0.899	0.52	0.95	8	14	-379	-544	-0.981	-1.407	1.04	1.49	15	22
Bugaba I	192	28	0.186	0.027	0.00	0.00	0	0	63	-78	0.061	-0.075	0.00	0.08	0	1
Bugaba II	207	46	0.319	0.071	0.00	0.00	0	0	83	-55	0.128	-0.084	0.00	0.09	0	1
Changuinola	-234	-389	-6.442	-10.70	6.84	11.35	100	166	-410	-571	-11.28	-15.70	11.96	16.66	175	243
Cochea	231	67	0.455	0.131	0.00	0.00	0	0	106	-44	0.209	-0.086	0.00	0.09	0	1
Concepción	188	23	0.586	0.070	0.00	0.00	0	0	57	-91	0.178	-0.284	0.00	0.30	0	4
Dolega	224	59	0.516	0.135	0.00	0.00	0	0	102	-45	0.236	-0.105	0.00	0.11	0	2
El Alto	162	0	1.406	0.004	0.00	0.00	0	0	7	-155	0.060	-1.343	0.00	1.43	0	21
Estí	259	93	3.463	1.246	0.00	0.00	0	0	145	4	1.938	0.055	0.00	0.00	0	0
Fortuna	160	-1	0.505	-0.003	0.00	0.00	0	0	33	-121	0.104	-0.381	0.00	0.40	0	6
Fraile	837	696	2.544	2.114	0.00	0.00	0	0	744	551	2.261	1.675	0.00	0.00	0	0
Gatún	5	-136	0.000	0.000	0.00	0.00	0	0	-163	-400	0.000	0.000	0.00	0.00	0	0
Gualaca	267	100	0.315	0.118	0.00	0.00	0	0	153	12	0.180	0.014	0.00	0.00	0	0
La Cuchilla	229	61	0.356	0.095	0.00	0.00	0	0	93	-60	0.145	-0.093	0.00	0.10	0	1
La Estrella	99	-53	0.259	-0.139	0.00	0.15	0	2	-24	-176	-0.064	-0.460	0.07	0.49	1	7
La Potra	480	302	0.000	0.000	0.00	0.00	0	0	320	156	0.000	0.000	0.00	0.00	0	0
La Yeguada	568	428	0.208	0.157	0.00	0.00	0	0	495	318	0.182	0.117	0.00	0.00	0	0
Las Cruces	900	755	6.040	5.062	0.00	0.00	0	0	853	693	5.720	4.648	0.00	0.00	0	0
Lorena	266	98	0.572	0.212	0.00	0.00	0	0	156	20	0.335	0.044	0.00	0.00	0	0

Table 4 Impact of rainfall change on installed hydropower generation capacity (continued)

	SCENARIO SSP1-2.6								SCENARIO SSP5-8.5							
	CHANGE IN PRECIPITATION (mm)		CHANGE IN INFLUENT FLOW (m³/s)		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)		CHANGE IN PRECIPITATION (mm)		CHANGE IN INFLUENT FLOW (m³/s)		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)	
NAME	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
Los Valles	125	-33	0.138	-0.036	0.00	0.04	0	1	-3	-156	-0.003	-0.172	0.00	0.18	0	3
M. Monte	276	106	0.230	0.089	0.00	0.00	0	0	131	-29	0.109	-0.024	0.00	0.03	0	0
Macano	234	66	0.241	0.068	0.00	0.00	0	0	98	-55	0.101	-0.057	0.00	0.06	0	1
Madden	200	55	0.000	0.000	0.00	0.00	0	0	28	-223	0.000	0.000	0.00	0.00	0	0
Mendre	187	28	0.643	0.095	0.00	0.00	0	0	66	-82	0.227	-0.282	0.00	0.30	0	4
Mendre II	211	51	0.725	0.174	0.00	0.00	0	0	92	-54	0.315	-0.187	0.00	0.20	0	3
Monte Lirio	71	-83	0.370	-0.437	0.00	0.46	0	7	-80	-247	-0.417	-1.291	0.44	1.37	6	20
Pando	14	-136	0.049	-0.475	0.00	0.50	0	7	-131	-297	-0.458	-1.039	0.49	1.10	7	16
Paso Ancho	116	-40	0.239	-0.081	0.00	0.09	0	1	-28	-193	-0.057	-0.396	0.06	0.42	1	6
Pedregalito I	172	16	0.746	0.069	0.00	0.00	0	0	59	-74	0.255	-0.320	0.00	0.34	0	5
Pedregalito II	134	-18	0.581	-0.077	0.00	0.08	0	1	27	-101	0.115	-0.441	0.00	0.47	0	7
Perlas Norte	177	12	0.553	0.037	0.00	0.00	0	0	46	-103	0.142	-0.320	0.00	0.34	0	5
Perlas Sur	189	26	0.588	0.081	0.00	0.00	0	0	64	-78	0.198	-0.242	0.00	0.26	0	4
Planetas I	237	72	0.276	0.084	0.00	0.00	0	0	120	-23	0.140	-0.027	0.00	0.03	0	0
Planetas II	221	57	0.289	0.075	0.00	0.00	0	0	107	-31	0.140	-0.041	0.00	0.04	0	1
Prudencia	269	104	0.578	0.223	0.00	0.00	0	0	162	28	0.348	0.060	0.00	0.00	0	0
RP-490	211	44	0.217	0.046	0.00	0.00	0	0	78	-72	0.080	-0.074	0.00	0.08	0	1
Salsipuedes	366	190	0.000	0.000	0.00	0.00	0	0	215	62	0.000	0.000	0.00	0.00	0	0
San Andrés	165	2	0.145	0.002	0.00	0.00	0	0	20	-140	0.018	-0.123	0.00	0.13	0	2
San Lorenzo	285	121	2.770	1.182	0.00	0.00	0	0	196	61	1.903	0.597	0.00	0.00	0	0
Antón	972	810	0.533	0.444	0.00	0.00	0	0	846	612	0.464	0.335	0.00	0.00	0	0
Hidrocandela	-1	-151	0.000	-0.040	0.00	0.04	0	1	-155	-322	-0.041	-0.086	0.04	0.09	1	1
Total					**12.4**	**28.0**	**181**	**408**					**30.8**	**61.2**	**450**	**893**

Notes: GWh = gigawatt hour; m3/s = cubic metre per second; mm = millimetre; MW = megawatt; SSP = Shared Socio-economic Pathway.

Solar infrastructure

Under the SSP1-2.6 scenario, it is estimated that by 2050 the maximum temperature increase will compromise the installed capacity of solar photovoltaic (PV) generation by 7.3 MW and power generation by 12.74 GWh/year. Projecting the scenario to the year 2070, the compromised capacity would be 7.5 MW, equivalent to an energy volume of about 13.18 GWh/year. The energy volumes compromised under this scenario would be equivalent to 8% of the gross generation recorded for solar PV power plants in Panama in 2022 (160.15 GWh).

As for the SSP5-8.5 scenario, it is projected that by 2050, the compromised solar PV generation capacity will be 8.7 MW, and by 2070, it is expected to increase to 11.1 MW. Meanwhile, the compromised energy volumes are estimated at 15.17 GWh/year and 19.41 GWh/year, respectively. These low compromised power volumes represent between 9% and 12% of the gross generation registered for solar PV power plants in Panama by 2022 (160.15 GWh). Table 5 disaggregates the impact of the maximum temperature increase on installed solar PV generation.

Table 5 Impact of increasing maximum temperatures on installed solar photovoltaic generation capacity

	SCENARIO SSP1-2.6								SCENARIO SSP5-8.5							
	TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)		TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)	
NAME	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070	2050	2070
Bejuco Solar	2.48	2.58	-1.2%	-1.3%	0.012	0.012	0.02	0.02	3.10	4.21	-1.6%	-2.1%	0.015	0.020	0.03	0.04
Bugaba	3.20	3.30	-1.6%	-1.7%	0.038	0.040	0.07	0.07	3.84	4.95	-1.9%	-2.5%	0.046	0.059	0.08	0.10
Caldera	3.39	3.47	-1.7%	-1.7%	0.089	0.092	0.16	0.16	4.02	5.11	-2.0%	-2.6%	0.106	0.135	0.19	0.24
Caoba Solar	3.38	3.50	-1.7%	-1.7%	0.167	0.173	0.29	0.30	4.03	5.17	-2.0%	-2.6%	0.199	0.256	0.35	0.45
Cedro Solar	3.38	3.50	-1.7%	-1.7%	0.169	0.174	0.30	0.31	4.03	5.17	-2.0%	-2.6%	0.201	0.258	0.35	0.45
Chiriquí	4.35	4.48	-2.2%	-2.2%	0.215	0.221	0.38	0.39	4.99	6.12	-2.5%	-3.1%	0.246	0.302	0.43	0.53
Coclé	3.15	3.25	-1.6%	-1.6%	0.141	0.146	0.25	0.26	3.76	4.85	-1.9%	-2.4%	0.169	0.218	0.30	0.38
Coclé Solar 1	3.55	3.66	-1.8%	-1.8%	0.017	0.018	0.03	0.03	4.18	5.30	-2.1%	-2.6%	0.020	0.025	0.04	0.04
Daconan Solar Star	3.46	3.59	-1.7%	-1.8%	0.433	0.449	0.76	0.79	4.13	5.27	-2.1%	-2.6%	0.516	0.658	0.90	1.15
David	4.44	4.58	-2.2%	-2.3%	0.176	0.181	0.31	0.32	5.09	6.20	-2.5%	-3.1%	0.201	0.246	0.35	0.43
Divisa Solar	3.67	3.78	-1.8%	-1.9%	0.182	0.187	0.32	0.33	4.30	5.42	-2.2%	-2.7%	0.213	0.268	0.37	0.47
Don Félix	3.66	3.78	-1.8%	-1.9%	0.037	0.038	0.06	0.07	4.30	5.42	-2.1%	-2.7%	0.043	0.054	0.08	0.09
ECOSOLAR I & II	3.38	3.50	-1.7%	-1.7%	0.338	0.350	0.59	0.61	4.03	5.17	-2.0%	-2.6%	0.403	0.517	0.71	0.91
El Espinal	3.11	3.23	-1.6%	-1.6%	0.144	0.150	0.25	0.26	3.71	4.78	-1.9%	-2.4%	0.172	0.221	0.30	0.39
El Fraile 2	2.55	2.64	-1.3%	-1.3%	0.006	0.006	0.01	0.01	3.15	4.24	-1.6%	-2.1%	0.008	0.010	0.01	0.02
Estrella Solar	3.66	3.77	-1.8%	-1.9%	0.088	0.090	0.15	0.16	4.29	5.41	-2.1%	-2.7%	0.103	0.129	0.18	0.23
Farallón II	3.06	3.16	-1.5%	-1.6%	0.073	0.076	0.13	0.13	3.66	4.75	-1.8%	-2.4%	0.088	0.114	0.15	0.20
Ikako	4.30	4.42	-2.2%	-2.2%	0.215	0.221	0.38	0.39	4.94	6.06	-2.5%	-3.0%	0.247	0.303	0.43	0.53
Ikako I	4.29	4.41	-2.1%	-2.2%	0.215	0.221	0.38	0.39	4.92	6.05	-2.5%	-3.0%	0.246	0.302	0.43	0.53
Ikako II	4.29	4.41	-2.1%	-2.2%	0.214	0.220	0.38	0.39	4.92	6.04	-2.5%	-3.0%	0.246	0.302	0.43	0.53
Ikako III	4.28	4.40	-2.1%	-2.2%	0.214	0.220	0.37	0.39	4.91	6.03	-2.5%	-3.0%	0.246	0.302	0.43	0.53
Jaguito Sol	3.38	3.50	-1.7%	-1.7%	0.169	0.175	0.30	0.31	4.03	5.17	-2.0%	-2.6%	0.201	0.258	0.35	0.45
Los Ángeles	3.11	3.23	-1.6%	-1.6%	0.148	0.154	0.26	0.27	3.72	4.79	-1.9%	-2.4%	0.177	0.228	0.31	0.40
Macano Solar	0.97	1.05	-0.5%	-0.5%	0.010	0.011	0.02	0.02	1.60	2.71	-0.8%	-1.4%	0.016	0.027	0.03	0.05
Madre Vieja	1.52	1.62	-0.8%	-0.8%	0.025	0.026	0.04	0.05	2.17	3.29	-1.1%	-1.6%	0.035	0.053	0.06	0.09
Mayorca Solar	3.38	3.50	-1.7%	-1.7%	0.168	0.174	0.30	0.31	4.03	5.17	-2.0%	-2.6%	0.201	0.258	0.35	0.45
Milton	3.63	3.74	-1.8%	-1.9%	0.186	0.192	0.33	0.34	4.26	5.38	-2.1%	-2.7%	0.218	0.276	0.38	0.48
Panasolar	3.43	3.54	-1.7%	-1.8%	0.170	0.175	0.30	0.31	4.06	5.17	-2.0%	-2.6%	0.201	0.256	0.35	0.45
Paris	3.52	3.63	-1.8%	-1.8%	0.158	0.163	0.28	0.29	4.16	5.26	-2.1%	-2.6%	0.187	0.237	0.33	0.41

Table 5 Impact of increasing maximum temperatures on installed solar photovoltaic generation capacity (continued)

	SCENARIO SSP1-2.6								SCENARIO SSP5-8.5							
	TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)		TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)	
NAME	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
Parque Solar Prudencia	3.38	3.50	-1.7%	-1.7%	0.164	0.169	0.29	0.30	4.03	5.17	-2.0%	-2.6%	0.195	0.250	0.34	0.44
Penonomé	3.24	3.34	-1.6%	-1.7%	1.942	2.006	3.40	3.51	3.85	4.94	-1.9%	-2.5%	2.312	2.962	4.05	5.19
Pese Solar	3.38	3.50	-1.7%	-1.7%	0.168	0.174	0.30	0.31	4.03	5.17	-2.0%	-2.6%	0.201	0.258	0.35	0.45
Pocrí Solar	3.38	3.50	-1.7%	-1.7%	0.270	0.280	0.47	0.49	4.03	5.17	-2.0%	-2.6%	0.322	0.413	0.56	0.72
PROGSOL20	3.38	3.50	-1.7%	-1.7%	0.168	0.174	0.30	0.31	4.03	5.17	-2.0%	-2.6%	0.201	0.258	0.35	0.45
Santiago GEN	3.50	3.62	-1.8%	-1.8%	0.088	0.091	0.15	0.16	4.14	5.24	-2.1%	-2.6%	0.103	0.131	0.18	0.23
Sarigua	3.54	3.65	-1.8%	-1.8%	0.042	0.044	0.07	0.08	4.17	5.27	-2.1%	-2.6%	0.050	0.063	0.09	0.11
Sboqueron	3.38	3.50	-1.7%	-1.7%	0.034	0.035	0.06	0.06	4.03	5.17	-2.0%	-2.6%	0.040	0.052	0.07	0.09
Sol Real	4.25	4.47	-2.1%	-2.2%	0.229	0.241	0.40	0.42	4.99	6.06	-2.5%	-3.0%	0.269	0.327	0.47	0.57
SolPac	3.38	3.50	-1.7%	-1.7%	0.051	0.052	0.09	0.09	4.03	5.17	-2.0%	-2.6%	0.060	0.078	0.11	0.14
Sunrise MasPV1	1.34	1.42	-0.7%	-0.7%	0.003	0.004	0.01	0.01	1.95	3.06	-1.0%	-1.5%	0.005	0.008	0.01	0.01
Vista Alegre	3.38	3.50	-1.7%	-1.7%	0.139	0.144	0.24	0.25	4.03	5.17	-2.0%	-2.6%	0.166	0.212	0.29	0.37
Total					**7.3**	**7.5**	**12.74**	**13.18**					**8.7**	**11.1**	**15.17**	**19.41**

Notes: GWh = gigawatt hour; MW = megawatt; SSP = Shared Socio-economic Pathway.

Wind infrastructure

Within the installed energy infrastructure, wind power generation has the least impact in relation to the increase in maximum temperatures.

Under the SSP1-2.6 scenario, the average compromised wind generation capacity is estimated to reach approximately 16 kilowatts (kW), and the volume of power generation would be reduced by about 50 megawatt hours (MWh)/year. For the SSP5-8.5 scenario, the compromised capacity is projected to be 19.25 kW by 2050, and by 2070 it is expected to increase to 25 kW. Under this scenario, the energy that would no longer be produced is estimated at 59 MWh/year and 77 MWh/year, respectively, for the years 2050 and 2070.

Table 6 breaks down the impact of the increase in maximum temperature on installed wind generation. These results highlight the lower impact of wind generation compared to other energy sources in relation to the increase in maximum temperatures.

Table 6 Impact of increasing maximum temperatures on installed wind generation capacity

	SCENARIO SSP1-2.6								SCENARIO SSP5-8.5							
	TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		COMPROMISED CAPACITY (kW)		COMPROMISED ENERGY (MWh/year)		TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		COMPROMISED CAPACITY (kW)		COMPROMISED ENERGY (MWh/year)	
NAME	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
Marañón	3.07	3.18	-0.005%	-0.005%	0.86	0.89	2.64	2.73	3.69	4.78	-0.006%	-0.008%	1.03	1.34	3.17	4.10
Nuevo Chagres I	3.08	3.19	-0.005%	-0.005%	2.71	2.80	8.31	8.60	3.70	4.79	-0.006%	-0.008%	3.25	4.21	9.97	12.91
Nuevo Chagres II	3.26	3.37	-0.005%	-0.005%	3.26	3.37	10.01	10.33	3.88	4.96	-0.006%	-0.008%	3.88	4.96	11.89	15.22
Portobelo	3.27	3.38	-0.005%	-0.005%	1.70	1.76	5.22	5.39	3.89	4.97	-0.006%	-0.008%	2.02	2.59	6.20	7.93
Rosa de los Vientos I	3.04	3.15	-0.005%	-0.005%	2.56	2.64	7.84	8.11	3.66	4.75	-0.006%	-0.008%	3.07	3.99	9.42	12.23
Rosa de los Vientos II	3.04	3.15	-0.005%	-0.005%	2.43	2.52	7.46	7.72	3.66	4.75	-0.006%	-0.008%	2.93	3.80	8.97	11.64
Toabré	1.99	2.08	-0.003%	-0.003%	2.10	2.20	6.44	6.74	2.60	3.68	-0.004%	-0.006%	2.75	3.88	8.42	11.90
Total	**2.97**	**3.07**	**-0.005%**	**-0.005%**	**15.95**	**16.51**	**48.90**	**50.61**	**3.58**	**4.67**	**-0.006%**	**-0.007%**	**19.25**	**25.09**	**59.01**	**76.94**

Notes: kW = kilowatt; MWh = megawatt hour; SSP = Shared Socio-economic Pathway.

Transmission infrastructure

According to the SSP1-2.6 scenario, the increase in maximum temperature is expected to have an impact on electricity transmission infrastructure. This would be reflected in an average reduction of approximately 2.85% in electricity transmission by 2050, and 2.79% by 2070.

On the other hand, under the SSP5-8.5 scenario, an average reduction in transmission efficiency of around 3.70% by 2050 and 5.23% by 2070 is projected. These values indicate a greater impact compared with the SSP1-2.6 scenario. Table 7 provides a breakdown of the impact of temperature increase on electricity transmission capacity.

Table 7 Impact of increasing maximum temperatures on transmission capacity

			SCENARIO SSP1-2.6				SCENARIO SSP5-8.5			
			AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)	
LINE	**VOLTAGE**	**km**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**	**2050**	**2070**
ADS		5.5	4.30	4.4	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
24 de Diciembre- Bayano	230	60.0	2.00	2.3	-2.40%	-2.76%	2.50	4.57	-3.00%	-5.48%
Bella Vista – Llano Sánchez	230	107.1	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%
Boquerón 3 – Mata de Nance	230	24.0	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Caldera – La Estrella	115	6.1	2.00	1.80	-2.40%	-2.16%	3.65	4.57	-4.38%	-5.48%

Table 7 Impact of increasing maximum temperatures on transmission capacity (continued)

			SCENARIO SSP1-2.6				SCENARIO SSP5-8.5			
			AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)	
LINE	VOLTAGE	km	2050	2070	2050	2070	2050	2070	2050	2070
Caldera – Los Valles	115	1.7	3.15	2.30	-3.78%	-2.76%	4.80	5.78	-5.76%	-6.94%
Cañazas – Changuinola	230	77.7	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%
Cativá II – Santa Rita	115	6.6	1.00	0.80	-1.20%	-0.96%	1.65	3.35	-1.98%	-4.02%
Changuinola – Cahuita	230	13.2	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Changuinola – La Esperanza	230	24.5	4.30	3.35	-5.16%	-4.02%	4.80	5.78	-5.76%	-6.94%
Chilibre – Bahía Las Minas	115	31.5	1.00	0.80	-1.20%	-0.96%	1.65	2.35	-1.98%	-2.82%
Chorrera – Panamá	230	154.2	1.00	0.80	-1.20%	-0.96%	1.65	2.35	-1.98%	-2.82%
El Higo – Chorrera	230	121.1	1.00	0.80	-1.20%	-0.96%	1.65	4.57	-1.98%	-5.48%
Guasquitas – Cañazas	230	44.6	0.20	0.45	-0.24%	-0.54%	0.62	2.20	-0.74%	-2.63%
Guasquitas – Fortuna	230	16.0	1.50	1.85	-1.80%	-2.22%	2.70	3.49	-3.24%	-4.19%
Guasquitas – Veladero	230	168.5	3.15	3.35	-3.78%	-4.02%	4.80	5.78	-5.76%	-6.94%
La Esperanza – Fortuna	230	96.6	0.20	0.45	-0.24%	-0.54%	0.62	2.20	-0.74%	-2.63%
Las Minas 1- Cativá II	115	0.9	2.00	1.80	-2.40%	-2.16%	2.50	3.35	-3.00%	-4.02%
Las Minas 1 – Santa Rita	115	6.7	1.00	0.80	-1.20%	-0.96%	1.65	3.35	-1.98%	-4.02%
Las Minas 2 – Cemento Panamá	115	25.2	1.00	0.80	-1.20%	-0.96%	1.65	2.35	-1.98%	-2.82%
Llano Sánchez – Chorrera	230	309.9	1.50	1.80	-1.80%	-2.16%	2.70	4.57	-3.24%	-5.48%
Llano Sánchez – El Coco	230	89.0	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Llano Sánchez – El Higo	230	163.2	2.15	2.30	-2.58%	-2.76%	3.65	3.35	-4.38%	-4.02%
Mata de Nance – Caldera	115	50.3	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%
Mata de Nance – Fortuna	230	75.1	1.50	1.85	-1.80%	-2.22%	2.70	4.57	-3.24%	-5.48%
Mata de Nance – Veladero	230	170.3	3.15	3.35	-3.78%	-4.02%	4.80	5.78	-5.76%	-6.94%
Pacora – Bayano	230	50.3	2.00	2.30	-2.40%	-2.76%	2.50	4.57	-3.00%	-5.48%
Panamá – Cáceres	115	0.8	2.00	2.30	-2.40%	-2.76%	2.50	4.57	-3.00%	-5.48%
Panamá – Calzada Larga	115	22.6	2.00	1.80	-2.40%	-2.16%	2.50	4.57	-3.00%	-5.48%
Panamá – Cemento Panamá	115	31.0	1.00	0.80	-1.20%	-0.96%	1.65	3.49	-1.98%	-4.19%
Panamá – Panamá II	230	26.0	2.00	0.80	-2.40%	-0.96%	2.50	4.57	-3.00%	-5.48%
Panamá II – 24 de Diciembre	230	10.6	2.00	0.80	-2.40%	-0.96%	2.50	3.35	-3.00%	-4.02%
Panamá II – El Coco	230	299.6	1.50	1.85	-1.80%	-2.22%	2.70	3.49	-3.24%	-4.19%
Panamá II – Pacora	230	19.0	2.00	1.80	-2.40%	-2.16%	2.50	4.57	-3.00%	-5.48%
Progreso – Boquerón 3	230	29.7	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Progreso – Charco Azul	115	27.6	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Progreso – Costa Rica	230	9.5	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
San Bartolo – Llano Sánchez	230	135.4	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%

Table 7 Impact of increasing maximum temperatures on transmission capacity (continued)

			SCENARIO SSP1-2.6				SCENARIO SSP5-8.5			
			AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)		AVERAGE TEMPERATURE INCREASE (°C)		EFFICIENCY REDUCTION (%)	
LINE	VOLTAGE	km	2050	2070	2050	2070	2050	2070	2050	2070
Santa María	115	0.8	2.00	1.80	-2.40%	-2.16%	2.50	4.57	-3.00%	-5.48%
Santa Rita – Cáceres	115	94.2	1.00	0.80	-1.20%	-0.96%	1.65	3.49	-1.98%	-4.19%
Santa Rita – Panamá II	230	98.8	1.00	0.80	-1.20%	-0.96%	1.65	2.35	-1.98%	-2.82%
Subterránea Panamá – Cáceres	115	0.8	2.00	1.80	-2.40%	-2.16%	2.50	4.57	-3.00%	-5.48%
Veladero – Bella Vista	230	8.5	4.30	4.40	-5.16%	-5.28%	4.80	5.78	-5.76%	-6.94%
Veladero – Llano Sánchez	230	330.4	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%
Veladero – San Bartolo	230	84.6	3.15	3.35	-3.78%	-4.02%	3.65	4.57	-4.38%	-5.48%
		3129	2.37	2.33	-2.84%	-2.79%	3.08	4.36	-3.70%	-5.23%

Notes: km = kilometre; SSP = Shared Socio-economic Pathway.

Under the scenarios analysed in Table 7, two average groups of energy losses in the Panamanian transmission system can be identified. The first group corresponds to high losses, ranging between 4.47% and 4.61% for the SSP1-2.6 scenario, and between 5.21% and 6.06% for the SSP5-8.5 scenario. On the other hand, the second group shows low losses, with a reduction in power transmission of 1.69% to 1.76% for the SSP1-2.6 scenario, and losses of between 2.49% and 3.56% for the SSP5-8.5 scenario, as indicated in Table 8.

Table 8 Levels of energy losses of the electricity transmission system under the change scenarios analysed

	SCENARIO SSP1-2.6		SCENARIO SSP5-8.5	
	EFFICIENCY REDUCTION (%)		EFFICIENCY REDUCTION (%)	
LEVELS	2050	2070	2050	2070
High losses	-4.47%	-4.61%	-5.21%	-6.06%
Low losses	-1.76%	-1.69%	-2.49%	-3.56%

Note: SSP = Shared Socio-economic Pathway.

Taking as an example a power transmission volume of approximately 15 000 GWh per year, it is estimated that the minimum transmission losses would be between 254 GWh/year and 264 GWh/year in the SSP1-2.6 scenario, and between 373 GWh/year and 534 GWh/year in the SSP5-8.5 scenario. On the other hand, the maximum losses in the transmission system could reach between 670 GWh/year and 692 GWh/year in the SSP1-2.6 scenario, while in the SSP5-8.5 scenario, losses would increase between 782 GWh/year and 909 GWh/year.

In summary, changes in precipitation and temperature for the years 2050 and 2070 are projected to compromise installed power generation capacity in the range of 20 MW to 36 MW and generation volume between 194 GWh/year and 422 GWh/year in the SSP1-2.6 scenario. For the SSP5-8.5 scenario, the compromised installed capacity is estimated to be 40 MW to 72 MW, and the compromised generation volume will range between 466 GWh/year and 912 GWh/year. Table 9 summarises the impact of changes in precipitation and temperature on the installed power generation capacity in the scenarios analysed, considering projections up to 2050 and 2070.

Table 9 Installed and power generation capacity compromised under analysed scenarios

	SCENARIO SSP1-2.6				SCENARIO SSP5-8.5			
	COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)		COMPROMISED CAPACITY (MW)		COMPROMISED ENERGY (GWh/year)	
INFRASTRUCTURE	2050	2070	2050	2070	2050	2070	2050	2070
Hydroelectric	12.4	28.0	181.2	408.3	30.8	61.2	450.4	892.9
Solar photovoltaic	7.3	7.5	12.7	13.2	8.7	11.1	15.2	19.4
Wind	0.016	0.017	0.049	0.051	0.019	0.025	0.059	0.077
Total	**20**	**36**	**194**	**422**	**40**	**72**	**466**	**912**

Notes: GWh = gigawatt hour; MW = megawatt; SSP = Shared Socio-economic Pathway.

Among hydroelectric plants, the Bayano and Changuinola plants are most affected in terms of compromised volume of power generation. Among solar PV plants, the most affected are Penonomé, Daconan Solar Star, Ecosolar I and II, Pocrí Solar, Chiriquí, Ikako, Milton and Sol Real. Of wind power plants, the largest volumes of compromised generation are observed in the Nuevo Chagres I and II plants, as well as Rosa de los Vientos I and II.

7. CLIMATE CHANGE RESILIENCE MEASURES

This section outlines climate change adaptation measures that aim to reduce risks, mitigate impacts, decrease vulnerabilities and increase the resilience of Panama's energy and related infrastructure in the face of climate change. These measures are based on the results of the risk assessment, focusing on factors that affect the operational and physical integrity of energy infrastructure.

Based on the results presented in previous sections, it was possible to identify existing and planned infrastructure exposed to moderate to high climate risks (detailed in annexes), as well as the main impacts associated with variations in precipitation and temperature up to 2050. Specific adaptation measures were then selected for each identified risk factor, with the aim of increasing the resilience of the country's energy infrastructure. The choice of these measures is based on previous studies and international experiences.

In the following, a detailed description of adaptation measures is presented, starting with existing infrastructure and then addressing planned infrastructure.

7.1 EXISTING INFRASTRUCTURE

Existing infrastructure will be affected by various risk variables, and the main impacts will be linked to decreases in power generation and transmission, damage to infrastructure, as well as interruptions in services and fuel supplies. Table 10 identifies potential adaptation measures applicable for each type of infrastructure, with the aim of reducing risk factors and associated impacts.

Table 10 Main climate change impacts and adaptation measures for installed infrastructure

CLIMATE RISK VARIABLE	INFRASTRUCTURE AT MODERATE TO HIGH RISK OF DAMAGE	MAIN IMPACTS	MEASURES
Precipitation (droughts)	Hydroelectric	Reduction of energy generation	Increase water storage capacity. Optimise the efficiency of hydropower plants. Decrease evaporation rate in water reservoirs.
Precipitation (flooding)	Hydroelectric	Damage to infrastructure and disruption of services	Implement flood control infrastructure. Nature-based measures.
	Transmission lines		
	Substations		
	Road infrastructure		
Temperature (extreme heat)	Thermoelectric	Reduction in generation efficiency and damage to electronic components	Improve cooling systems.
	Solar photovoltaic		Implement cooling measures. Use of efficient solar panels.
	Transmission lines	Reduced transmission efficiency	Replace lines with more efficient conductors (advanced conductors).
Sea level rise	Fuel terminal ports	Damage to infrastructure and disruption of fuel supply	Build coastal defences (dykes and bulkheads). Implement buffer zones.
	Roads		

Sources: (Abd-Elhamid *et al.* 2021); (ADB, 2013); (Ciapessoni *et al.*, 2023); (Clerc *et al.*, 2021); (Dottori *et al.*, 2023); (Dwivedi *et al.*, 2020); (Hallegatte *et al.*, 2019); (Liu *et al.*, 2017); and (Shalaby *et al.*, 2021).

Adaptation measures for hydropower infrastructure to drought occurrence

Hydropower infrastructure is exposed to a high risk of being affected by the occurrence of extreme droughts. Measures to increase the resilience of hydropower infrastructure to droughts include increasing the water storage capacity of reservoirs and optimising the efficiency of hydropower plants.

Increased water storage capacity

A structural measure to increase the water storage capacity of reservoirs involves increasing the height of the dams, which in turn increases the height and useful volume of water stored in the reservoirs. This can be achieved through the construction of additional structures, such as extensions to the top of the dam or the installation of lifting devices. Engineering examples that support this measure include the Grande Dixence dam in Switzerland (Clerc *et al.*, 2021), the Songyue dam in China (Lu *et al.*, 2008), the Roseires dam in Sudan (OPEC Fund, 2008) and the Steenbras dam in South Africa (Morris and Garrett, 1956).

Another action is the construction of small upstream reservoirs to increase water availability and regulate flows during times of drought. Water transfer works can also be implemented between neighbouring dams or basins, allowing additional water resources to be tapped in times of scarcity. An example of water transfer at the local level centres on the Fortuna hydroelectric power plant; the project seeks to increase the power generation of this plant by diverting usable flows from nearby water sources (Hispagua, s.f.).

In Spain there is a project proposal to interconnect reservoirs in the Guadiana river basin district, in order to improve management and maximise water use (Confederación Hidrográfica del Guadiana, 2022).

Measures to increase water storage capacity and inter-basin transfers are used globally to strengthen hydropower infrastructure in the face of droughts, taking into account project-specific characteristics and local conditions.

Optimising the efficiency of hydropower plants

Beyond increasing water storage capacity, it is important to optimise the efficiency of hydropower plants. This involves various strategies to maximise energy production during periods of limited water availability.

For example, when turbined flows are reduced, hydroelectric generation can be shifted from constant to variable speed. This in turn requires the installation of efficient turbines, advanced control systems and real-time monitoring equipment. Variable speed turbines are important when operating below design water head due to declining reservoir levels and benefit the recovery of generation performance (Bortoni *et al.*, 2019).

Several hydropower plants worldwide have implemented variable-speed generation turbines. These include the Goldisthal hydropower plant in Germany, Jirau in Brazil, Frades II in Portugal, Z'Mutt in Switzerland and La Muela in Spain (IRENA, 2020a). These plants have been able to improve power generation efficiency and performance by rapidly adapting hydropower production to fluctuations in available water flow.

Decrease of evaporation rate in water reservoirs

Technologies and methods for reducing evaporation from reservoirs are essential to conserve water. Physical methods, including floating covers made from materials such as polyethylene sheets, are particularly effective. Polyethylene covers can reduce evaporation by up to 95% (Shalaby *et al.*, 2021; Waheeb and Khodzinskaya, 2019).

Modular systems such as caps and plastic balls also decrease evaporation significantly. Aquacaps, which are dome-shaped discs, cut evaporation by over 60% (Waheeb and Khodzinskaya, 2019; Yao *et al.*, 2010). Similarly, 4-inch high-density polyethylene balls reduce evaporation rates by 40% to 60% (Shalaby *et al.*, 2021; Kumar *et al.*, 2018).

Additionally, floating PV systems on water bodies have proven effective in reducing evaporation. Covering 30% of a water surface can lead to a 49% reduction in evaporation (Yousuf *et al.*, 2020). Research on Lake Nasser in Egypt shows that different coverage levels can significantly save water and generate additional energy (Abd-Elhamid *et al.*, 2021). In 2017, the Panama Canal Authority installed 88 floating solar panels in a small lake in the area known as Lake View, adjacent to Lake Miraflores. This pilot project aims to evaluate technical feasibility and maximise water use in its operations (CF, 2018).

Adaptation measures for hydroelectric infrastructure, transmission lines and roads in the event of flooding due to extreme rainfall

Rainfall flooding represents one of the main risk factors for infrastructure in Panama, especially for hydroelectric infrastructure, transmission lines, substations and access roads. International experience has shown that cost-effective flood control measures exist, such as the construction of dikes, embankments, retention ponds and the relocation of infrastructure.

Dams

Flood control levees, also known as check dams, are structures built to prevent or reduce the effects of flooding by containing and redirecting the flow of water. These levees are designed to resist water pressure and keep it within safe limits. In Germany, for example, dykes have been built along the Elbe River to protect inhabited areas as well as energy infrastructure and roads from flooding. In China, a levee system was built upstream of the Three Gorges dam, generating hydropower and also contributing to flood control downstream, while protecting energy infrastructure and urban areas along the Yangtze River.

Embankments

Raising roads above water level with embankments protects roads from flooding and strengthens their resilience to extreme weather conditions. By ensuring safe passage even in adverse weather conditions, connectivity is guaranteed and risks to road users are minimised. A notable example is the Pan-American Highway in Peru, where embankments in several sections protect against flooding from heavy rains.

Retention ponds

Retention ponds serve as temporary reservoirs, where rainwater is stored and retained before being released in a controlled manner. These structures are designed to collect run-off water and reduce its flow, thus preventing flash flooding in vulnerable areas. Retention ponds can be found around the world. In Japan, they are used to mitigate flood risk in densely populated urban areas such as Tokyo and Yokohama (World Bank, 2019). In the United Kingdom, the Balmore retention pond in Glasgow protects the city from river flooding (Climatescan, 2022).

Undergrounding transmission lines

Undergrounding power lines protect the electrical grid from severe weather, which can damage overhead lines and cause power outages. By burying power lines, Panama would reduce the occurrence of outages and eliminate the risks associated with downed wires during storms, improving public safety. Additionally, underground cables are less susceptible to damage from external factors like falling trees, further reducing repair needs. This method also supports critical infrastructure such as hospitals and ensures consistent power supply to disadvantaged communities, making it a strategic choice to maintain energy access amid climate impacts. For example, research shows that the state of California (United States) would benefit from burying power lines to mitigate the risks associated with overhead wires, which have been linked to nearly half of the state's most destructive wildfires (Brundy, 2020). The recent catastrophic fires, causing extensive damage and loss of life, have intensified public calls for infrastructure improvements to ensure a more resilient and safe power grid.

Relocation of infrastructure

Relocating infrastructure aims to reduce the vulnerability of energy assets to the impacts of climate change, minimising the risks of power supply disruptions and ensuring the security of operations. Sometimes the process involves relatively less capital-intensive measures such as raising facilities to a higher elevation, above the anticipated flood level. But relocation is typically expensive, and requires detailed planning, investment in new land, as well as the construction of new facilities. Long-term benefits in terms of resilience and energy security often outweigh the associated costs (Dottori *et al.*, 2023).

Nature-based measures

Nature-based measures, also known as ecosystem-based solutions, use natural processes and ecosystem-based services to control and mitigate floods. Among the most common are watershed reforestation and wetland creation. For example, a simulation of conservation practices in China's Miyun reservoir basin reduced run-off from 7% to 14% through the use of artificial wetlands (Qiu *et al.*, 2020). Also, the conversion of farmland to forest on 15° and 25° slopes reduced surface run-off by 6%-7%; this in turn reduced surface water flow and allowed water storage and infiltration into the soil (Qiu *et al.*, 2020).

Both structural measures (dikes, embankments, ponds) and nature-based measures (reforestation, wetlands) are effective strategies to reduce the impacts of floods on infrastructure. Nature-based solutions, in particular, can promote the development of green-grey infrastructure (*e.g.* retaining walls that combine traditional engineering elements with vegetation). Similarly, hybrid solutions, such as, for example, a combination of steel beams and afforestation to retain floods, are worth exploring. Also, hybrid solutions tend to be more feasible, from a technical perspective, than would infrastructure hardening.

Adaptation measures for thermoelectric, solar photovoltaic infrastructure and transmission lines in the face of rising temperatures

Extreme heat poses a serious threat to thermal and solar PV generation infrastructure as well as power transmission lines. Given projected temperature increases, the resilience of systems will be enhanced by cooling systems and the use of more efficient technologies.

Cooling of thermal power plants

Several prominent thermal power plants have adopted more effective operational cooling measures to cope with rising temperatures associated with climate change and to improve efficiency. A relevant example is the Yokohama Natural Gas Power Plant in Japan, which uses seawater to generate power and, at the same time, cool the generation system by condensing the steam (Sano, 2010).

This innovative cooling technique mitigates the negative effects of extreme heat on thermal generation infrastructure, improving both its performance and efficiency. By harnessing seawater as a cooling source, the Yokohama plant stands out as a leading example among sustainable and effective solutions to address the challenges of climate change in thermal power generation.

Cooling and efficiency of solar photovoltaic systems

To optimise solar PV systems against heat waves, designs that improve the passive airflow under mounting structures and the replacement of existing components with more efficient ones can be considered. Also, the use of cooling systems in solar PV power plants has become a crucial strategy to ensure optimal plant performance.

There are several techniques for cooling PV panels. These include active cooling, which can be by air or water, and requires additional power to drive the cooling system (fan or pump), and passive cooling, which can be by circulating air, water or thermal conduction, and does not require additional power to generate cooling (Sharaf *et al.*, 2022; Dwivedi *et al.*, 2020). Within passive systems, installing PV panels on water surfaces can enhance their efficiency. Research indicates that floating PV systems can increase generation efficiency up to 2% in comparison with land-based systems operating under similar environmental conditions (Liu *et al.*, 2017).

Worldwide, different cooling approaches have been implemented in solar PV systems. For example, a ground-coupled central panel cooling system installed in the Rajiv Gandhi Proudyogiki Vishwavidyalaya Energy Park in Bhopal, India, cools the solar panels through forced convection using a blower. The air passes through a ground-coupled heat exchanger to lower its temperature, and then it is circulated through the back surface of the solar panels for cooling (Sahay *et al.*, 2015, 2013). The Longyangxia Dam Solar PV Park uses a natural convection cooling system, its panels resting on a water surface (Masili, 2017). Biomaterials may also be used for passive cooling. For example, wet coconut fibre integrated into the back of the PV modules has been shown to reduce module temperature by up to 20% and improve electrical energy efficiency by almost 11% (Dwivedi *et al.*, 2020).

In addition, improvements are being made in solar panel design to increase performance and energy conversion efficiency, which would help reduce the effect of rising temperatures in the long term. For example, silicon heterojunction solar cells have achieved high efficiencies (>26%) in energy conversion due to their effective passivation contact structures. Improvements in the optoelectronic properties of these contacts could enable higher device efficiency (Lin *et al.*, 2023). These innovations in solar panel design offer promising prospects for meeting the challenges of extreme heat and improving the efficiency of solar PV generation.

Transmission line cooling and efficiency

Overhead transmission lines generally do not require cooling. However, patented methods for cooling transmission cables, such as underground transmission lines, could be evaluated in specific cases (Kataoka *et al.*, 1974).

For the past several years, researchers at the US Department of Energy's Idaho National Laboratory have been collaborating with industry to study the effects of wind cooling on power transmission lines. Their goal is to combine transmission systems with cooling processes. In areas with wind farms, the wind can cool nearby transmission lines while the farms generate power. This simultaneous cooling allows utilities to transmit more electricity through the lines, which increases transmission capacity limits and reduces costs (EERE, 2015).

Dynamic ratings, such as Dynamic Line Rating (DLR), can help adapt to climate change. DLR monitors real-time weather variations to adjust the thermal capacity of overhead power lines in response (IRENA, 2020b). This helps reduce congestion on power lines, optimise asset utilisation, improve efficiency and lower operating costs (Cradden and Harrison, 2013).

Another option is to replace existing transmission line sections with superconducting transmission lines. Superconducting materials can carry electrical energy without losses below a critical temperature, which differentiates them from conventional conductors, which are resistive and have energy losses associated with increasing temperature (Thomas *et al.*, 2016).

Finally, advanced conductors can deliver superior capacity and lower losses compared to traditional conductors. These new conductors' generation are capable of dissipating heat generated in the conductor more efficiently through radiation and convection, preventing cable overheating and enabling the transport of more current over longer distances (Caspary and Schneider, 2022). Studies show that the use of carbon nanostructure composites and epoxy in a multi-layer architecture can increase current carrying capacity by 40% and extend spans by 30% (Kumar *et al.*, 2018). This improvement in current carrying efficiency can help reduce losses and optimise the operation of power transmission lines.

Adaptation measures for fuel terminals and roads in the face of sea level rise

Sea level rise poses a high risk of impact on fuel terminal ports and roads located close to the coasts. To address this issue in existing infrastructure, the construction of coastal defences and the implementation of buffer zones have been identified as the main adaptation measures.

Coastal fences

Among coastal fence strategies, the construction of dykes has been widely used to reduce the impacts of sea level rise. An emblematic example is the Oosterscheldekering dike in the Netherlands, which is part of the famous Delta Works, a flood fence system in the region. This dike, built to protect the province of Zeeland, consists of a series of electronically controlled gates that can be closed during storm surges and storms to prevent water from entering the estuary of the Oosterschelde river.

An outstanding feature of the Oosterscheldekering barrage is that it allows water to flow normally through it under normal conditions. However, when severe storms are forecast, the gates can be closed to create a barrier against the water. This allows the water level to be controlled and reduces the risk of flooding.

A similar example is found in the Thames Embankment in the United Kingdom, which was built to protect infrastructure and urban areas from flooding. The “Tideway Flood Barrier”, a movable dyke located near the mouth of the river, was created. It can be closed at times of flooding to prevent the river from overflowing and thus protect infrastructure, including power stations and electricity substations.

Buffer zones

A complementary approach to structural measures to increase the resilience of infrastructure to sea level rise is the creation of buffer zones, also known as “brownfields” or transition zones. These zones play a crucial role in protecting coastal areas and mitigating the effects of sea level rise. Buffer zones are strategically located between coastal areas and human settlements and are managed in a way that minimises the impact of flooding. These areas can take various forms and be managed in different ways, depending on local characteristics and specific needs.

A common strategy is the restoration and conservation of coastal wetlands, such as mangroves, swamps and marshes. These natural ecosystems are highly effective in protecting against flooding and reducing the impact of sea level rise. They act as natural barriers, absorb excess water and dissipate wave energy, which helps to reduce coastal erosion and protect human settlements.

Another way of creating buffer zones is through the creation of artificial beaches and dunes. These structures provided an additional layer of coastal protection by reducing erosion and acting as barriers to flooding caused by extreme weather events.

A prominent example of this approach is the “Room for the River” project in the Netherlands. This project uses water management strategies, including the creation of buffer zones and the widening of rivers and floodplains, with the aim of reducing flood risk and protecting urban areas (NWP, 2019).

7.2 PLANNED INFRASTRUCTURE

Mitigation measures applicable to planned energy infrastructure are similar to those used for existing infrastructure (described in the previous section), but with a specific focus on the design and planning of new works. In the case of infrastructure design, it is essential to incorporate climate resilience considerations from the initial planning stages. To achieve this, detailed scale research and modelling is required in those areas and infrastructure identified as being at high climate risk.

A crucial aspect is to conduct detailed hydrological and flood modelling for infrastructure planned in areas at high risk of droughts and floods. Such modelling helps to understand how extreme weather events can affect water availability and flow, as well as flood dynamics and infrastructure vulnerability. It also allows simulating different design scenarios and assessing the effectiveness of proposed measures, which contributes to informed and data-supported decision making.

Planning should analyse alternative locations for infrastructure. This involves considering relocation options to lower risk areas and analysing the associated technical, economic and social aspects. The aim is to increase resilience and reduce the risk of damage from extreme weather events. The advantages and disadvantages of each potential location need to be carefully assessed, taking into account existing infrastructure, terrain conditions, projected changes in climate and socio-economic impacts.

It is also essential to evaluate existing generation technologies and explore new options that are better suited to meet climate challenges. For example, in the case of hydropower plants, more efficient turbines and equipment can be considered that optimise power generation, even in conditions of reduced or fluctuating flows due to droughts or changes in precipitation patterns. In addition, more flood and corrosion-resistant construction materials can be used to ensure the durability and operability of the facilities.

In the case of solar PV power plants, advances in solar panel technologies that improve their resistance to extreme weather conditions, such as high temperatures or adverse weather exposures, can be explored. In addition, the design of mounting systems can include projects that improve heat dissipation such as floating power plants and low-cost measures such as airflow devices to maximise panel efficiency.

In addition, research and technology development is essential to drive the adoption of emerging technologies that are more efficient and resilient to climate change. This may include the use of advanced materials in infrastructure construction, the development of smart monitoring and control systems to optimise operation and maintenance, and encouraging the integration of renewable energy and energy storage to increase the flexibility and resilience of energy systems.

In summary, detailed-scale research and modelling is essential to support the design and planning of energy infrastructure in areas of high climate risk. As such, it is critical to consider climate resilience from the early planning stages to ensure the sustainability and adaptation of infrastructure. In addition, the analysis of more efficient and robust technologies in the face of climate change is necessary to optimise generation by adopting materials and technologies that are resilient to extreme weather events. Research and technology development drives innovation, strengthening energy infrastructure and enabling greater resilience and adaptation to climate change impacts.

8. CONCLUSIONS AND RECOMMENDATIONS

Panama's energy infrastructure has significant potential for improvement to address the challenges of climate change and ensure a sustainable and resilient energy supply. This report considers the infrastructure at risk and explores various adaptation measures for existing and new infrastructure. These measures include increasing water storage capacity at hydropower plants, building dams and coastal defences, relocating infrastructure to lower-risk areas, and adopting more efficient and climate-resilient technologies. Relevant findings related to the risks associated with extreme weather events are described below.

Extreme droughts

The main risk to hydropower infrastructure arises from extreme droughts and changes in precipitation, which threaten long-term power generation. To address this challenge, it is crucial to implement measures that increase water storage in reservoirs and improve the efficiency of power generation through technologies that can be adapted to reduced turbined flows.

The first step is to implement tailored measures at the country's main hydropower plants, such as Bayano, Changuinola and La Fortuna.

In the provinces of Bocas del Toro, Chiriqui and Veraguas, it is essential to integrate climate resilience into the design and planning of new hydropower plants. This implies carrying out detailed hydrological modelling to assess surface water availability under different climate scenarios, and to obtain solid information for decision making and the adoption of efficient measures in each operating context.

Risk of flooding

Hydropower plants, transmission infrastructure, substations and roads will also be exposed to a high risk of flooding due to extreme rainfall events, especially in the western region of Panama, which is home to about 40 hydropower plants, 200 km of main roads, 15 power substations and 800 km of transmission lines. The provinces of Chiriqui and Bocas del Toro are particularly vulnerable. To strengthen the resilience of infrastructure to flooding, priority measures include the construction of dikes, embankments and retention ponds, and the relocation of infrastructure. Local hydrological and hydraulic simulation models provide essential information on the extent, depth and location of flooded areas, which is essential for the design of appropriate adaptation strategies.

Extreme temperatures

It is also important to consider the impact that extreme temperatures can have on solar photovoltaic (PV) infrastructure and transmission lines. The largest number of solar PV plants – both in operation and planned – are in the central region of the country, which includes the provinces of Coclé, Herrera, Los Santos and Veraguas. The solar infrastructure in this region is exposed to a high risk of rising temperatures, which could compromise between 9% and 12% of the long-term energy generation volume. Among the priority solar power plants to be considered are Penonomé, Daconan Solar Star, Ecosolar I and II, Pocrí Solar, Chiriquí, Ikako, Milton and Sol Real. Likewise, the transmission infrastructure that extends through the provinces of Veraguas, Coclé, Panamá and Panamá Oeste, with an extension of some 1 930 km of lines, are at high risk associated with the occurrence of extreme temperatures.

In this context, it is essential to promote the adoption of technologies and materials that are more resistant to high temperatures and that optimise both solar PV generation and power transmission. This implies the use of cooling systems and the implementation of more efficient transmission lines in terms of capacity and thermal resistance. These measures are necessary to ensure the safety and efficiency of the solar power and transmission system in the face of future climate challenges.

Risk to sea level rise

Hydrocarbon terminal ports and segments of roads to coastal infrastructure are particularly at risk to sea level rise. Coastal defences and buffer zones need to be set up. Also, the Sarigua solar power plant and the planned solar power plants RPM Caizán 02 and La Victoria, in the province of Herrera, are at risk of coastal flooding.

8.1 FINAL REMARKS

Strengthening local capacities in climate research

It is important to enhance local capabilities in climate research and modelling. Specific initiatives may include the preparation of in-field experts and academic programmes. Also, it is important to deepen collaborations among academic institutions, research institutes and government entities to encourage knowledge exchange.

The government might consider assigning the Panama Institute of Meteorology and Hydrology (IMHPA) the the task of modernising the country's network of climate stations, as well as the systematisation, analysis, and dissemination of data necessary for climate modelling. This could improve the calibration of climate threat analysis tools and facilitate access to accurate models for decision making.

The government might also consider creating climate-related capacities within ministries. Specialised units dedicated to the analysis of climate risks to energy infrastructure would inform adaptation strategies. Also, it is important to promote knowledge sharing in cross-cutting areas. Collaborative working groups would optimise resources, align development strategies and facilitate the adoption of innovative solutions to strengthen the energy sector.

Economic assessment

It is essential to analyse the economic implications of energy infrastructure's vulnerability to extreme weather events and compare them with the cost of adaptation measures. This process involves assessing operational risks in the power industry and related infrastructure for energy and services. Through cost-benefit analysis, the economic viability of adaptation measures can be determined, prioritising those that are most critical, effective and cost-efficient in mitigating climate risks.

Emergency response plans

The preparation of emergency response plans is fundamental to reduce negative impacts and ensure operational continuity during climate crises. These plans must be developed comprehensively, considering various emergency scenarios and establishing action protocols. Specifically, these should assign roles and responsibilities for all stakeholders involved in emergency management, including government authorities, energy companies and civil protection agencies. Effective co-ordination among different actors creates enabling conditions for a rapid and effective response to extreme weather events.

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ANNEXES

ANNEX 1. GEOREFERENCED EXISTING INFRASTRUCTURE

Table A1.1 Hydroelectric plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	Algarrobos	8.722831	-82.290847	9.86
1	Baitún	8.610918	-82.794700	85.90
2	Bajo del Totuma	8.836653	-82.711470	6.33
3	Bajo Mina	8.683881	-82.824739	56.80
4	Barro Blanco	8.215148	-81.596242	28.84
5	Bayano	9.176457	-78.886900	260.00
6	Bonyic	9.337744	-82.618498	31.31
7	Bugaba I	8.532653	-82.666177	5.14
8	Bugaba II	8.501734	-82.650649	6.33
9	Changuinola	9.236630	-82.496992	222.46
10	Cochea	8.608836	-82.428565	15.50
11	Concepción	8.571323	-82.599989	10.00
12	Dolega	8.587362	-82.411502	3.13
13	El Alto	8.728252	-82.836149	75.00
14	Estí	8.543100	-82.297648	120.00
15	Fortuna	8.679068	-82.264762	300.00
16	Fraile	8.569790	-80.590092	6.71
17	Gatún	9.263871	-79.931246	3.00
18	Gualaca	8.534006	-82.298533	25.00
19	La Cuchilla	8.614511	-82.594852	8.40
20	La Estrella	8.716672	-82.366744	47.20
21	La Porta	8.596472	-82.789893	27.90
22	La Yeguada	8.430995	-80.843505	8.20
23	Las Cruces	8.308335	-81.267583	20.44
24	Lorena	8.455946	-82.333150	37.60
25	Los Valles	8.716670	-82.399575	54.80
26	M. Monte	8.684083	-82.606958	2.40
27	Macano	8.611820	-82.589844	5.25
28	Madden	9.210070	-79.617196	36.00

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
29	Mendre	8.646433	-82.351841	19.75
30	Mendre II	8.621657	-82.359104	8.12
31	Monte Lirio	8.801448	-82.744620	53.75
32	Pando	8.801536	-82.689540	32.60
33	Paso Ancho	8.799109	-82.645445	6.16
34	Pedregalito I	8.466445	-82.578235	21.00
35	Pedregalito II	8.438146	-82.575314	13.49
36	Perlas Norte	8.561581	-82.603415	10.00
37	Perlas Sur	8.534746	-82.607445	10.00
38	Planetas I	8.529342	-82.406467	4.82
39	Planetas II	8.500163	-82.407139	8.89
40	Prudencia	8.441966	-82.327517	62.78
41	RP-490	8.590549	-82.595070	14.30
42	Salsipuedes	8.580110	-82.789832	27.90
43	San Andrés	8.667453	-82.689118	9.89
44	San Lorenzo	8.403527	-82.087702	8.70
45	Antón	8.883140	-82.759690	4.30
46	Hidrocandela	8.635790	-80.137580	0.54

Source: Portal SIG-SNE of the Republic of Panama. Power plants as of 29 March 2023, https://sne.maps.arcgis.com/home/item.html?id=eacbd8b8de6c41b2b3b29199e152b76b#overview.

Note: MW = megawatt.

Table A1.2 Solar power plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	Bejuco Solar	8.611983	-79.883526	0.96
1	Bugaba	8.542649	-82.660460	2.40
2	Caldera	8.616956	-82.358815	5.28
3	Chiriquí	8.248222	-81.986988	9.87
4	Coclé	8.456769	-80.416652	8.99
5	Coclé Solar 1	8.193460	-80.694799	0.96
6	David	8.421756	-82.804190	7.92
7	Divisa Solar	8.182885	-80.709397	9.90
8	Don Félix	8.182984	-80.713072	2.00
9	El Espinal	7.878326	-80.323703	9.26
10	El Fraile 2	8.564957	-80.584043	0.48
11	Estrella Solar	8.174312	-80.667252	4.79
12	Farallón II	8.382805	-80.120153	4.80

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
13	Ikako	8.377311	-82.346950	10.00
14	Ikako I	8.372442	-82.349641	10.00
15	Ikako II	8.370957	-82.350461	10.00
16	Ikako III	8.368881	-82.351609	10.00
17	Los Ángeles	7.886469	-80.341823	9.52
18	Milton	8.188355	-80.731321	10.26
19	Panasolar	8.212473	-80.694576	9.90
20	Paris	8.044387	-80.559554	8.99
21	Pocrí Solar	8.189863	-81.002698	16.00
22	Santiago GEN	7.927375	-80.591286	5.00
23	Sarigua	8.092682	-80.498997	2.40
24	Sol Real	8.420663	-82.944920	10.78
25	Vista Alegre	8.189863	-81.002698	8.22
26	ECOSOLAR I & II	8.446312	-82.840837	20.00
27	Mayorca Solar	7.680280	-80.162410	9.97
28	Pese Solar	7.906179	-80.608491	9.97
29	PROGSOL20	8.423377	-82.808372	9.97
30	Jaguito Sol	8.172230	-80.670800	9.99
31	Parque Solar Prudencia	8.417457	-82.347302	9.69
32	Sboqueron	8.534017	-82.570789	2.00
33	SolPac	9.070094	-79.238693	3.00
34	Caoba Solar	8.655454	-82.874441	9.90
35	Cedro Solar	8.535954	-82.576433	9.98
36	Daconan Solar Star	8.153580	-81.045230	3.24
37	Macano Solar	8.664610	-82.588780	2.00
38	Madre Vieja Solar	8.651860	-82.830920	25.00
39	Penonomé	8.379700	-80.388780	120.00
40	Sunrise MasPV1	8.964670	-79.872090	0.50

Source: Portal SIG-SNE of the Republic of Panama. Power plants as of 29 March 2023, Idem.
Note: MW = megawatt.

Table A1.3 Wind power plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	Marañón	8.465959	-80.337972	17.50
1	Nuevo Chagres I	8.466537	-80.382402	55.00
2	Nuevo Chagres II	8.402302	-80.436565	62.50
3	Portobelo	8.403684	-80.454490	32.50
4	Rosa de los Vientos I	8.477303	-80.373138	52.50
5	Rosa de los Vientos II	8.477303	-80.373138	50.00
6	Toabré	8.651860	-80.322140	66.00

Source: Portal SIG-SNE of the Republic of Panama. Power Plants as of 29 March 2023, https://sne.maps.arcgis.com/home/item.html?id=eacbd8b8de6c41b2b3b29199e152b76b#overview.

Note: MW = megawatt.

Table A1.4 Thermal power plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	ACP	8.999288	-79.593020	81.62
1	BLM	9.376263	-79.823615	68.00
2	Cativá	9.377544	-79.821681	87.00
3	Cobre Panamá	8.847409	-80.635435	350.00
4	Costa Norte	9.337751	-79.908996	381.00
5	Esperanza	9.367836	-79.884601	129.36
6	Estrella de Mar	9.386222	-79.822348	72.00
7	Jinro Power	9.326522	-79.796799	57.80
8	Pacora	9.104387	-79.272474	55.34
9	Panam	8.908598	-79.783176	147.00
10	Termocolón	9.374258	-79.825226	150.00
11	Tropitérmica	9.334342	-79.906186	5.05
12	Urbalia Panama	9.046347	-79.565806	8.10
13	Sparkle Power	9.266120	-79.669630	49.20

Source: Portal SIG-SNE of the Republic of Panama. Power Plants as of 29 March 2023, https://sne.maps.arcgis.com/home/item.html?id=eacbd8b8de6c41b2b3b29199e152b76b#overview.

Note: MW = megawatt.

Table A1.5 Thermal power plants

	SUBSTATION NAME	LATITUDE	LONGITUDE
0	Chorrera	8.909124	-79.777835
1	Llano Sánchez	8.195875	-80.700728
2	Mata de Nance	8.453349	-82.378255
3	Progreso	8.426692	-82.799151
4	Chanquinola	9.407474	-82.563670
5	San Bartolo	8.234003	-81.278773
6	Panamá	9.037738	-79.525704
7	Panamá II	9.095758	-79.431688
8	Boquerón 3	8.525731	-82.577778
9	Caldera	8.665848	-82.356695
10	Charco Azul	8.214712	-82.884780
11	La Estrella	8.716260	-82.364699
12	Los Valles	8.677778	-82.347606
13	Fortuna	8.678848	-82.262594
14	Esperanza	9.271297	-82.512229
15	Bella Vista	8.215452	-81.598601
16	El Coco	8.402680	-80.369535
17	24 de Diciembre	9.116673	-79.355359
18	Pacora	9.106306	-79.273542
19	Bayano	9.177412	-78.885411
20	Chilibre	9.193946	-79.621103
21	Cemento Panamá	9.256923	-79.662253
22	Cativa II	9.376859	-79.823045
23	Las Minas 2	9.379262	-79.822481
24	Las Minas 1	9.375048	-79.823852
25	Cáceres	9.031418	-79.523260
26	Santa Rita	9.327513	-79.794303
27	Guaquitas	8.542364	-82.294007
28	Veladero	8.252158	-81.656387
29	Cañazas	8.870046	-82.177594
30	El Higo	8.463211	-80.048416

Source: Portal SIG-SNE of the Republic of Panama. Electrical substations, https://sne.maps.arcgis.com/home/item.html?id=6e9d02224619469397c1b87624bc4d91#overview .

Note: MW = megawatt.

Table A1.6 Oil terminal ports

	NAME OF POWER PLANT	LATITUDE	LONGITUDE
0	COASSA	9.371887	-79.879660
1	Decal Panama	8.789283	-79.569672
2	Melones Oil Terminal	8.811062	-79.517245
3	POTSA Balboa	8.942978	-79.557709
4	POTSA Cristóbal	9.333803	-79.903551
5	Payardi	9.393001	-79.820671
6	PATSA	8.951177	-79.586204
7	PETROPORT	9.344464	-79.549713
8	Charco Azul	8.204064	-82.873171
9	Chiriquí Grande	8.955408	-82.118861
10	AES Colón	9.339546	-79.908116

Source: AMP (2023).

ANNEX 2. GEOREFERENCED PLANNED INFRASTRUCTURE

Table A2.1 Hydropower plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	El Alto G4	8.734597	-82.837785	1.17
1	Chuspa	8.620962	-82.587410	8.80
2	Colorado	8.363999	-82.807609	5.14
3	San Bartolo	8.230357	-81.257816	19.44
4	San Bartolo Minicentral	8.113047	-81.263252	1.00
5	The Sindigo	8.425700	-82.265538	10.00
6	La Herradura	8.404436	-81.061839	5.48
7	Barriles	8.798276	-82.686021	1.00
8	Cotito	8.852902	-82.725088	5.00
9	Burica	8.432978	-82.305117	65.30
10	Terra 4-Tizingal	8.585061	-82.788100	4.64
11	El Recodo	8.340978	-82.077886	10.01
12	Changuinola II	9.271272	-82.518289	214.76
13	Changuinola II Unidad 3	9.279235	-82.511425	13.70
14	Caña Blanca	8.524888	-82.238424	7.78

Source: ETESA (2022).
Note: MW = megawatt.

Table A2.2 Solar power plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	Pacora II - 1	9.068778	-79.299656	3.00
1	Daconan	8.131909	-81.018378	0.24
2	Penonomé	8.380094	-80.390195	120.00
3	Cedro	8.532172	-82.572466	9.98
4	Caoba	8.529166	-82.572593	9.98
5	Pesé	8.531342	-82.580797	9.97
6	Mayorca	7.679898	-80.162450	9.98
7	Farallón II	7.679573	-80.165674	4.80
8	Llano Sánchez	8.182550	-80.713610	9.99
9	La Esperanza	8.418319	-82.809591	19.99
10	Panasolar II	8.234572	-80.531090	5.00
11	Panasolar III	8.232699	-80.531520	5.00
12	Pedregalito	8.433655	-82.603522	10.00
13	RPM Caizán 01	8.731111	-82.821440	10.00

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
14	RPM Caizán 02	8.067151	-80.507936	10.00
15	Jagüito	8.171584	-80.670772	9.99
16	Providencia 1	9.175407	-79.099904	9.95
17	Celsia Prudencia	8.422515	-82.341283	10.58
18	La Victoria	8.012773	-80.439686	10.00
19	Cerro Viejo	8.579311	-79.924816	20.00
20	Mendoza	9.028566	-79.881109	3.00
21	Los Santos	7.881656	-80.338883	7.56
22	Estí I	8.648503	-82.385200	9.90
23	RPM Caizán 03	8.733058	-82.821508	10.00
24	RPM Caizán 04	8.730324	-82.823943	10.00
25	Baco Solar	8.443668	-82.838047	25.90
26	Madre Vieja	8.444917	-82.838093	25.90
27	La Salamanca	8.170417	-80.813082	8.00
28	El Chumical I	8.086519	-80.941532	40.00
29	El Coco	8.390800	-80.356463	10.00
30	Agua Fría	8.393505	-80.356674	10.00
31	Las Lajas	8.394917	-80.350898	30.00
32	La Mata 1	8.072491	-80.989988	2.00
33	La Mata 2	8.100792	-81.003342	3.00
34	La Mata 3	8.098371	-80.999332	5.00
35	Bajo Frío	9.157662	-79.090836	19.95
36	Camarones	8.717550	-79.903424	100.00
37	Antón 01	8.409734	-80.277420	10.00
38	Progreso 01	8.415020	-82.819934	30.00
39	Progreso 02	8.395733	-82.823778	10.00
40	Pacora II - 2	9.061395	-79.302926	4.00
41	Gualaca 01	8.523669	-82.292722	19.89
42	Gualaca 02	8.528791	-82.289238	19.89
43	Gualaca 03	8.538098	-82.291429	19.89
44	Gualaca 04	8.515015	-82.290484	19.89
45	Progreso 03	8.402545	-82.822424	10.00
46	Pacora 01	9.107646	-79.307673	10.00
47	Aguadulce 01	8.230317	-80.550121	9.90
48	Las Lomas 01	8.424303	-82.403723	19.80
49	Boquerón 01	8.485985	-82.559772	19.80
50	Progreso 05	8.435671	-82.814863	49.70
51	El Roble 01	8.196204	-80.634259	10.00

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
52	El Roble 02	8.190483	-80.619179	10.00
53	El Roble 03	8.179684	-80.605034	20.00
54	Nata01	8.350589	-80.512805	9.95
55	Nata 02	8.325573	-80.519490	9.95
56	Nata 03	8.325303	-80.505164	9.96
57	Nata 04	8.307570	-80.488857	9.95
58	Nata 05	8.316296	-80.474027	9.95
59	Juan Díaz 01	8.467184	-80.282529	5.00
60	Gualaca 05	8.558018	-82.319734	17.30
61	Progreso 04	8.470275	-82.844952	71.00
62	Los Santos II	7.885383	-80.340758	9.98
63	Los Santos III	7.881130	-80.337391	9.98
64	Pedasí	7.626867	-80.057251	9.98
65	Corotú	8.512358	-82.574967	9.98

Source: ETESA (2022).
Note: MW = megawatt.

Table A2.3 Wind power plants

	NAME OF POWER PLANT	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	Toabré 1	8.656727	-80.323435	66
1	Toabré 2	8.648827	-80.330576	22
2	Nuevo Chagres Fase 2 - 2	9.031384	-79.827319	51.75
3	Portobelo Etapa 2 C	9.549248	-79.645871	17.25
4	Escudero	8.489455	-81.114774	111.6
5	Toabré 3	8.648383	-80.313521	22
6	Antón	8.588200	-80.135358	105
7	Viento Sur	8.348005	-81.057880	115.2
8	Paja de Sombrero	8.668940	-82.317838	25
9	Santa Cruz	8.561797	-80.360271	74
10	Pacora	9.094010	-79.292968	32
11	Líbano	8.597131	-79.818236	136
12	El Cuay	8.398197	-81.092063	104.4
13	Hornito	8.721342	-82.274291	19.8
14	El Salado	8.188629	-80.486059	80
15	Santa Fe	8.485872	-81.068919	108

Source: ETESA (2022).
Note: MW = megawatt.

Table A2.4 Thermal power plants

	NAME OF POWER PLANT (AUTHORISED)	LATITUDE	LONGITUDE	INSTALLED CAPACITY (MW)
0	GTPP	9.356337	-79.896433	458.10
1	C.T. Gatún	9.327602	-79.907400	670.00

Source: ETESA (2022).
Note: MW = megawatt.

ANNEX 3. EXPOSURE OF EXISTING INFRASTRUCTURE TO CLIMATE HAZARD

Table A3.1 Hydropower plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Algarrobos	High	High	Low	None
1	Baitún	High	High	Low	None
2	Bajo del Totuma	High	High	Low	None
3	BajoMina	High	High	Low	None
4	Barro Blanco	High	High	Low	None
5	Bayano	Low	Moderate	Moderate	None
6	Bonyic	Moderate	Moderate	Low	None
7	Bugaba I	High	High	Low	None
8	Bugaba II	High	High	Low	None
9	Changuinola	Moderate	Moderate	Low	None
10	Cochea	High	High	Low	None
11	Concepción	High	High	Low	None
12	Dolega	High	High	Low	None
13	El Alto	High	High	Low	None
14	Estí	High	High	Low	None
15	Fortuna	High	High	Low	None
16	Fraile	Low	High	High	None
17	Gatún	Low	Moderate	Moderate	None
18	Gualaca	High	High	Low	None
19	La Cuchilla	High	High	Low	None
20	La Estrella	High	High	Low	None
21	La Potra	High	High	Low	None
22	La Yeguada	Moderate	High	Moderate	None
23	Las Cruces	Moderate	High	Moderate	None
24	Lorena	High	High	Low	None
25	M. Monte	High	High	Low	None
26	Los Valles	High	High	Low	None
27	Macano	High	High	Low	None
28	Madden	Low	Moderate	Moderate	None
29	Mendre	High	High	Low	None
30	Mendre II	High	High	Low	None
31	Mount Lirio	High	High	Low	None
32	Pando	High	High	Low	None
33	Paso Ancho	High	High	Low	None

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
34	Pedregalito I	High	High	Low	None
35	Pedregalito II	High	High	Low	None
36	Perlas Norte	High	High	Low	None
37	Perlas Sur	High	High	Low	None
38	Planetas I	High	High	Low	None
39	Planetas II	High	High	Low	None
40	Prudencia	High	High	Low	None
41	RP-490	High	High	Low	None
42	Salsipuedes	High	High	Low	None
43	San Andrés	High	High	Low	None
44	San Lorenzo	High	High	Low	None
45	Antón	Low	High	High	None
46	Hidrocandela	High	High	Low	None

Table A3.2 Solar power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Bejuco Solar	Low	Moderate	Moderate	None
1	Bugaba	High	High	Low	None
2	Caldera	High	High	Low	None
3	Chiriquí	High	High	Low	None
4	Coclé	Low	High	High	None
5	Coclé Solar 1	Low	High	High	None
6	David	High	High	Low	None
7	Divisa Solar	Low	High	High	None
8	Don Félix	Low	High	High	None
9	El Espinal	High	High	Low	None
10	El Fraile 2	Low	High	High	None
11	Estrella Solar	Low	High	High	None
12	Farallón II	Low	High	High	None
13	Ikako	High	High	Low	None
14	Ikako I	High	High	Low	None
15	Ikako II	High	High	Low	None
16	Ikako III	High	High	Low	None
17	Los Ángeles	High	High	Low	None

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
18	Milton	Low	High	High	None
19	Panasolar	Low	High	High	None
20	Paris	High	High	Moderate	None
21	Pocrí Solar	Moderate	High	Moderate	None
22	Santiago GEN	High	High	Moderate	None
23	Sarigua	High	High	Moderate	High
24	Sol Real	High	High	Low	None
25	Vista Alegre	Moderate	High	Moderate	None
26	ECOSOLAR I & II	Moderate	High	Moderate	None
27	Mayorca Solar	Moderate	High	Moderate	None
28	Pese Solar	Moderate	High	Moderate	None
29	PROGSOL20	Moderate	High	Moderate	None
30	Jaguito Sol	Moderate	High	Moderate	None
31	Parque Solar Prudencia	Moderate	High	Moderate	None
32	Sboqueron	Moderate	High	Moderate	None
33	SolPac	Moderate	High	Moderate	None
34	Caoba Solar	Moderate	High	Moderate	None
35	Cedro Solar	Moderate	High	Moderate	None
36	Daconan Solar Star	Moderate	High	Moderate	None
37	Macano Solar	High	High	Low	None
38	Madre Vieja Solar	High	High	Low	None
39	Penonomé	Low	High	High	None
40	Sunrise MasPV1	Low	Moderate	Moderate	None

Table A3.3 Wind power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Marañón	Low	High	High	None
1	Nuevo Chagres I	Low	High	High	None
2	Nuevo Chagres II	Low	High	High	None
3	Portobelo	Low	High	High	None
4	Rosa de los Vientos I	Low	High	High	None
5	Rosa de los Vientos II	Low	High	High	None
6	Toabré	Low	High	High	None

Table A3.4 Thermal power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
0	ACP	Low	Moderate	Moderate	None
1	BLM	Low	Moderate	Moderate	None
2	Cativá	Low	Moderate	Moderate	None
3	Cobre Panamá	Low	Moderate	Moderate	None
4	Costa Norte	Low	Moderate	Moderate	None
5	Esperanza	Low	Moderate	Moderate	None
6	Estrella de Mar	Low	Moderate	Moderate	None
7	Jinro Power	Low	Moderate	Moderate	None
8	Pacora	Low	Moderate	Moderate	None
9	Panam	Low	Moderate	Moderate	None
10	Termocolón	Low	Moderate	Moderate	None
11	Tropitérmica	Low	Moderate	Moderate	None
12	Urbalia Panama	Low	Moderate	Moderate	None
13	Sparkle Power	Low	Moderate	Moderate	None

Table A3.5 Substations

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
0	Chorrera	Low	Moderate	Moderate	None
1	Llano Sánchez	High	High	High	None
2	Mata de Nance	High	High	Low	None
3	Progreso	High	High	Low	None
4	Chanquinola	Moderate	Moderate	Low	None
5	San Bartolo	Moderate	High	Low	None
6	Panamá	Low	Moderate	Moderate	None
7	Panamá II	Low	Moderate	Moderate	None
8	Boquerón 3	High	High	Low	None
9	Caldera	High	High	Low	None
10	Charco Azul	High	High	Low	None
11	La Estrella	High	High	Low	None
12	Los Valles	High	High	Low	None
13	Fortuna	High	High	Low	None
14	Esperanza	Moderate	Moderate	Low	None
15	Bella Vista	High	High	Low	None

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
16	El Coco	High	High	High	None
17	24 de Diciembre	Low	Moderate	Moderate	None
18	Pacora	Low	Moderate	Moderate	None
19	Bayano	Low	Moderate	Moderate	None
20	Chilibre	Low	Moderate	Moderate	None
21	Cemento Panamá	Low	Moderate	Moderate	None
22	Cativa II	Low	Moderate	Moderate	None
23	Las Minas 2	Low	Moderate	Moderate	None
24	Las Minas 1	Low	Moderate	Moderate	None
25	Cáceres	Low	Moderate	Moderate	None
26	Santa Rita	Low	Moderate	Moderate	None
27	Guaquitas	High	High	Low	None
28	Veladero	High	High	Low	None
29	Cañazas	Moderate	High	Low	None
30	El Higo	High	Moderate	Moderate	None

Table A3.6 Hydrocarbon terminal ports

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	COASSA	Low	Moderate	Moderate	Moderate
1	Decal Panama	Low	Moderate	Moderate	High
2	Melones Oil Terminal	Low	Moderate	Moderate	High
3	POTSA Balboa	Low	Moderate	Moderate	Moderate
4	POTSA Cristóbal	Low	Moderate	Moderate	None
5	Payardi	Low	Moderate	Moderate	None
6	PATSA	Low	Moderate	Moderate	Moderate
7	PETROPORT	Low	Moderate	Moderate	None
8	Charco Azul	High	High	Low	Moderate
9	Chiriquí Grande	Moderate	Moderate	Low	Moderate
10	AES Colón	Low	Moderate	Moderate	None

ANNEX 4. PLANNED INFRASTRUCTURE EXPOSURE TO CLIMATE HAZARD

Table A4.1 Hydroelectric power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	El Alto G4	High	High	Low	None
1	Chuspa	High	High	Low	None
2	Colorado	High	High	Low	None
3	San Bartolo	Moderate	High	Moderate	None
4	San Bartolo Minicentral	Moderate	High	Moderate	None
5	El Sindigo	High	High	Low	None
6	La Herradura	Moderate	High	Moderate	None
7	Barriles	High	High	Low	None
8	Cotito	High	High	Low	None
9	Burica	High	High	Low	None
10	Terra 4-Tizingal	High	High	Low	None
11	El Recodo	High	High	Low	None
12	Changuinola II	Moderate	Moderate	Low	None
13	Changuinola II Unidad 3	Moderate	Moderate	Low	None
14	Caña Blanca	High	High	Low	None

Table A4.2 Solar power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME CENTRAL	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Pacora II - 1	Low	Moderate	Moderate	None
1	Daconan	Moderate	High	Moderate	None
2	Penonomé	Low	High	High	None
3	Cedro	High	High	Low	None
4	Caoba	High	High	Low	None
5	Pesé	High	High	Low	None
6	Mayorca	High	High	Low	None
7	Farallón 2	High	High	Low	None
8	Llano Sánchez	Low	High	High	None
9	La Esperanza	High	High	Low	None
10	Panasolar II	Low	High	High	None
11	Panasolar III	Low	High	High	None
12	Pedregalito	High	High	Low	None

		LEVEL OF EXPOSURE TO THREAT			
	NAME CENTRAL	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
13	RPM Caizán 01	High	High	Low	None
14	RPM Caizán 02	High	High	Low	Moderate
15	Jagüito	Low	High	High	None
16	Providencia 1	Low	Moderate	Moderate	None
17	Celsia Prudencia	High	High	Low	None
18	La Victoria	High	High	Low	High
19	Cerro Viejo	Low	Moderate	Moderate	None
20	Mendoza	Low	Moderate	Moderate	None
21	Los Santos	High	High	Low	None
22	Estí I	High	High	Low	None
23	RPM Caizán 03	High	High	Low	None
24	RPM Caizán 04	High	High	Low	None
25	Baco Solar	High	High	Low	None
26	Madre Vieja	High	High	Low	None
27	La Salamanca	Moderate	High	Moderate	None
28	El Chumical I	Moderate	High	Moderate	None
29	El Coco	Low	High	High	None
30	Agua Fría	Low	High	High	None
31	Las Lajas	Low	High	High	None
32	La Mata 1	Moderate	High	Moderate	None
33	La Mata 2	Moderate	High	Moderate	None
34	La Mata 3	Moderate	High	Moderate	None
35	Bajo Frío	Low	Moderate	Moderate	None
36	Camarones	Low	Moderate	Moderate	None
37	Antón 01	Low	High	High	None
38	Progreso 01	High	High	Low	None
39	Progreso 02	High	High	Low	None
40	Pacora II - 2	Low	Moderate	Moderate	None
41	Gualaca 01	High	High	Low	None
42	Gualaca 02	Low	High	Low	None
43	Gualaca 03	Low	High	Low	None
44	Gualaca 04	Low	High	Low	None
45	Progreso 03	High	High	Low	None
46	Pacora 01	Low	Moderate	Moderate	None
47	Aguadulce 01	Low	High	High	None
48	Las Lomas 01	High	High	Low	None
49	Boquerón 01	High	High	Low	None

		LEVEL OF EXPOSURE TO THREAT			
	NAME CENTRAL	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
50	Progreso 05	High	High	Low	None
51	El Roble 01	Low	High	High	None
52	El Roble 02	Low	High	High	None
53	El Roble 03	Low	High	High	None
54	Nata 01	Low	High	High	None
55	Nata 02	Low	High	High	None
56	Nata 03	Low	High	High	None
57	Nata 04	Low	High	High	Moderate
58	Nata 05	Low	High	High	Moderate
59	Juan Díaz 01	Low	High	High	None
60	Gualaca 05	High	High	Low	None
61	Progreso 04	High	High	Low	None
62	Los Santos II	High	High	Low	None
63	Los Santos III	High	High	Low	None
64	Pedasí	High	High	Low	None
65	Corotú	High	High	Low	None

Table A4.3 Wind power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Toabré 1	Low	High	High	None
1	Toabré 2	Low	High	High	None
2	Nuevo Chagres Fase 2 - 2	Low	Moderate	Moderate	None
3	Portobelo Etapa 2 C	Low	Moderate	Moderate	None
4	Escudero	Moderate	High	Moderate	None
5	Toabré 3	Low	High	High	None
6	Antón	Low	High	High	None
7	Viento Sur	Moderate	High	Moderate	None
8	Paja de Sombrero	High	High	Low	None
9	Santa Cruz	Low	High	High	None
10	Pacora	Low	Moderate	Moderate	None
11	Líbano	Low	Moderate	Moderate	None
12	El Cuay	Moderate	High	Moderate	None
13	Hornito	High	High	Low	None
14	El Salado	Low	High	Moderate	Moderate
15	Santa Fe	Moderate	High	Moderate	None

Table A4.4 Thermal power plants

		LEVEL OF EXPOSURE TO THREAT			
	NAME OF POWER PLANT (AUTHORISED)	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	GTPP	Low	Moderate	Moderate	Low
1	T.C. Gatún	Low	Moderate	Moderate	None

ANNEX 5. CLIMATE RISK – EXISTING INFRASTRUCTURE

Table A5.1 Hydroelectric power plant risk

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Algarrobos	High	High	Low	None
1	Baitún	High	High	Low	None
2	Bajo delTotuma	High	High	Low	None
3	Bajo Mina	High	High	Low	None
4	Barro Blanco	High	High	Low	None
5	Bayano	Low	High	Moderate	None
6	Bonyic	High	High	Low	None
7	Bugaba I	High	High	Low	None
8	Bugaba II	High	High	Low	None
9	Changuinola	High	High	Low	None
10	Cochea	High	High	Low	None
11	Concepción	High	High	Low	None
12	Dolega	High	High	Low	None
13	El Alto	High	High	Low	None
14	Estí	High	High	Low	None
15	Fortuna	High	High	Low	None
16	Fraile	Low	High	High	None
17	Gatún	Low	High	Moderate	None
18	Gualaca	High	High	Low	None
19	La Cuchilla	High	High	Low	None
20	La Estrella	High	High	Low	None
21	La Potra	High	High	Low	None
22	La Yeguada	High	High	Moderate	None
23	Las Cruces	High	High	Moderate	None
24	Lorena	High	High	Low	None
25	Los Valles	High	High	Low	None
26	M. Monte	High	High	Low	None
27	Macano	High	High	Low	None
28	Madden	Low	High	Moderate	None
29	Mendre	High	High	Low	None
30	Mendre II	High	High	Low	None
31	Monte Lirio	High	High	Low	None
32	Pando	High	High	Low	None
33	Paso Ancho	High	High	Low	None

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
34	Pedregalito I	High	High	Low	None
35	Pedregalito II	High	High	Low	None
36	Perlas Norte	High	High	Low	None
37	Perlas Sur	High	High	Low	None
38	Planetas I	High	High	Low	None
39	Planetas II	High	High	Low	None
40	Prudencia	High	High	Low	None
41	RP-490	High	High	Low	None
42	Salsipuedes	High	High	Low	None
43	San Andrés	High	High	Low	None
44	San Lorenzo	High	High	Low	None
45	Antón	Low	High	High	None
46	Hidrocandela	High	High	Low	None

Table A5.2 Solar power plant risk

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Bejuco Solar	Low	Moderate	Moderate	None
1	Bugaba	Low	Moderate	Low	None
2	Caldera	Low	Moderate	Low	None
3	Chiriquí	Low	Moderate	Low	None
4	Coclé	Low	Moderate	Moderate	None
5	Coclé Solar 1	Low	Moderate	Moderate	None
6	David	Low	Moderate	Low	None
7	Divisa Solar	Low	Moderate	Moderate	None
8	Don Félix	Low	Moderate	Moderate	None
9	El Espinal	Low	Moderate	Low	None
10	El Fraile 2	Low	Moderate	Moderate	None
11	Estrella Solar	Low	Moderate	Moderate	None
12	Farallon II	Low	Moderate	Moderate	None
13	Ikako	Low	Moderate	Low	None
14	Ikako I	Low	Moderate	Low	None
15	Ikako II	Low	Moderate	Low	None
16	Ikako III	Low	Moderate	Low	None
17	Los Ángeles	Low	Moderate	Low	None

		CLIMATE RISK			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
18	Milton	Low	Moderate	Moderate	None
19	Panasolar	Low	Moderate	Moderate	None
20	Paris	Low	Moderate	Moderate	None
21	Pocrí Solar	Low	Moderate	Moderate	None
22	Santiago GEN	Low	Moderate	Moderate	None
23	Sarigua	Low	Moderate	Moderate	Moderate
24	Sol Real	Low	Moderate	Low	None
25	Vista Alegre	Low	Moderate	Moderate	None
26	ECOSOLAR I & II	Low	Moderate	Moderate	None
27	Mayorca Solar	Low	Moderate	Moderate	None
28	Pese Solar	Low	Moderate	Moderate	None
29	PROGSOL20	Low	Moderate	Moderate	None
30	Jaguito Sol	Low	Moderate	Moderate	None
31	Parque Solar Prudencia	Low	Moderate	Moderate	None
32	Sboqueron	Low	Moderate	Moderate	None
33	SolPac	Low	Moderate	Moderate	None
34	CaobaSolar	Low	Moderate	Moderate	None
35	Cedro Solar	Low	Moderate	Moderate	None
36	Daconan Solar Star	Low	Moderate	Moderate	None
37	Macano Solar	Low	Moderate	Low	None
38	Madre Vieja	Low	Moderate	Low	None
39	Penonomé	Low	Moderate	Moderate	None
40	Sunrise MasPV1	Low	Moderate	Moderate	None

Table A5.3 Wind power plant risk

		CLIMATE RISK			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
0	Marañón	Low	Low	Low	None
1	Nuevo Chagres I	Low	Low	Low	None
2	Nuevo Chagres II	Low	Low	Low	None
3	Portobelo	Low	Low	Low	None
4	Rosa de los Vientos I	Low	Low	Low	None
5	Rosa de los Vientos II	Low	Low	Low	None
6	Toabré	Low	Low	Low	None

Table A5.4 Thermal power plant risk

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	ACP	Low	Low	Moderate	None
1	BLM	Low	Low	Moderate	None
2	Cativá	Low	Low	Moderate	None
3	Cobre Panamá	Low	Low	Moderate	None
4	Costa Norte	Low	Low	Moderate	None
5	Esperanza	Low	Low	Moderate	None
6	Estrella de Mar	Low	Low	Moderate	None
7	Jinro Power	Low	Low	Moderate	None
8	Pacora	Low	Low	Moderate	None
9	Panam	Low	Low	Moderate	None
10	Termocolón	Low	Low	Moderate	None
11	Tropitérmica	Low	Low	Moderate	None
12	Urbalia Panamá	Low	Low	Moderate	None
13	Sparkle Power	Low	Low	Moderate	None

Table A5.5 Substation risk

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Chorrera	Low	Low	Moderate	None
1	Llano Sánchez	High	Low	High	None
2	Mata de Nance	High	Low	Low	None
3	Progreso	High	Low	Low	None
4	Chanquinola	High	Low	Low	None
5	San Bartolo	High	Low	Low	None
6	Panamá	Low	Low	Moderate	None
7	Panamá II	Low	Low	Moderate	None
8	Boquerón3	High	Low	Low	None
9	Caldera	High	Low	Low	None
10	Charco Azul	High	Low	Low	None
11	La Estrella	High	Low	Low	None
12	Los Valles	High	Low	Low	None
13	Fortuna	High	Low	Low	None
14	Esperanza	High	Low	Low	None
15	Bella Vista	High	Low	Low	None

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
16	El Coco	High	Low	High	None
17	24 de Diciembre	Low	Low	Moderate	None
18	Pacora	Low	Low	Moderate	None
19	Bayano	Low	Low	Moderate	None
20	Chilibre	Low	Low	Moderate	None
21	Cemento Panamá	Low	Low	Moderate	None
22	Cativa II	Low	Low	Moderate	None
23	Las Minas 2	Low	Low	Moderate	None
24	Las Minas 1	Low	Low	Moderate	None
25	Cáceres	Low	Low	Moderate	None
26	Santa Rita	Low	Low	Moderate	None
27	Guaquitas	High	Low	Low	None
28	Veladero	High	Low	Low	None
29	Cañazas	High	Low	Low	None
30	El Higo	High	Low	Moderate	None

Table A5.6 Hydrocarbon terminal ports

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	COASSA	Low	Low	Moderate	High
1	Decal Panamá	Low	Low	Moderate	High
2	Melones Oil Terminal	Low	Low	Moderate	High
3	POTSA Balboa	Low	Low	Moderate	High
4	POTSA Cristóbal	Low	Low	Moderate	None
5	Payardi	Low	Low	Moderate	None
6	PATSA	Low	Low	Moderate	High
7	PETROPORT	Low	Low	Moderate	None
8	Charco Azul	High	Low	Low	High
9	Chiriquí Grande	High	Low	Low	High
10	AES Colón	Low	Low	Moderate	None

ANNEX 6. CLIMATE RISK – PLANNED INFRASTRUCTURE

Table A6.1 Hydroelectric power plants

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	El Alto G4	High	High	Low	None
1	Chuspa	High	High	Low	None
2	Colorado	High	High	Low	None
3	San Bartolo	High	High	Moderate	None
4	San Bartolo Minicentral	High	High	Moderate	None
5	The Sindigo	High	High	Low	None
6	La Herradura	High	High	Moderate	None
7	Barriles	High	High	Low	None
8	Cotito	High	High	Low	None
9	Burica	High	High	Low	None
10	Terra 4-Tizingal	High	High	Low	None
11	El Recodo	High	High	Low	None
12	Changuinola II	High	High	Low	None
13	Changuinola II Unidad 3	High	High	Low	None
14	Caña Blanca	High	High	Low	None

Table A6.2 Solar power plant

		CLIMATE RISK			
	NAME OF POWER PLANT	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	Pacora II - 1	Low	Moderate	Moderate	None
1	Daconan	Low	Moderate	Moderate	None
2	Penonomé	Low	Moderate	Moderate	None
3	Cedro	Low	Moderate	Low	None
4	Caoba	Low	Moderate	Low	None
5	Pesé	Low	Moderate	Low	None
6	Mayorca	Low	Moderate	Low	None
7	Farallón 2	Low	Moderate	Low	None
8	Llano Sánchez	Low	Moderate	Moderate	None
9	La Esperanza	Low	Moderate	Low	None
10	Panasolar II	Low	Moderate	Moderate	None
11	Panasolar III	Low	Moderate	Moderate	None
12	Pedregalito	Low	Moderate	Low	None

		CLIMATE RISK			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
13	RPM Caizán 01	Low	Moderate	Low	None
14	RPM Caizán 02	Low	Moderate	Low	Moderate
15	Jagüito	Low	Moderate	Moderate	None
16	Providencia 1	Low	Moderate	Moderate	None
17	Celsia Prudencia	Low	Moderate	Low	None
18	La Victoria	Low	Moderate	Low	Moderate
19	Cerro Viejo	Low	Moderate	Moderate	None
20	Mendoza	Low	Moderate	Moderate	None
21	Los Santos	Low	Moderate	Low	None
22	Estí I	Low	Moderate	Low	None
23	RPM Caizán 03	Low	Moderate	Low	None
24	RPM Caizán 04	Low	Moderate	Low	None
25	Baco Solar	Low	Moderate	Low	None
26	Madre Vieja	Low	Moderate	Low	None
27	La Salamanca	Low	Moderate	Moderate	None
28	El Chumical I	Low	Moderate	Moderate	None
29	El Coco	Low	Moderate	Moderate	None
30	Agua Fría	Low	Moderate	Moderate	None
31	Las Lajas	Low	Moderate	Moderate	None
32	La Mata 1	Low	Moderate	Moderate	None
33	La Mata 2	Low	Moderate	Moderate	None
34	La Mata 3	Low	Moderate	Moderate	None
35	Bajo Frío	Low	Moderate	Moderate	None
36	Camarones	Low	Moderate	Moderate	None
37	Antón 01	Low	Moderate	Moderate	None
38	Progreso 01	Low	Moderate	Low	None
39	Progreso 02	Low	Moderate	Low	None
40	Pacora II - 2	Low	Moderate	Moderate	None
41	Gualaca 01	Low	Moderate	Low	None
42	Gualaca 02	Low	Moderate	Low	None
43	Gualaca 03	Low	Moderate	Low	None
44	Gualaca 04	Low	Moderate	Low	None
45	Progreso 03	Low	Moderate	Low	None
46	Pacora 01	Low	Moderate	Moderate	None
47	Aguadulce 01	Low	Moderate	Moderate	None
48	Las Lomas 01	Low	Moderate	Low	None
49	Boquerón 01	Low	Moderate	Low	None

		CLIMATE RISK			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
50	Progreso 05	Low	Moderate	Low	None
51	El Roble 01	Low	Moderate	Moderate	None
52	El Roble 02	Low	Moderate	Moderate	None
53	El Roble 03	Low	Moderate	Moderate	None
54	Nata 01	Low	Moderate	Moderate	None
55	Nata 02	Low	Moderate	Moderate	None
56	Nata 03	Low	Moderate	Moderate	None
57	Nata 04	Low	Moderate	Moderate	Moderate
58	Nata 05	Low	Moderate	Moderate	Moderate
59	Juan Díaz 01	Low	Moderate	Moderate	None
60	Gualaca 05	Low	Moderate	Low	None
61	Progreso 04	Low	Moderate	Low	None
62	Los Santos II	Low	Moderate	Low	None
63	Los Santos III	Low	Moderate	Low	None
64	Pedasí	Low	Moderate	Low	None
65	Corotú	Low	Moderate	Low	None

Table A6.3 Wind power plant

		CLIMATE RISK			
	NAME OF POWER PLANT	**FLOODING**	**DROUGHT**	**EXTREME HEAT**	**SEA LEVEL RISE**
0	Toabré 1	Low	Low	Low	None
1	Toabré 2	Low	Low	Low	None
2	Nuevo Chagres Fase 2 - 2	Low	Low	Low	None
3	Portobelo Fase 2 C	Low	Low	Low	None
4	Escudero	Low	Low	Low	None
5	Toabré 3	Low	Low	Low	None
6	Antón	Low	Low	Low	None
7	Viento Sur	Low	Low	Low	None
8	Paja de Sombrero	Low	Low	Low	None
9	Santa Cruz	Low	Low	Low	None
10	Pacora	Low	Low	Low	None
11	Líbano	Low	Low	Low	None
12	El Cuay	Low	Low	Low	None
13	Hornito	Low	Low	Low	None
14	El Salado	Low	Low	Low	Low
15	Santa Fe	Low	Low	Low	None

Table A6.4 Thermal power plant

		CLIMATE RISK			
	NAME POWER PLANT (AUTHORISED)	FLOODING	DROUGHT	EXTREME HEAT	SEA LEVEL RISE
0	GTPP	Low	Low	Moderate	Low
1	Gatun T.C.	Low	Low	Moderate	None

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