

## CLIMATE CHANGE IMPACT ASSESSMENT

### I. Background

1. With its mountainous terrain and abundant rivers, Bhutan has large potential for generating clean renewable energy through the available hydropower resources. The technically feasible hydropower potential in the country is estimated at 26,760 megawatt (MW), of which a very small proportion (6%) has been put to use. At present, the total installed capacity is about 1,614 MW, of which Bhutan exports more than 75% of the generated electricity to India. It is envisaged that sustainable hydropower development in Bhutan will enhance regional energy security and the country's inclusive economic benefits.

2. The Nikachhu hydropower development was identified as part of the Bhutanese government's long-term strategic development plan.<sup>1</sup> The project's reconnaissance study was given and the prefeasibility study was further conducted by the Druk Green Power Corporation (DGPC). DGPC upgraded the project to the feasibility studies including social and environmental impact assessments. In 2013, a detailed project report was finalized by a qualified and experienced engineering firm. In 2014, DGPC incorporated the Tangsibji Hydro Energy (THyE) as a project special purpose company to implement the project. In parallel, the consultant under the Asian Development Bank (ADB) technical assistance conducted comprehensive due diligence studies, including extensive field and laboratory investigations such as social, environmental, hydrological, geological, geo-technical and geophysical, sedimentation, mechanical and electrical requirements.<sup>2</sup>

3. The project site is located on the Nikachhu river, which is one of tributaries of the Mangdechhu river in Trongsa district of central Bhutan. The Nikachhu river originates at an elevation of about 3,918 meters (m). The dam on the Nikachhu river is planned at Lorim, and the underground power house location is at Norbuodi. The project's installed capacity is 118 MW.

4. It was decided to develop and assess a set of climate projections at suitable spatial and temporal resolution for the Nikachhu watershed area scheduled hydropower development. This study has provided critical inputs to the project's climate risk assessment and adaptation planning. It also has helped assess the current project design, and implementation and management plans with regard to hydrological flows to ensure that they are sufficiently effective in light of the potential impacts of climate change as reflected in the projections and scenarios developed.

5. For these purposes, the climate change study was carried out for the project's focuses on hydrological assessments of its watershed and the likely hydrological and allied risks associated under different climate change scenarios (essentially mid-century analysis between 2040–2060). Other climate change associated risks and CO<sub>2</sub> reduction under the clean development mechanism (CDM) were also assessed.

6. The mid-century analysis has been carried out using the following climate models:

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<sup>1</sup> 2003. The Ministry of Economic Affairs. *Water Resource Management Plan and Update of the Power System Master Plan, Bhutan*. Thimphu.

<sup>2</sup> The ADB provided project preparatory technical assistance for Preparing the Green Power Development Project II (TA7889-BHU) in 2011.

<b>Model name</b>	<b>Modelling Group</b>	<b>No. of Long.</b>	<b>No. of Lat.</b>	<b>Grid Size</b>
1. BCC	Beijing Climate Center, China Met Agency, PRC	128	64	2.8125 x 2.8125
2. BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, PRC	128	64	2.8125 x 2.8125
3. CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada	128	64	2.8125 x 2.8125
4. CCSM4	University of Miami (RSMAS), the US	288	192	1.25 x 0.9375
5. CSIRO-MK3.6.0	Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence, Australia	192	96	1.875 x 1.875
6. GFDL-ESM2M	National Oceanic and Atmospheric Administration's Geophysical Fluid Dynamics Laboratory, the US	144	90	2.5 x 2.0
7. IPSL-CM5A-MR	Institute Pierre-Simon Laplace, France	144	143	2.5 x 1.2587
8. MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	256	128	1.40625 x 1.40625

## **II. Assessment**

### **A. Methodology and Approach**

7. The main objective of this study is to assess the hydrology and the impacts of climate change in the hydrological regime of Nikachhu watershed which is spread across 373 square kilometres (km<sup>2</sup>). The elevation of the watershed varies between 2,310 m above mean sea level (amsl) and 5,110m amsl, with occurrence of orographic precipitation formation.

8. The temperature profile also varies across watershed with change in elevation. The medium-term (1996–2011) mean minimum (maximum) temperature varies between -4.3°C (4.9°C) in January and 9°C (15.5°C) in August as per the data collected at Pelela station (3,400m amsl) located within the watershed; while for Bhur station (380m amsl), mean minimum (maximum) temperature varies between 13°C (22°C) in January and 24.2°C (30.1°C) in August.

9. Bhutan enjoys clear four seasons per year with specific months for rainfall. The rainfall in Bhutan is predominantly influenced by the mountain system and major fraction of annual rainfall takes place during the South-West monsoon which generally sets in June and continues until September. About 75% to 80% of rainfall occurs during the monsoon period with average

annual rainfall of the watershed being around 1,200 millimeter (mm). The mean annual rainfall recorded at Chendebji station is around 1,500 mm.

10. The analysis is based on geographic information systems and remote sensing based integrated model Soil and Water Assessment Tool (SWAT).<sup>3</sup> SWAT is a physically based, spatial, time-continuous, distributed hydrological model widely used for describing hydrological processes including snowmelt and snow accumulation processes, sub-surface water and stream flows (river flow or discharge).<sup>4</sup>

11. As inputs to SWAT model, the study used digital elevation data, land use/land cover data and soil data, which were based on information from satellite and remotely sensed records maintained by the United States National Aeronautics and Space Administration (NASA), the International Water Management Institute's (IWMI), Global Irrigated Area Map (GIAM), and Food and Agriculture Organization (FAO). In addition to this available long term rainfall data for select stations and available observed stream flow data was used for assessing the watershed hydrology.

12. The rainfalls in the mountainous region have the tendency of frequent and larger variations because of limited representation of local climatic effects of varied topography. Topography is particularly found to have a profound effect on spatial patterns in this region. To define the spatial patterns in the Nikachhu watershed with varying topography, elevations ranging between 2,310m amsl to 5,110 m (amsl), the study made use of:

- (i) Rainfall data available for rain gauges within/close to watershed
- (ii) Tropical Rainfall Measuring Mission (TRMM), NASA database
- (iii) Inclusion of basin/sub-basin elevation bands, lapse rates for temperature and precipitation, allowing discretization of snowmelt processes based on basin topographic controls.

13. The study presents a scenario where changing climate could pose risks and opportunities for the hydropower project. The outcomes are based on simulation of eight climate models from Coupled Model Inter-comparison Project Phase 5 (CMIP5)<sup>5</sup> provided, under this project, by the Indian Institute of Tropical Meteorology (IITM), Pune, and include (i) historical data for the period 1986-2005 (i.e., present century simulation), and (ii) projected data for the scenario Representative Concentration Pathway (RCP) 4.5 for the middle of the next century 2041–2060.

14. The results from multiple climate simulation models with RCP 4.5 scenario were used to determine precipitation and temperature time series for the period 1986-2060. RCPs provide a rich resource to develop scenarios based on future policy of a set of four emission, concentration and land-use trajectories. Each of the RCPs represents a larger set of scenarios in the literature and is not simply emissions scenarios, but contain information about the concentration of greenhouse gases and aerosols. In total, a set of four pathways were designed that lead to radiative forcing levels of 8.5, 6, 4.5 and 2.6 W/m<sup>2</sup>. The projected changes in precipitation and temperature have been studied under the RCP 4.5 towards the middle of the

<sup>3</sup> SWAT is dynamic, computationally efficient, time-continuous model with spatially explicit parameterization, applicable to ungauged and/or partially gauged watersheds.

<sup>4</sup> SWAT model is both deterministic and stochastic modelling tool, to analyze physical and hydrometeorological datasets (such as weather generators) that are representative of orographic changes and vertical gradients especially considering that the watershed is located in the Himalayas.

<sup>5</sup> CMIP5 is meant to provide a framework for coordinated climate change experiments for the next 5 years and thus includes simulations for assessment in IPCC AR5.

century (2041–2060). In general, precipitation is projected to increase in the near future over the study area and the warming in minimum and maximum temperature is likely to be of the order of 0.5°C to 2°C.

15. Both precipitation and temperature daily time series were used as inputs to the hydrological model for Nikachhu watershed for the period 1986–2060. The hydrological model results for the water balance and the stream flow of Nikachhu watershed was considered in this study, with particular emphasis on the control period 1986–2005 and projection period 2041–2060. The hydrological model simulations are transient, i.e. hydrological model was run from 1986 until 2060, where the results for the control and projection periods were extracted from the transient simulations. The hydrological model has a high precision with regard to simulating stream flows both with input from meteorological data or with input from climate model data. Increasing concentrations of greenhouse gases (GHGs), resulting in increasing ground temperatures and precipitation will lead to changes in the components of the land phase of the hydrological cycle with impacts on runoff.

16. The risk analysis undertaken in this study aims to identify the climate variability and change that can affect the project's operations. The impact relationships between climate factors and direct and indirect impacts on the project's operations have been carried out based on available information on the watershed. The analysis also identifies direct project risks, and vulnerabilities followed by adaptive measures.

## B. Results

17. The salient key features, outcomes and likely hydrological and other climate change risks associated with the project are summarized in Tables 1 and 2.

**Table 1: Hydrological Outcomes of the Project**

<b>I. Location/Features</b>		
i. Country, district	Bhutan, Trongsa Dzongkhag	
ii. Name of the stream/river	River Nikachhu, tributary of River Mangdechhu	
iii. Project location	Dam: 27°26'54.84N; 90°22'24.25 E Powerhouse: 27°29'29.23N; 90°29'19.38E	
iv. Watershed area up to dam site (km <sup>2</sup> )	373	
v. Installed capacity	118 MW	
vi. Topography of the Watershed	m (amsl)	
a) Maximum elevation	5,110	
b) Minimum elevation	2,310	
c) Mean elevation	3,460	
d) Std. deviation	540	
<b>II. Land use of the watershed</b>	<b>Area (sq. km)</b>	<b>Percent (%)</b>
Evergreen Forests	182.6	48.73
Deciduous Forests	151.1	40.33
Mixed Forests	3.2	0.85
Rangelands-Grasses	25.1	6.70
Barren lands-exposed rocks	12.7	3.39
<b>III. Soils</b>	Sandy loam and silty loam soils	
<b>IV. Hydro-meteorology (Precipitation)</b>		
<b>Station</b>	<b>Elevation (amsl)</b>	<b>Annual avg. rainfall (mm)</b>
Trongsa	2,300 m	~1,500mm (1996–2011)

Arithmetic average of the annual rainfall for 9 stations lying within 25 km of the watershed		~1,220mm <sup>6</sup>
<b>Temperature</b> (Pelela station)	The long-term mean minimum (maximum) temperature varies between -4.3°C (4.9°C) in January and 9°C (15.5°C) in August.	
<b>V. Potential and Actual Evapotranspiration</b> <sup>7</sup> (based on simulation results using SWAT)	Actual evapotranspiration averaging at ~ 450 mm per year. Potential evapotranspiration averaging at ~ 1,150 mm per year. This is estimated using Penman-Monteith method.	
<b>VI. Hydrology</b>		
Simulated flows (based on simulation results of SWAT)	At dam site (m <sup>3</sup> /sec)	
50 percentile flows	~ 7 m <sup>3</sup> /sec	
90 percentile flows	~ 3 m <sup>3</sup> /sec	
Water availability (SWAT model outcome)	(i) Mean flow: 12 m <sup>3</sup> /sec. (ii) Monsoon flow (averaged over June–Oct) is 22 m <sup>3</sup> /sec ranging between 10–40 m <sup>3</sup> /sec. (iii) The slow and consistent release of around 2.5–3.5 m <sup>3</sup> /sec is contribution from soil matrix and delayed yield from snow melt that mostly occurs in non-monsoon months.	

18. The mid-century scenarios indicate possible increase in precipitation over the study area coupled with increase in temperatures between 0.5°C to 2°C. Higher precipitation and temperature increase projected under climate change models for the RCP 4.5 scenario is likely to result in increased discharge in the Nikachhu watershed.

19. The projections of average monthly rainfall for the middle of next century period (2041–60) show a variance across global climate models (GCMs). Overall, change in mean annual precipitation from 1986–2005 to 2041–2060 is mostly positive (IPSL-CM5A-MR and MIROC5 predict an increase in rainfall of around 9% and 10.2% respectively).

20. The projections of temperature for the Nikachhu watershed based on GCMs indicate a likely increase in temperature across the models considered. The minimum temperature for winter months is likely to increase in the range 0.65°C to 2.4°C across models, by 2060 while in summer months the minimum temperature is likely to increase by 0.8°C to 2.5°C by the 2060s. Similarly, change in maximum temperatures are approximately 0.7°C to 2.4°C (winter months) and 0.5°C to 2.7°C (summer months), across the global climate models, for the above time slice.

21. The model which closely represents observed characteristics over the study region amongst the various GCMs considered is IPSL-CM5A-MR (2.5 x 1.2587 long/lat). This was further considered for assessing the climate risks from hydrological perspective.

22. The mean annual flow available for hydropower production from 1986–2005 to 2041–2060 is estimated to remain more or less the same showing a slight increase varying between 3% to 5% for the considered climate model.

<sup>6</sup> The stations include Bjizam, Chendebji, Kuengarabten, Langthel, Nobding, Pelela, Phobjikha, Samtengang and Trongsa.

<sup>7</sup> SWAT model results validated through World Evapotranspiration Map, NASA's Moderate Resolution Imaging Spectro-radiometer (MODIS) Database, ESRI Mapping Center.

23. The flow duration curves show a slight increase in peak flows by 5% to 8% and variability in lean flows (1% to 3%). However, these flows are not likely to impact the operations adversely.

**Table 2: Summary of Hydrological and Other Risks Associated with Under Climate Change**

<b>I. Hydro-meteorology Risk (Precipitation)</b>		
	<p>Tropical Rainfall Measuring Mission (TRMM), NASA database, extracted for Nikachhu watershed shows the average areal rainfall of around 1,150 mm, with spatial variability across the watershed ranging between 330 mm to 1,860 mm.</p>	<p>As can be seen from adjacent figure the northern parts of the watershed receive low rainfall (500m) compared to the southern and central parts of the watershed (around 1,500 mm). The northern tip of the watershed receives the lowest rainfall i.e. 330 mm.</p>
<b>II. Associated Risk Analysis Based on Hydrological Assessment Under Climate Change</b>		
<b>Associated risks</b>	<b>Risk evaluation</b>	<b>Adaptation measures</b>
<p>Hydrological variation during dry and wet seasons</p>	<p><b>Risk is considered to be low.</b>                      Monsoon flows are mostly higher in the wet season (June till November). In the dry season (December till March), the slow and consistent flow is contribution from soil matrix and delayed yield from snow melt.                      High confidence in projections of temperatures from an ensemble of 8 global climate models (1985–2060). The precipitation projection results showed a variance among models used. However, precipitation is mostly projected to increase for the middle of the next century period. Temperature is also projected to increase. The variability in the lean flows likely to occur in the mid century period, which is estimated to range from 1% to 3%.</p>	<p>No adverse changes are expected in the stream both during pre and post monsoon seasons.                       The project's design energy has been based on 22 year hydrological data; the risk of any deviation is considered minimal. The financial analysis has been based on the design energy on 90% dependability (P-90 generation and plant availability of 95%), which is quite conservative (This means that there would be more water for 90% of the time than designed on the hydrological data).</p>
<p>Flood events</p>	<p><b>Risk is considered to be moderate.</b>                      Flood events may occur due to increase in precipitation as well as temperature during the medium to long term operational life of the project. The monsoon season in particular will have a relatively higher discharge due to increased precipitation in the catchment.                       The flood discharge for different return periods (Stochastic Approach) is presented below:</p>	<p>Early warning systems will be installed.                       The project design has assumed a maximum flood discharge of 2,400 m<sup>3</sup>/s which is 2.8 times the flood discharge with 1000 year return frequency and can</p>

	<p>25 years – 410 m<sup>3</sup>/s  50 years – 478 m<sup>3</sup>/s  100 years – 552 m<sup>3</sup>/s  500 years – 755 m<sup>3</sup>/s  1000 years – 857 m<sup>3</sup>/s</p> <p>The flood discharge for Nikachhu catchment at the dam site following hydro-meteorological approach comes out to be around 2,400 m<sup>3</sup>/s (keeping a safety factor of 2.8).</p>	<p>be assumed as conservative. An early warning system will be installed as defined in the project's environmental management plan (EMP).</p>
Drought	None.	None.
Glacial Lake Outburst Flood (GLOF) <sup>8</sup>	<p><b>Risk is considered to be low.</b></p> <p>The GLOF risk is low for this catchment. There are very few small lakes visually identified in the extreme north of the watershed from the available satellite images. These however are at a considerable distance from the site and will have a low contribution towards sudden extreme discharge.</p>	<p>Any specific adaptive measure monitoring is unnecessary for THyE while keeping regular attention of GLOF data updates from DGPC environmental unit.</p>
Landslides	<p><b>Risk is considered to be low.</b></p> <p>Southern Bhutan falls between the major fault lines of different geological formations. The Nikachhu watershed has moderate to steep gradients; some of the studies carried out for the region confirm possibility of landslides in Trongsa but none of them indicate any major impact on the Nikachhu watershed.</p>	<p>As part of the environmental management plan, the project has made a necessary afforestation program for a large number of tree plantation for slope stabilization and avoided deforestation.</p>
Earthquakes	<p><b>Risk is considered to be moderate to low.</b></p> <p>A seismic hazard map of Bhutan has been prepared by the Indian Institute of Technology, Roorkee. It divides Bhutan into seismic zones of very high, high, moderate and low hazard. Haa, Chukha, Trashiang, Mongar, Lhuentse, Trashiyangste and the southern Dzongkhags are placed in high to very high hazard zone. Thimphu, Paro, Punakha, Bumthang and Trongsa valleys fall in moderate to low hazard zones.</p> <p>A total of 30 earthquakes have been recorded in Bhutan during the period 1937–1998. Of them, the earthquake on 21 January 1941 with magnitude of 6.75 is considered most powerful in Tashigang in the eastern region of Bhutan.</p> <p>Geological surveys of Bhutan opined that seismically active zone of the country had further shifted away by 180 km from the Himalayan foothills to the Shillong plateau (in India). With the plate moving away, Bhutan has become safer. It has further been reported that the probability of a major earthquake (magnitude 7–8) is low.</p>	<p>Given the small size of the reservoir with a concrete gravity dam, the risk of reservoir-induced seismic activity can be extremely small. The dam is designed based on site specific seismic parameters which have been studied and determined by the Indian Institute of Technology, Roorkee, India as per the guidelines prescribed by the National Committee on seismic design parameters, India. Nevertheless, during implementation, an emergency preparedness and awareness programs will be developed and implemented for the safety of downstream while there is no human settlement downstream of the dam until its confluence with the Mangdechhu river (this is included in the EMP).</p>

<sup>8</sup> GLOF events are severe geo-morphological hazards and their floodwaters can wreak havoc on all human structures located on their path. Much of the damage created during GLOF events is associated with the large amounts of debris that accompany the floodwaters. Damage to settlements and farmland can take place at very great distances from the outburst source.



### III. Conclusions

24. From the above analysis, the project is hydrologically feasible and sound. The study indicates low impact of climate change during the operational life of the project based on the mid-century scenarios. Overall climate change is unlikely to impose negative effect on hydropower plant based on the following outcomes analysed (Annex 1):

- (i) Projections of temperature for the Nikachhu watershed based on the climate models indicate a likely increase in temperature across most models considered. The precipitation projection results however show a variance among models considered. For most models, an increase in total annual precipitation for the middle of the next century period (2041–2060) compared to present century (1986–2005) is projected.
- (ii) The minimum temperature for winter months is likely to increase in the range 0.65°C to 2.4°C across models, by 2060 while in summer months the minimum temperature is likely to increase by 0.8°C to 2.5°C by the 2060s. Similarly, change in maximum temperatures are approximately 0.7°C to 2.4°C (winter months) and 0.5°C to 2.7°C (summer months), across the global climate models, for the above time slice.
- (iii) Higher precipitation and temperature increase under climate scenario RCP 4.5 is likely to result in slight increase of discharge. The mean annual flow from 1986-2005 to 2041-2060 is likely to slightly increase, varying between 3% to 5% for the climate models considered. Seasonal analysis shows an average increase in flows in the monsoon months of around 5% to 8%. For the non-monsoon months, model results depict a very slight increase in flows of around 1% to 3%.
- (iv) The flow duration curves show a slight increase in peak flows and the variability in lean flows. The possibility of accommodating increased intensity of seasonal precipitation due to presence of the reservoir is of particular importance.
- (v) The climate change risks on hydrology are low and unlikely to impose negative effect impact on the project operation in the middle of the next century period (2041–2060) compared to present century (1986–2005). The flood levels due to critical meteorological and hydrological conditions in the watershed are estimated to be much below 2,400 cubic meters per second (m<sup>3</sup>/sec) even after increase in discharge towards mid-century. In order to minimize the impact due to dam failure, early warning systems linked to continuous weather monitoring and forecasts will be installed.
- (vi) The project activity is run-of-river with electricity generation from renewable source. The project is proposed to be developed as a candidate CDM opportunity. At 47.55% plant load factor with a baseline emission factor of 0.9467 tCO<sub>2</sub>e /MWh, the project is expected to sequester 459,734 t CO<sub>2</sub>e annually (Annex 2). The present estimate is based on the regional baseline. The project is expected to get registered with UNFCCC as the cross-border CDM case following the Dagachhu and the Punatsangchhu-I hydropower projects in Bhutan.

## Project Climate Risk Assessment and Management Summary Report

### I. Basic Project Information

<b>Project Title: BHU Second Green Power Development Project</b>
<b>Project Budget: \$ 198.18 million</b>
<b>Location: Bhutan, Trongsa Dzonghag</b>
<b>Sector: Energy, Renewable</b>
<b>Theme:</b>
<b>Brief Description</b> ( <i>particularly highlighting aspects of the project that could be affected by weather/climate conditions</i> ):  The hydropower component of the project depends greatly on the future hydrological characteristics of the area. Change in precipitation, temperature and other climate related hazards can have significant effect on hydrology – water availability and quality.

### II. Summary of Climate Risk Screening and Assessment

<b>A. Sensitivity of project component(s) to climate/weather conditions and sea level</b> <i>[describe how climate/weather condition ( e.g. temperature and seasonal contrast, rainfall amount and seasonality, wind, solar radiation, etc.)and sea level could affect the relevant project component(s)]</i>	
<i>Project component</i> 1. 118 MW run-of-river Nickachhu hydropower plant	<i>Sensitivity to climate/weather conditions and sea level</i>  Hydropower Projects  1. Increased variability in river runoff; 2. Increased sedimentation; 3. Increasing risks of GLOF; 4. Reduced runoff in the long term.
<b>B. Climate Risk Screening</b>	
<i>Risk topic</i>  1. Temperature increase 2. Rainfall increase	<i>Description of the risk</i>  1. The temperature profile varies across the watershed. Using the simulation results of eight climate models from Coupled Model Inter-comparison Project Phase 5 (CMIP5), temperature increase during winter months ranges from 0.65°C to 2.4°C by 2016. In summer, temperature increase ranges from 0.8°C to 2.5°C by 2060.  2. Rainfall increase is mostly positive, ranging from 9% to 10.2% by 2060. This, together with potential evapotranspiration has minimal positive influence on the mean annual flow available ranging from 3% to 5% using the eight climate models used.
Climate Risk Classification: <i>Medium</i>	
<b>C. Climate risk assessment</b>	
<i>Hydrological variations during dry and wet seasons</i> <i>Risk from hydrological variations is considered low since the precipitation will mostly increase, and dry season flow are supported by the soil matrix and delayed yield from snow melt.</i>	
<i>Flood events</i> <i>Risk from flood events is moderate mainly due to the possibility of higher flood discharge resulting from increase in precipitation. The discharge rate is expected to be around 2,400m<sup>3</sup>/s (keeping a safety factor of 2.8).</i>	
<i>GLOF</i> <i>Risk is considered low due to few and far and small lakes identified.</i>	
<i>Earthquakes</i> <i>Risk for earthquakes is moderate to low. A seismic hazard map of Bhutan shows the project area falls within the low to moderate hazard zones.</i>	
<i>Landslides</i> <i>Risk for landslides are also considered low even though some areas have moderate to steep gradients. None of the landslide prone areas indicate major impact on Nikachhu watershed.</i>	

### III. Climate Risk Management Response within the Project

*Hydrological variations during dry and wet seasons*

*No adverse changes are expected, thus no measures were required.*

*Flood events*

*Early warning systems will be installed.*

*GLOF*

*Regular GLOF updates will be provided from DGPC environment unit.*

*Earthquakes*

*Emergency preparedness and awareness program will be prepared.*

*Landslides*

*As part of the EMP, the project will make necessary afforestation / tree planting program for slope stabilization and avoiding deforestation.*

DGPC = Druk Green Power Corporation, EMP = environment management plan, GLOF = glacial lake outburst flood.

**Carbon Sequestration**  
**- Project's Emission Reduction Potential**  
**based on UNFCCC Approved Methodology ACM 0002**

The Second Green Power Development Project for the Nikachhu hydropower development envisages implementation of new grid connected renewable energy facility (hydro electricity). The generated electricity is expected to strengthen local grids with Bhutan and is likely to contribute in regional export to India. UNFCCC approved ACM 0002 Version 14.0.0 (latest) can thus be applied for this project for estimation of emission reduction potential. The project design document to be applied for UNFCCC was drafted under this methodology.

**Rationale for application of ACM 0002:**

*“Electricity delivered to the grid by the project activity would have otherwise been generated by the operation of grid-connected power plants and by the addition of new generation sources, as reflected in the combined margin (CM) calculations described in the “Tool to calculate the emission factor for an electricity system”.*

Since the project does not modify or retrofit an existing generation facility, the baseline scenario is the emissions generated by the operation of grid-connected power plants and by the addition of new generation sources. This is estimated using calculation of combined margin multiplied by electricity delivered to the grid by the project. Accordingly the baseline emissions are given as:

$$BE_y = EG_{PJ,y} * EF_{grid,CM,y} \text{ (Equation 6 of the methodology)}$$

Where:

$BE_y$	=	Baseline emissions (tCO <sub>2</sub> e)
$EG_{PJ,y}$	=	Electricity generation by the project activity (MWh)
$EF_{grid,CM,y}$	=	Combined margin CO <sub>2</sub> emission factor for grid connected power generation in year y calculated using the latest version of the “Tool to calculate the emission factor for an electricity system” (tCO <sub>2</sub> /MWh)

**Estimation of Baseline Emissions:**

Baseline emissions include only CO<sub>2</sub> emissions from electricity generation in fossil fuel fired power plants that are displaced due to the project activity. The methodology assumes that all project electricity generation above baseline levels would have been generated by existing grid-connected power plants and the addition of new grid-connected power plants. The baseline emissions are to be calculated as follows:

$$BE_y = EG_{PJ,y} \cdot EF_{grid,CM,y}$$

Where:

$BE_y$	=	Baseline emissions in year y (tCO <sub>2</sub> )
$EG_{PJ,y}$	=	Quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the CDM project activity in year y (MWh)
$EF_{grid,CM,y}$	=	Combined margin CO <sub>2</sub> emission factor for grid connected power generation in year y calculated using the latest version of the “Tool to calculate the emission factor for an electricity system” (tCO <sub>2</sub> /MWh)

Since the project activity is the installation of a new grid connected renewable power plant the  $EG_{P,J,y}$  is calculated as :

$$EG_{P,J,y} = EG_{\text{facility},y}$$

Where:

- $EG_{P,J,y}$  = Quantity of net electricity generation that is produced and fed into the grid as a result of the implementation of the CDM project activity in year  $y$  (MWh)
- $EG_{\text{facility},y}$  = Quantity of net electricity generation supplied by the project plant/unit to the grid in year  $y$  (MWh)

The project activity will be synchronized to the India's central region and the Bhutan electricity grids, baseline emission factor for which is calculated as combined margin, consisting of a combination of operating margin and build margin factors according to the procedures prescribed in the latest tool for calculating the emission factor for an electricity system. The steps of calculation are as follows:

### **STEP 1. Identifying the Relevant Electricity Systems**

Historically, the Indian power system was divided into five independent regional grids, namely Northern, Eastern, Western, Southern, and North-Eastern. Each grid covered several states. Since August 2006, however, all regional grids except the Southern Grid have been integrated and are operating in synchronous mode, i.e. at same frequency. Consequently, the Northern, Eastern, Western and North-Eastern grids will be treated as a single grid and is being named as NEWNE grid from FY 2007–08 onwards as depicted in the CO<sub>2</sub> baseline database. The Southern grid has also been planned to be synchronously operated with rest of all Indian grid by early 12<sup>th</sup> Plan (2012–2017).

As the Project is connected to the Bhutan electricity grid and would feed power to the NEWNE electricity grid the “project electricity system” is the combination of both these grids. Accordingly, the project boundary encompasses the physical extent of the NEWNE electricity grid and the Bhutan electricity grid, which includes the project site and all power plants connected physically to the electricity system.

### **STEP 2. Choose Whether to Include Off-grid Power Plants in the Project Electricity System (optional)**

Only grid power plants are included in the calculation of operation margin and build margin.

### **STEP 3. Select a Method to Determine the Operating Margin (OM)**

According to the tool the calculation of the operating margin emission factor is based on one of the following methods:

- (i) Simple OM, or
- (ii) Simple adjusted OM, or
- (iii) Dispatch data analysis OM, or
- (iv) Average OM.

Any of the four methods can be used, however, the simple OM method (option A) can only be used if low cost/must-run resources constitute less than 50% of total grid generation in: (i) average of the five most recent years, or (ii) based on long-term averages for hydroelectricity production.

The share of low cost / must-run (% of net generation) in the generation profile of the two grids is less than 50%. The details are provided in the baseline emission reduction calculation sheet. Hence, the Simple OM method can be used to calculate the operating margin emission factor.

The project proponents choose an ex-ante option for calculation of the OM with a 3-year generation-weighted average, based on the most recent data available at the time of submission of the CDM project design document (PDD) to the government of Bhutan for validation, without requirement to monitor and recalculate the emissions factor during the crediting period.

#### **STEP 4. Calculate the Operating Margin Emission Factor According to the Selected Method ( $EF_{grid,OM,y}$ )**

The simple OM emission factor is calculated as the generation-weighted average CO<sub>2</sub> emissions per unit net electricity generation (tCO<sub>2</sub>/MWh) of all generating power plants serving the system, not including low-cost / must-run power plants / units. It may be calculated:

- Based on data on fuel consumption and net electricity generation of each power plant/unit (Option A), or
- Based on data on net electricity generation, the average efficiency of each power unit and the fuel type(s) used in each power unit (Option B), or
- Based on data on the total net electricity generation of all power plants serving the system and the fuel types and total fuel consumption of the project electricity system (option C)

The Central Electricity Authority (CEA), Ministry of Power, Government of India has published a database of carbon dioxide (CO<sub>2</sub>) emission from the power sector in India based on detailed authenticated information obtained from all operating power stations in the country. This database i.e. The CO<sub>2</sub> baseline database provides information about the generation and emission factors of all the regional electricity grids in India. Similarly, data for all power plants operating in Bhutan has been considered for calculation the emission factor. The combined margin in the CEA database is calculated ex-ante using the guidelines provided by the UNFCCC in the "Tool to calculate the emission factor for an electricity system." We have, therefore, used the generation and emission data published in the CEA database, for calculating the baseline emission factor.

The CEA database uses option B i.e., data on net electricity generation, the average efficiency of each power unit and the fuel type(s) used in each power unit, to calculate the OM of the different regional grids. The simple OM emission factor is calculated based on the electricity generation of each power unit and an emission factor for each power unit, as follows:

$$EF_{grid, OMsimple, y} = \sum (EG_{m, y} \times EF_{EL, m, y}) / \sum EG_{m, y}$$

Where:

$EF_{grid, OMsimple, y}$	=	Simple operating margin CO <sub>2</sub> emission factor in year y (tCO <sub>2</sub> /MWh)
$EG_{m, y}$	=	Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)
$EF_{EL, m, y}$	=	CO <sub>2</sub> emission factor of power unit m in year y (tCO <sub>2</sub> /MWh)
m	=	All power units serving the grid in year y except low-cost / must-run power units
y	=	Either the three most recent years for which data is available at

the time of submission of the CDM PDD to the government of Bhutan for validation (ex ante option) or the applicable year during monitoring (ex post option), following the guidance on data vintage in step 2.

The emission factor of each power unit m has been determined using Option B1.

$$EF_{EL,m,y} = (\sum FC_{i,m,y} \times NCV_{i,y} \times EF_{CO_2,i,y}) / EG_{m,y}$$

Where:

$EF_{EL,m,y}$	=	CO <sub>2</sub> emission factor of power unit m in year y (tCO <sub>2</sub> /MWh)
$FC_{i,m,y}$	=	Amount of fossil fuel type i consumed by power unit m in year y (Mass or volume unit)
$NCV_{i,y}$	=	Net calorific value (energy content) of fossil fuel type i in year y (GJ / mass or volume unit)
$EF_{CO_2,i,y}$	=	CO <sub>2</sub> emission factor of fossil fuel type i in year y (tCO <sub>2</sub> /GJ)
$EG_{m,y}$	=	Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)
m	=	All power units serving the grid in year y except low-cost / must-run power units
i	=	All fossil fuel types combusted in power unit m in year y
y	=	Either the three most recent years for which data is available at the time of submission of the CDM-PDD to the DOE for validation (ex ante option) or the applicable year during monitoring (ex post option), following the guidance on data vintage in step 2.

The ex-ante generation weighted OM value obtained is 0.9832 tCO<sub>2</sub>/MWh.

#### STEP 5. Calculate the Build Margin Emission Factor ( $EF_{grid, BM,y}$ )

The sample group of power units used to calculate the build margin consists of either:

- (i) The set of five power units that have been built most recently, or
- (ii) The set of power capacity additions in the electricity system that comprise 20% of the system generation (in MWh) and that have been built most recently.

The project should use the set of power units that comprises the larger annual generation. The build margin emission factor has been calculated ex-ante based on the most recent information available on units already built for sample group m at the time of CDM PDD submission to the government for validation. This option does not require monitoring the emission factor during the crediting period.

The build margin emissions factor is the generation-weighted average emission factor of all power units m during the most recent year y for which power generation data is available, calculated as follows:

$$EF_{grid, BM, y} = (\sum EG_{m, y} \times EF_{EL, m, y}) / \sum EG_{m, y}$$

Where:

$EF_{grid, BM, y}$	=	Build margin CO <sub>2</sub> emission factor in year y (tCO <sub>2</sub> /MWh)
$EG_{m, y}$	=	Net quantity of electricity generated and delivered to the grid by power unit m in year y (MWh)
$EF_{EL, m, y}$	=	CO <sub>2</sub> emission factor of power unit m in year y (tCO <sub>2</sub> /MWh)
m	=	Power units included in the build margin

$y$  = Most recent historical year for which power generation data is available

The CO<sub>2</sub> emission factor of each power unit  $m$  ( $EF_{EL,m,y}$ ) is determined as per the procedures given in step 3 (a) for the simple OM, using options B1 using for  $y$  the most recent historical year for which power generation data is available, and using for  $m$  the power units included in the build margin. The build margin value obtained is 0.9102 tCO<sub>2</sub>/MWh.

#### STEP 6. Calculate the Combined Margin Emissions Factor ( $EF_{grid, CM, y}$ )

The emission factor  $EF_y$  of the grid is represented as a combination of the operating margin (OM) and the Build Margin (BM). Considering the emission factors for these two margins as  $EF_{OM,y}$  and  $EF_{BM,y}$ , then the  $EF_y$  is given by:

$$EF_y = w_{OM} * EF_{grid,OM,y} + w_{BM} * EF_{grid,BM,y}$$

Where:

$EF_{grid, BM, y}$  = Build margin CO<sub>2</sub> emission factor in year  $y$  (tCO<sub>2</sub>/MWh)  
 $EF_{grid, OM, y}$  = Operating margin CO<sub>2</sub> emission factor in year  $y$  (tCO<sub>2</sub>/MWh)  
 $w_{OM}$  = Weighting of operating margin emissions factor (50%)  
 $w_{BM}$  = Weighting of build margin emissions factor (50%) (where  $w_{OM} + w_{BM} = 1$ ).

Using the values for operating and build margin emission factor provided in the CEA database and their respective weights for calculation of combined margin emission factor, the baseline carbon emission factor (CM) is 0.9467 tCO<sub>2</sub>e/MWh.

#### Estimation of Project Emissions

The power density of the project activity reservoir is greater than 10 W/m<sup>2</sup>. Hence, no project emissions are to be considered as per ACM0002 Version 14.0.0,

Thus,  $PE_y = 0$ .

#### Estimation of Leakage Emissions

As per ACM0002 Version 14.0.0, no leakage has been considered for the calculation of emission factor ( $LE_y = 0$ ).

Ex-ante calculation of emission reductions is equal to ex-ante calculation of baseline emissions as project emissions and leakage are nil.

#### Emission reductions = Baseline emissions – Project emissions - Leakage

Ex-ante calculation of emission reductions is equal to ex-ante calculation of baseline emissions and project emissions, as leakage are nil.

As per the approved CDM methodology, baseline emissions for the amount of electricity supplied by project activity,  $BE_y$  is calculated as

$$BE_y = EG_{PJ,y} * EF_{grid,CM,y}$$

Where:

$EG_{PJ,y}$  = is the electricity supplied to the grid,  
 $EF_{grid,CM,y}$  = is CO<sub>2</sub> emission factor of the grid



CO<sub>2</sub> emission factor (combined margin) for the grid  
= 0.9467 tCO<sub>2</sub>e/MWh

**Annual electricity supplied to the grid by the Project**

= Total Capacity x Designed PLF x Generating Hours (in a year) – Losses  
= 118 MW (Capacity) x 47.55% (PLF) x 8760 (hours) – 1.20% losses (auxiliary consumption)  
= 491.52 MWh – 1.2% Auxiliary Consumption  
= 485,617 MWh (saleable units – net export)

**Annual baseline emissions, BE<sub>y</sub>**

= 0.9467 tCO<sub>2</sub>e/MWh x 485,617 MWh  
**= 459,734 tCO<sub>2</sub>e**