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VUNERABILITY AND RISK OF THE ENERGY SYSTEMS OF LATIN AMERICA AND THE CARIBBEAN IN THE FACE OF THE THREATS OF CLIMATE CHANGE

Cooperación Española
MEDIO AMBIENTE / ARAUCLIMA

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VUNERABILITY AND RISK OF THE ENERGY SYSTEMS OF LATIN AMERICA AND THE CARIBBEAN IN THE FACE OF THE THREATS OF CLIMATE CHANGE.

1. INTRODUCTION

Based on the warning given by experts on the imperative need to keep global warming below 2 °C to avoid catastrophic consequences that threaten the sustainability of the next generations, which became evident during the COP 21 in 2015 and led to the signing of the Paris Agreement in 2016, all countries subscribing to this agreement, committed to undertake or accelerate their policies of decarbonization of their economies, to contribute to the global goal of reaching 2050 with zero carbon emissions to the atmosphere, an initiative known as NET ZERO 2050.

Within the framework of this Agreement, each of the subscribing countries proceeded to prepare their National Determined Contributions or NDCs, establishing goals and commitments for cleaner and sustainable development in the medium and long term and to reorient their public policies towards the fulfillment of these goals. LAC countries were no exception, implementing actions in this regard in the different socio-economic sectors. Specifically in the energy sector, the increased use of renewable sources and the increase in the rate of energy efficiency have been promoted.

Although the region's position is consistent with the global situation, the impact of its actions with respect to the global objective of climate change mitigation is relatively low, considering that the entire LAC region contributes only about 8% of the planet's total CO_2e emissions and its energy sector contributes only 3.5%. However, despite this low responsibility for global warming, the region has decidedly opted for renewable energy. As a result of this trend, their national energy systems can be very sensitive to the effects of climate change, with risks of both productivity losses and infrastructure stability and integrity.

In this context, the member countries of OLADE, through different ministerial decisions, have instructed this Organization to manage and execute studies related to adaptation of the energy sector to climate change. Under this directive, OLADE, with the financial support of its multilateral cooperating partners, has carried out or participated in projects such as: "Vulnerability to climate change of hydroelectric production systems in Central America and their adaptation options", "Vulnerability to climate change and adaptation measures of hydroelectric systems in Andean countries", "Evaluation of the impact of climate change on electricity generation in Southern Cone countries", and the study "Incidence of climate change on energy planning: Screening for the global assessment of vulnerability and climate risks of the energy system in Latin America and the Caribbean - Screen-ALC", being a summary of the methodology and results of the latter, the subject to be addressed in this article.

2. GENERAL DATA OF THE SCREEN- ALC PROJECT

2.1. Objective

Increase the resilience of the energy sector in Latin America and the Caribbean to climate change by analyzing the risks and vulnerability of infrastructure and determining the changes that must be implemented in the planning and operation of the systems, making it possible to establish differentiated priorities in the definition of energy plans and adaptation and resilience strategies.

2.2. Cooperating entity

The study was carried out thanks to funding from the Spanish Agency for International Development Cooperation AECID, within the framework of the ARAUCLIMA Program.

2.3. Participating countries:

The project actively involved 12 countries in the LAC region members of OLADE: Argentina, Bolivia, Brazil, Chile, Ecuador, El Salvador, Honduras, Panama, Paraguay, Peru, Dominican Republic and Uruguay.

2.4. Technical assistance

For the execution of the project, OLADE had the technical assistance of the Tecnalia Foundation, a center specialized in science and technology.

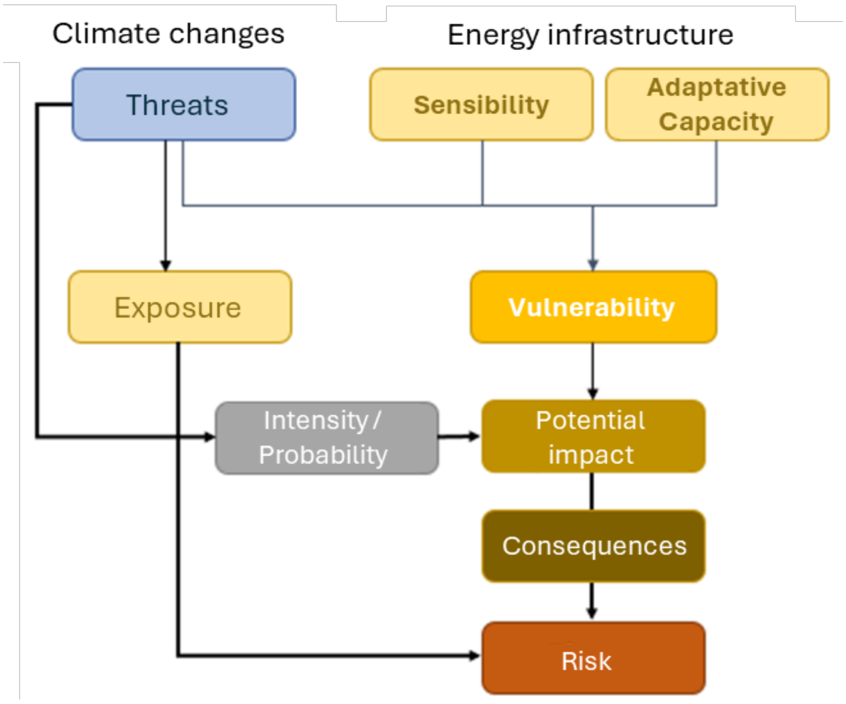
2.5. Implementation period

The project was executed between 2020 and 2021. With a duration of 21 months.

3. METHODOLOGY OVERVIEW

The methodology proposed for the study covers the analysis of each of the aspects that make up the term "RISK". Following the recommendations of the Intergovernmental Panel on Climate Change (IPCC), risk is defined by the relationship between threats associated with climate, the exposure of systems to them and their vulnerability. Figure 1 below outlines the relationship between the different components involved.

Figure 1. General methodology aspects



Source: Screen-ALC Project Final Report, Tecnalia, 2021

Within this conceptual framework, the methodology has been divided into four stages:

I. Characterization of the threat of climate change.
II. Analysis of exposure and vulnerability of the energy sector to climate change.
III. Potential impact assessment.
IV. Preliminary risk assessment.

3.1. Characterization of the threat of climate change.

The objectives of this stage are to define the climate scenarios to be analyzed and to download and process the data to obtain, as a result, the climate indicators that will be used to estimate the most critical hazards and the potential impact of climate change on the infrastructure under study.

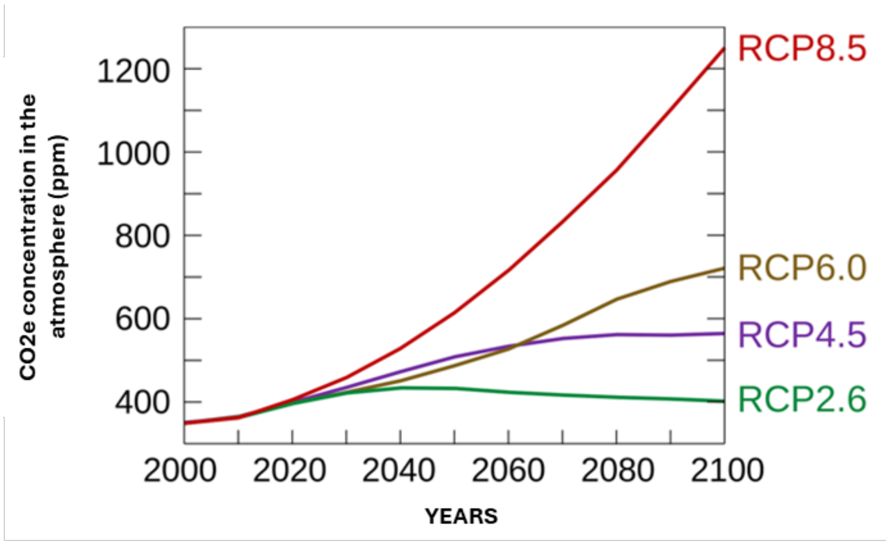
The availability of information in climate databases (level of information available and its quality) determines the scope of this stage, defining aspects such as scenarios (time horizons, RCP), resolution and models to be used. Current knowledge gaps require in many cases qualitative approaches, the use of scenarios and the making of hypotheses or assumptions.

At present, it is not known how the planet will evolve socioeconomically or what the trajectory of greenhouse gas (GHG) concentrations in the atmosphere will be like, nor whether the models that generate climate and extreme hazard projections are sufficiently accurate. It is therefore important to be aware of these uncertainties and to present and interpret them in a transparent manner, and to manage them appropriately. For this reason, different scenarios are studied and a range of possible risk valuations are provided.

To define the climate scenarios to be analyzed, for each climate variable or ECV[1], a study of all available combinations of models, RCPs[2] and time horizons is carried out in order to homogenize the scenarios for all the variables considered in the study.

Specifically for this study, the climate scenarios selected for analysis were RCP 4.5, as a scenario of average evolution of global temperature and the rest of the processes associated with climate change, and RCP 8.5, as a scenario of a sharp increase in global temperature with drastic repercussions on a large part of the natural and human systems.

Figure 2. Representative concentration trajectories (RCPs)



Source: Screen-ALC Project Final Report, Tecnalia, 2021

As a general criterion, several future scenarios and a reference (historical) scenario are used for comparison purposes. It is also important to evaluate periods that are sufficiently long to capture inter- and intra-annual variability. In this case, 30-year periods are managed.

On the other hand, for risk quantification, it is necessary to specify and calculate, for each ECV, the climate indicators that will condition the impact and how these are modified with respect to certain scales and critical thresholds defined on the basis of historical information and estimates. It is not enough to specify that a change in ambient temperature (ECV) has an impact on a certain element, but to quantify it, it is necessary to specify whether it is the change in average, maximum or minimum temperature (climate indicator) that has that effect. The definition of

[1] "Essential Climate Variable" is the term given to each of the physical, biological or chemical variables (or a set of such variables) that contribute critically to the characterization of the global climate.
[2] "Representative Concentration Pathway" describes different possible climate futures depending on the volume of greenhouse gases (GHG) emitted and captured in the coming years and the effect that their accumulation in the atmosphere would have in terms of global warming.

these climate indicators is entirely conditioned by the characterization of sensitivity and impact indices and are accompanied in many cases by "threshold" values that define the range of values in which impacts are observed.

For this particular study, ECV observations were obtained from reanalysis datasets such as ERA5-Land[3] and ERA5[4], while regional climate model ensembles from the CORDEX project[5] nested to global models from the CMIP5 project were used for their forward projections, as can be seen in the following table:

Table1. Relationship between climate variables and reanalysis data sets and climate models.

CLIMATE VARIABLE	OBSERVATION	PROJECTION
TEMPERATURE ON THE GROUND	ERA5-LAND	CORDEX
SEA TEMPERATURE	ERA5	CMIP5
WIND SPEED	ERA5-LAND	CORDEX
SOLAR RADIATION	ERA5-LAND	CMIP5
WATER SUPPLY	AQUEDUCT	AQUEDUCT

Source: Screen-ALC Project Final Report, Tecnalia, 2021

In the case of hydrological information, where the output of global and regional models does not allow us to estimate impacts on the hydrological cycle adequately, the data provided by the Aqueduct project were used[6].

3.2. Analysis of the exposure and vulnerability of the energy sector to climate change

In the area of climate change, vulnerability can be defined as the propensity or predisposition of an element to be negatively affected by climate change and depends on the sensitivity or susceptibility to damage of the element itself and its lack of capacity to cope and adapt. Applying it to the energy sector, in order to assess its vulnerability, it is necessary to know which elements compose it and its characteristics (which will define its sensitivity and adaptive capacity) and its exposure to the threats caused by climate change. The steps involved in this process are described below.

3.2.1. Preliminary identification of existing energy technologies in the study area.

In order to define the scope of the vulnerability analysis, it is necessary to know the particularities of the sector under study in each of the participating countries. Taking into account the entire energy chain (procurement, treatment and storage of raw materials, energy generation, transportation and distribution of fuels and electricity), a list of technologies or types

[3] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-land?tab=overview
[4] https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5
[5] https://cordex.org/
[6] https://www.wri.org/aqueduct

of infrastructure for which the sensitivity to climate change will be evaluated has been generated.

3.2.2. Sensitivity analysis

It begins with a bibliographic analysis of the sensitivity of the different technologies identified to any climate-induced hazards. Sensitivity defines whether a given element (technology/facility) could be affected by projected changes in climate variables if exposed to them, and how it would be affected (e.g., decreased performance, shutdown, plant closure, etc.). In some cases, the literature provides "impact indices" (standard values) that allow the magnitude of the impact to be quantified.

Como resultado de este análisis de sensibilidad, se ha generado una matriz que muestra, en filas, todas las tecnologías identificadas y, en columnas, todas las amenazas climáticas que podrían afectarles en caso de encontrarse expuestas. At the junction of the two, the way in which the threat could affect each element (impact on the resource, on the operation, on the integrity of the infrastructure, etc.) is described in summary form, adding, if available, a "type" impact index that allows quantifying the magnitude of such impact. This data is key, as it will condition the final scope of the study.

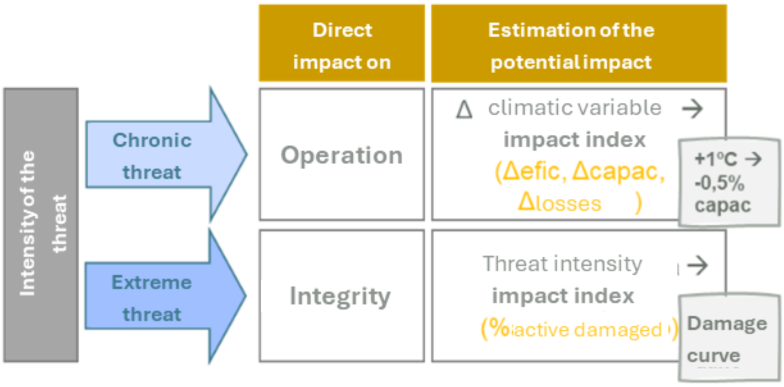
This first sensitivity study does not include information at the facility level (exposure of the infrastructure or specific characteristics that define its adaptive capacity) but allows filtering or prioritizing for each type of technology, the threats for which it could show a high degree of sensitivity.

3.3. Potential impact assessment

The quantification of the potential impact is based on "type-specific impact indexes", obtained from specialized bibliography for each technology or type of infrastructure. These relate, for each technology, the magnitude of the threat (for different future scenarios) to the magnitude of the impact or damage caused. Two types of impact indexes have been used:

- Those that quantify an impact on the operation of a facility (effect on production, capacity), which are generally more related to chronic hazards such as changes in wind and precipitation patterns, etc.
- Those that quantify an impact on the physical integrity of a facility (damage to infrastructure), which are generally more closely linked to extreme hazards.

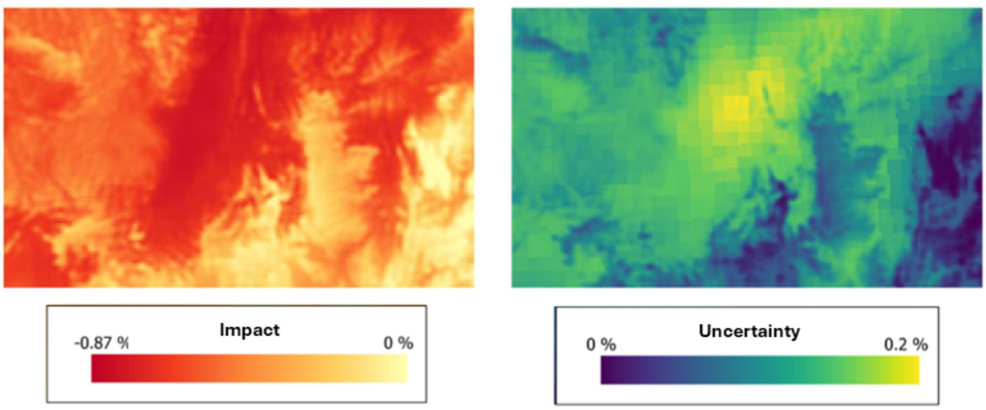
Figure 3. Methodology for estimating potential impact



Source: Screen-ALC Project Final Report, Tecnalia, 2021

The result of this impact assessment is a set of "raster" layers or "grids". For a given scenario, the impact that a given threat could have on a given technology (depending on where it is located) will be defined by pairs of layers: one showing the impact and the other showing the uncertainty (to be predicted). Figure 5 shows an example of the type of result that would be obtained. In this case, the potential impact that projected changes in ambient temperature would have, for a given future scenario, on solar photovoltaic installations located in the area shown is shown.

Figure 4. Example of potential impact layers: impact of ambient temperature increase on solar PV production/capacity



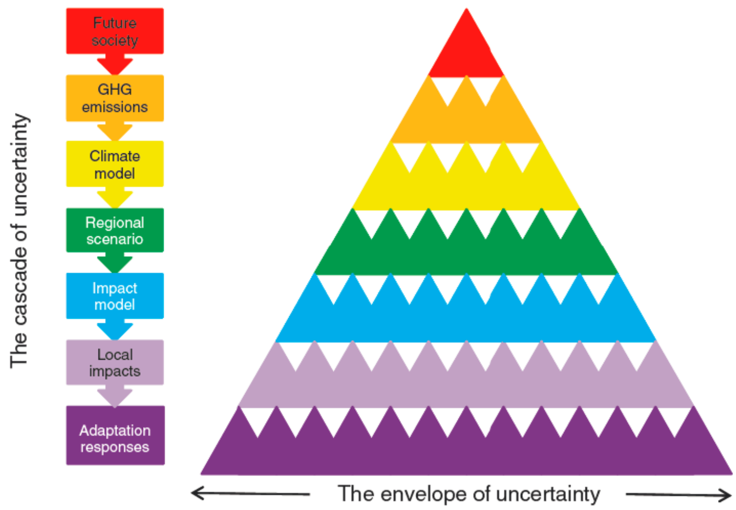
Source: Screen-ALC Project Final Report, Tecnalia, 2021

The image on the left shows the change that could occur in the production of the facility (in this case, there could be a reduction in production of between 0% and 0.87% depending on the exact location of the facility). The image on the right shows the uncertainty of these results (between ±0% and ±0.2%).

3.4. Preliminary risk assessment

This last stage includes a screening to identify the climate risk faced by each of the facilities included in the study in different future scenarios. This information will make it possible to prioritize future actions.

Figure 5. Cascade of uncertainties associated with climate risk assessment



Source: Screen-ALC Project Final Report, Tecnalia, 2021

To assess the risk, it is necessary to know the consequences of the potential impacts To assess the risk it is necessary to know the consequences of the occurrence of the potential impacts identified in the previous stage, i.e., how critical it may be for the energy system if a certain activity becomes inoperative. To this end, it is essential to know the contribution of each facility to the energy system by analyzing its energy activity (its power/capacity or the energy it produces, treats, consumes, distributes, etc., depending on the type of facility). This concept is included under the term "weight" of the installation.

Thus, to estimate the risk, the infrastructure layers (exposure) will be crossed with the potential impact layers and the "weight" of each installation will be applied, thus quantifying the "relative damage" to the energy system. The final result will be a series of tables/graphs showing the risk values obtained for the facilities analyzed in each of the future scenarios considered.

Figure 6. Preliminary risk estimation methodology

Source: Screen-ALC Project Final Report, Tecnalia, 2021

4. SENSITIVITY AND RISK BY TYPE OF ENERGY INSTALLATION

Based on the general methodological aspects described above and the detailed study of the different types of energy facilities, we obtained shades of sensitivity and risk to climate change for the different types of energy facilities analyzed, for the different essential climate variables (ECVs) and a prioritized sensitivity matrix from which we have extracted some examples presented below:

Table2. Prioritized sensitivity summary matrix.

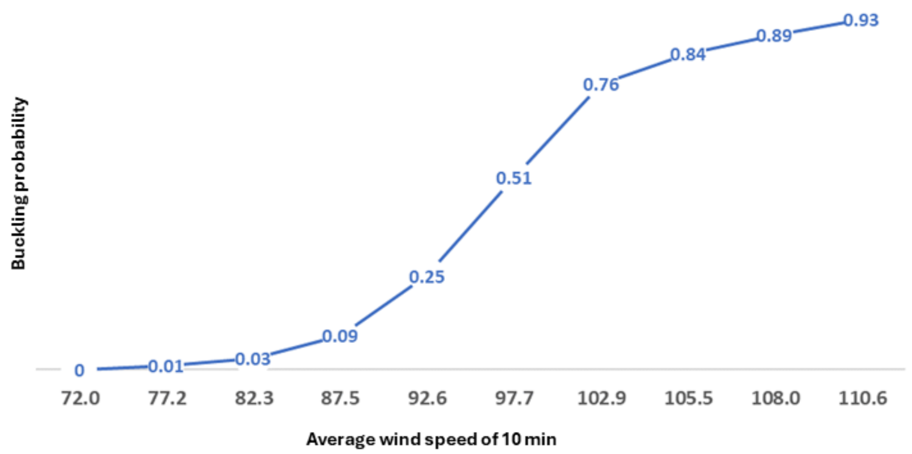
Climate variable	Indicator	Installation Type	Technology	Threshold	Sensitivity
Ambient temperature	Temperature change (absolute)	Photovoltaic power plant	Crystalline silicon	25°C	If it rises 1ºC above the threshold, energy production drops by 0.66%.
Ambient temperature	Temperature change (absolute)	Thermal power plant	Combined Cycle	15°C	If it increases by 1ºC, the effective capacity drops by 0.25%.
Ambient temperature	Temperature change (absolute)	Electricity transmission	Transmission Line	20 °C	If the temperature rises by 1ºC, the energy transported drops by 0.4%.
Ambient temperature	Temperature change (absolute)	Natural gas transportation	Gas pipeline		**Integrity:** rising temperatures can melt permafrost and cause ground subsidence, resulting in damage to pipelines. **Operation:** In pipeline transportation, possible reduction of pipeline transmission capacity. Gas expansion in conduits Possible supply safety problems if compressor

					stations are not designed to operate at elevated temperatures.
Ambient temperature	Temperature change (absolute)	Agro-energy farms (biofuel production)			Operation: Changes in temperature could increase or decrease the productivity of the raw material and thus the corresponding energy production. It could affect the area needed to grow the raw materials and the costs and, thus, the production of raw materials. There could be positive and negative impacts depending on the type of crop. for example, a reduction in frost would improve the productivity of sugarcane crops.
Seawater temperature	Temperature change (absolute)	Thermal power plant	Seawater cooling	5 °C	If it increases by 1ºC, energy production drops by 0.2%.
Radiation	Change in radiation (percentage)	Photovoltaic power plant	All		If it drops by 1%, energy production drops by 3%.
Wind	Change in average wind speed (absolute) at rotor height (assumed 100 meters)	Wind power plant	All	Between 1m/s and 25m/s	If the average wind speed drops by 1 m/s, energy production drops by 6.67%. If the average wind speed

					increases by 1 m/s, energy production increases by 6.67%.
Wind	Change in average wind speed (absolute)	Electricity transmission			If the average wind speed increases by 1m/s, the transport capacity increases by 20%
Flow	Change in Flow Rate (Percent)	Hydroelectric power plant			If the flow rate drops by 1%, the energy production may drop by 1%. If the flow rate increases by 1%, the energy production may increase by 1%.
Extreme wind	Extreme wind speed of 10 min at rotor height	Wind power plant	Active yaw systems		Damage curves Figure 7[7]

Source: Screen-ALC Project Final Report, Tecnalia, 2021

Figure 7. Damage curve of a wind power plant due to a wind gust



[7] For climatic variables that involve the probability of damage to the physical integrity of the infrastructure, the sensitivity is associated to a damage curve, which relates the magnitude of the variable to the probability of damage occurrence.

Source: Screen-ALC Project Final Report, Tecnalia, 2021

5. EXAMPLES OF PROPOSED ADAPTATION MEASURES

In addition to assessing the sensitivity, potential impact and risk of energy infrastructure to the effects of climate change, the study also included identifying possible adaptation measures that could be implemented according to the type of facility, technology and type of impact. Below are some examples of proposed adaptation measures.

Table3. Examples of proposed adaptation measures.

Risk	Proposed measure	Installation Type
Excessive increase in runoff and sediment inputs to watercourses and reservoirs.	Land use management: forest restoration. Adequate reforestation of watersheds reduces the risk of infrastructure damage and reservoir siltation.	Hydroelectric power plant
Increased water availability.	Increase the height of the dam and/or build new small dams upstream.	Hydroelectric power plant
Severe damage to the dam and generation equipment caused by extreme floods and increased maintenance requirements for facilities and reservoirs.	Improved flood forecasting methods to assess the adequacy of the infrastructure for the lifetime of the facility and to anticipate possible emergency situations. It will be necessary to manage quality information on future precipitation, storm and flood patterns, which could be modified by climate change. Regular monitoring of available climate information and models is key to ensure that the best available information is being used and to minimize uncertainty.	Hydroelectric power plant
Excessive change in the generation pattern due to changes in the resource resulting from climate change.	Introduce turbine designs more adapted to the new conditions, capable of operating over a wider range of wind speeds (e.g., vertical axis) and withstand higher wind speeds, gusts and changes in direction.	Wind power plant
Affect on production due to increase in ambient temperature.	Introduce more heat-resistant designs and module components designed to withstand high temperature peaks.	Photovoltaic power plant
Capacity impairment due to increased ambient temperature.	Use lines of materials that are more resistant to high temperatures.	Electrical networks
Increased frequency and severity of damage as a result of extreme storm and wind events.	Adapt designs to make them more robust (particularly offshore) by developing and implementing higher structural standards for new or	Fossil fuel extraction and transportation

	renovated buildings/infrastructure or by using stronger designs or materials (concrete instead of metal, for example).	
Decrease in plant efficiency as a result of excessive increase in ambient temperature resulting in loss of efficiency and production.	Adaptation of thermal power plants to ambient temperature increases by adding new elements (e.g., an additional chiller at the compressor inlet to improve the operation and performance of the gas turbine) or replacing existing systems with alternative ones (e.g., changing air-cooled systems to water-cooled or mixed systems, which are less affected by ambient temperature increases).	Thermoelectric power plants
Water from extreme weather events (overflowing rivers, waves, storms, etc.) or rising sea levels can reach and damage sensitive infrastructure.	Elevation or relocation of sensitive equipment or infrastructure to flood-protected locations.	Any facility located in flood zones

Source: Screen-ALC Project Final Report, Tecnalia, 2021

6. CONCLUSIONS

- Although energy facilities are designed to maintain their integrity during their useful life and operate efficiently according to the climatic conditions of their location, climate change can drastically alter these conditions, generating threats and risk of potential negative impacts, which can endanger both the physical integrity and productivity of such facilities, so it is necessary to include in their design studies and in the planning of their operation, a methodology to assess the inherent risks.

- Even for facilities that are already built and in operation, it is important to assess their vulnerability to potential climate change impacts and identify in advance possible adaptation measures to increase their resilience to such impacts.

- Considering that the electricity generation matrix of the Latin American and Caribbean region is predominantly dependent on direct energy sources such as hydropower, which in turn is highly dependent on climate, the sensitivity of this sector and its vulnerability to extreme climate variations are factors that must be evaluated and anticipated in order to take the corresponding adaptation measures to avoid energy shortages or even catastrophic events.

- Climate change projections not only point to notable impacts, but also to benefits for the sector, such as the increase of energy resources in certain areas, so that the analysis of the foreseeable evolution of climate variables has a high importance in planning.