FOREST COVER LOSS DUE TO HYDROPOWER PROJECTS AND TRANSMISSION LINES

PHPA I, PHPA II and MHPA

Forest Resources Management Division
Department of Forest and Park Services
Ministry of Agriculture and Forests

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FRMD. 2019, Forest cover loss from three hydropower projects (Punatsangchhu-I, Punatsangchhu-II, and Mangdechhu Hydroelectric Project Authorities) and their corresponding transmission lines

FORWARD

The Royal Government of Bhutan has declared hydropower as one of the five jewels of economy. Hydropower continues to take precedence as major economy development goal for Bhutan. This is evident by the Bhutan's ambitious target to harness 10,000 MW by 2020 from the total hydropower potential of 30,000 MW. On the other hand, Royal Government of Bhutan has also committed to remain carbon neutral at all time, where forests of Bhutan act as major carbon sink and pool. Therefore, the Royal Government of Bhutan has a vital responsibility of ensuring that development of hydropower is in line with the sustainable development policies of Bhutan.

With the constitutional mandate of maintaining 60% of forest cover in perpetuity, currently Department of Forests and Park Service has managed to maintain 71% of forest cover. With ongoing pace of hydropower development, monitoring the effects of hydropower construction to the forests and environment is crucial. To address this need, Department of Forests and Park Service has conducted a study to assess extent of forest cover loss from three major hydropower projects namely; Punatshangchhu-I, Punatshangchhu-II and Mangdechhu and their transmission lines.

The Department of Forests and Park Services would like to thank Forest Resources Management Division for initiating such studies in close consultation with other relevant agencies. We would also like to extend the acknowledgement to all the task force members involved, Bhutan Power Corporation Limited and management authorities of Punatshangchhu-I, Punatshangchhu-II and Mangdechhu for their cooperation and support in sharing the required information and data for the study.

This report provides baseline information on forest cover loss due to aforementioned hydropower projects and their transmission lines. This report will also guide the policy makers in understanding the effects of hydropower construction on the forests and environment thereby ensuring the requirement of sustainable development policies of Bhutan.

Lobzang Dorji

DIRECTOR

EXECUTIVE SUMMARY

Bhutan is a country with high forest and low deforestation. With a forest cover of 71%, Bhutan has a rich natural biodiversity significant for its ecological, cultural and economic values. The water resource of the country has a huge potential for hydropower generation, which has the biggest share of contribution to its economy. In the process of harnessing this hydroelectric power, State Reserve Forest are often cleared for construction of various hydropower infrastructure, road and transmission lines. To understand the extent of forest cover lost and its impact to the surrounding landscape, the study on forest cover loss from three major hydropower projects Punatsangchhu-I, Punatsangchhu-II and Mangdechhu was conducted by DoFPS.

The forest cover loss analysis is done through a remote sensing technique using very high-resolution satellite imageries on Google Earth, Sentinel-2 images and available land use land cover maps based on the forest cover definition of the National Forest Policy of Bhutan.

The total forest cover loss from PHPA-I, PHPA-II and MHPA due to construction of infrastructure, roads and transmission lines is 390, 308.5 and 700.6 hectare respectively. Accordingly, the per megawatt forest cover loss for PHPA-I, PHPA-II and MHPA is estimated to be 0.33, 0.30 and 0.97 hectare respectively.

From this study, it is also observed that forest cover loss is more from the establishment of transmission line than from the construction of infrastructure and roads for hydropower development within the project sites

This study has provided baseline information on forest cover loss due to three major hydropower projects and its transmission lines.

ACRONYMS AND ABBREVIATIONS

Asl	Above Sea Level
ALOS	Advanced Land Observing Satellite
AVNIR	Advanced Visible and Near Infrared Radiometer
BPC	Bhutan Power Corporation Limited
cm	Centimeter
CRS	Co-ordinate Reference System
D/C	Double Circuit
DGPC	Druk Green Power Corporation Limited
DHPS	Department of Hydropower and Power Systems
DoFPS	Department of Forests and Park Services
ESA	European Space Agency
FRMD	Forest Resources Management Division
GMES	Global Monitoring for Environment and Security
ha	Hectare
HRT	Head Race Tunnel
IPCC	Intergovernmental Panel on Climate Change
kml	Keyhole Markup Language
kV	Kilovolts
LCMP	Land Cover Mapping Project
LILO	Loop-In-Loop-out
LULC	Land Use Land Cover
m	Meter
MoAF	Ministry of Agriculture and Forests
MHPA	Mangdechhu Hydroelectric Project Authority
MW	Mega Watt
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
PHC	Powerhouse Complex
PHPA-I	Punatsangchhu-I Hydroelectric Project Authority
PHPA-II	Punatsangchhu-II Hydroelectric Project Authority
RGoB	Royal Government of Bhutan
RoW	Right of Way
sq.km	Square kilometer
SRF	State Reserved Forest
SWIR	Short-wave infrared
TRT	Tail Race Tunnel

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1. Introduction

Bhutan is a small Himalayan country situated between China and India. Country falls within the longitude of 88^{0}54’ and 92^{0}10’ East and latitude of 26^{0}40’ and 28^{0}15’ North. The entire 38,394 sq.km geographical area of Bhutan is mountainous with little flat plain limited to southern parts of the country. The elevation varies from 100 m asl in the southern foothills to more than 7000 m asl in the northern mountains.

Forests constitute 71% of the geographical land of Bhutan. The forests of Bhutan display wide range of altitudinal variation, ranging from sub-tropical forests in the southern foothills to alpine scrub in the North. According to the latest land use and land cover (LULC) map of Bhutan (FRMD, 2017), 45.94% is broadleaf, 13.53% is mixed conifer, 6.02% is fir, 2.64% is blue pine and 2.64 is chir pine forests.

This diverse forest types of Bhutan are not only carbon sink but also an ambient home for more than 270 mammals and more than 700 bird species. The forest is also an important reservoir of different forestry resources for more than 7 million people of Bhutan. Currently, around 7% of total forest area is used for commercial timber extraction to meet the demand at domestic market. Another 3.1% of the total forest area is managed as community forests. Forests that are accessible and near to settlements is being used for extraction of rural house building timber.

Even the constitution of Bhutan states that 60% of total geographical land should be maintained under forest cover in perpetuity because of their significant role in cultural, ecological and biological diversity. Besides its productive function and its role as an enormous carbon pool, forests of Bhutan have a major contribution to the country’s economy in the hydropower sector.

Bhutan has four major river systems: Ammochu, Manas, Sunkosh and Wangchu with an estimated hydropower potential of 30,000 MW (DHPS, 2008). The Royal Government of Bhutan (RGoB) has targeted to develop at least 10,000 MW of hydropower by 2020 (DHPS, 2008). However, as per the DGPC (2014), the achievement of this target might not be possible without considering the detail evaluations of social and environmental impacts. Currently, an installed hydropower capacity of 1606 MW is generated from various hydropower projects namely, Chukha (336 MW), Kurichu (60 MW), Dagachhu (126 MW), Basochhu (64 MW) and Tala (1020 MW). Beside this few more hydropower projects namely Mangdechhu (720 MW), Punatsangchhu I (1200 MW), Punatsangchhu II (1020 MW), Nikachu (210 MW) and Kholongchu (600 MW) are under construction.

The sustenance of the hydropower projects is hugely dependent on the geography and fluvial processes set by the water catchments of river systems. The water catchments in turn are replenished by the vegetation and forest cover present on the landscape. The forests of Bhutan regulate the abundant rainfall into large volume of regular river flow, whose potential energy is tapped into hydroelectricity.

In spite of hydropower being an important source of country's economy, deforestation due to construction of hydropower projects is also undeniable fact. Infrastructure construction from hydropower often have significant impact on forests, as well as other ecosystems. Negative impact of construction is associated with both biotic and abiotic environment. For instance, dam construction often has the largest impact on forests loss, as well as displacement of local communities and wildlife due to accumulation of water in the reservoir. Another huge impact to forests comes from laying transmission lines. Forests falling underneath transmission line is often cleared as Right of Way (RoW) corridor. In Bhutan, RoW of 52 m is cleared for 400 kV, 35 m for 220 kV, 27 m for 132 kV and 18 m for 66 kV transmission line (DHPS, 2018). The area lying beneath the transmission lines is maintained treeless permanently. The other commonly noted impact of transmission line is deterioration of aesthetic value of landscape. In addition, building of any kind of structure is not allowed in transmission line areas. High voltage transmission line passing through agriculture land may permanently reduce the area under cultivation.

Forest loss due to construction of hydropower projects and transmission lines is evidently observed across the landscape of Bhutan. The studies carried out by DoFPS to understand the drivers of deforestation and degradation highlighted that hydropower is one of the major drivers of deforestation (MoAF, 2017). However, no proper study has been conducted on the extent of forest cover lost and its impact to the surrounding.

This study aims to assess the extent of forest cover loss from the three major hydropower projects namely; Punatshangchhu-I Hydroelectric Project Authority (PHPA-I), Punatshangchhu-II Hydroelectric Project Authority (PHPA-II) and Mangdechhu Hydroelectric Project Authority (MHPA) and its corresponding transmission lines using Google Earth, Sentinel-2 and existing Land Use and Land Cover (LULC) maps of Bhutan.

2. Project Area Description

The study is conducted for three run-of-river scheme hydropower projects. According to DHPS (2008), these three hydropower projects have been classified as large (MHPA) and mega (PHPA-I and PHPA-II) projects based on its power generation capacity.

2.1. PHPA-I

Punatsangchhu I project is a run-of-river scheme on river Punatsangchhu located in Wangduephodrang Dzongkhag. The project with a power generation capacity of 1200 megawatt (MW) is accessible from Wangduephodrang-

Tsirang highway. The dam is located about 6.5 km downstream of Wangduephodrang Bridge. The Head Race Tunnel (HRT) runs 9 km from dam to the underground Power House Complex (PHC) located on the left bank of the river. The Tail Race Tunnel (TRT) runs 1.3 km for discharge of water back into the river. The surge shaft is located on the left side of the river approximately 850 m above the PHC.

2.2. PHPA-II

Punatsangchhu II project is also a run-of-the river scheme on the same river located approximately 3 km below PHPA-I in Wangduephodrang Dzongkhag. Punatsangchhu II project with a capacity of 1020 MW is located on the right bank of Punatsangchhu river. The dam site is located at Dungkhar Bjak, about 21.50 km downstream of Wangduephodrang bridge. The HRT runs approximately 8.58 km from the dam to the underground PHC located at Kamechhu. A TRT of around 11 m extends from Kamechhu to Dogarthang. The surge shaft is located at Semtharigang around 1 km above the PHC.

2.3. MHPA

Mangdechhu project lies in Central Bhutan and is located in Trongsa Dzongkhag. The project with a capacity of 720 MW is a run-of-river scheme located on river Mangdechhu. The dam site is located about 14 km downstream of Trongsa town. The underground power house is located inside the mountain below Yurmu village. The HRT traverses a length of around 13.5 km, which is approachable through three intermediate adits located at Dzongkha Lumpa stream, Bubja and Nikachhu. The surge shaft is located at Samchholing.

2.4. Transmission lines

PHPA-I has two 400 kV D/C transmission lines running from pothead yard at Ruepisa, Wangduephodrang to Lhamoizingkha pooling station, Dagana for power evacuation to India. One transmission line runs directly from Ruepisa, Wangduephodrang to Lhamoizingkha, Dagana, measuring around 93.5 km in length with 228 transmission towers. The other line starts from Ruepisa, Wangduephodrang and gets connected to pothead yard of PHPA-II at Kamechhu, Wangduephodrang, measuring around 12.9 km in length with 38 transmission towers.

From the pothead yard of PHPA-II, one LILO transmission line of 400 kV D/C runs till Lhamoizingkha pooling station, Dagana, measuring around 79.1 km in length with 207 transmission towers. This line is shared between PHPA-I and PHPA-II according to the project management. PHPA-II has another 400 kV D/C single transmission line running from pothead to Jigmeling pooling, Sarpang, measuring approximately 65 km in length with 151 transmission towers.

MHPA has two 400 kV D/C transmission lines running from pothead yard at

Yurmu, Langthel, Trongsa to Jigmeling pooling station, Sarpang via Goling switching station, Zhemgang measuring around 84.8 and 84.7 km in length with 186 towers in each line.

3. Methodology

To detect the forest cover loss due to hydropower projects, change detection technique is applied. Google Earth, Sentinel-2 and historical LULC map of Bhutan popularly known as Land Cover Mapping Project (LCMP) 2010 is used for analysis.

Google Earth is a computer-based program which provides a platform to view the 3D representation of earth based on very high-resolution satellite imageries. Google Earth is free program available for different operating systems and enables users to view the earth through very high-resolution satellite imageries. This program also allows users to view the historical image of various spatial resolution. However, the temporal and spatial resolution of the images vary from place to place. The resolution of the satellite images in Google Earth ranges from 15 m to 15 cm.

Sentinel-2 is developed by European Space Agency (ESA) in partnership with European Commission in the frame of the Global Monitoring for Environment and Security (GMES) program. Sentinel-2 is multispectral optical imaging space mission devoted to operational monitoring of land and coastal area globally. This program is operational since 2015. The spatial resolution of Sentinel-2 ranges from 10 m to 60 m depending on individual bands.

LCMP, 2010 was derived from ALOS AVNIR2 with spatial resolution of 10 m. This land cover map was produced by Ministry of Agriculture and Forests (MoAF) in 2010.

For the analysis, the areas with complete change in land use between two timestamps was defined as 'disturbed area'. The timestamps were determined as 'reference' for the latest image and 'baseline' for the historical image available in the Google Earth. Reference images for the study area ranges from 2017 to 2018 and similarly the baseline images consist of imagery from 2002, 2003 and 2014 in the Google Earth. In places where baseline images were missing in Google Earth, it was compensated with LCMP 2010 map.

The disturbed areas were manually delineated on the Google Earth platform based on reference image and were classified into three categories viz; infrastructures, roads and transmission lines (Figure 1).

Figure 1. Manual delineation of (a) infrastructure, (b) road, (c) transmission line

Since most of the infrastructure construction falls in deep valleys and gorges for hydropower projects, shadow was major constraints in properly viewing and delineating the disturbed areas in Google Earth. In such cases, latest Sentinel-2 image was utilized as reference image. Advantage of Sentinel-2 over Google Earth image is because of the presence of multispectral bands in Sentinel-2. Band ratioing was carried out using multispectral bands of Sentinel-2 to eliminate the shadow effect. Upon band rationing, normalized difference vegetation index (NDVI) was found to be most effective in shadow elimination (Figure 2,1a & b). Further, to enhance the visualization, different band combinations were executed and healthy vegetation band combination was effective for interpretation on shadow areas (Figure 2, 2a & b).

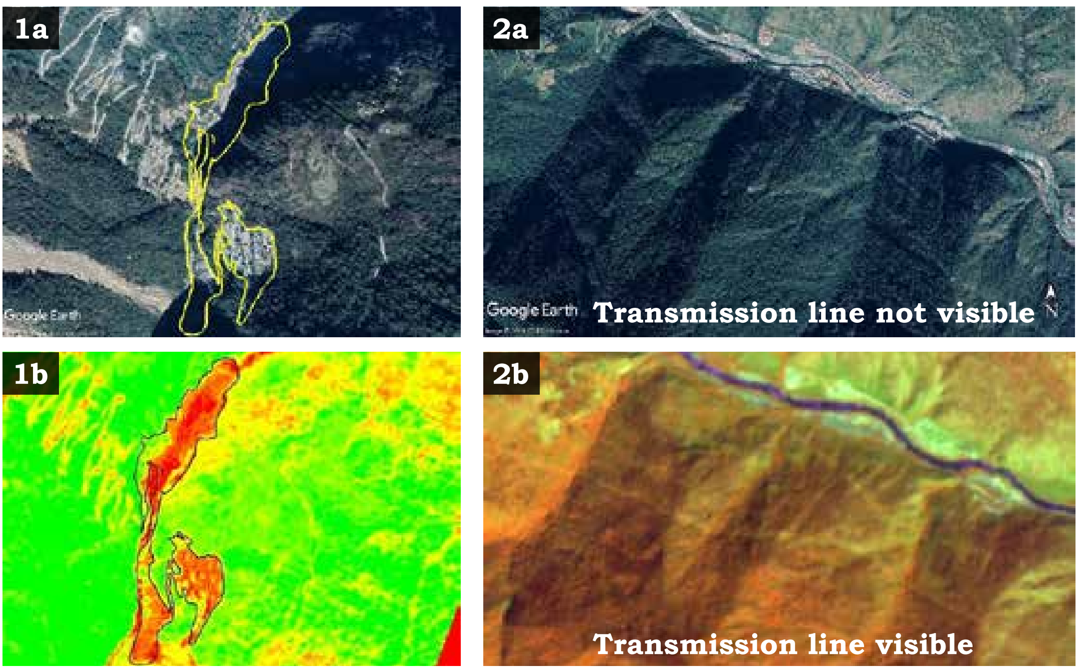


Figure 2 Image interpretation in shadow area through band ratioing (1a: GE image & 1b: Sentinel-2 NDVI) and image visualization through band combinations (2a: GE image & 2b: Sentinel-2 healthy vegetation)

Bhutan Power Corporation Limited (BPC) clears 52 m corridor as RoW for 400 kV transmission line (DHPS, 2018). All transmission lines originating from the aforesaid three hydropower projects are of 400 kV. To compute forest loss due to the transmission line, RoW corridors were digitized manually on very high-resolution Google Earth image. In places where RoW corridor was undetectable on the Google Earth due to shadow effect, vegetation indices and band combinations from Sentinel-2 was used.

$\boldsymbol{NDVI} = \frac{(NIR - RED)}{(NIR + RED)}$	Healthy vegetation band combination of Sentinel-2 multispectral image; **Red**: Band 8 NIR, **Green**: Band 11 SWIR, **Blue**: Band 2]

In order to identify the historical land cover status on the disturbed areas, disturbed area polygons delineated based on reference images were overlaid on the baseline images in the Google Earth. Visual interpretation of land and land cover is based on texture, coarseness and closeness of the tree canopy structure observed in the Google Earth image. In areas, where baseline images are missing in historical archive in Google Earth, LCMP 2010 map is used as proxy to infer the historical land cover status (Figure 3).

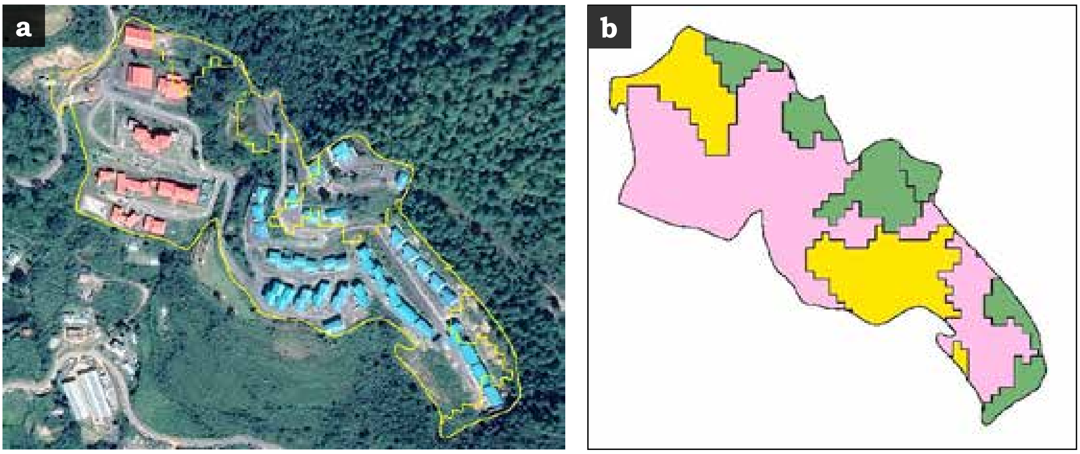


Figure 3 Substitution of missing historical GE image with historical national land use and land cover map (a) GE image 2018, (b) LCMP 2010

Upon overlaying the disturbed area polygons over baseline images, historical land cover was delineated and classified as "forests" and "non-forests". Classification of forest and non-forest is based on definition adopted from National Forest Policy of Bhutan (MoAF, 2011) within the polygons. According to this policy, forest is defined as "Forests mean land with trees spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent. It does not include land that is predominantly under agriculture or urban land use". Whereas, "Non-forests" include land use and land cover other than forests such as agricultural land, shrubs, meadows, built-up, rocky outcrops and water bodies.

The delineated polygons on Google Earth platform were stored in "kml." format in WGS84 Coordinate Reference System (CRS). These files were imported to QGIS and converted into vector shapefile. The CRS of these shapefiles were converted from WGS84 to national CRS (Drukref03).

The change in land cover from forest class in baseline image to non-forest class in the reference image is considered as 'forest loss'. Non-forest from baseline line image remaining non-forest in the reference image is considered as no change and named as 'non-forest'. Accordingly, the areas of forest loss and non-forest are computed (Figure 4).

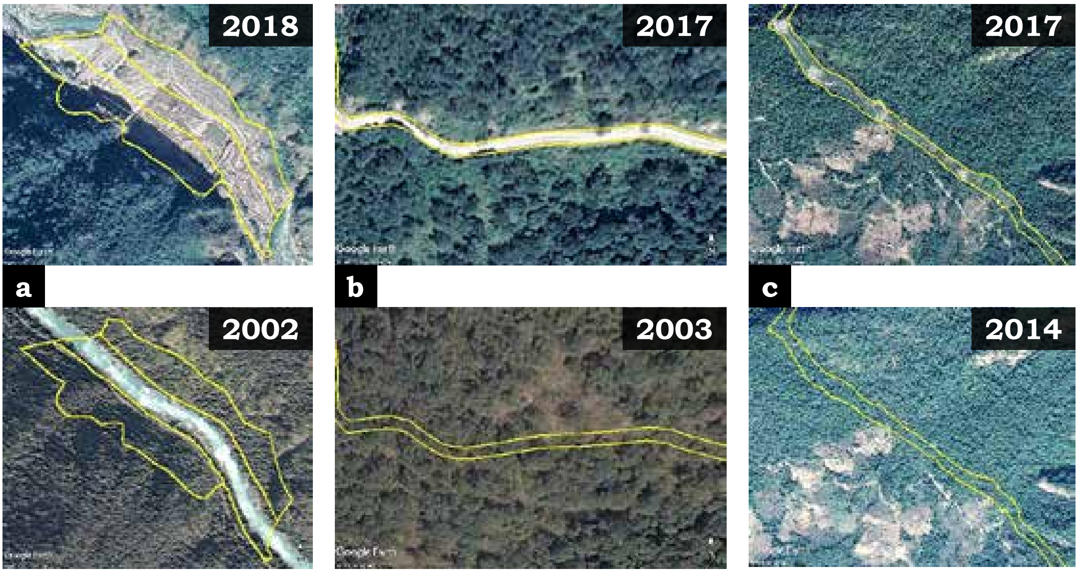


Figure 4 Land use and land cover status in the reference and baseline images (a) infrastructure, (b) road, (c) transmission line

Concurrently, each disturbed area polygons were verified with the records of respective project managements and joint confirmation of the disturbed area was conducted in the field with respective project management team. Field verification for the forest cover due to transmission lines were jointly conducted with BPCL.

The entire process for the analysis is summarized in the following methodological flowcharts.

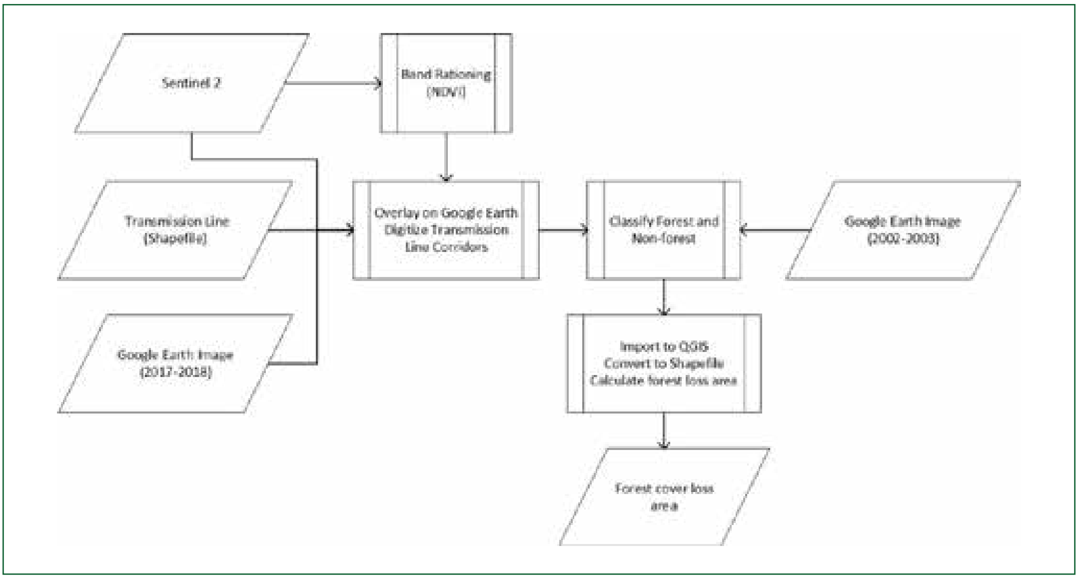


Figure 5 Flow chart for analysis of forest cover loss from transmission lines

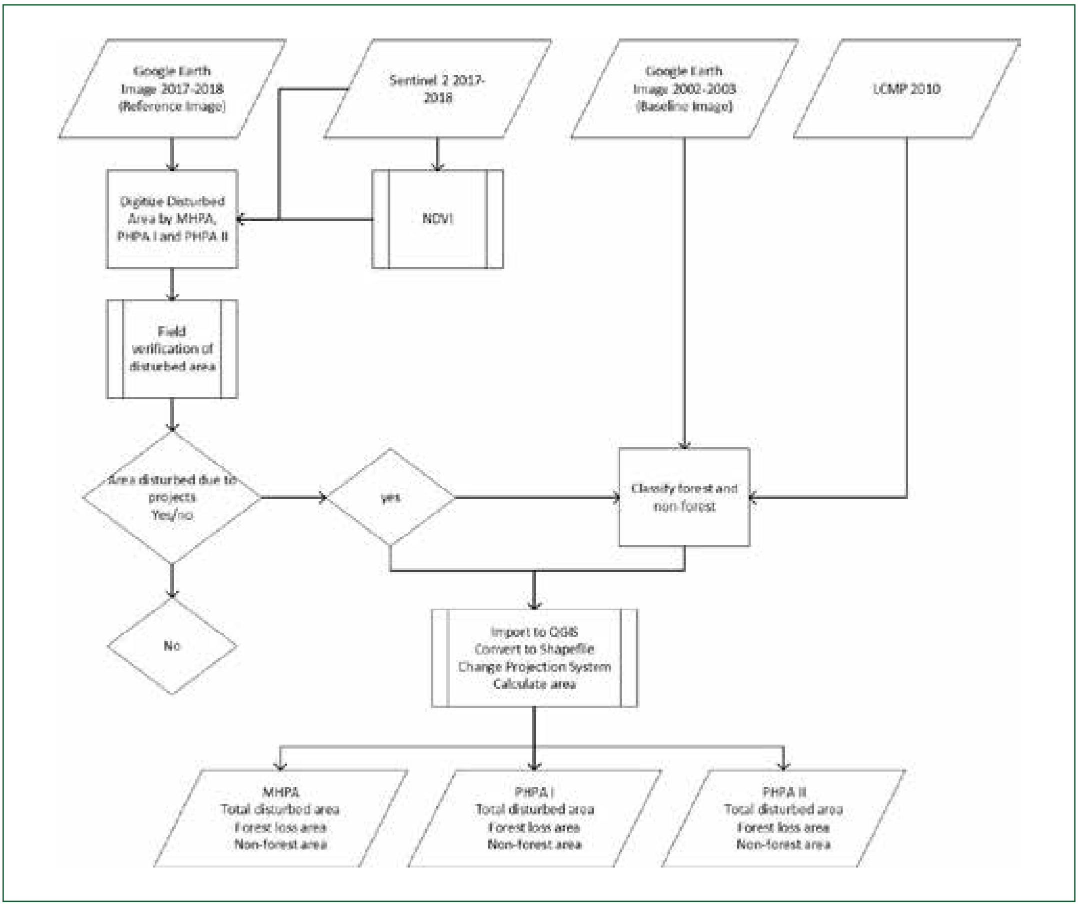


Figure 6 Flow chart for analysis of forest cover loss from infrastructure and roads

4. Result

The construction of hydropower projects has affected various land use categories. Agriculture and forests were dominant land use categories that were affected. Other land use category affected due to the project includes meadow, shrubs, orchards, settlements and small water bodies.

The disturbed area due to infrastructure consist of construction of buildings, temporary camps, muck dumping yards, crushing plants, quarries or any other land moving activities resulting from project funding. Similarly, disturbed area due to road constructions includes all roads constructed under the project fund including temporary service roads. For transmission line, the disturbed area consists of RoW corridors running through various land use categories and construction of towers.

4.1. PHPA-I

Total disturbed area due to infrastructure construction based on the reference image is approximately 208.1 ha. The total forest cover lost due to the infrastructure construction resulting from PHPA-I is around 78.8 ha (Figure 7a). The other land use categories which sum up to 129.3 ha is considered as non-forest.

Total disturbed area due to road construction is approximately 14.9 ha. From this around 9.5 ha is forests and 5.4 ha consist of other land use category in the baseline image (Figure 7b).

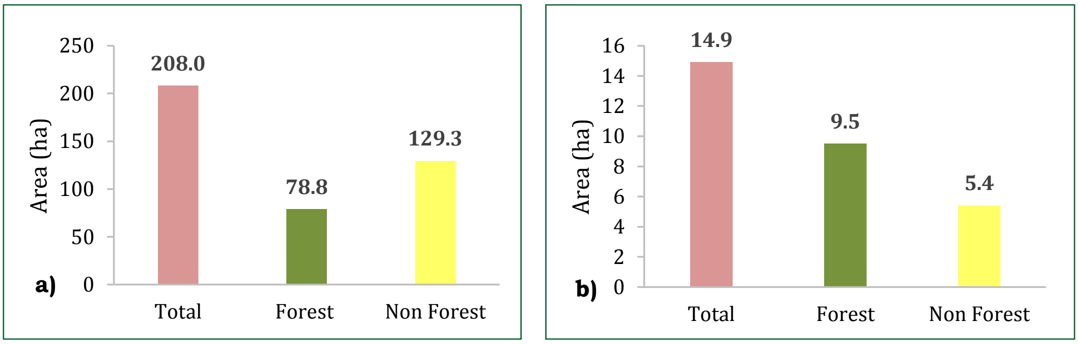


Figure 7 Total disturbed area, forest cover loss and non-forest area from construction of (a) infrastructure and (b) road under PHPA-I

Total forest lost due to the construction of infrastructure and roads from PHPA-I sums up to be 88.3 ha from the total disturbed area of 223 ha. The remaining disturbed area of other land use categories is approximately 134.7 ha (Figure 8).

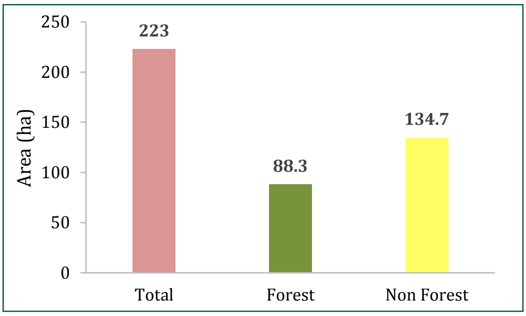


Figure 8 Total disturbed area, forest cover loss and non-forest area from combined construction of infrastructure and road under PHPA-I

From one 400 kV D/C transmission line running directly from Ruepisa pothead yard to Lhamoizingkha measuring 93.5 km with 228 transmission towers approximately 186 ha of forest cover have been removed. From another 400 kV D/C transmission line running from Ruepisa to PHPA-II pothead yard measuring around 12.9 km with 38 transmission towers around 18.3 ha of forest cover have been lost. Forest cover loss from the shared 400 kV D/C LILO transmission line running till Lhamoizingkha is approximately 195 ha. As per the agreement between two project management, the forest cover loss had to be equally shared between two projects thereby around 97.5 ha is attributed to each project. Upon summing, the forest cover loss from all the transmission lines resulting from PHPA-I project is approximately 301.7 ha.

Therefore, the total forest cover loss from the construction of infrastructure, roads and transmission lines under PHPA-I project sums up to be approximately 390 ha.

4.2. PHPA-II

Due to the construction of infrastructure, approximately 131.7 ha has been disturbed. Out of this total forest cover loss is around 62.8 ha and other land use categories disturbed sums up to 68.9 ha referred as non-forest (Figure 9a).

Forest cover loss due to PHPA-II road construction is approximately 13.6 ha from the total disturbed area of around 16.2 ha. Around 2.6 ha consist of other land use category (Figure 9b).

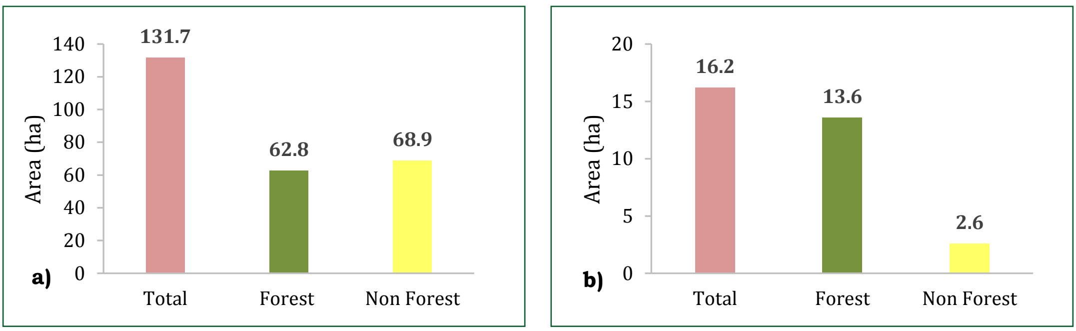


Figure 9 Total disturbed area, forest cover loss and non-forest area from construction of (a) infrastructure and (b) road under PHPA-II

Total forest cover lost due to the construction of infrastructure and roads from PHPA-II amount to around 76.4 ha from the total disturbed area of approximately 147.9 ha. The remaining disturbed area of other land use categories is approximately 71.5 ha (Figure 10).

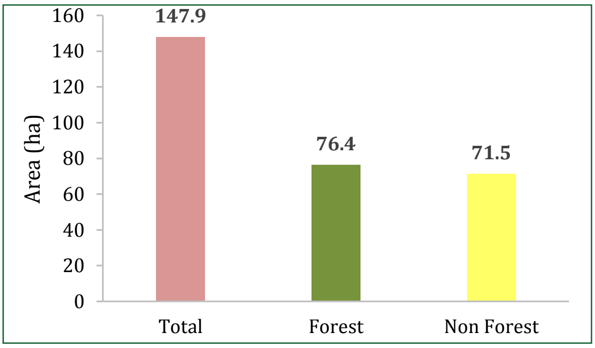


Figure 10 Total disturbed area, forest cover loss and non-forest area from combined construction of infrastructure and road under PHPA-II

From the clearing of 52 m as RoW corridor for a single 400 kV D/C transmission lines running from PHPA-II pothead yard to Jigmeling measuring 65 km in length with 151 transmission towers, around 134.6 ha of forest cover has been removed. Similarly, from the commonly used 400 kV LILO transmission line, around 97.5 ha of forest cover loss is attributed to PHPA-II. Upon summing the forest cover loss from all the transmission lines resulting from PHPA-II project is approximately 232.1 ha.

Therefore, the total forest cover loss from the construction of infrastructure, roads and transmission lines under PHPA-II project amounts to approximately 308.5 ha.

4.3. MHPA

Under MHPA project, total disturbed area of 122.6 ha is attributed to the construction of infrastructure. From this, forest cover loss of 61.1 ha is observed and 61.5 ha consist of other land use category (Figure 11a).

Around 7.2 ha of land is disturbed as a result of road construction. From this, 4.8 ha of land is observed as forest cover loss and remaining 2.4 ha consist of non-forest (Figure 11b).

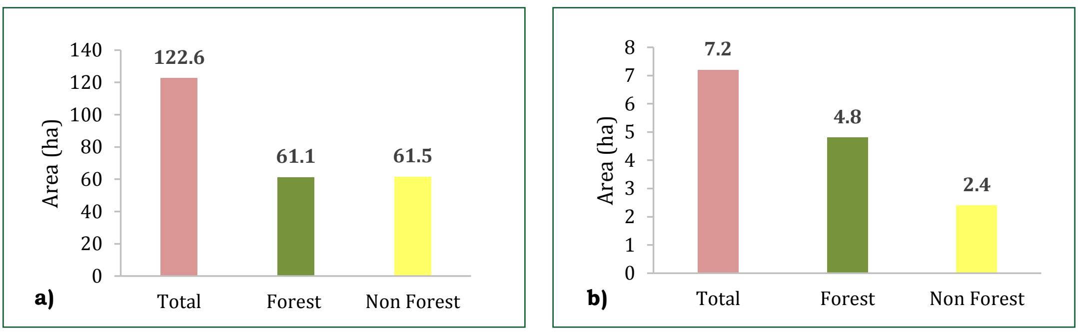


Figure 11 Total disturbed area, forest cover loss and non-forest area from construction of (a) infrastructure and (b) road under MHPA

Total area disturbed due to the construction of infrastructure and roads from MHPA amounts to around 129.8 ha and 65.9 ha is observed as forest cover loss. The other land use categories disturbed equals to around 63.9 ha (Figure 12).

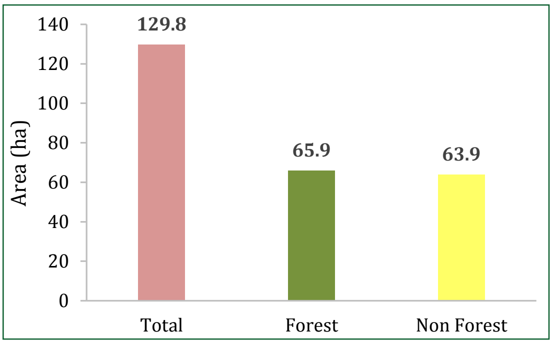


Figure 12 Total disturbed area, forest cover loss and non-forest area from combined construction of infrastructure and road under MHPA

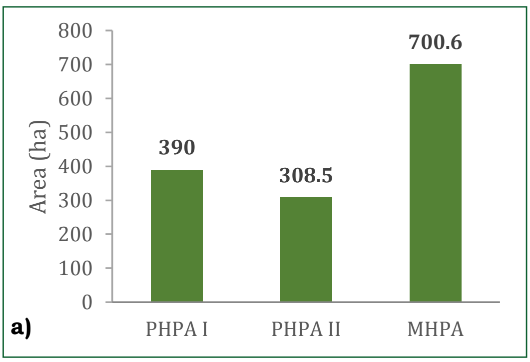
Around 634.7 ha of forest cover is observed to be permanently removed due to the corridor clearing of two 400 kV D/C transmission lines. The transmission line runs from Yurmu to Jigmeling measuring 169.5 km with 202 towers.

Therefore, total forest cover loss from construction of infrastructure, roads and transmission lines under MHPA project is observed to be approximately 700.6 ha.

4.4. Total forest cover loss from the three hydropower projects

The total forest cover loss for each hydropower project is estimated by adding the forest cover loss due to construction of infrastructure, road and transmission line of respective projects. A total forest cover of approximately 390, 308.5 and 700.6 ha are lost from PHPA-I, PHPA-II and MHPA respectively (Figure 13a). Approximately 1,399.1 ha of forest cover has been removed cumulatively till date from construction of three hydropower projects and its transmission lines.

The per unit of forest cover loss against the power generation capacity of each hydropower project is estimated to be 0.33, 0.30 and 0.97 ha per megawatt for PHPA-I, PHPA-II and MHPA respectively (Figure 13b).



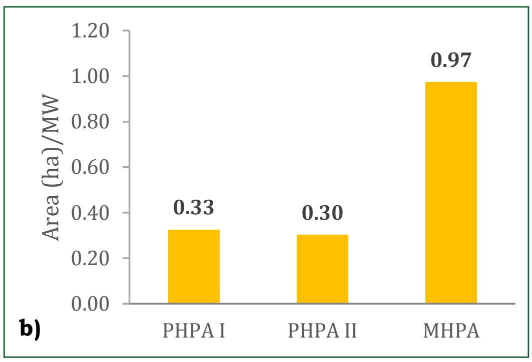


Figure 13 (a) Total forest cover loss and (b) Per unit forest cover loss from the three hydropower projects

4.5. Effects of forest cover loss

Forest plays a critical role in terms of providing both tangible and intangible services. Timber and non-wood forest produce are the two most important products that the people benefit from forests. In addition, forest also serves an important habitat in terms of the biological diversity and ecological functions they provide.

Taking the average number of tree (diameter ≥ 10 cm) per hectare in Bhutan to be 280 (FRMD, 2016), around 84,504 trees are estimated to be removed due to the various construction activities resulting from PHPA-I project. Approximately 86,380 trees are estimated to be removed as a result of PHPA-II construction activities. Similarly, around 1,96,168 trees are anticipated to be removed due to MHPA project. In total around 3,67,052 trees are estimated to be removed due to three projects construction activities.

Considering the average volume per hectare for tree with diameter ≥ 10 cm to be 346 m^3 (FRMD, 2016), around 1,04,422.8 m^3 of growing stock is estimated to be harvested from various construction activities of PHPA-I project. Approximately, 1,06,741 m^3 of growing stock is anticipated to be removed form PHPA-II construction activities. Similarly, around 2,42,407.6 m^3 of growing stock is estimated to be harvested from construction activities of MHPA project. Therefore, the removal of growing stock due to the construction of infrastructure, roads and transmission line from the three hydropower projects is estimated to be approximately 4,53,571.4 m^3.

When the construction of hydropower project is initiated, often the land gets converted from one land use to another. Due to infrastructure construction, forest gets converted to either settlement or other land as per IPCC (2006) land use category. While during the construction of transmission line, the forest is permanently removed beneath the transmission line (or RoW). Trees beneath the transmission lines are never allowed to regrow, the land is permanently kept tree-less, where only growth of grasses and herbs are associated. In such cases, the forest gets converted to grassland according to IPCC (2006) land use category. Therefore, when the forests land gets converted to other land use, not only the stored carbon from the forest stand is lost but also the carbon sequestration and storage capacity of the forest land is permanently removed.

For this study, we assume that all forest land lost to construction of infrastructure and road in the project site is converted to settlement and forest land lost to the construction of transmission line is converted to grassland. Taking 699.08 tonnes of CO_2 equivalent (FRMD, 2018) as carbon emission factor for forests land being converted to settlements, around 0.06, 0.05 and 0.05 million tonnes of CO_2 is estimated to be emitted from construction sites of PHPA-I, PHPA-II and MHPA respectively. Similarly taking 484.08 tonnes of CO_2 equivalent (FRMD, 2018) as carbon emission factor for forests land being converted to grasslands, around 0.15, 0.11 and 0.31 million tonnes of

CO_2 is estimated to be emitted from construction of transmission line under PHPA-I, PHPA-II and MHPA respectively. Therefore, the total emissions of CO_2 from PHPA-I, PHPA-II and MHPA is estimated to be approximately 0.21, 0.16 and 0.36 million tonnes of CO_2 respectively.

4.6. Compensatory afforestation

The Forest and Nature Conservation Rules and Regulation of Bhutan (FNCRR) 2017, requires all major hydropower projects to carry out compensatory plantation for SRF land acquired for project development (DoFPS, 2017). Emphasis on providing adequate funds for carrying out compensatory plantation in twice the area occupied by the project is also highlighted in FNCRR, 2017. Further, it is stated that compensatory plantation should not be limited to project area but may be extended to any potential SRF area. However, amendment of this clause was made only in FNCRR 2017, much later to the inception of these hydropower projects, and the stated clause may not be applicable here. Therefore, the area of compensatory afforestation required may not match to the forest cover loss area.

So far, DoFPS has carried out compensatory plantation in 343.4 ha from the fund provided by PHPA-I. The compensatory plantation is carried out in both project occupied area and other suitable SRF land. Further PHPA-I has carried out compensatory plantation in 21.74 ha by themselves within the project surroundings.

Under PHPA-II funding, DoFPS has carried out compensatory plantation in 428.20 ha in both inside the project area and other suitable SRF land. Additionally, the project authority has also carried out compensatory plantation in 24 ha of area within the project sites.

Similarly, under MHPA funding, DoFPS has carried out compensatory plantation in 220 ha of SRF land.

5. Limitations of the study

For the analysis, forest cover definition “land with trees spanning more than 0.5 ha with trees higher than 5 meters and a canopy cover more than 10 percent” as defined in the National Forest Policy of Bhutan, 2011 was applied. This definition limits the inclusion of single trees that are sporadically distributed over the area from being considered into to the analysis for estimating forest cover loss. Further, the definition also restricts tree species with height below 5 m from being taken into the analysis despite having their ability to grow more than 5 m in height in future. This means that areas under compensatory afforestation could not be considered as forest for not meeting the criteria under forest definition. The forest definition also does not carry any land tenure status i.e. State Reserved Forest (SRF) or private land. Therefore, the forest cover loss is not differentiated between SRF and private forest.

Very high-resolution Google Earth image was used for manually digitizing forest cover loss. Latest updated image and available historical image was the main source of information for the change detection over the period. Main constraints for such approaches and methodology is in acquiring the image of same time period for across the study area.

In some locations, where very high-resolution historical image was missing, historical LUCL map had to be used. This caused inconsistency in interpreting and maintaining the spatial resolution for change detections.

In optical remote sensing, shadow often poses challenge for image interpretation in mountainous terrain. Such challenges would be partially overcome by carrying out shadow correction if satellite image could be downloaded. Due to restriction of downloading the Google Earth image, the shadow correction could not be conducted. Thereby the visual interpretation of area falling under the shadow like deep gorges, steep and narrow valleys was still a challenge in Google Earth platform. In such cases, the interpretation is carried out using NDVI and other indices derived from Sentinel-2. However, it should be noted that due to the coarser spatial resolution of Sentinel-2 compared to very high-resolution Google Earth image, the interpretation of forest cover loss may be underestimated.

The analysis of disturbed area is based on reference image of 2017 to 2019 for all three hydropower projects. This limits detecting disturbed area until 2018. However, PHPA I and PHPA II are still under construction phase, therefore, any disturb area due to extension of construction after 2018 cannot be included for the analysis. Especially the dam of all three projects is still under construction, the actual area under the submergence of water could not be estimated and included in the analysis.

6. Conclusion

The construction of the three hydropower projects which fall between 2008 and 2018 has varying forest cover loss in each of their sites. PHPA I, which was initiated in 2008 with capacity of 1200 MW, has caused 88.3 ha of forest cover loss from construction of infrastructure and roads and 301.7 ha from its transmission lines. PHPA II, which was initiated in 2010 with the capacity of 1020 MW has caused 76.4 ha of forest cover loss from construction of infrastructures and roads and 232.1 ha from its transmission lines. Similarly, MHPA, which was initiated in 2012 with capacity of 720MW has caused 65.9 ha of forest cover loss from the construction infrastructure and roads and 634.7 ha from its transmission lines. If we take the average forest cover loss from only these three major hydropower projects over their generating capacity, then the average forest cover loss per megawatt would be estimated to 0.5 ha.

From this analysis, it is evidently clear that more forest cover is lost from the construction of transmission line than from the construction of infrastructure and roads within the project sites. Carrying out compensatory afforestation in twice the area occupied does not apply to the construction of transmission lines. However, looking at the extent of area that needs to be permanently treeless under the transmission lines, same clause needs to be reviewed for transmission line as well.

Generally, it is viewed that forest cover loss is directly proportional to the generating power capacity of the hydropower. However, through this study it is observed that forest cover loss is closely related to the selection of sites rather than its generating capacity. It is also found that forest cover loss is more prominently observed if hydropower construction is situated in broadleaf forests.

Forests plays an integral part of human wellbeing in Bhutan. Forests provide number of ecosystem services, including provisioning, regulating and culture services (Millennium Ecosystem, 2005). The valuation of the forest cover loss in this study is limited to only timber harvested and stored carbon content loss. Since this study was more focused on knowing only the extend of forest cover loss, detail accounting and valuation of ecosystem services lost could not be studied.

Lastly, this study has provided baseline information on forest cover loss due to three major hydropower projects and its transmission lines. This study has also provided some form of validation on findings of study on drivers of deforestation and forest degradation in Bhutan carried out by DoFPS at National level.

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