Georgia – Bakhvi 2 HPP

Impacts on macro- and micro-climate

Date: 20.03.2022

Version: B

Reference: 18k33B

Prepared for: CCEH Hydro VII

CONTACT

Pierre Biedermann

Alpage EURL

38970 Les Côtes-de-Corps - France

Tel : + 33 7 68 112 137

pierre.biedermann@alpage-consult.com

VERSION

Version	Date	Reference	Comment	Status
A	14.03.2022	18k33A	-	First version
B	20.03.2022	18k33B	-	Final version after internal review

ABBREVIATIONS

E&S	Environmental & Social
ESIA	Environmental & Social Impact Assessment
GSE	Georgian State Electrosystem
HPP	Hydropower Project
ICOLD	International Commission on Large Dams
IFC	International Finance Cooperation
IFI	International Financial Institution
IUCN	International Union for Conservation of Nature
TL	Transmission Line

CONTENT

TABLES

FIGURES

PICTURES

Introduction

CCEH Hydro VII is developing the Bakhvi 2 Hydropower Project (HPP) (the “Project”) located on the Bakhvitskali river in the Guria Region of Georgia. Bakhvi 2 is located downstream the planned Bakhvi 1 HPP and upstream the existing Bakhvi 3 HPP on the Bakhvitskali river.

CCEH Hydro VII has an internal policy requirement to develop projects that meet the environmental and social requirements of the international Finance Corporation and of the European Investment Bank (the "Applicable E&S Requirements").

The aim of this report is to provide an assessment of macro- and microclimate impacts risks that could potentially be caused by Bakhvi 2 HPP, in Bakhvitskali river basin.

1 Definitions

1.1 Climate

In this report, "**climate**" is used to refer to the composite of generally prevailing weather conditions in a given region, such as temperature, air pressure, humidity, precipitation, sunshine, cloudiness, and winds, throughout the year, when considering a series of years.

The term "climate" does not have a strict scientific and universally recognized definition: however, the notion of "climate" is commonly understood as a reference to both average weather conditions and extreme meteorological events that occur in the considered area. More precisely, "climate" refers to the mean and variability of meteorological variables over a time spanning from months ("seasonal climate") to millions of years.

When describing a given "climate", it is essential to define the temporal and spatial boundaries that are considered, because climate is not temporally steady or geographically constant.

1.2 Global climate and macroclimate

"**Global climate**" is a term that refers to the climate prevailing on the Earth, without spatial limits.

Global climate is the resulting state from the interaction of five major components that form the "climate system": the atmosphere (air), the hydrosphere (water), the cryosphere (ice and permafrost), the lithosphere (earth's upper rocky layer) and the biosphere (living things).

Heat circulation in the atmosphere and oceans is primarily driven by solar radiation that transports heat from the tropical regions to regions that receive less energy from the Sun.

"**Macroclimate**" refers to the local representation of global climate over a defined region. The considered region can be as large as a significant portion of a continent (e.g. the Siberian climate) or a specific region of a country (Guria region climate).

Macroclimate is typically affected by the region's latitude/longitude, terrain, and altitude, as well as nearby water bodies and their currents, ice fields and glaciers. Consequently, in a region whose geography is not uniform, macroclimate can be a composite of areas with significantly different weather conditions.

1.3 Climate variability

"Climate variability" refers to the variations around the mean state of a given climate's characteristics, on all spatial and temporal scales. It does not refer to seasonal variations of the weather, that are a characteristic of the climate.

The assessment of a climate's variability typically looks at the likelihood for the occurrence of extreme events (droughts, heat waves…). A highly variable climate will have a higher occurrence of unusual events.

1.4 Climate change

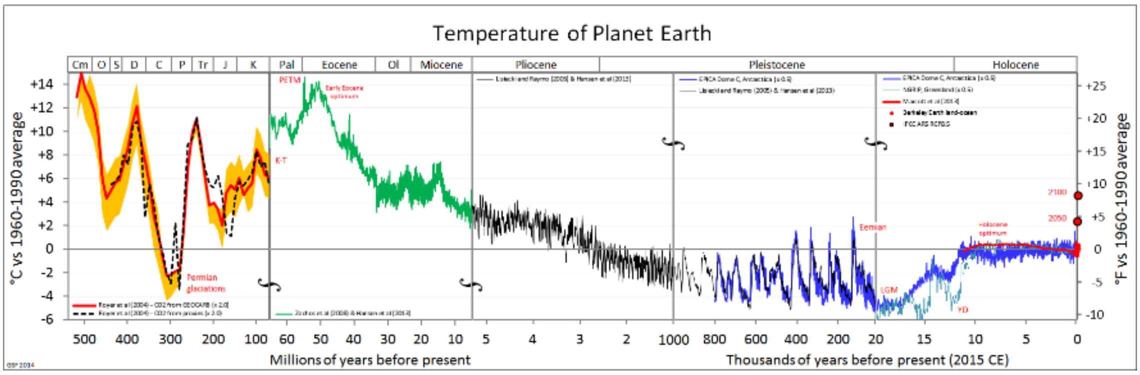
"Climate change" refers to the variations over time of the mean state or variability of a given climate's characteristics, within given spatial boundaries. It reflects changes in the atmosphere over time scales ranging from decades to millions of years.

Changes to the global climate have been driven during the first billions of years by processes internal to the Earth and variations in sunlight intensity.

The Earth's heat flow has had a significant influence on the global climate billions of years ago, but this is no more the case as the Earth progressively cooled down: the steady heat flow from the Earth (0.09 W/m²) represents only 0.026 % of the incoming solar radiation (341.3 W/m²).

Figure 1 shows estimates of global average surface air temperature over the last 540 million years, since the first major proliferation of complex life formed on our planet[1].

Figure 1 - Temperature of planet Earth

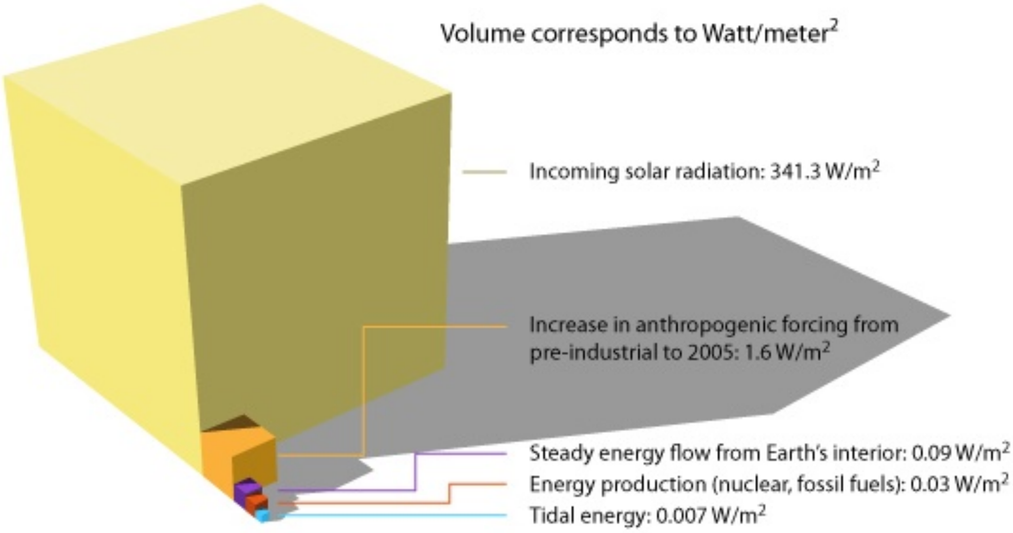


[1] Author: Glen Fergus – detailed data sources on https://commons.wikimedia.org/wiki/File:All_palaeotemps.png

From the 19th century, human activities have started influencing the climate through the release of greenhouse gases which had a global warming effect.

This is illustrated on Figure 2 that shows the present flows of energy from various sources [2] (the volumes of the cubes are proportional to the magnitude of the energy flows). The net increase in the amount of planetary energy flow arising from human activities (mainly the emission of carbon dioxide) since the industrial revolution is nowadays more than twenty times more than the steady-state heat flow from the Earth's interior.

Figure 2 - Comparison of energy inputs to Earth's climate system



1.5 Microclimate

"**Micro-climate**" is defined as the local set of atmospheric and weather conditions that prevail in a specific area, usually with a small extent. The term may refer to areas as small as a few square meters (for example a tree shade or a cave) or as large as several square kilometres.

Microclimates exist in many different forms, for example, near bodies of water or forests which may cool the local atmosphere, or in urbanized areas where brick, concrete, and asphalt absorb the sun's energy, heat up, and re-radiate that heat to the ambient air.

In areas with significant geographic variations (such as mountains), macro-climate's parameters may be subject to significant spatial variations and may actually form a set of microclimates. In this regard, it is important to keep in mind that the concept of micro-climate is always relative to the surrounding macro-climate. A micro-climatic zone does not exist in itself, but only as an anomaly to the prevailing climate of the wider environment where it is located.

[2] Source: The solar irradiance is the incident energy, averaged over the area of the Earth (divided by four); irradiance varies over 11 year cycles and, at the top of recent cycles, can reach 341.7 Wm^{-2}. The increase in anthropogenic forcing since pre-industrial times comes from the IPCC. The heat flow from the Earth's interior is the 47 TW figure averaged over the surface area. The energy flow from the human energy production is based on Flanner (2009) "Integrating anthropogenic heat flux with global climate models".

2 Macro- and micro-climate physics

2.1 Macro- and micro-climate characterization

The main parameters that are used to characterise a macro-climate are:

- Temperature regime
- Air humidity
- Precipitation
- Solar radiation (sunshine and cloudiness)
- Wind regime

The same parameters can be used to characterize a microclimate. The notion of micro-climate however implies significant, systemic and localized variations of one or several of these parameters compared to the surrounding macro-climate conditions. Microclimate can in addition be shaped by a conglomerate of different influences, hence the importance of understanding the factors that influence macro- and micro-climate.

2.2 Factors influencing macro- and micro-climate

2.2.1 Latitude

Globally, over the course of the year, the Earth system -land surfaces, oceans, and atmosphere- absorbs an average of about 240 watts of solar power per square meter. However, the Sun doesn’t heat the Earth evenly, because the Earth is a sphere: the Sun heats equatorial regions more than polar regions, because the incidence angle of solar radiation increase with the latitude.

While latitude significantly determines macro-climate, it is not considered as a factor that determines micro-climate, because microclimatic zones are located under the same latitude as the macroclimatic zones to which they are compared.

2.2.2 Albedo

Albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation and measured on a scale from 0, corresponding to a black body that absorbs all incident radiation, to 1, corresponding to a body that reflects all incident radiation.

Said simply, the albedo is a measure of the proportion of the sun rays that is reflected back and consequently do not contribute to heating a surface exposed to the sun. The proportion reflected is not only determined by properties of the surface itself, but also by the spectral and angular distribution of solar radiation reaching the surface. These factors vary with atmospheric composition, geographic location and time.

Table 1 - Albedo samples

Surface	Typical albedo
Lake	0.02 to 0.04
Fresh asphalt	0.04
Worn asphalt	0.12
Conifer forest (summer)	0.08 to 0.15
Deciduous forest	0.15 to 0.18
Rock, bare soil	0.17
Green grass	0.25
Mountain river	0.30 to 0.40
Desert sand	0.40
New concrete	0.55
Fresh snow	0.80

Picture 1 - Snowy mountains reflect 80% of sun light – Leafed forests absorb 85%

2.2.3 Shade

Some places never receive direct sun light, and therefore the concept of albedo is not relevant for these places. The absence of direct sun light on a given site has a direct influence on the amount of energy this site receives, and consequently on its surface temperature and humidity.

Shade can be caused by a range of factors, with the prominent ones being:

- **Slopes**: North-facing slopes in the Northern Hemisphere and south-facing slopes in the Southern Hemisphere are exposed to less direct sunlight than opposite slopes and can even receive no direct sun light at all during part or all of the year. The lowest area of a valley may frost sooner or harder than a nearby spot uphill, because of cold air sinks caused by the local terrain morphology and the absence of direct sun light.
- **Vegetation** can be dense enough to prevent sun rays from reaching the ground, thereby creating specific microclimatic conditions under the canopy. Dense forests are particularly known for creating a shaded environment.

- **Artificial constructions** can create artificially shaded places, whether intentionally (roof) or not (north side of buildings).

Picture 2, (taken in Devashi river valley, Lower Svaneti, in February 2018) shows how very different microclimatic conditions can develop on mountain slopes that are exposed to the sun (in the background) compared to mountain slopes that do not receive sun (in the foreground).

Picture 2 – Microclimatic zones in Devashi river valley northern and southern slopes

2.2.4 Altitude

Barometric pressure decreases with altitude, and is directly related to temperature and humidity. The consequence is that the air is colder and drier at higher altitudes within a given climatic zone.

The decrease of air temperature is in average 0.65°C/100m (0.5°C in wet air conditions, and 1 °C in dry air conditions), and the amount of water vapor in the air decreases by around 7% as temperature decreases by 1 °C.

2.2.5 Exposure to wind

Exposure to wind has a direct influence on the wind regime of a given area, but also has an indirect influence on its temperature and humidity regime. Areas exposed to wind tend to be cooler (because wind evacuates the heat that could be retained by the surface in the absence of wind) and drier (because soils and vegetations that are more exposed to wind have less capacity to retain water).

2.2.6 Vegetation cover

The type and density of the vegetation cover in natural environments influences microclimatic conditions, through their various effects on the water cycle (facilitated infiltration and evapotranspiration), surface albedo, shade density and exposure to wind.

2.2.7 Vicinity of water bodies

Water bodies, although they have a little thermal response to direct sun light, are known to be good radiation absorber and provide evaporative cooling in which the water vaporizes, as the solar radiation reaches the water surface and remove the heat, thereby cooling the surrounding features.

2.2.8 Effects of buildings

Buildings create micro-climates by shading the ground, changing wind flow patterns, and changing the albedo.

One example of how buildings affect the local climate is the heat island effect in large cities where the average temperature is higher than the surrounding area:

Solar energy absorbed and re-emitted from building surfaces, pavements roads etc. creates a warming effect on the surrounding air. Also the large quantities of buildings break up the wind flow, reducing wind speeds and causing the warm air to remain stagnant in the city. This also causes increased pollution as well as temperatures.

2.2.9 Atmospheric greenhouse gases concentration

The concentration of greenhouses gases in the atmosphere influences its energy balance, and subsequently the global circulation. The consequence of an increase of the average atmosphere temperature by 1.5, 2 or 4°C as discussed internationally, is not just an increase of local temperatures in equivalent proportions, but an increase of the energy available in the atmosphere to generate extreme meteorological events.

The effects of the concentration of greenhouses gases are global only: greenhouses gases concentrations in the air cannot be the cause of given microclimate, but microclimates would be influenced by the global warming caused by greenhouses gases concentrations.

3 Methodology for the assessment

3.1 International references and guidance

3.1.1 International financing institutions

The largest International Financing Institutions have issued guidances for the assessment and mitigation of environmental, climate and social issues associated with hydropower schemes. The following table provides a comprehensive summary of the requirements by International Financing Institutions regarding the assessment of hydropower schemes impacts in relation with climate.

Table 2 - International Financing Institutions requirements regarding climate risk assessment

Financing Institution	**Reference document**	**Requirements for climate risk assessment**		
		Assessment of the hydropower scheme's impact on microclimate	**Assessment of the hydropower scheme's impact on global climate change**	**Assessment of global climate change's impact on the hydropower scheme**
European Investment Bank	Environmental, Climate and Social Guidelines on Hydropower Development (2019)	The list of most significant potential social impacts includes the "*disruption of ecosystem services, including inter alia those caused by alteration to water and sediment flows and by changes in microclimate, which may affect agricultural productivity.*" No specific methodology or objective is defined.	"*A carbon footprint assessment must be carried out for all hydropower projects. […] For all potentially carbon-intensive hydropower projects (e.g. those with large reservoirs and/or emissions greater than 20 kt CO2eq/year), alternative project design configurations must be considered to minimise emissions.[…] the EIB will not consider financing hydropower projects that emit more than 550 g of CO2/kWh*"	"*A climate risk and vulnerability assessment must be carried out as part of the project feasibility study*"

Financing Institution	Reference document	Requirements for climate risk assessment		
		Assessment of the hydropower scheme's impact on microclimate	**Assessment of the hydropower scheme's impact on global climate change**	**Assessment of global climate change's impact on the hydropower scheme**
International Finance Corporation	Good practice note, Environmental, Health, and Safety Approaches for Hydropower Projects	Not identified as a risk. No requirement.	The handbook includes "*recommended measures to minimize generation and release of methane and other greenhouse gas emissions.*"	"Climate change risks or vulnerability" to be included in the ESIA
African Development Bank	Integrated Safeguards System, Guidance Materials, Volume 3: Sector Keysheets, Energy / electricity sector: hydroelectric power projects (2015)	Not identified as a risk. No requirement.	The Project shall "*consider clearing the vegetation before flooding the reservoir, [as] the decomposition of flooded vegetation may cause release of methane (a powerful greenhouse gas).*"	Climate change risk screening and Adaptation Review and Evaluation Procedures.
European Bank for Reconstruction and Development	Environmental and Social Guidance Note for Hydropower Projects (2016)	The list of "*Reservoir associated risks*" includes "*micro-climatic changes.*" No specific methodology or objective is defined.	"*The environmental assessment should include a lifecycle (or 100 year) assessment of GHG emissions for greenfield reservoir projects. In the case of large reservoirs, the risk of methane emissions as a result of the development of anoxic conditions should be addressed. […] The lifecycle assessment of GHG emissions should include a calculation of annual emissions during the construction, impoundment and operation periods.*"	"*The vulnerability of the project to climate change should also form part of the [ESIA]*"

3.1.2 Good international practice

There are two reference and internationally recognized associations that produce science, knowledge and guidance in the hydropower sector: the International Hydropower Association (IHA), and the International Committee on Large Dams (ICOLD).

The IHA was initiated in the early 2000's by the World Bank and WWF, with the objective to develop good practice for sustainable hydropower. The IHA regularly issues

The ICOLD is a professional and non-profit association that gathers professional from the entire world (it has national representations in multiple countries, including Georgia).

Table 3 - Recognized dams and hydropower associations recommendations regarding climate risk assessment

Financing Institution	Reference document	Requirements for climate risk assessment		
		Assessment of the hydropower scheme's impact on microclimate	**Assessment of the hydropower scheme's impact on global climate change**	**Assessment of global climate change's impact on the hydropower scheme**
International Hydropower Association	Hydropower Sector Climate Resilience Guide	Not addressed	Not addressed	The IHA guide has become the reference
	How-to guide, Hydropower Environmental and Social Assessment and Management	Not addressed	Recommends a Greenhouse gas emissions calculation using the tool develop by the IHA	Recommends an assessment of vulnerability and resilience, using the IHA Hydropower Sector Climate Resilience Guide
International Committee on Large Dams	Technical bulletin 50 - Dams and the environment - Notes on regional influences	The influence of dams on microclimate is not described as an issue in temperate regions. for tropical regions, the report discusses the formation of fog at night above the reservoir and its banks, in arid regions with warm daytime temperature and low night temperatures, and in the absence of wind. Similar fog formations are observed in boreal regions with severe winter, before lakes freeze.	Not addressed	Not addressed

Financing Institution	**Reference document**	**Requirements for climate risk assessment**		
		Assessment of the hydropower scheme's impact on microclimate	**Assessment of the hydropower scheme's impact on global climate change**	**Assessment of global climate change's impact on the hydropower scheme**
	Technical bulletin 96 - Dams and environment: Water quality and climate	This bulletin presents the state of the art regarding the influence of large reservoirs on local climate. The bulletin discusses the influence on climate of large reservoirs only (>600 km²), as small reservoirs are not considered as influential: "*small reservoirs at high altitude or where there is high humidity and precipitation have a negligible climatic effect*"	Not addressed	Not addressed
	Technical bulletin 169 - Global climate change, dams, reservoirs and related water resources	Not addressed	Not addressed	This bulletin addresses the potential impacts of climate change on dams and reservoirs, with a focus on risks assessments, resilience and adaptation, and a description of the role that large reservoirs can play to mitigate climate risks at country/basin levels.

3.1.3 National practices

3.1.3.1 European Union

In the European Union, the Environmental Impact Assessment (EIA) legislation (EU Directive 2014/52/EU), which was integrated in the Georgian legislation, requires each project subject to an EIA to assess "*the impact of the project on climate (for example the nature and magnitude of greenhouse gas emissions) and the vulnerability of the project to climate change*". A specific assessment of microclimate risks is not required. This legislation applies to all EU alpine countries (Austria, Italy, Germany, France, Slovenia) that have hundreds of schemes similar to Bakhvi 2.

3.1.3.2 Switzerland

Outside the EU but still in the Alps, the Swiss hydropower legislation[3] does not require specific climate assessments. The federal hydropower guidelines[4] yet require the safety of dams to be regularly checked against climate change, but no assessment of hydropower schemes on microclimate is required or even discussed).

3.1.3.3 Russia

Russia is one of the rare countries that have developed some form of normative approach to assess the impact of reservoirs on microclimate. This is historically due to the fact that Russia has built early very large reservoirs in areas with very cold winter temperatures, and consequently faced microclimatic issues, essentially in relation to the development of freezing fog nearby reservoirs in winter, before reservoir freeze and under low- or no-wind weather conditions.

In 1987, Moscow Gidroproekt institute, which is Russia's historical and internationally renowned design institute for hydraulic facilities, issued "Recommendations for predicting changes in the local climate and its impact on the national economy in the coastal zone of reservoirs (P 850-87 / Gidroproekt. M., 1987)"[5]. These recommendations were part of the "Methodological guidelines for assessing the impact of hydraulic structures on the environment"[6]. Chapter 3.1 of these guidelines discusses "Local climatic changes", but the first sentence states that the discussion is limited to reservoirs with a large volume: the given examples are the Krasmoïarsk reservoir (200 000 ha) and the Sayano-Shushenskaya reservoir (18 000 ha), which aremore than 10 000 times larger than Bakhvi 2 ponds (totally 0.285 ha).

[3] "Loi fédérale sur l'utilisation des forces hydrauliques" (Loi sur les forces hydrauliques1, LFH2) dated 22.12.1916, last updated in January 2020

[4] Département fédéral de l'environnement, des transports, de l'énergie et de la communication DETEC - Sécurité des ouvrages d'accumulation - Documentation de base relative à la vérification de la sécurité en cas de crue

[5] «Рекомендации по прогнозированию изменений местного климата и его влияния на отрасли народного хозяйства в прибрежной зоне водохранилищ» (П 850-87/ Гидропроект. М., 1987)

[6] Российское акционерное общество энергетики и электрификации «ЕЭС России» - Департамент научно-технической политики и развития - Методические указания по оценке влияния гидротехнических сооружений на окружающую среду - РД 153-34.2-02.409-2003

Picture 3 - Example of fog formation above a large reservoir

Sautet reservoir, France. The reservoir is 350 ha (1200 times more than Bakhvi 2 pond). The formation of fog occurs only in the absence of wind, when the reservoir water temperature is globally much warmer than the air, thus leading to localized condensation. These fog events occur essentially in November-December. The fog covers the whole reservoir, as well as its banks. In a flat plain, the fog could extend significantly, but in mountainous areas, its expansion is physically limited by the mountain slopes. The fog disappears as soon as the sun warms up the air or if wind starts blowing.

3.1.4 Conclusion on international guidance and case studies for climate risk assessment

The above review of guidances, recommendations, requirements and legislations shows the following:

- The assessment of climate change impact on hydropower schemes is a recent concern, fuelled by the global warming, and guidances as well as requirements have been developed in the recent years to address this concern.
- The assessment of the impact of hydropower schemes on microclimate is an issue that is considered as a risk only for large reservoirs (thousands of times larger than Bakhvi 2 pond), and only in the context of tropical regions or regions with very severe winters.
- Although tens of guidances and recommendations have been developed in the hydropower sector over the last 20 years, none addresses the impact of hydropower schemes on microclimate.
- None of the available documents that were consulted go against the ICOLD conclusion that "*small reservoirs at high altitude or where there is high humidity and precipitation have a negligible climatic effect*."

3.2 Bakhvi 2 climate assessment spatial and temporal boundaries

The spatial and temporal boundaries for the assessment of Bakhvi 2 climate related impacts are the following ones:

- For the assessment of impacts of the hydropower scheme on macroclimate:
  - The reference period that will be considered is 1986-2005, in order to ensure consistency of the proposed assessment with the recommendations of the International Panel on Climate Change (IPCC). This means that we consider 1986-2005 as the starting point of climate change[7], and we therefore already are within the climate change period.
  - Bakhvi 2 greenhouse gas emissions will be considered over 100 years, as per the recommendations of the International Hydropower Association.
  - Bakhvi 2impact on global climate will be considered, meaning that no spatial boundary is set.
- For the assessment of impacts of the hydropower scheme on microclimate:
  - The assessment is spatially limited to the upper Bakhvi river basin (upstream from Bakhvi 3 intake). This includes Bakhmaro resort, which is the receptor for which microclimatic impacts concerns were initially raised..
  - The temporal boundaries are limited to the next 30 years, as per the recommendations of the International Hydropower Association.

3.3 Methodology for calculations

3.3.1 Impact of the hydropower scheme of macroclimate

The methodology is based on an estimate of (i) the greenhouse gas emissions that will be generated by Bakhvi 2 hydropower scheme construction and operation, and (ii) a comparison with the greenhouse gas emission factors of the Georgian grid and of thermal power plants, for the same energy output.

The method that is followed is based on international ad publicly available guidances and studies that are described in the text (see chapter 4).

3.3.2 Impact of the hydropower scheme on microclimate

Based on chapter 2.2 discussion and on the ICOLD bulletin 96 recommendations, the methodology focuses on two key effects of the creation of a pond and of the reduction of flow in the Bakhvistskali river reach by-passed by Bakhvi 2 HPP:

- The modification of albedo: this impact is assessed through a comparison of local albedos before and after Bakhvi 2 construction.

[7] This is of course not exact because climate change actually started in the 19th century with the massive use of fossil fuels, but taking 1986-2005 as a reference allows comparing different regions and countries over consistent time periods, for which meteorological data is globally available.

- The changed interaction of water and air temperatures: this impact is assessed through a comparison of wet surfaces interacting with the air, before and after Bakhvi 2 construction.
- Changes in evapotranspiration: this impact is assessed through a comparison of evapotranspiration from vegetation, before and after Bakhvi 2 construction.

The increased effect of the wind on the reservoir surface, also mentioned in the ICOLD bulletin 96 recommendations, is not investigated because it is not deemed relevant to the Project context: the pond formed at Bakhvi 2 intake is too small to affect the wind regime;

3.4 Key parameters of Bakhvi 2 HPP project

The key parameters required to evaluate the impacts of Bakhvi 2 hydropower project on micro-climate are the following ones:

- Area of the ponds that will be formed: 0.285 ha = 2850 m² , equivalent to a 53x53m square, which is a little bit more than two Olympic swimming pools.
- Area of forest which will be affected with the tree cutting including HPP, access roads and TL: 33.21 ha - 332100 m², from where 19.65 is permanent loss and 13.56 ha is temporary loss.
- Area of forest that will be replanted as a compensation: 40 ha = 400 000 m².
- The flow in Bakhvistskali river will be reduced seasonally (July to March) to (i) 0.34 m^3/s on 3.1 km for Bakhvi 2a, and (ii) 0.39 m^3/s on 3.6 km for Bakhvi 2b.

4 Impacts on macroclimate

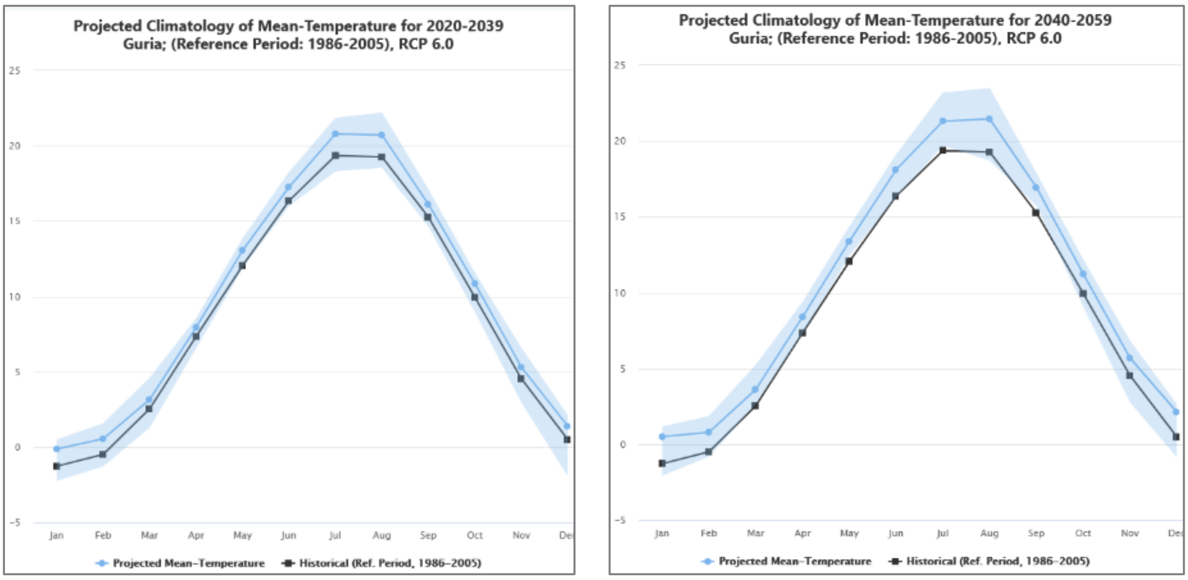
4.1 Existing changes of macroclimate

The World Bank Climate Knowledge Portal[8] is the reference website for climate projections. It provides regional scale estimate of the existing and expected impacts of the global climate change on meteorological parameters. The figures presented and discussed in this chapter are from this website. The geographic scale that is used is Guria region. The discussion focuses on the mean scenario of all , under RCP 6.0 pathway, which is presently the most realistic one.

4.1.1 Temperatures

In comparison with the 1986-2005 reference period, an increase of temperatures by about 1°C was already observed in Guria region, and an additional 1°C increase is expected in the coming 20-30 years. These figures are consistent with observations made in western Europe. It is however important to point the fact that these are averages at the regional level. Observations made in mountainous regions however show that the increase of temperatures is approximately twice faster in the alpine zone (at higher altitude): this is due to the reduction of the size and duration of the snow cover, that results in a lower average albedo of the soil, and consequently a higher retention of heat.

Figure 3 - Guria region temperature projections (°C)



Bakhmaro is located in the Alpine zone and therefore is (and will be) subject to such sharper changes. For the local ecosystems :that are highly influenced by the temperature gradient caused by altitude, an increase of temperatures by 2 to 4 °C in Bakhmaro would be equivalent to a decrease of altitude by 300 to 600 m

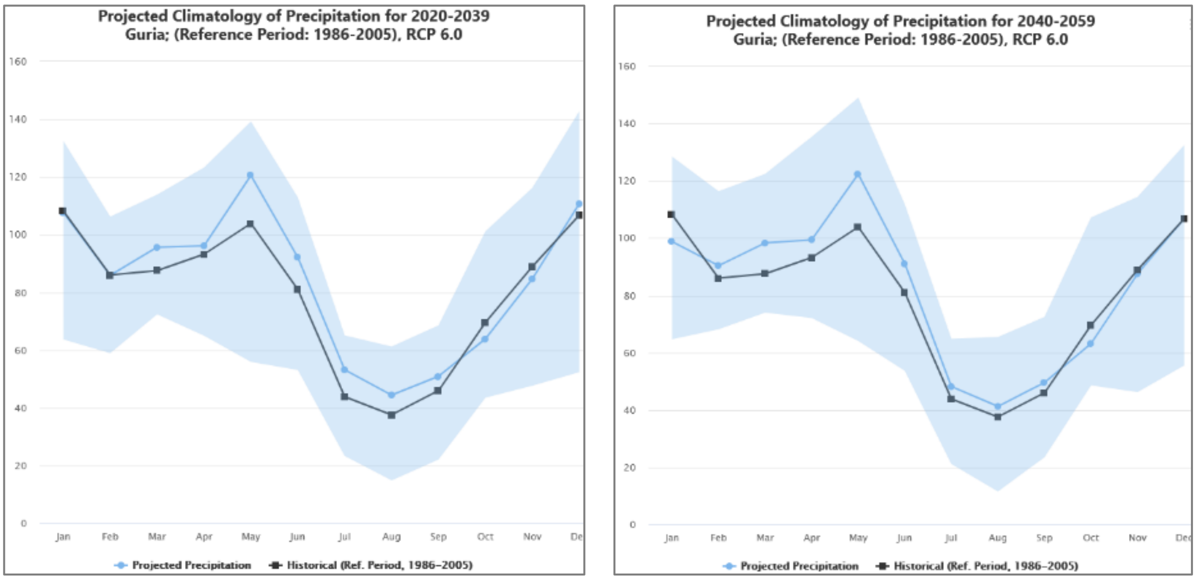
[8] https://climateknowledgeportal.worldbank.org/country/georgia/climate-data-projections

(0.65°C/100m). This means for example that the tree species that grow at lower altitude will tend to colonize higher altitudes (with an advantage for pioneering species), and the tree line will tend to move upward.

4.1.2 Precipitations

In comparison with the 1986-2005 reference period, a slight increase of annual precipitations is expected, but it is unevenly distributed. Higher precipitations are essentially expected around Springtime (March to June), and to a lesser extent in Summer. Autumn and winter are expected to become slightly dryer.

Figure 4 - Guria region monthly precipitation projections (mm)



4.2 Additional changes caused by Bakhvi 2 project

The only direct effect of Bakhvi 2 HPP project on macroclimate is related to its influence on atmospheric greenhouse gas (GHG) concentrations. On the one hand, the construction of Bakhvi 2 HPP will be a source of greenhouse gases during construction. On the other hand, the operation of Bakhvi 2 will generate no GHG, and will therefore help avoiding energy production from fossil fuel origin, that are highly emitting.

4.2.1 GHG emitted during construction and commissioning

Bakhvi 2 HPP does not have a large reservoir and the main source of greenhouse gas (GHG) emissions will therefore be related to the construction. The emissions related to the construction were estimated on the basis of volumes and quantities necessary for the construction of the Project. The methodology followed is that of the Inter-American

Development Bank[9]: it is the most recent and comprehensive methodology available. It provides emission factors that, when applied to project quantities and volumes, allow the footprint of construction activities to be deducted.

Table 4 – Construction GHG emissions

Item	Quantity		GHG unit content		GHG footprint tons CO2eq
Concrete	27 146	m³	1905	kgCO2eq/m³	51 713
Reinforced steel	1 350	ton	1.1	kgCO2eq/kg	1 485
Excavation	459 548	m³	36.7	kgCO2eq/m³	16 865
Fuel (cars and generators)	4 050 000	l	2.7	kgCO2eq/l	10 935
Flooded soil	0.285	ha	10	tons C/ha	3
Trees cut (before reforestation)	19.65	ha	217	tonsCO2/ha	4 264
Total					**85 265**

The result, 85 265 tons CO2eq (totally for Bakhvi 2a and 2b), is consistent with other small hydropower projects, whose GHG footprint during construction is usually around 50 000 tons CO2eq for one scheme. The main source of CO2 emissions is as always from the volume of concrete that is needed for construction.

4.2.2 GHG avoided during operation

The volumes of GHG that are avoided by a hydropower scheme can be estimated in two ways: by comparing with the average GHG content of the national grid, or by comparison with the technically available alternative in the country.

The expected annual average output from Bakhvi 2a and 2b schemes will be respectively 45.5 GWh and 92.8 GWh.

Georgia's grid electricity emission factor is 333 gCO2/kWh [10] produced, meaning that Bakhvi 2 project, which will have zero production related emissions, will outperform the equivalent grid energy and allow avoiding the emission of 46 054 tCO2eq / year.

The technically available alternative to a small hydro is a gas powered thermal power plant, fed by gas from Russia. The emissions of a "modern" (still highly emittive) gas power plant are around 400 gCO2/kWh meaning that Bakhvi 2 project would in comparison with such technology allow avoiding the emission of **55 320 tCO2eq / year** (this is without accounting the construction emissions of a gas power plant, as well as the gas supply losses that are major GHG contributors).

The construction emissions will be covered in less than two years, which is the standard case for small hydropower.

[9] IDB. (2012). *Greenhouse gas emissions assessment methodology.*
[10] EBRD's GHG Assessment Methodology

4.2.3 Conclusion: macro-climate impact of Bakhvi 2

The global GHG emissions in 2019 were estimated[11] to 57 Gtons CO2eq. The Construction of Bakhvi 2 will therefore represent 0.0001 % of the global annual emissions, and its operation will then allow avoiding 0.00008 % of the global annual emissions.

The impact of Bakhvi 2 on macro-climate will therefore be marginal but positive on short and long term, after a construction period during which the project will be a net marginal contributor to GHG emissions.

[11] PBL (2020-12-21). *"Trends in Global CO2 and Total Greenhouse Gas Emissions; 2020 Report"*. PBL Netherlands Environmental Assessment Agency.

5 Impacts on micro-climates

5.1 Existing micro-climates and changes

5.1.1 Within and around Bakhvi 2 scheme footprint

Bakhvi 2 cascade is located is located in the Bakhvistskali river valley, between altitudes ranging from 1378 m upstream (intake) and 506 m downstream (powerhouse).

Bakhvistskali river valley does not have a specific micro-climate, but, instead, provides a composite set of microclimates. This set of microclimates is influenced by five predominant factors:

- **Altitude**, with an average loss of 0.65°C/100m. This means that the annual average temperature at Bakhvi 2 powerhouse must be approximately 2.34 °C more compared to Bakhvi 2 intake location;
- **Orientations**, with the south-facing slopes being warmer than the North facing slopes;
- **Vegetation type and density**, with densely forested zone being likely cooler and more humid in comparison with grassland or bare rocks;
- **Vicinity** to rivers or springs: the temperature cycle and heat retention capacity of water is significantly different from that of the air. Water temperature is also influenced by underground circulations, and, as a result, water is cooler than the air in summer (hence a cooling effect in the vicinity of waterbodies) but is warmer than the air in winter;
- **Climate change** (global warming) which is affecting the entire planet (see the discussion in chapter 4.1).

The effect of water vicinity on microclimates is not as pronounced in Bakhvistskali river valley as it can be in different ecosystems. This is particularly visible through the absence of a specific riparian vegetation, compared to the species that grow on the slopes: the same tree species grow along the river and on the slopes far from the river. The main particularity of these trees is that they can stand the long and cold winters in the area: at lower altitudes and along the Supsa river valley, the situation is different and the river banks are colonized by specialized riparian trees.

So the vicinity of the river generates a microclimatic cooling effect that can be felt by visitors, but this microclimate is not enhanced by a specific riparian vegetation that would extend the cooling effect at several tens of meters from the banks, similarly to the gallery forest that can be seen in tropical regions.

Picture 4 - Bakhvitskali river banks host the same vegetation as the slopes

Among the five above-listed predominant factors:

- Altitudes, orientations and vicinity to the river can be considered as constant in time.
- The vegetation cover is presently experiencing changes, with localized effects under the joined influence of logging activities (whether legal or not) and reforestation initiatives. The vegetation cover is also expected to undergo systemic changes, under the influence of climate change that will affect the distribution and abundance of species.
- Climate change (global warming) is ongoing and affects the entire Bakhvitskali river catchment, without any exception.

5.1.2 In Bakhmaro

The situation in Bakhmaro resort is similar to what was described for Bakhvitskali river basin, which is not surprising since the resort occupies the upstream part of Bakhvitskali river catchment. The same observations can be made: Bakhmaro does not have a specific micro-climate, but, instead, offers a composite set of microclimates.

In addition to the five factors that influence microclimates distribution in Bakhvitskali river basin (altitude, orientation, vegetation cover, river vicinity and climate change), microclimates in Bakhmaro resort are also exposed to the rapid changes in land use that are caused by urbanization: Picture 5 shows as an example the rapid increase of the number of houses in one of Bakhmaro's neighbourhoods over just three years (source of the pictures: google earth).

Picture 5 - Development of houses in Bakhmaro (2017-2020)

Urbanization results in a change of albedo in four different ways, that all result in an albedo reduction, meaning an increase of the quantity of heat that is absorbed and contributes to higher temperatures, instead of being reflected back to the sky:

- Grassland replaced by earth road
- Grassland replaced by buildings
- Trees cut and replaced by buildings
- Earth road replaced by asphalted road

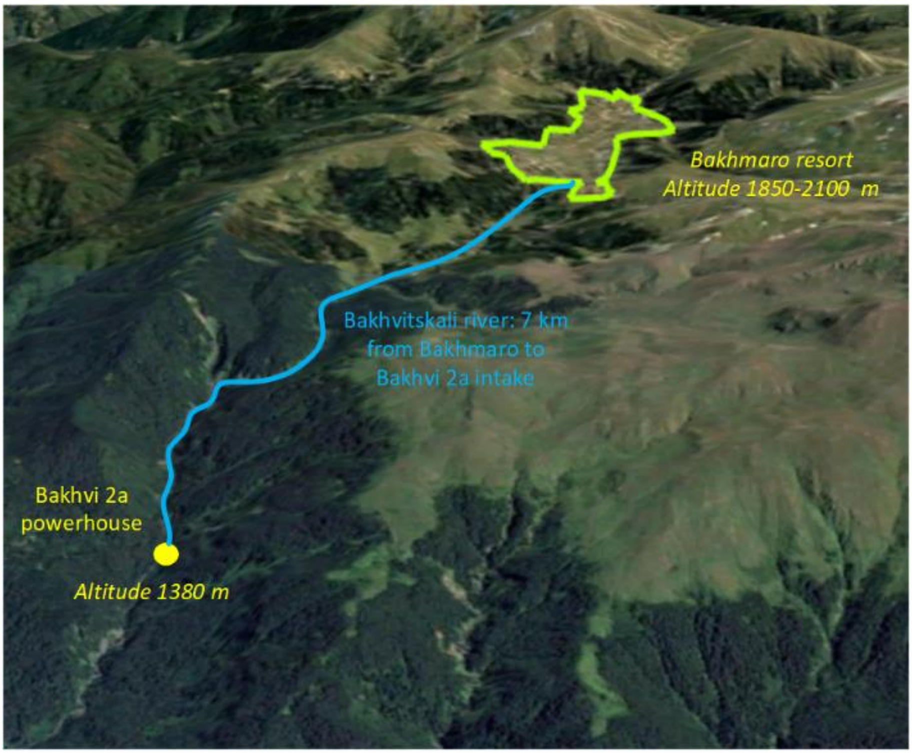
5.1.3 Geographic link between Bakhvi 2 scheme and Bakhmaro resort

The constructed territory of Bakhmaro resort is located at altitudes ranging from 1850 to 2100m. Bakhvitskali river flows through Bakhmaro resort and leaves it at an altitude of 1850m. Bakhvitskali river valley flows west-north-westward. The distance between Bakhmaro resort and Bakhvi 2 intake, when following this valley, is 3400m.

So, in summary, the closest object of Bakhvi 2 HPP scheme (namely its intake) is located:

- BK2A headwork is 500 m lower, BK2B headwork is 900 m lower At a distance of 7 km when following the valley.

Picture 6 - Location of Bakhvi 2 intake compared to Bakhmaro resort



5.2 Changes induced by Bakhvi 2 project

This chapter provides an exhaustive review of the changes that will be induced by Bakhvi 2 scheme to the factors that determine microclimate (see chapter 5.1), taking into account the microclimate physics.

Among all the factors that influence microclimate (see their description in chapter 2.2), some will be modified by Bakhvi 2 scheme construction and operation, while others will not:

- Bakhvi 2 scheme will not change the latitude, altitude, shade caused by the geography and the exposure to wind.
- Bakhvi 2 scheme will marginally affect greenhouse gas concentrations – see the discussion on this matter in chapter 4.2.
- Bakhvi 2 scheme will change the local albedo, vegetation cover (where trees will be cut), and area of waterbodies (creation of a pond, and reduction of the river flow in the by-passed river reach). This is discussed in the following sub-chapters, topic by topic.

5.2.1 Change of albedo

The construction and operation of Bakhvi 2 scheme will result in a change of albedo of the surfaces used by the Project. The long list of these surfaces is provided in Table 5.

As the entire area will be covered with snow in winter, the calculations are don using summer albedo values (when the landscape is free of snow).

Table 5 - Albedo variations induced by Bakhvi 2

Activity	Albedo conversion	Area	Albedo x hectares variation
Forested zones replaced by concrete (buildings and canal)	From forest to concrete 0.15 to 0.55	0.65 ha	0.26
Grassland replaced by concrete structures (buildings and canal)	From grassland to concrete 0.25 to 0.55	0.0 ha	0
Forested zones replaced by bare land (earth road creation)	From forest to bare land 0.15 to 0.17	19.00 ha	0.38
Net gain of forested areas through reforestation	From grassland to forested zone 0.25 to 0.15	40 ha	-4
River width reduced by 2m on 6.7 km	From waterbody to bare land 0.35 to 0.17	1.34 ha	-0.24
Creation of a pond at each intake	From forest to waterbody 0.15 to 0.35	0.285 ha	0.057
Total			**-3.543**

The project implementation will therefore result in a loss of 3.543 albedo-hectares.

In comparison, Bakhvitskali upper catchment (6200 ha) is covered 2/3 with forest and 1/3 with grassland (average albedo: 0.18), thus representing an albedoxhectares value of 1116, the Project will represent a comparative variation of 0.3% of the albedo.

The relative effect of Bakhvi 2 project on heat absorption/reflection on Bakhmaro resort and within Bakhvitskali upper river basin is therefore considered as negligible.

5.2.2 Change of vegetation cover

The change of vegetation cover induced by the Project will result in the following variations:

- A change of albedo, and of the heat absorption / reflection capacity of the affected areas – this topic is discussed in the previous chapter 5.2.1.
- A change in the water balance regime, through the replacement of trees by grass.

For water balance impacts assessment, the primary focus is on understanding the portion of precipitation that is intercepted by the canopy and lost by evaporation without reaching the ground[12], and will actually reach the ground in areas where trees will be cut. Interception values tend to be greater (40-60%) in dark fir and spruce forest in the Caucasus mountains[13].

[12] UNU, Forests, Climate, and Hydrology: Regional Impacts, The Influence of forests and forest reclamation practice on streamflow and water balance, 1988, 217 pages
[13] Rakhmanov, V. V. 1962. Vodookhrannaya rol lesov (Water-conserving role of forests). Goslesbumizdat, Moscow, 236 pp.

In the project area the average annual precipitation is around 1500 mm, meaning that the annual volume of precipitation in the upper Bakhvitskali river basin (62 km²) is around 93 million m^3.

The forested area that will be gained through the project reforestation represents an area of 0.2 km², i.e. 0.5% of the forest surface of the upper Bakhvitskali river basin. The addition of forests will represent an incremental increase by 50% of rain interception (average between 40 and 60%) on these 0.2 km², thus resulting in a modification of the water balance by 0.15 million m3 per year.

This represents 0.16 % of the atmospheric water balance of the upper Bakhvitskali river basin, and is therefore deemed negligible.

5.2.3 Change of wet surfaces

The change of wet surfaces induced by the Project will result from the following variations:

- A reduction of the riverbed width caused by the reduction of flow in the by-passed reach (6.7 km). The river which is presently 3-5m wide, will be typically reduced to 1-3m wide (reduction of the width by 2m), based on observations made in Bakhvi 3 depleted flow reach.
- The creation of two ponds covering totally 0.285 ha.

Totally, there will be a loss of 1.34 ha of wet surfaces, and a gain of 0.285 ha, meaning a net reduction of 1.035 ha.

Assuming an average evaporation[14] of 1000 mm/year, the reduction of wet surfaces would result in an evaporation loss representing 10 350 m^3/year. This is 0.01 % of the volume of precipitation in the upper Bakhvitskali river basin. The effect of the reduction of wet surfaces on atmospheric humidity will therefore be negligible.

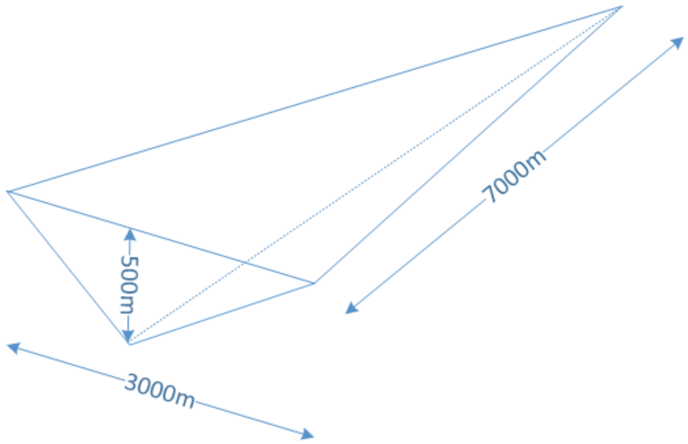
5.3 Impacts on factors influencing micro-climate

5.3.1 Risk of additional fog generated by Bakhvi 2

The formation of fog above Bakhvi 2 intake pond is not considered as a likely phenomenon, because of the very small size of the pond.

The formation of a fog that would reach Bakhmaro resort, would require the formation of a fog more than 500m thick above the pond (because the pond is 500m lower than Bakhmaro resort, and fog extends horizontally), and 7km long (because the pond is 7 km from Bakhmaro resort). The following simplified representation of Bakhvitskali river valley between the pond and Bakhmaro resort is used to calculate the volume of such fog cloud: 1750 million m3.

[14] No measured data is available from the project area. Evaporation in mountain streams typically range between 500-1500 mm / year



With a conservative assumption that the air temperature would be of 0°C, and the fact that water reaches saturation at 4.85 g/m3 at this temperature, the volume of water that the cloud would contain is 8487 m^3: this represents an evaporation of 2978 mm from the pond, which represents 2 to 3 times the annual evaporation.

The evaporation[15] of8487 m^3 requires 331.6 MWh. As the maximum solar radiation on earth is approximately 1 000 W/m² and Bakhvi 2 pond is 2850 m², it would take the sun 1476 hours of continuous irradiation to provide the 5685 MWh necessary to the evaporation of 8487m^3, which of course is impossible because of the day/night cycles. The calculations show that the formation of a fog from Bakhvi 2 pond that would Bakhmaro resort is not possible.

5.3.2 Risk of reduced fog in Bakhmaro caused by Bakhvi 2

The formation of fog above Bakhmaro is a periodic phenomenon. The formation of the fog is caused by the condensation of water contained in the air.

As Bakhmaro resort covers approximately 3 km², the formation of a very thin fog above Bakhmaro resort, for example only 20 m thick (meaning a 60 million m^3 cloud), requires the evaporation (caused by a heat source) and recondensation (caused by a cooling effect) of 900 m^3 of water[16].

To make such a fog cloud disappear, a source of heat would be needed (to counterbalance the cooling effect): this is the opposite phenomena of the one describe in chapter 5.3.1, and massive quantities of heat would be needed to prevent the formation of the fog: the sun can be such a source of heat (which is why fog generally tends to disappear when heated by the sun), but Bakhvi 2 intake and pond will not generate any heat that could result in the evaporation of a fog cloud over Bakhmaro.

The risk for the Project to reduce natural fog processes in Bakhmaro is therefore considered as nil.

[15] The evaporation of 1 gramme of water requires 0.67 Wh for water at 25°C – which is a very conservative assumption in the case of Bakhvitskali river whose temperature is closer to 10°C in summer.
[16] in air at 20°C, water condensates when it reaches 15 g of water per m^3 of air

5.3.3 Risk of increased or lower temperatures

A change of temperatures in Bakhmaro could only be induced by Bakhvi 2 project activities:

- if the project was to release significant volumes of heat in the atmosphere: this risk is excluded, since the Project, to the difference with a thermal power plant that generates more heat than electricity, will not emit any heat.
- if the project was going to significantly modify the absorption/reflexion capacity of surfaces around Bakhmaro – this risk has been addressed in chapter 5.2.1, where we showed that the effect of the project on the regional albedo will be negligible.

There is consequently no risk for the Project to generate increased or lower temperatures in Bakhmaro resort.

Bakhmaro resort will face increased temperatures due to the global warming, but this is totally independent from the construction and operation of Bakhvi 2 scheme.

5.3.4 Risk of increased or decreased or increased humidity

The presence of Bakhvi 2 scheme will not modify the precipitation regime in Bakhvitskali river basin or in Bakhmaro. Consequently, a change of humidity in Bakhmaro could only be induced by Bakhvi 2 project activities:

- if evaporation from waterbodies was a significant source of humidity in the project area – this is not the case as is explained in chapter 5.2.3.
- if the forest cover that will be modified by the Project was a significant contributor to atmospheric humidity – this is not the case as is explained in chapter5.2.2.

There is consequently no risk for the Project to generate increased or lower humidity in Bakhmaro resort.

The increase of temperatures due to the global warming Bakhmaro resort will result in higher air humidity (at ambient temperatures, the water content in the air increase by 7% as air temperature increases by 1°C), but this is totally independent from the construction and operation of Bakhvi 2 scheme.

6 Conclusion

The macro- and micro-climate impact assessments presented in this report show that:

- The construction and operation of Bakhvi 2 scheme cannot have measurable or significant impacts on the macro or microclimate in Bakhmaro or, more widely, in Bakhvitskali river basin catchment;
- Bakhmaro and Bakhvitskali river basin catchment are and will continue experiencing climatic changes caused by the global warming, and these changes will significantly affect the local ecosystems. These impacts are ongoing, and their magnitude and consequences will not be significantly modified, increased or decreased in any way by the construction or operation of Bakhvi 1, 2a and 2b schemes.

In the absence of significant adverse impact of Bakhvi 2 scheme on macro- and microclimate, no mitigation measure is proposed.