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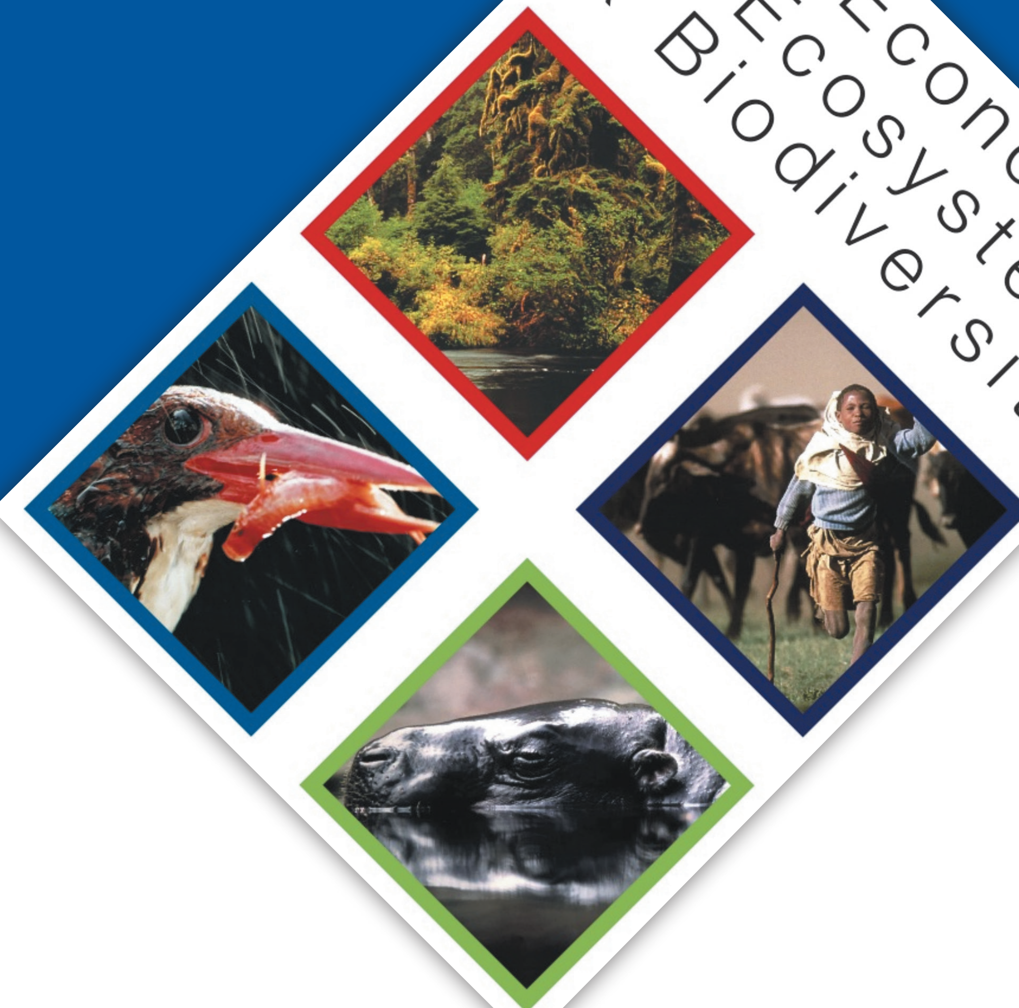

Relationship Between Land-Use Management and Hydropower Development in Bhutan

Ugyen Wangchuck Institute for Conservation and Environmental Research

The Economics of Ecosystems & Biodiversity

Relationship Between Land-Use Management and Hydropower Development in Bhutan

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Department of Forests and Park Services
Ministry of Agriculture and Forests
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Kuri – Gongri river

CONTENT

Acknowledgements

The Economics of Ecosystems and Biodiversity (TEEB) Bhutan team would like to express our humble gratitude to the Ministry of Agriculture and Forests, Royal Government of Bhutan for having opted to become one of the UNEP initiated TEEB country studies. The study would have not been possible without the generous support of European Commission and UN Environment office – Geneva.

During the process of the study, many stakeholders within the country were consulted to participate in various meetings organized to pursue the study. TEEB Bhutan team remains highly indebted to all the stakeholders involved: Gross National Happiness Commission, Druk Green Power Corporation, Department of Forests and Park Services, Bhutan Power Corporation Ltd, Department of Hydropower and Power Systems, Department of Renewable Energy, National Center for Hydrology and Meteorology, National Land Commission, National Statistical Bureau, Tourism Council of Bhutan, Department of Culture, Department of Renewable Energy, National Environment Commission, WWF – Bhutan, National Biodiversity Center and all officials who were involved in the course of the study.

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Limitation of the study

The study is based on the modelling exercises and the models does not take into account any changes that may occur within the predicted time frame. The model also do not consider any of the mitigation measures reflected within the Detailed Project Report and Environmental and Social Impact Assessment of each selected plant. The study forecasts the data based on landuse and land cover change projections estimated from system dynamics model.

Since, site specific data were not available, the study considered some global data as well as the national data to feed in the model, which may not necessarily fit well within Bhutan's context.

Executive Summary

Royal Government of Bhutan (RGoB) confirmed Bhutan's participation as one of the pilot countries for the European Commission funded project on January 10, 2013, for The Economics of Ecosystems and Biodivesity (TEEB) national implementation. Thus, as a part of TEEB country study, a TEEB scoping workshop was held in Thimphu, Bhutan, from 10 – 12 March, 2014. The workshop recommended TEEB-Bhutan to assess changes in ecosystem services provisioning (with focus on watershed services from forests) under different hydropower diversification scenarios.

The overall objective of TEEB Bhutan study, therefore was to develop simulation models and compare alternative scenarios for the expansion of hydropower capacity in Bhutan. This objective was further refined during the course of the project – in its final scope, it was decided that the TEEB Bhutan study would examine the role of upstream land management practices on ecosystem services, with a particular focus on water quality for hydropower generation. The Business As Usual (BAU) scenario was compared to alternative scenarios involving mitigating policies, conservation policies, and a combination of both.

TEEB Bhutan selected eight hydropower plants [3 commissioned; 2 under construction and 3 planned for construction] and generated three scenarios to simulate changes in ecosystem services provisioning from 2010 to 2030. Three scenarios were; i. Business as usual; ii. hydropower construction; iii. hydropower construction but with mitigation works.

To pursue TEEB assessments in Bhutan, spatial models were used to understand how upstream land use changes impact the quality of water delivered to hydropower stations; and these spatial analyses were linked to a system model that includes social and economic variables to ensure that relationships between hydropower and socio-economic development were also captured to generate more realistic land use scenarios. The study was achieved through various methods:

i. Series of stakeholder workshops
ii. Spatial modeling through InVEST
iii. System dynamics model
    a. System thinking
    b. Mathematical model

The modeling results suggest that scenario three could offer a win win situation, wherein mitigation actions upstream (in the form of reforestation and water shed management programmes) could reduce sediment loading for hydropower companies, and provide ecosystem services for communities. Reduced sediment loading would reduce the opearations and maintenance costs currently incurred by hydropower plants to remove sediment. Upstream mitigation activities also add further benefits in the form of ecosystem services, mainly habitat improvements for animals and increase in carbon sequestration.

Scenario "iii" took into account just 20% of the 1% plough back funds, which Druk Green Power Corporation is obliged to pay to the Ministry of Agriculture and Forests for integrated sustainable water resouces management as per the Bhutan Sustainable Hydropower Development Policy 2008, article 12.4 . This may be achieved through instituting Payment for Environmental Services (PES) scheme. PES should be targeted towards proper land-use management, which may include undertaking plantation activities of the right species and minimizing ground excavation and mining.

The study shows that there are both potential benefits and drawbacks of expanding hydropower generation in Bhutan. While the benefits include increase in revenue from the generation and export of electricity, side effects include the potential increase in sedimentation which would reduce the electricity generation and increase dredging costs. The study suggests implementing ecosystem restoration interventions to curb and offset some of these emerging environmental pressures and side effects. The analysis shows that reallocating part of the revenues to local environmental preservation can avoid most of the negative impacts forecasted.

TEEB Bhutan study recommends institutionalizing sustainable funding mechanisms and better target spending of these funds at the watershed level and to evaluate and strengthen watershed management plans that affect or are affected by hydropower installations and integrate with environmental management plans. The study also strongly recommends a follow up study to identify the sources of sediments and to target management activities to the source and also to pursue similar valuation exercises to the downstream of the hydropower project sites. Furthermore, the study did not look at the direct impacts of hydropower development on riverine ecosystems, future work must also focus on examining these.

TEEB Bhutan study clearly demonstrates the need to consider the study at watershed level than at the project sites during the phase of project planning and while undertaking Environmental and Social Impact Assessment.

Glacier water flowing from Lemthrang in Bumthang [4650 masl]

INTRODUCTION

The Economics of Ecosystems and Biodiversity (TEEB) sets out the case for the identification of the key services provided by nature and their use in decision making. This includes highlighting the value of nature (including its goods and services) through natural capital valuation. TEEB follows a three-tiered approach towards ecosystem valuation by recognizing, demonstrating, and capturing value. This approach helps to make nature more economically visible and thereby influencing key actors to change their decisions and behaviours.

Royal Government of Bhutan (RGoB) expressed confirming Bhutan's participation as one of the pilot countries for the European Commission funded project on January 10, 2013, for TEEB national implementations. Thus, as a part of TEEB country study, a TEEB scoping workshop was held in Thimphu, Bhutan, from 10 – 12 March, 2014, with around twenty participants from various agencies. One of the major objectives of the workshop was to identify policy questions that TEEB Bhutan would inform through both biophysical and valuation exercises. During the scoping workshop, it was decided that TEEB-Bhutan would inform the Sustainable Hydropower Development Policy of 2008, and the Alternative Renewable Energy Policy of 2013. The workshop also recommended that the study should assess changes in ecosystem services provisioning (with focus on watershed services from forests) under different hydropower diversification scenarios, assuming that each scenario would seek to meet the 2020 energy goals set by the Royal Government of Bhutan. The workshop also identified set of ecosystem services, which should be considered to undertake the assessment. However, the objective of TEEB Bhutan study was further refined during the course of the project – in its final scope, it was decided that the TEEB Bhutan study would examine the role of upstream land management practices on ecosystem services, with a particular focus on water quality for hydropower generation.

Thus, the overall objective of TEEB Bhutan studies was to develop simulation models and compare alternative scenarios for the expansion of hydropower capacity in Bhutan. Emphasis was put on the changes in ecosystem services and biodiversity impacts. The Business As Usual (BAU) scenario was compared to alternative scenarios involving mitigating policies, conservation policies, and a combination of both.

The need for valuing ecosystem services stems from the fact that ecological life support systems are essential for economic performance and human well-being. Therefore, the main objective of ecosystem valuation is to clarify socio-ecological relationships, document the way in which human decisions affect ecosystem services, and to quantify in monetary terms ecosystem value changes in order to incorporate them in public decision-making processes.

BACKGROUND INFORMATION

The rugged terrain, compounded by the fact that the country is landlocked does not provide much economic advantage to Bhutan; thus, hydropower forms the backbone of Bhutan's economy. The decision by the RGoB to exploit its water resources for the production of electricity may change the economic scenario for Bhutan as hydropower development has now taken a center stage. Bhutan has estimated hydropower potential of 30,000 MW of which, 23,760 MW has been identified and assessed to be technically feasible. So far, only about 6.5 percent of the total hydropower potential totaling to 1,060 MW has been harnessed. However, this alone contributes to over 20% of RGoB's revenue. Considering the huge impact hydropower sector has had on the socio- economic development of the country, the RGoB has embarked on a mission to generate 10,000 MW of hydro-electricity by 2020 in cooperation with the Government of India (GoI). GoI has agreed to a minimum import of 5000 MW of electricity from Bhutan by the year 2020. However, it is anticipated that 10, 000 MW of hydro-electricity development target by 2020 will not be possible owing to the size of the projects to be taken up and other major constraints like financing and marketing. However, in addition to the 10, 000 MW projects, some projects are taken up on Public Private Partnership (PPP) models by the Druk Green Power Corporation (DGPC) with the prospective private investors. Currently, construction of 118 MW Nikachhu project is being implemented under PPP mode.

Apart from the above projects, the RGoB in the 11th FYP (2013 – 2018) has planned to undertake preparation of five Detailed Project Reports (DPR), eight pre-feasibility study and seven reconnaissance study of different hydropower projects in the country.

Chapter 1, article 1.3 of the Bhutan Sustainable Hydropower Development Policy 2008*,* states that RGoB intends to develop hydropower projects in an accelerated manner in order to have an installed capacity of at least 10,000 MW by 2020. The key reasons for acceleration of hydropower development are:

- hydropower is the main source of revenue for the country and its development would help the country achieve its goal of economic self-reliance; and
- huge energy demand in the region offers a big opportunity for Bhutan to develop its rich hydropower resources for export.

Hydropower is a strategic national resource of Bhutan and is the main driver of economic growth since the commissioning of Chukha hydroelectric project in 1986. The Power System Master Plan 2003 – 2022*,* shortlisted 76 projects, of which 70 are run of the river and 6 reservoir schemes. The total estimated capacity of these 76 projects is about 23,760 MW. For the purpose of this policy, the projects are classified as follows:

- Micro/Mini Projects – having installed capacity of up to 1 MW
- Small Projects – having installed capacity from 1 MW to 25 MW
- Medium Projects – having installed capacity from 25 MW to 150 MW
- Large Projects – having installed capacity from 150 MW to 1000 MW
- Mega Projects – having installed capacity of more than 1000 MW.

There are two major power utility companies in Bhutan: Druk Green Power Corporation (DGPC) and the Bhutan Power Corporation (BPC). DGPC owns and operates the larger hydropower plants (> 5 MW) in the country and BPC owns and operates plants below 5 MW, including mini and micro-hydro and diesel power plants. BPC also manages the transmission and distribution system and then retails electricity to customers in the country.

The environmental assessment report for hydropower projects in Bhutan focuses on physical, biological and social impacts arising from the project and proposes measures to mitigate adverse impacts and measures to enhance positive impacts of the construction and operation of the hydropower plant. Physical impacts of the hydropower plant arise from the construction of roads, transmission lines, powerhouses, tunnels, dams, and reservoirs. Biological impacts consider the change in the river flow, in aquatic ecosystems and fish population, and in the water level when changing the load. On the other hand, social impacts include household relocation, influx of workers, temporary contractor camp's use of cook stoves, and displacement of agricultural production.

Damsite of Chhukha Hydropower Plant

SCENARIOS

Scenario 1 (Business As Usual (BAU))

The Business As Usual (BAU) scenario is simulated to estimate projected baseline changes in geographical area interested by the future construction of hydropower dams. This scenario assumes the continuation of existing trends (e.g. population growth) and estimates impacts on land use (e.g. agriculture and settlement) and related impacts on the environment (e.g. carbon sequestration and water yield). While no new interventions are assumed to be implemented, existing baseline decisions are projected to continue (e.g. building new roads to accommodate the growing population).

Scenario 2 (Hydropower scenario)

Scenario 2 simulates the construction of five hydropower dams across the country. It uses information on the size and capacity of the hydropower dam to estimate its expected electricity generation. It also projects construction costs, as well as revenues, operations and management costs. Further, it assumes the creation of new infrastructure (e.g. roads, as part of the commissioning of the hydropower dam) and transmissions lines (especially concerning the potential to export electricity to India). Outcomes of hydropower dam construction are also projected on land use and population growth. Population could in fact be affected positively or negatively, depending on localized impacts on agriculture land, water availability and access to markets.

Scenario 3 (Mitigation scenario)

Scenario 3 simulates the construction of five hydropower dams and the reinvestment of part of the proceeds (20% of 1% of electricity sales revenue) into reforestation and forest conservation at the watershed level. This intervention is assumed to lead to the expansion of the forest stock, with measurable outcomes on carbon sequestration, nutrient loadings and export as well as on water availability.

HYDROPOWER PROJECTS AND SITES

TEEB Bhutan study selected eight hydropower plants to assess the relationship between land use management and hydropower development for 5 plants (3 planned and 2 under construction), using information such as sediment removal and other associated costs from 3 already commissioned hydropower plants. The study sites were chosen during the TEEB-Bhutan study core team member's meeting. While deciding on the hydropower plants to study, following criterias were considered:

- Location of the plant within the country
- Installed or projected capacity of the plant
- Current status of the plant [commissioned; under-construction or planned for construction].

COMMISSIONED HYDROPOWER SITES

Three commissioned hydropower plants were selected to generate information/data on economic generation and associated running costs for the hydropower plants in Bhutan. The experiences and data generated from these hydropower plants served as huge data source for economic gains and maintenance costs such as duration of plants required to shut down to remove sediments and other debris to run hydropower plants.

Chhukha Hydropower Plant

Chhukha hydropower plant (CHP) is Bhutan's oldest mega power project. It is constructed on the Wangchhu river basin, which uses the discharges of Thimphu, Paro and Haa valleys.

Kurichhu Hydropower Plant

Kurichhu hydropower plant is located at Gyalpozhing, Mongar district on the Kurichhu river in eastern Bhutan. It is a run-of-river scheme with a dam of height 55 m. The construction work of this plant began in 1995 and the commercial operation of the plant started on 1st November 2001.

Dagachhu Hydropower Plant

Dagachhu hydropower project is located in Dagana district and is a large-scale Clean Development Mechanism (CDM) hydropower project. It is a run-of-the-river hydropower project with a dam of 20.5 m above the riverbed creating reservoir with live storage volume of 0.07 M m^3.

PLANNED HYDROPOWER SITES

For those hydropower plants, which are under construction, ecosystem services assessment were undertaken. Since there is proper documentation of environmental and possible social impacts recorded during the Environment and Social Impact Assessment (ESIA) for each hydropower plants, which are planned, and under construction, baseline bio-physical and social data are already available. The information from ESIA were used to model bio-physical and ecosystem service changes over time. Though the scope of ESIA remained within the project sites, it helped the study to model the available information to the watershed level.

Kuri I Hydropower Plant

Kuri I hydropower plant will be located at an elevation from 500 – 850 meters above sea level. All the construction sites of the Kuri I project will be located within Mongar district, however the reservoir is expected to extend to Lhuntse district. A 65 m high intake dam will be built which is expected to create reservoir of 5.5 km long and 300 meter wide reservoir. The total area of the reservoir is expected to be about 1.6 to 1.7 square kilometers.

Gamrichhu II Hydropower Plant

The entire project of Gamrichhu II hydropower plant is located in Sakteng dungkhag in Trashigang district and falls in and around the protected areas of Sakteng Wildlife Sanctuary. The project area would range from the elevation of 2320 m to 2900 m. For this project, construction of 22 m concrete gravity dam located at about 600 meters downstream of Sakteng village is envisioned.

Bunakha Reservoir

Bunakha hydroelectric project is proposed to be constructed across the Wangchhu, near Bunakha village. It is about 3.56 km, upstream of Chukha hydroelectric project. It is expected to create reservoir of 17.253 km long. This hydroelectric project will be first of its kind in Bhutan as it is the first reservoir project in the country. Over all land requirement for this project is estimated to be about 820.68 ha of which 797.78 ha is State Reserve Forest land (SRF) and 22.90 ha is private land or state. Bunakha hydroelectric project will submerge 699.94 ha of land comprising of 684.82 ha and 12.12 ha of private land.

UNDER-CONSTRUCTION HYDROPOWER SITES

Nikachhu II Hydropower Plant

The dam of the project will be about 33 meters high above the riverbed and is being constructed approximately 6 km downstream of Chendebji. The dam will create reservoir of about 12.28 acres (4.9 hectares). Based on the detail land survey and socio-economic assessment, the project is expected to impact about 3.57 acres (1.43 hectares) of private land belonging to 11 households and a public institution and the rest will be in the government land. The area is dominated by forests (87%) with natural pastures of about 8% and arable land of about 2% and other uses making up the rest. Most of the forests comprise of broadleaf and the project is located in the northern side of the Nikachhu where the area is comparatively degraded as the southern side of the project is in the Jigme Singye Wangchuck National Park.

Punatsangchhu Hydropower Plant

Punatsangchhu hydropower project is a run-off river scheme on Punatsangchhu. This project will construct 137 m high concrete dam above the deepest foundation level across river Punatsangchhu.

The submergence area for the project at full reservoir level is expected to be 59.638 ha and the catchment area intercepted at the dam site is 6390 km^2. The transmission line construction would require about 520 ha and of this about 10 km length has been estimated passing through the biological corridor, connecting Jigme Dorji National Park with Jigme Singye Wangchuck National Park. The forests in this area generally comprises of warm broad-leaved and chir-pine forest.

METHODOLOGY

A stakeholder meeting was conducted to determine the scenario for the study along with choosing the study sites for TEEB Bhutan. Hydropower sites were selected based on the current status of the plant [commissioned; under-construction and planned for construction], capacity of the plant and spatial location of the plant. The meeting also decided to look at the time horizon for the period 2010-2030, with an assessment of the changes in ecosystem services in 2030 compared to 2010 under different scenarios. The stakeholder decided to compare for 2030 as models generally do not simulate correct as the duration of prediction gets longer.

Series of stakeholder meetings within the core TEEB study team and relevant institutions were followed after the initial planning meeting. System dynamics model for the study was developed by the stakeholder during one of the meetings organized for the study. Integrated Spatial Planning (ISP) was utilized to effectively support policy formulation and assessment (identifying policy options that will have the desired impact on the system and the right degree of impact) and evaluation (simulating selected intervention options). In the watershed management sector a spatial planning approach that is integrated and systematic looked at the interactions among several biophysical phenomenon, such as rainfall, runoff, erosion and sediment transport, pollutant loading, and stream transport.

Besides, following tools were applied:

1. **Spatial planning tools**: used to plot out optimal physical placement of economic activities, human settlements etc. Used InVEST and System Dynamics Model (SDM) or Green Economy Model (GEM). InVEST was used to achieve and/or inform the following:

    a. Identify areas of current ES provision in the landscapes and to evaluate their values in biophysical and monetary metrics;

    b. Model future changes in ES provision based on planned infrastructure development;

    c. Quantify, map and where feasible value key ecosystem services in order to inform and help stakeholders and policy makers during the land use planning process;

    d. Inform the development of financing mechanism options to offset the upfront costs of constructing sustainable transport infrastructure; and

    e. Three InVEST models were used:

        i. sediment delivery ratio model;

        ii. water purification model; and

        iii. climate regulation model.

Information derived from spatial planning tools were coupled with socio-economic analysis to create a causal map of the system to identify the main drivers and impacts of land use change in the region. System dynamics methods require an integrated mathematical model that incorporates the key drivers of change and impacts, such as investments and policies, as well as the economic valuation of ecosystem services. Mathematical models were calibrated using InVEST's outputs through validating the direction and magnitude of relationships between biophysical variables and ecosystem services variables, i.e. changes in surface water flow corresponding to hectares of forest lost in the region as a result of road construction, among others. The results of the socio-economic analysis include the estimation of impacts on poverty (monetary and in terms of access to resources). Finally, the result of the simulations generated with GEM were fed back into Marxan and InVEST to visualize spatially the indirect and induced social, economic and environmental impacts of road construction.

2. **Non-market environmental valuation methods**: used to value the external costs/benefits of losing/maintaining ecosystems and their services.

3. **Socio-Economic models**: used to project growth in GDP, trade trends and inform public policy.

ES VALUATION METHODS CHOSEN

To allow the comparison of the benefits of various goods and services, the Total Economic Value (TEV) approach was used to encompass all components of utility derived from ecosystem services using money as a common unit of measurement. In this case, a conservative estimate of the economic value of an ecosystem service can be defined as $EV = s_i p_i$, where s_i is the supply and p_i is the price or shadow price of an ecosystem service i. Consequently, the TEV of ecosystem services can be calculated as:

$$TEV = \sum_{i=1}^{n} s_i p_i$$

where n is the total number of services considered in the TEEB Bhutan study. Since the provisioning services (e.g. food and timber) are proper market commodities, market price information were used to calculate their values. However, for non-commodity ecosystem services, such as the regulating services, there are no individually observed market prices, so that non-market valuation methods were followed.

As far as the time path of carbon prices is concerned, the general conclusion is that the price should rise steadily for many years. However, establishing the correct rate of interest or discount rate is a moot point. According to models in which the greenhouse gas externality is the only one that policy-makers have to worry about, it should increase at a constant rate close to the real rate of interest (that is, after correcting for inflation), which would be around 7%. This would ensure that the marginal cost of abatement, discounted to the present, is the same in all periods, so that total costs cannot be reduced by shifting around when abatement efforts are carried out. However, as the benefits of stabilization are far into the future, applying a typical real market discount rate would result in a minuscule present value of future avoided harms. As a result, a 7% discount rate can introduce a strong bias against any preventive action. Consequently, the Stern Review suggests a 1.5% discount rate. However, most of the simulation models have typically adopted a real interest rate of 3% to 5% per year. For the present study a 4% discount rate is applied to the InVEST Carbon model.

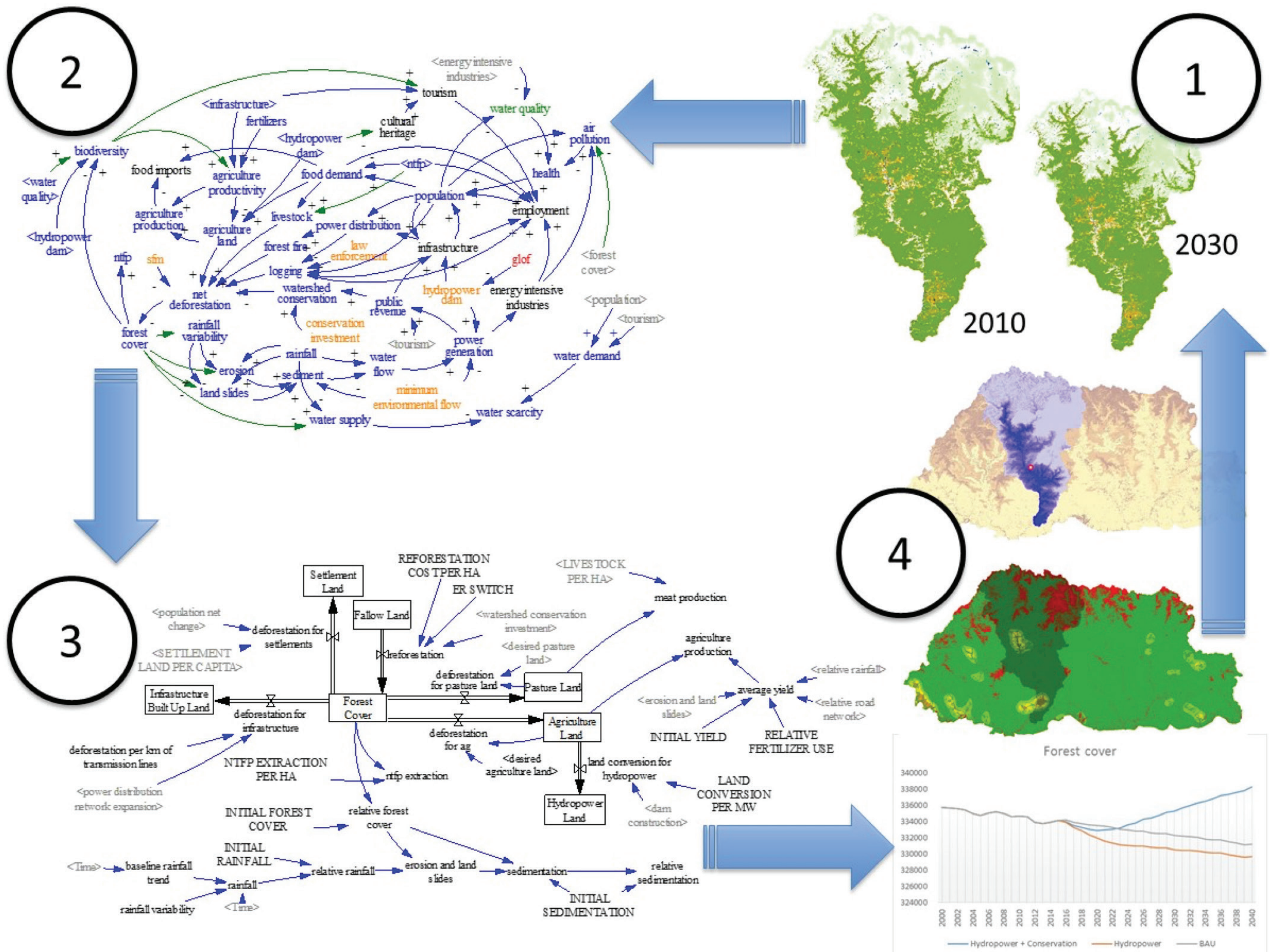

Figure 1: The main methodologies and models utilized: (1) InVest; (2) System Thinking; (3) GEM (System Dynamics) and their (4) Joint use to create future (aggregated) socio-economic and (spatial) land use project

Punakha Dzong with Phochhu and Mochhu. Notice the difference in color of water because of sediment load

PUNATSANGCHHU HYDROPOWER PLANT

BAU scenario

Socio-economic trends

The geographical area which may likely be affected by the construction of the Punatsangchhu Hydro Power-I comprises of the following dzongkhags: Gasa, Punakha and Wangdue. Within these districts, population is expected to increase from 45,780 people in 2010 to 57,880 people in 2030, with an overall percentage increase of 26% and with an average yearly increase of 1.18% between 2010 and 2030. Food demand, which is driven by population change and calories consumption is estimated at a steady value of 3,403 kcal/day per capita and is estimated to increase from 56.8 billion kcal/year in 2010 to 71.9 billion kcal/year in 2030.

Desired agricultural land refers to cropland needed to satisfy local food demand and it is determined by agricultural yield and food demand for local production. In the BAU scenario, desired agricultural land is expected to increase from 9,640 ha in 2010 to 11,860 ha in 2030, with an overall percentage increase of 23% and with an average yearly increase of 1.3%. Desired pasture land, which is determined by livestock density and local livestock production, is estimated to increase from 710 ha in 2010 to 900 ha in 2030, with an overall percentage increase of 26.4% and with an average yearly increase of 1.2%.

Tourism, in addition to population growth and agriculture production, is expected to influence economic growth and employment creation. Tourism arrivals, which in the model are primarily determined by habitat quality and by the historical growth rate of visitors, is expected to rise from 42,510 person/year in 2010 to 84,750 person/year in 2030 marking an overall percentage increase of 99.4% and with an average yearly increase of 3.5%.

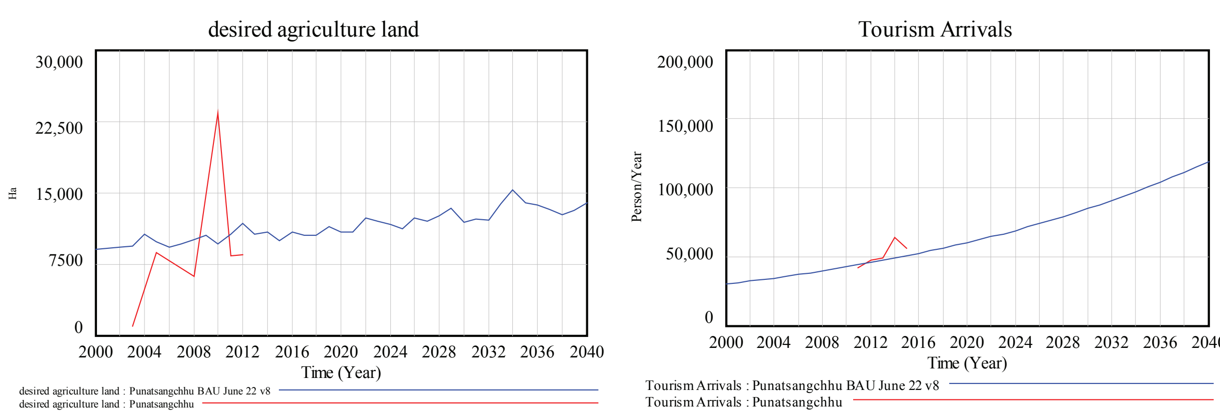

Figure 2: Desired agriculture land and tourism arrivals, BAU scenario; 2000 – 2040

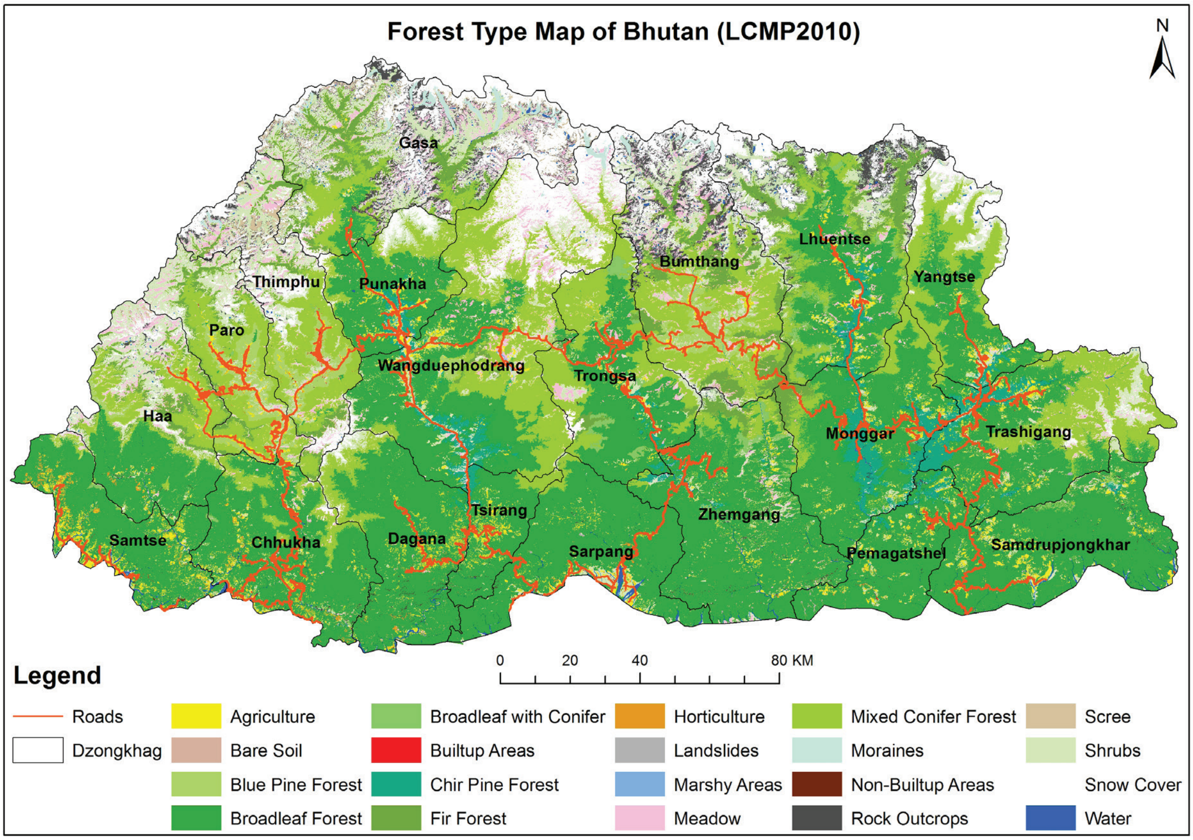

Figure 3: National land use map 2010

Land use changes and ecosystem services

Forest cover in this scenario, which is determined by deforestation for agricultural land, infrastructure, pasture land, and settlements, is expected to decrease from 334,510 ha in 2010 to 331,620 ha in 2030 with an overall percentage decrease of 0.9% and with an average yearly decrease of 0.04%.

Agricultural production, which is determined by agricultural land and average yield, is expected to increase from 106,400 tons in 2010 to 135,400 tons in 2030 with an overall percentage increase of 27.2% and with an average yearly increase of 1.5%. The projected change in agricultural land amounts to 23.7% from 2010 to 2030 with an average yearly change of 1.1%; concerning yield the change is 2.8% from 2010 to 2030 with an average yearly change of 0.4%.

Habitat Quality in the BAU scenario is expected to be mostly affected by agricultural expansion through the year 2030. In the present InVEST simulation only cropland is accounted for and agricultural land expansion is expected to take place mostly in the proximity of already existing agricultural land.

Runoff - which is determined by surface water inflow and surface water use (for residential/urban use and irrigation) - is expected to oscillate around 4.8 and 7.5 billion m^3/year (based on rainfall variability) and is projected to be 7.2 billion m^3/year in 2010 and at 7 billion m^3/year in 2030. While climate scenarios are not simulated (i.e. variations in the underlying trend of precipitation and modifications in rainfall variability), the historical trend of variability is embedded in the model and evaporation and evapotranspiration, as well water retention by vegetation are taken into account.

The total loadings of nitrogen and phosphorus in this area, which is the sum of the nutrients contribution from all LULC types without filtering from the landscape is expected to increase for the former from 1.56 million kg/year in 2010 to 1.64 million kg/year, representing an overall increase of 5%, and for the latter from 4.13 million kg/year in 2010 to 4.58 million kg/year, representing an overall increase of 10.8%. On the other hand, total nutrients export from this area is expected to increase from 386,210 kg/year in 2010 to 501,630 kg/year in 2030, representing an overall increase of 29.9%.

Finally, total emissions, which are determined by emission from energy use and land use change are expected to change based on deforestation and the occurrence of forest fires. Two values for carbon sequestration are used (and two simulations have been created), considering an upper (maximum 394.74 ton/ha, including carbon in biomass and soil) and a lower value (78.82 ton/ha) for forest. The annual amount of emissions (not the net amount, which compensates for increase carbon storage in biomass) is higher in 2030, being at 43,780 ton/year in 2010 and 51,275 ton/year in 2030 (+17%) when using the lower range for carbon sequestration; being at 82,920 ton/year in 2010 and 90,130 ton/year in 2030 (+8.7%) when using the upper range for carbon sequestration. The difference in the % change is to be attributed to the fact that energy emissions do not change under both scenarios, while the carbon sequestration does. On the other hand, the average amount of emissions during the same period is 60,530 ton/year when using the lower range and 144,710 ton/year when using the upper range.

When considering carbon sequestration in the area affected by the construction of Punatsangchhu I with the boundaries set at the watershed level, instead than at the district level, the change in the period 2010-2030 amounts to -200,577 ton in the lower range and to -3,567,196 ton in the upper range.

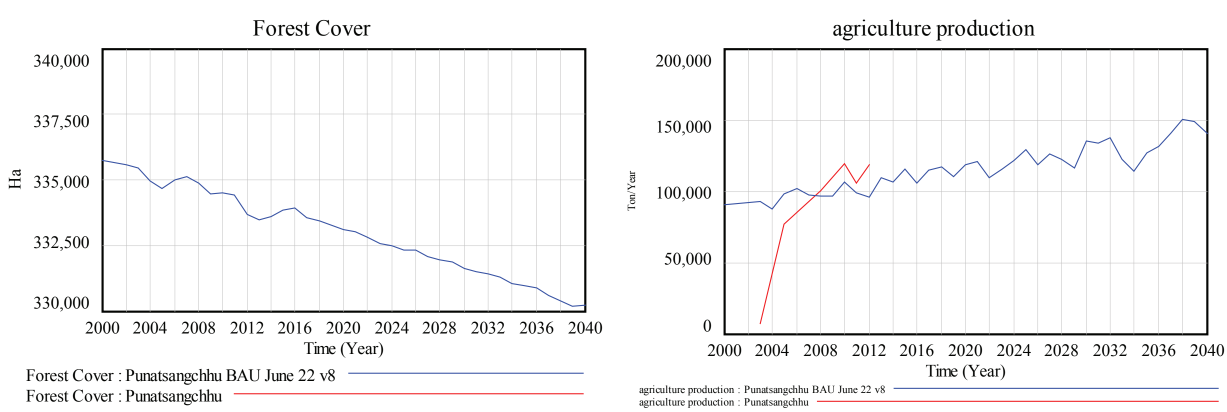

Figure 4: Forest cover and agriculture production, BAU scenario; 2000 – 2040

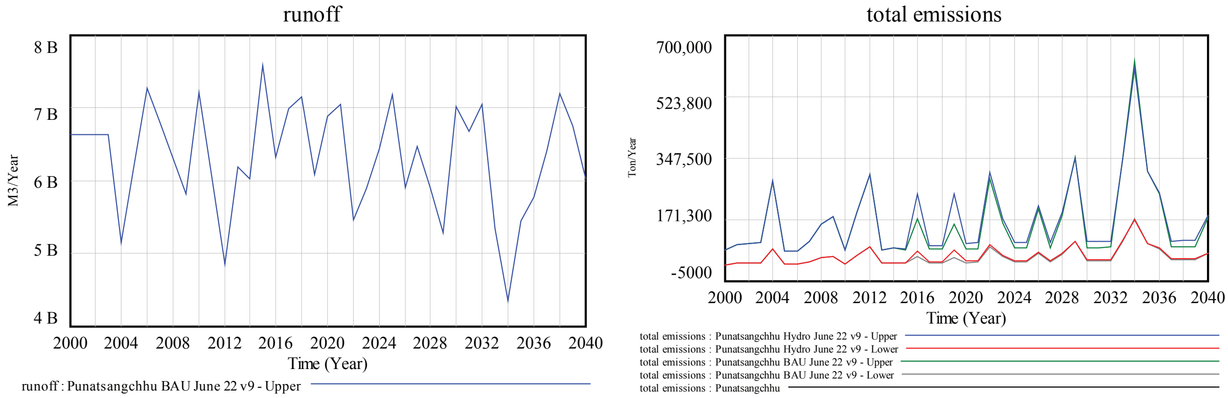

Figure 5: Runoff and total emissions, BAU scenario; 2000 – 2040

Hydropower scenario

Hydropower construction and capacity starts increasing as of 2015 and it reaches 1,200 MW/ year in 2021 and it remains constant afterwards. Hydroelectric power generation reaches close to 7 million MWh/year in 2030 and it remains fairly constant afterwards, oscillating due to rainfall variability and slightly declining over time due to sedimentation.

From an economic perspective, the value of the hydropower dam (reaching close to $900 million) slowly declines over time (due to depreciation). It is also projected that costs (including both capital and operation and management costs) will outweigh revenues until 2027, after which the annual cash flow will be positive.

Total dam employment increases substantially in the period 2015-2020 reaching a maximum level of 3,590 people (due to construction employment), it then decreases and reaches 1,420 people for activities related to operation and management. Employment wages follows the same trend as total dam employment and peak at 8.6 million US$/year in 2020 to then decline to 3.4 million US$/year for the operation and management of the hydropower dam (with the assumption that a full time job will be compensated on average $2,400 per year).

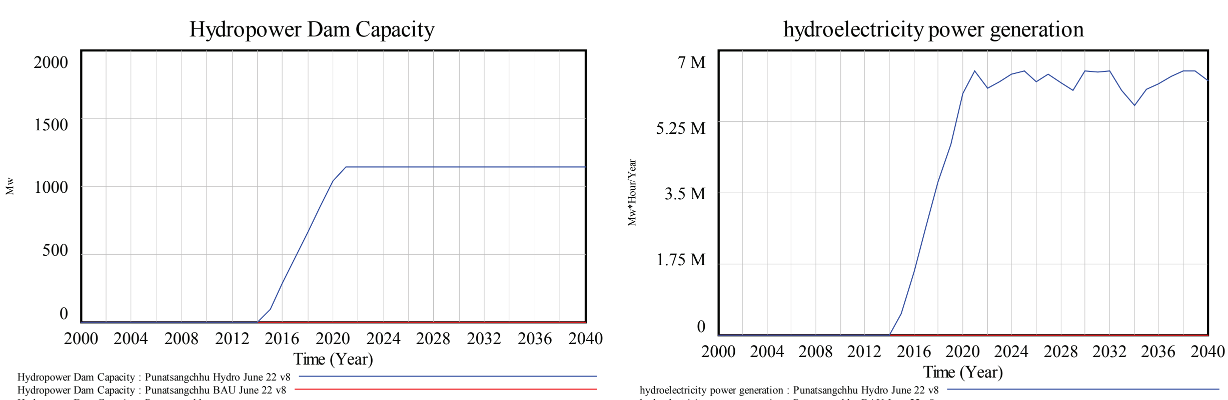

Figure 6: Hydropower dam capacity and electricity generation, Hydropower scenario; 2000 – 2040

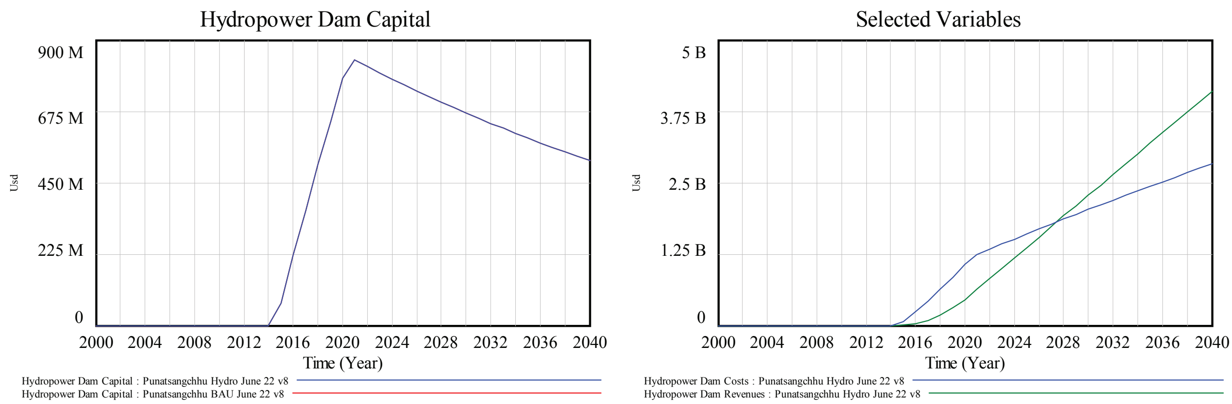

Figure 7: Hydropower dam capital and cash flow (investment and costs, and revenues), Hydropower scenario; 2000 – 2040

Under the Hydropower scenario, population is 2.8% lower than under the BAU scenario in 2030 with an yearly average increase of 1% in the period 2010-2030. This is primarily due to the change in land cover (with the addition of roads and the utilization of land that could be otherwise allocated to agriculture) and to an increase in air emissions, which may drive current residents to consider relocating. On the other hand, alternative scenarios could be tested in which population would increase (especially due to job creation in the secondary and tertiary sectors), which would lead to an increase in settlement land as well as food demand.

With the projections on population, food demand, as well as of the land that would be used by the hydropower dam and related infrastructure, forest cover is expected to be 0.5% lower than under the BAU scenario in 2030 with an yearly average decrease of 0.1% in the period 2010-2030. Agricultural land is also expected to be 5% lower than under the BAU scenario in 2030 with a yearly average decrease of 0.8% in the period 2010-2030. Agricultural production follows the same trend and it is also expected to be 2.6% lower than under the BAU scenario in 2030 with a yearly average decrease of 1.3% in the period 2010-2030.

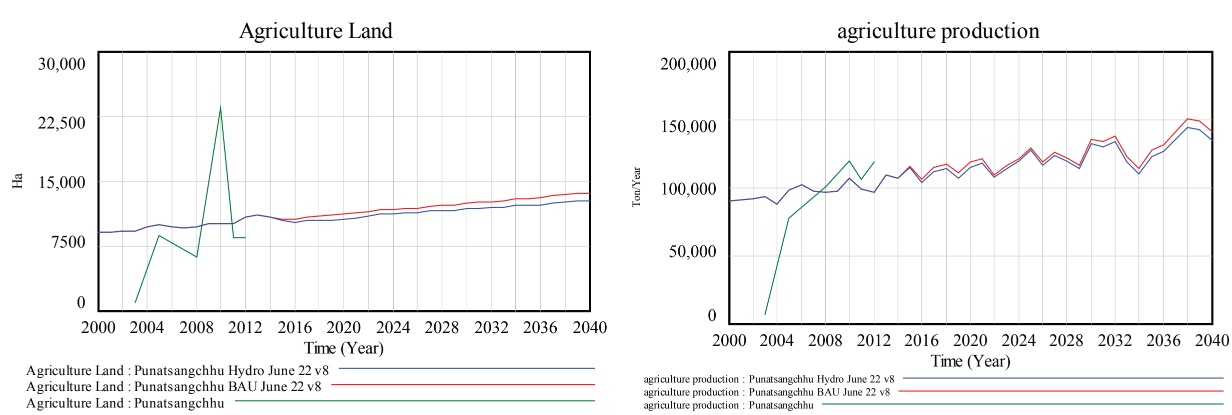

Figure 8: Agriculture land and production, BAU and Hydropower scenarios; 2000 – 2040

Under the Hydropower scenario, the road construction budget has a considerable increase in the period 2015-2020 when it reaches a maximum of 4.4 million US$/year and then it levels out to the same level as in the BAU scenario. This is due to the expansion of the road network due to the construction of the hydropower dam and related infrastructure (e.g. transmission lines). The total road network is 1,590 Km in 2010 and 2,174 Km in 2030, which is 12.9% higher than under the BAU scenario. Consequently, habitat quality is 2.7% lower compared to the BAU scenario with a yearly percentage decrease of 0.2% in the period 2010-2030. However, road construction is not the only threat affecting habitat quality, which also accounts for cropland, power distribution lines and urban areas.

Emissions from forest fires are expected to be 22% higher under this scenario in 2030 because of the construction of transmission and distribution lines. Total emissions are projected to be between 6% and 10.7% higher under this scenario (when using the lower and upper range for carbon sequestration) than under the BAU scenario. The average amount of emissions during the same period is 64,160 ton/year when using the lower range and 160,220 ton/year when using the upper range. The same trend is forecasted for annual emissions from land use change (including both deforestation and forest fires) which is expected to be 14.7% and 16.1% higher under this scenario than under the BAU scenario. Consequently, total carbon sequestration is expected to be 0.59% lower under this scenario than under the BAU scenario, reaching 17.1 and 78.1 million ton in 2030.

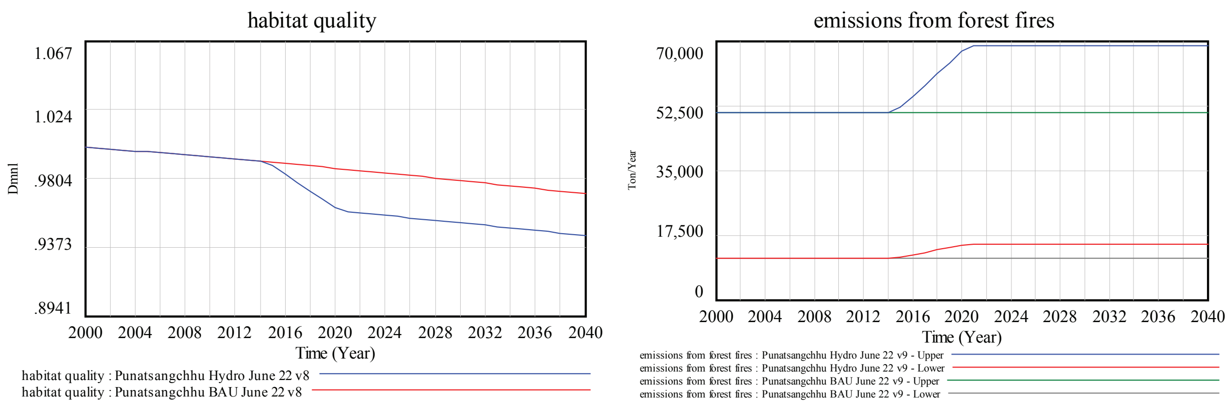

Figure 9: Habitat quality and emissions from forest fires (upper and lower carbon sequestration), BAU and Hydropower scenarios; 2000 – 2040

Mitigation scenario

Under the Mitigation scenario there is a reallocation of hydropower revenues to government budget for watershed conservation investments. 1% of the revenues from the sale of electricity are assumed to be reallocated to government budget, and 20% of this amount is assumed to be utilized for reforestation activities.

Under this scenario, forest cover is expected to be 0.9% and 1.4% higher than under the BAU and the Hydropower scenarios respectively. Reforestation would start in 2015 and increase to reach on average 363.4 ha/year once the hydropower dam is complete and operational. Watershed conservation investment would follow the trend of revenue from hydropower generation, reaching approximately 376,500 US$/year.

Due to the expansion of forest cover, total carbon sequestration is expected to be 0.84% and 0.91% higher under this scenario than under the BAU scenario (for the lower and upper ranges of carbon sequestration), reaching 17.3 and 78.8 million ton in 2030.

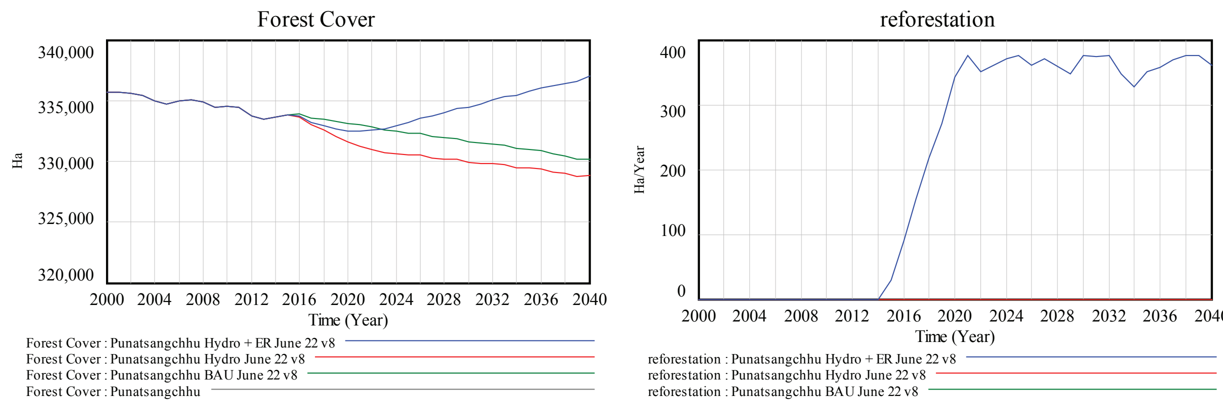

Figure 10: Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

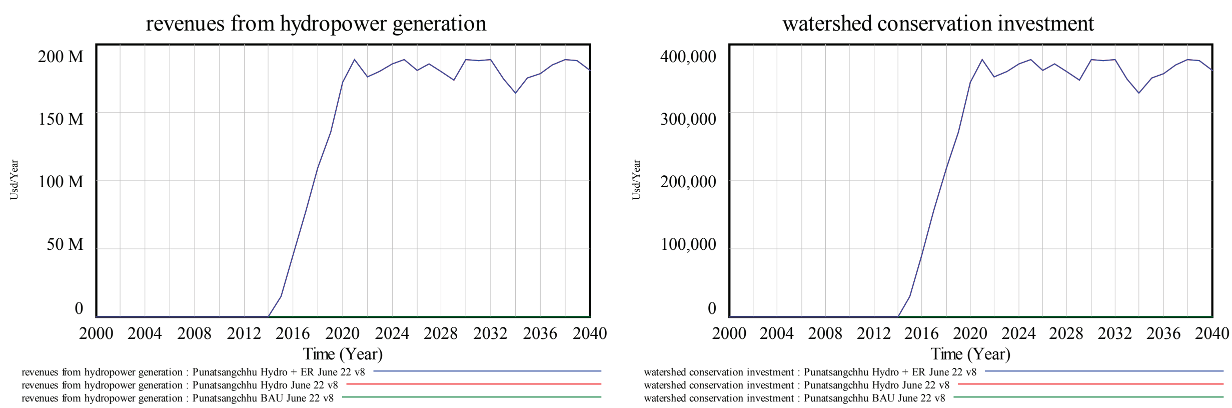

Figure 11: Revenues from hydropower generation and watershed conservation investment, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

ES	Estimation			Biophysical change (2010-2030): BAU	Hydro vs BAU	ES vs BAU	Economic value per unit	Economic valuation (year 2030)		Comments
	InVEST	SD	Benefit transfer					Hydro vs BAU	ES vs BAU	
Provision of food		X		24,155 ton	-4,179	-4,231	702.75 US$/ ton	-$2,936,798	-$2,973,203	Systemic approach, with endogenous changes to population and land use
					3,481	3,101		$2,446,579	$2,179,229	Sectoral approach with no change to land use, only yield
Sedimentation	X			0.05 mm3/km2	28.4%	11.9%	12,180 $/hour of hydropower dam operation	-$1,725,787	-$721,468	Only considers impact on sedimentation from land use
Provision of freshwater (quality) - nitrogen		X		0.0156 mg/l	-1.80%	-1.60%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Provision of freshwater (quality) - phosphorus		X		0.0118 mg/l	-2.60%	-2.50%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Habitat for species			X	2,378 ha	-1,747	3,027	5,192 US$/Ha	-$9,068,964	$15,714,075	Economic value per unit obtained from Kubiszewski et al. (2010)
		X		42,258 persons	-1,027	-984	1,128 US$/ person	-$1,158,773	-$1,109,511	Assumes that a reduction in habitat quality has a proportional impact on tourism visits (it could also be assumed that expenditure per visit might change)
Regulation of carbon sequestration and storage	X	X		-3,567,196 ton	-529,483	917,453	43 US$/ton	-$22,767,769	$39,450,479	Upper values of carbon coefficients from IPCC Report 2006
	X	X		-200,577 ton	-137,668	196,257	43 US$/ton	-$5,919,724	$8,439,051	Lower values of carbon coefficients from IPCC Report 2006
Genetic resources			X	2,378 ha	-1,747	3,027	19 $US/ha/ year	-$33,188	$57,505	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Timber			X	2,378 ha	-1,747	3,027	44 $US/ha/ year	-$76,856	$133,170	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Biological control			X	2,052 ha	-505	-476	28 $US/ha/ year	-$14,139	-$13,320	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	2,378 ha	-1,747	3,027	9 $US/ha/year	-$15,720	$27,239	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Pollination			X	2,052 ha	-505	-476	19 $US/ha/ year	-$9,594	-$9,039	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	2,378 ha	-1,747	3,027	376 $US/ha/ year	-$656,766	$1,137,999	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)

Table 1: Ecosystem service valuation, Punatsangchhu, year 2030

Construction of road in Bhutan leads to landslides and land degradation

KURI-I HYDROPOWER PLANT

BAU scenario

Socio-economic trends

The geographical area to be likely affected by the construction of the Kuri-I Hydro Power is comprised of Lhuntse and Mongar dzongkhags. Within these districts population is expected to increase from 56,911 people in 2010 to 73,709 people in 2030, with an overall percentage increase of 30% and with an average yearly increase of 1.28% in the BAU scenario between 2010 and 2030. Food demand, which is driven by population change and calories consumption is estimated to increase from 79.7 billion kcal/year in 2010 to 91.6 billion kcal/year in 2030 with an overall increase and an average yearly increase matching the percentage of population growth.

In this scenario, desired agricultural land is expected to increase from 6,186 ha in 2010 to 6,733 ha in 2030, with an overall percentage increase of 9%. Desired pasture land, which is determined by livestock density and local livestock production, is estimated to increase from 247 ha in 2010 to 320 ha in 2030, with an overall percentage increase of 29.5% and with an average yearly increase of 1.3%.

Tourism, in addition to population growth and agriculture production, is expected to influence economic growth and employment creation. Tourism arrivals, which in the model are primarily determined by habitat quality and by the historical growth rate of visitors, is expected to rise from 2,832 person/year in 2010 to 5,611 person/year in 2030 marking an overall percentage increase of 98.2% and with an average yearly increase of 3.5%.

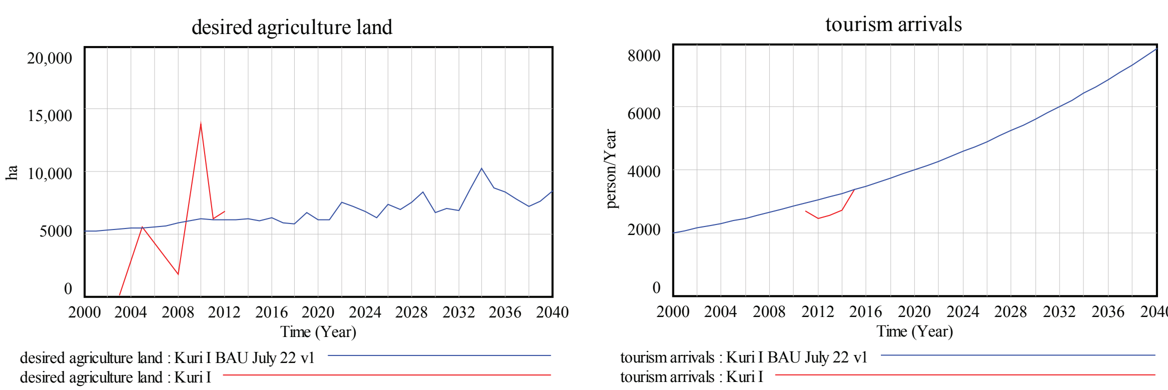

Figure 12. Desired agriculture land and tourism arrivals, BAU scenario; 2000 – 2040

Land use changes and ecosystem services

In the BAU scenario, forest cover is expected to decrease from 246,024 ha in 2010 to 243,675 ha in 2030 with an overall percentage decrease of 1% and with an average yearly decrease of 0.05%.

Agricultural production, which is determined by agricultural land and average yield, is expected to increase from 17,338 tons in 2010 to 26,920 tons in 2030 with an overall percentage increase of 55.3% and with an average yearly increase of 2.7%. The projected change in agricultural land amounts to 30.5% from 2010 to 2030 with an average yearly change of 1.3%; concerning yield the change is 19% from 2010 to 2030 with an average yearly change of 1.3%.

Habitat Quality in the BAU scenario is expected to be mostly affected by agricultural expansion through the year 2030. In the present InVEST simulation only cropland is accounted for and agricultural land expansion is expected to take place mostly in the proximity of already existing agricultural land.

Runoff -which is determined by surface water inflow, and surface water use (for residential/urban use and irrigation)- is expected to oscillate around 5.1 and 6.8 billion m3/year (based on rainfall variability) and is projected to be 6.1 billion m3/year in 2010 and at 6.7 billion m3/year in 2030. While climate scenarios are not simulated (i.e. variations in the underlying trend of precipitation and modifications in rainfall variability), the historical trend of variability is embedded in the model and evaporation and evapotranspiration, as well water retention by vegetation are taken into account.

The total loadings of nitrogen and phosphorus in this area -which is the sum of the nutrients contribution from all LULC types without filtering from the landscape- is expected to increase for the former from 762,908 kg/year in 2010 to 856,262.27 kg/year, representing an overall increase of 12.2%, and for the latter from 3.5 million kg/year in 2010 to 3 million kg/year, representing an overall increase of 21.3%. On the other hand, total nutrients export from this area is expected to decrease from 372,507 kg/year in 2010 to 304,813kg/year in 2030, representing an overall decrease of 18.2%.

Finally, total emissions -which are determined by emission from energy use and land use change- are expected to change based on deforestation and the occurrence of forest fires. Two values for carbon sequestration are used (and two simulations have been created), considering an upper (maximum 394.74 ton/ha, including carbon in biomass and soil) and a lower value (78.82 ton/ha) for forest. The annual amount of emissions (not the net amount, which compensates for increase carbon storage in biomass) is lower in 2030, being at 45,349 ton/year in 2010 and 36,413 ton/year in 2030 (-19.7%) when using the lower range for carbon sequestration; being at 207,225 ton/year in 2010 and 165,474 ton/year in 2030 (-20.1%) when using the upper range for carbon sequestration. The difference in the % change is to be attributed to the fact that energy emissions do not change under both scenarios, while the carbon sequestration does. On the other hand, the average amount of emissions during the same period is 40,069 ton/year when using the lower range and 182,617 ton/year when using the upper range.

When considering carbon sequestration in the area affected by the construction of Kuri-I with the boundaries set at the watershed level, instead than at the district level, the change in the period 2010-2030 amounts to -4,933 ton in the lower range and to -81,954 ton in the upper range.

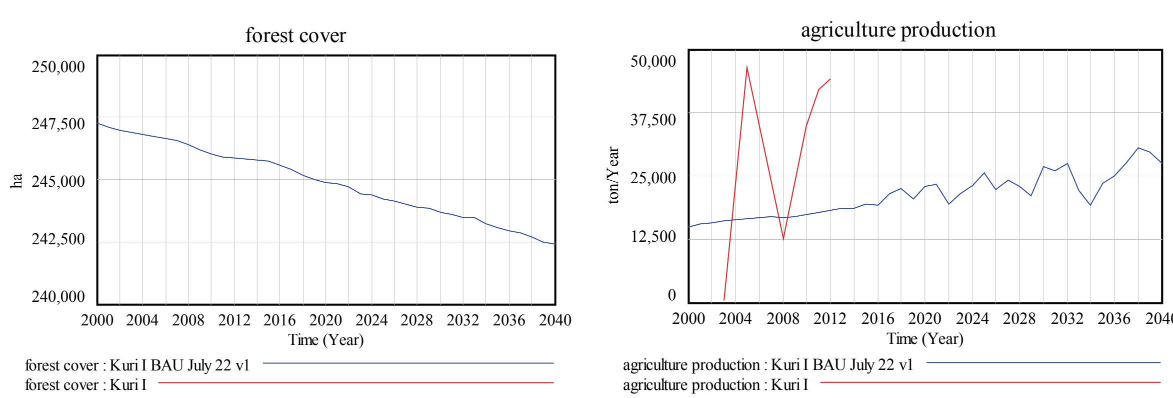

Figure 13. Forest cover and agriculture production, BAU scenario; 2000 – 2040

Hydropower scenario

Hydropower construction and capacity starts increasing as of 2018 and it reaches 1,230 MW/year in 2027 and it remains constant afterwards. Hydroelectric power generation reaches 6.4 million MWh/year in 2030 and it remains fairly constant afterwards, oscillating due to rainfall variability and slightly declining over time due to sedimentation.

From an economic perspective, the value of the hydropower dam (exceeding $1.1 billion in 2027) slowly declines over time (due to depreciation). It is also projected that costs (including both capital and operation and management costs) will outweigh revenues until 2035, after which the annual cash flow will be positive.

Total dam employment increases substantially in the period 2018-2026 reaching a maximum level of 2,985 people (due to construction employment), it then decreases and reaches 1,457 people for activities related to operation and management. Employment wages follows the same trend as total dam employment and peak at 7.2 million US$/year in 2026 to then decline to 3.5 million US$/year for the operation and management of the hydropower dam (with the assumption that a full time job will be compensated on average $2,400 per year).

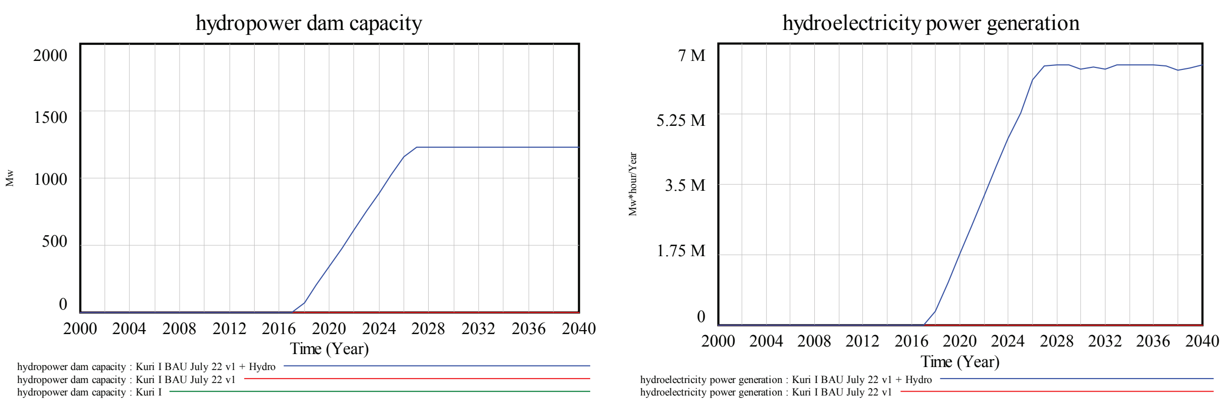

Figure 14. Hydropower dam capacity and electricity generation, Hydropower scenario; 2000 – 2040

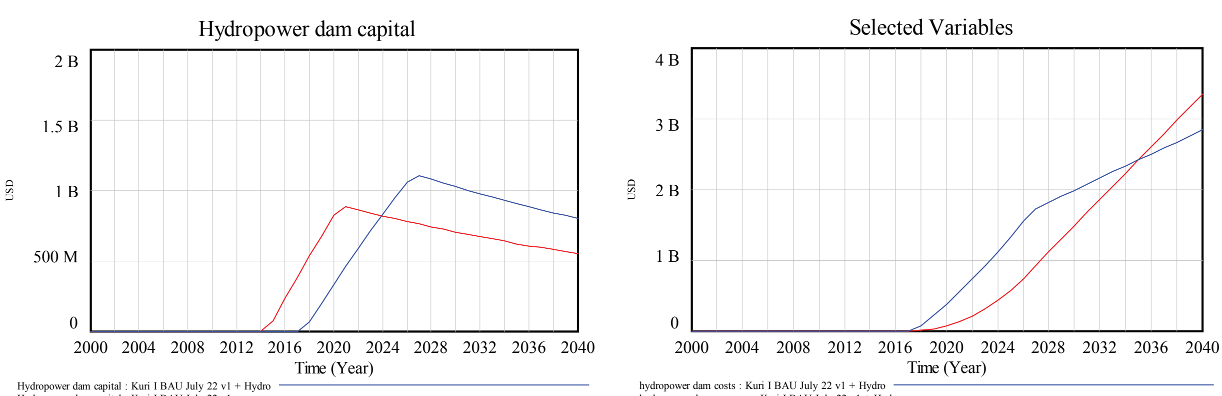

Figure 15. Hydropower dam capital and cash flow (investment and costs, and revenues), Hydropower scenario; 2000 – 2040

Under the Hydropower scenario, population is 0.12% higher than under the BAU scenario in 2030 with an yearly average increase of 1.3% in the period 2010-2030.

With the projections on population, food demand, as well as of the land that would be used by the hydropower dam and related infrastructure, forest cover is expected to be 0.6% lower than under the BAU scenario in 2030 with an yearly average decrease of 0.1% in the period 2010-2030. Agricultural land is also expected to be 13% lower than under the BAU scenario in 2030 with a yearly average increase of 0.6% in the period 2010-2030. Agricultural production follows the same trend and it is also expected to be 2.8% lower than under the BAU scenario in 2030 with a yearly average increase of 2.6% in the period 2010-2030.

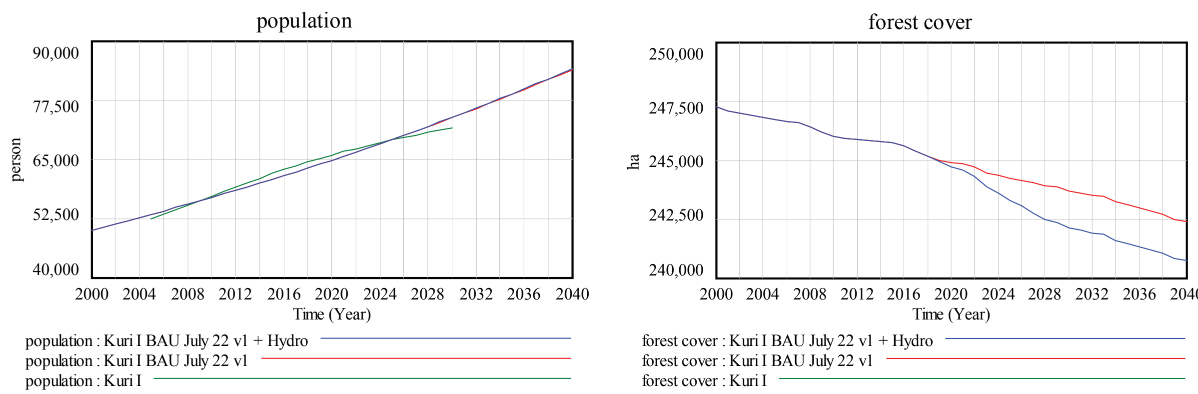

Figure 16. Population and forest cover, BAU and Hydropower scenarios; 2000 – 2040

Under the Hydropower scenario, the road construction budget has a considerable increase in the period 2018-2026 when it reaches a maximum of 15.7 million US$/year and then it levels out to the same level as in the BAU scenario. This is due to the expansion of the road network due to the construction of the hydropower dam and related infrastructure (e.g. transmission lines). The total road network is 1,762 Km in 2010 and 3,816 Km in 2030, which is 42.7% higher than under the BAU scenario. Consequently, habitat quality is 10.2% lower compared to the BAU scenario with a yearly percentage decrease of 0.7% in the period 2010-2030. However, road construction is not the only threat affecting habitat quality, which also accounts for cropland, power distribution lines and urban areas.

Emissions from forest fires are expected to be 27% higher under this scenario in 2030 because of the construction of transmission and distribution lines. Total emissions are projected to be between 34.7% and 35.2% higher under this scenario in 2030 (when using the lower and upper range for carbon sequestration) than under the BAU scenario. The average amount of emissions during the same period is 50,006 ton/year when using the lower range and 228,429 ton/year when using the upper range. The same trend is forecasted for annual emissions from land use change (including both deforestation and forest fires) which is expected to be 35.4% higher under this scenario than under the BAU scenario. Consequently, total carbon sequestration is expected to be 0.51% lower under this scenario than under the BAU scenario, reaching 14.8 and 68.3 million ton in 2030.

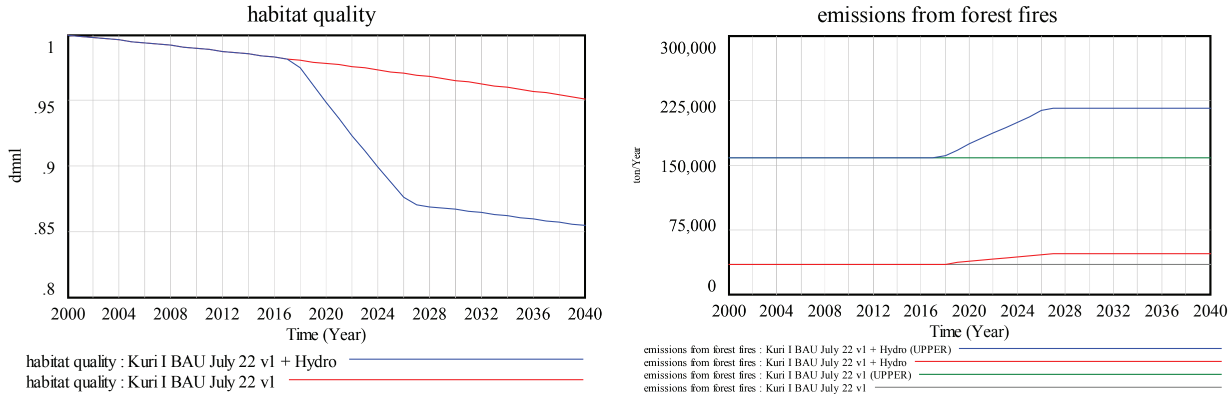

Figure 17. Habitat quality and missions from forest fires (upper and lower carbon sequestration), BAU and Hydropower scenarios; 2000 – 2040

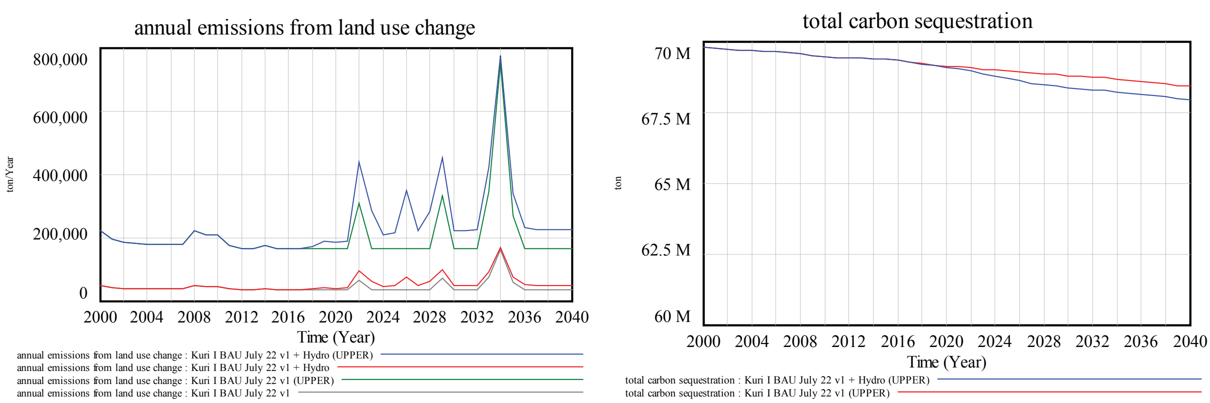

Figure 18. Annual emissions from land use change (upper and lower carbon sequestration) and total carbon sequestration (upper value), BAU and Hydropower scenarios; 2000 – 2040

Mitigation scenario

Under this scenario, forest cover is expected to be 0.6% and 1.2% higher than under the BAU and the Hydropower scenarios respectively. Reforestation would start in 2018 and increase to reach on average 372.6 ha/year once the hydropower dam is complete and operational. Watershed conservation investment would follow the trend of revenue from hydropower generation, reaching approximately 299,223 US$/year.

Due to the expansion of forest cover, total carbon sequestration is expected to be 0.7% and 0.58% higher under this scenario than under the BAU scenario (for the lower and upper ranges of carbon sequestration), reaching 15 and 69.2 million ton in 2030.

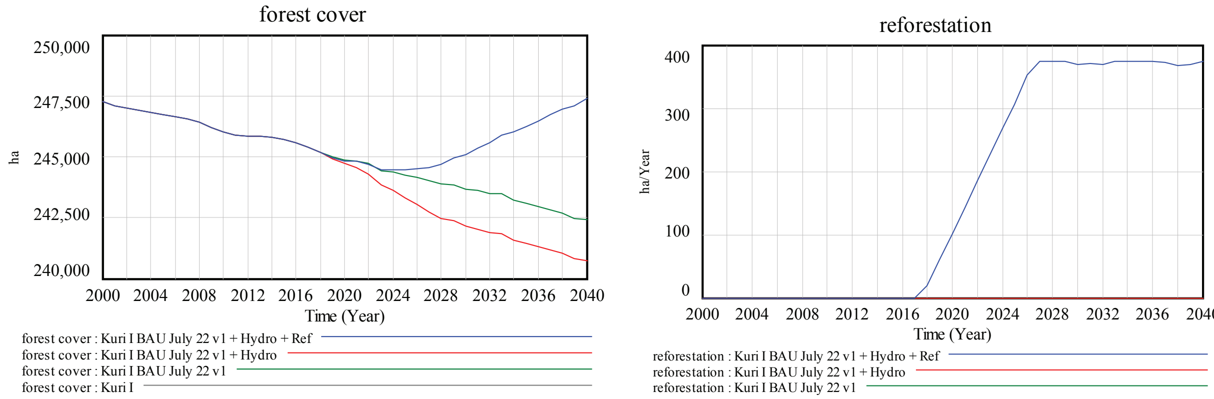

Figure 19. Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

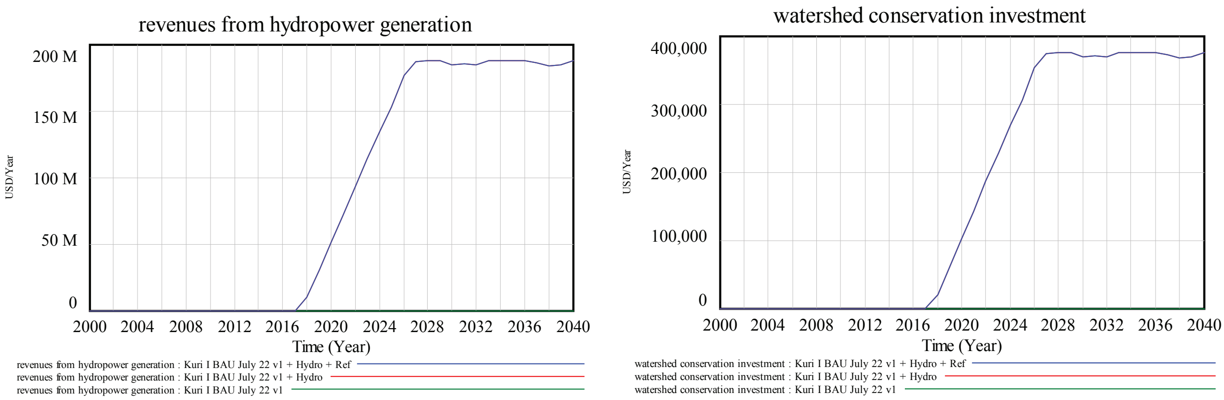

Figure 20. Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

ES	Estimation			Biophysical change (2010-2030): BAU	Hydro vs BAU	ES vs BAU	Economic value per unit	Economic valuation (year 2030)		Comments
	InVEST	SD	Benefit transfer					Hydro vs BAU	ES vs BAU	
Provision of food		X		9,581 ton	-752	-768	542.81 US$/ton	-$407,898	-$416,954	Systemic approach, with endogenous changes to population and land use
					3,215	3,142		$2,259,158	$2,207,937	Sectoral approach with no change to land use, only yield
Sedimentation	X			0.21 mm3/ km2	188.5%	-2.9%	12,484 $/ hour of hydro-power dam oper-ation	-$18,211,679	$281,590	Only considers impact on sedimentation from land use
Provision of freshwater (quality) - nitrogen		X		0.0008 mg/l	-3.27%	-3.16%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Provision of freshwater (quality) - phosphorus		X		0.0008 mg/l	-2.97%	-2.86%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Habitat for species			X	2,348 ha	-1,537	1,413	5,192 US$/Ha	-$7,981,483	$7,334,511	Economic value per unit obtained from Kubiszewski et al. (2010)
		X		2,780 per-sons	-156	-153	17,732 US$/per-son	-$2,760,841	-$2,719,680	Assumes that a reduction in habitat quality has a proportional impact on tourism visits (it could also be assumed that expen-diture per visit might change)
Regulation of carbon sequestration and storage	X	X		-81,954 ton	-71,216	65,435	43 US$/ ton	-$3,062,288	$2,813,705	Upper values of carbon coefficients from IPCC Report 2006
	X	X		-4,933 ton	-15,767	14,489	43 US$/ ton	-$677,981	$623,027	Lower values of carbon coefficients from IPCC Report 2006
Genetic resources			X	2,348 ha	-1,537	1,413	19 $US/ ha/year	-$29,208	$26,840	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Timber			X	2,348 ha	-1,537	1,413	44 $US/ ha/year	-$67,640	$62,157	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Biological control			X	1,839 ha	-1,036	-1,024	28 $US/ ha/year	-$29,006	-$28,665	Economic value per unit for cropland obtained from Kubisze-wski et al. (2010)
			X	2,348 ha	-1,537	1,413	9 $US/ha/ year	-$13,835	$12,714	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Pollination			X	1,839 ha	-1,036	-1,024	19 $US/ ha/year	-$19,683	-$19,451	Economic value per unit for cropland obtained from Kubisze-wski et al. (2010)
			X	2,348 ha	-1,537	1,413	376 $US/ ha/year	-$578,012	$531,159	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)

Table 2. Ecosystem service valuation, Kuri-I, year 2030

Removing sediments from damsite of Chhukha Hydro Power Plant

GAMRICHHU II HYDROPOWER PLANT

BAU scenario

Socio-economic trends

The geographical area affected by the construction of the Gamrichhu II Hydro Power is comprised in Trashigang dzongkhag. In this district, population is expected to increase from 28,433 people in 2010 to 36,797 people in 2030, with an overall percentage increase of 29% and with an average yearly increase of 1.28% in the BAU scenario between 2010 and 2030. Food demand, which is driven by population change and calories consumption -estimated at a steady value of 3,403 kcal/day per capita- (see Nutrition Main Report), is estimated to increase from 35.3 billion kcal/year in 2010 to 45.7 billion kcal/year in 2030 with an overall increase and an average yearly increase matching the percentage of population growth.

In the BAU scenario desired agricultural land is expected to increase from 6,176 ha in 2010 to 6,727 ha in 2030, with an overall percentage increase of 8.9%. Desired pasture land, which is determined by livestock density and local livestock production, is estimated to increase from 123 ha in 2010 to 159 ha in 2030, with an overall percentage increase of 29% and with an average yearly increase of 1.3%.

Tourism, in addition to population growth and agriculture production, is expected to influence economic growth and employment creation. Tourism arrivals, which in the model are primarily determined by habitat quality and by the historical growth rate of visitors, is expected to rise from 1,416 person/year in 2010 to 2,812 person/year in 2030 marking an overall percentage increase of 98.6% and with an average yearly increase of 3.5%.

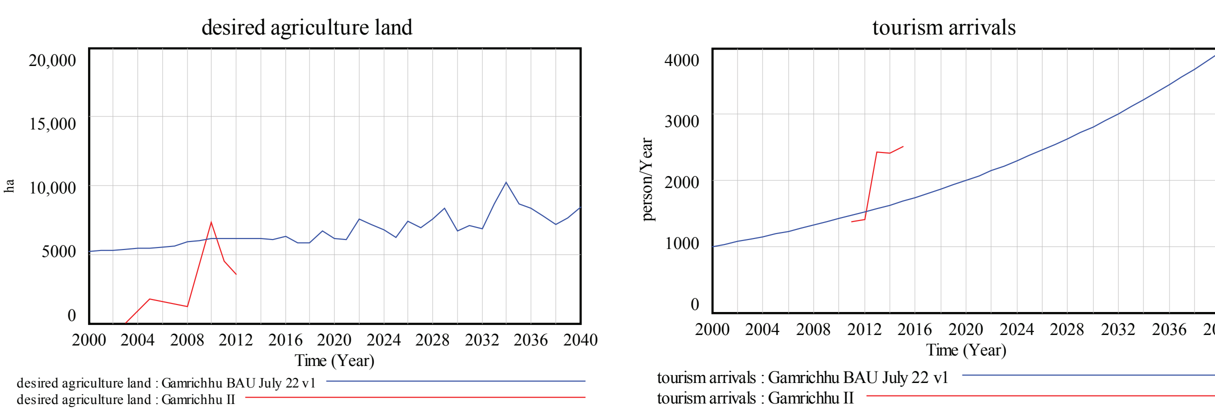

Figure 21. Population and food demand, BAU scenario; 2000 – 2040

Land use changes and ecosystem services

In the BAU scenario forest cover, which is determined by deforestation for agricultural land, infrastructure, pasture land, and settlements, is expected to decrease from 124,752 ha in 2010 to 122,659 ha in 2030 with an overall percentage decrease of 1.7% and with an average yearly decrease of 0.08%.

Agricultural production, which is determined by agricultural land and average yield, is expected to increase from 8,662 tons in 2010 to 13,435 tons in 2030 with an overall percentage increase of 55.1% and with an average yearly increase of 2.7%. The projected change in agricultural land amounts to 30.5% from 2010 to 2030 with an average yearly change of 1.3%; concerning yield the change is 18.8% from 2010 to 2030 with an average yearly change of 1.3%.

Habitat Quality in the BAU scenario is expected to be mostly affected by agricultural expansion through the year 2030. In the present InVEST simulation only cropland is accounted for and agricultural land expansion is expected to take place mostly in the proximity of already existing agricultural land.

Runoff -which is determined by surface water inflow, and surface water use (for residential/urban use and irrigation)- is expected to oscillate around 3.2 and 2.2 billion m3/year (based on rainfall variability) and is projected to be 2.8 billion m3/year in 2010 and at 3.2 billion m3/year in 2030. While climate scenarios are not simulated (i.e. variations in the underlying trend of precipitation and modifications in rainfall variability), the historical trend of variability is embedded in the model and evaporation and evapotranspiration, as well water retention by vegetation are taken into account.

The total loadings of nitrogen and phosphorus in this area -which is the sum of the nutrients contribution from all LULC types without filtering from the landscape- is expected to increase for the former from 410,129 kg/year in 2010 to 460,182 kg/year, representing an overall increase of 12.2%, and for the latter from 1.3 million kg/year in 2010 to 1.6 million kg/year, representing an overall increase of 21.2%. On the other hand, total nutrients export from this area is expected to increase from 154,844 kg/year in 2010 to 163,981 kg/year in 2030, representing an overall increase of 5.9%.

Finally, total emissions -which are determined by emission from energy use and land use change- are expected to change based on deforestation and the occurrence of forest fires. Two values for carbon sequestration are used (and two simulations have been created), considering an upper (maximum 394.74 ton/ha, including carbon in biomass and soil) and a lower value (78.82 ton/ha) for forest. The annual amount of emissions (not the net amount, which compensates for increase carbon storage in biomass) is higher in 2030, being at 127,220 ton/year in 2010 and 150,817 ton/year in 2030 (+18.5%) when using the lower range for carbon sequestration; and lower at 175,194 ton/year in 2010 and 162,687 ton/year in 2030 (-7.1%) when using the upper range for carbon sequestration. The difference in the % change is to be attributed to the fact that energy emissions do not change under both scenarios, while the carbon sequestration does. On the other hand, the average amount of emissions during the same period is 137,483 ton/year when using the lower range and 143,539 ton/year when using the upper range.

Hydropower scenario

In this scenario, hydropower construction and capacity starts increasing as of 2018 and it reaches 85 MW/year in 2024 and it remains constant afterwards. Hydroelectric power generation reaches 438,812 MWh/year in 2024 and it remains fairly constant afterwards, oscillating due to rainfall variability and slightly declining over time due to sedimentation.

From an economic perspective, the value of the hydropower dam (reaching up to $64.6 million in 2024) slowly declines over time (due to depreciation). It is also projected that costs (including both capital and operation and management costs) will outweigh revenues until 2032, after which the annual cash flow will be positive.

Total dam employment increases substantially in the period 2018-2023 reaching a maximum level of 256 people (due to construction employment), it then decreases and reaches 100 people for activities related to operation and management. Employment wages follows the same trend as total dam employment and peak at 616,096 US$/year in 2023 to then decline to 241,740 US$/year for the operation and management of the hydropower dam (with the assumption that a full time job will be compensated on average $2,400 per year).

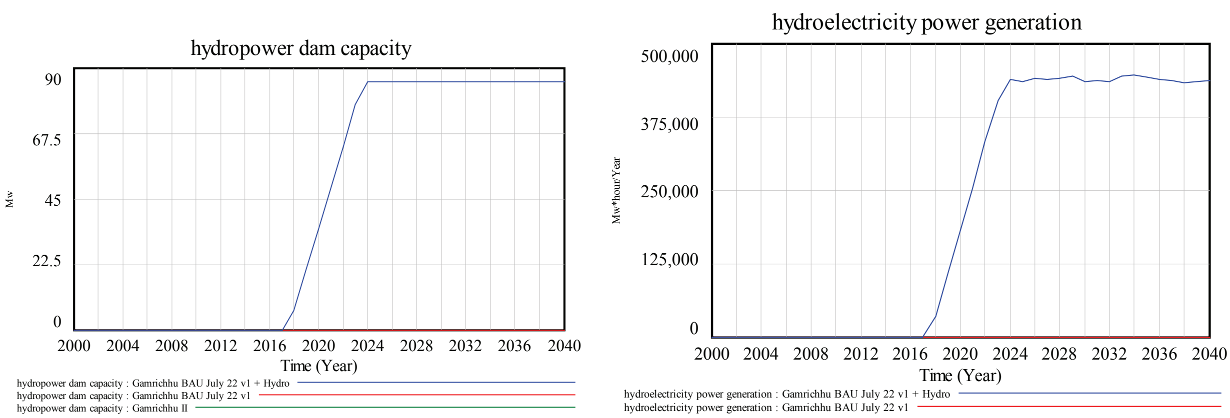

Figure 22. Hydropower dam capacity and electricity generation, Hydropower scenario; 2000 – 2040

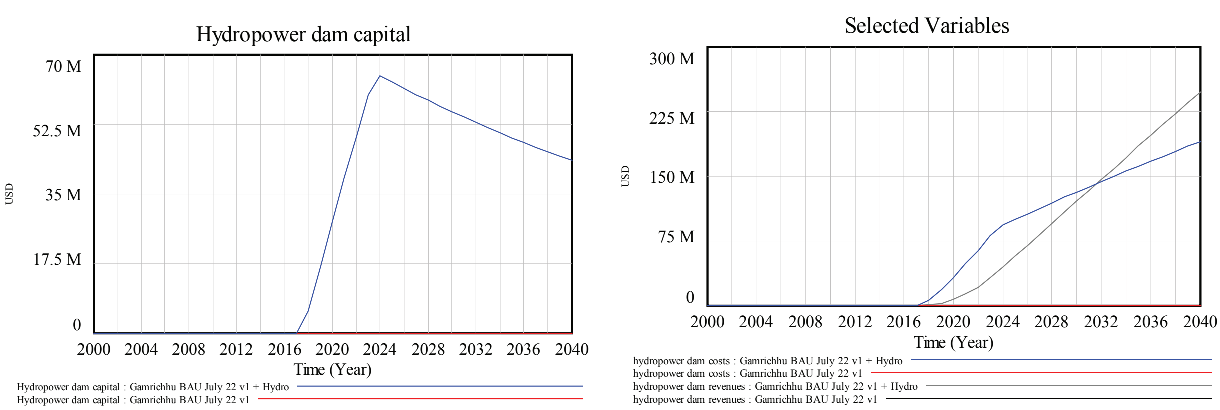

Figure 23. Hydropower dam capital and cash flow (investment and costs, and revenues), Hydropower scenario; 2000 – 2040

With the projections on population, food demand, as well as of the land that would be used by the hydropower dam and related infrastructure, forest cover is expected to be 0.04% lower than under the BAU scenario in 2030 with an yearly average decrease of 0.09% in the period 2010-2030. Agricultural land is also expected to be 1.7% lower than under the BAU scenario in 2030 with a yearly average decrease of 1.26% in the period 2010-2030. However, agricultural production is expected to be 0.16% higher than under the BAU scenario in 2030 with a yearly average increase of 2.7% in the period 2010-2030.

Under the Hydropower scenario, the road construction budget has a considerable increase in the period 2018-2023 when it reaches a maximum of 2 million US$/year and then it levels out to the same level as in the BAU scenario. This is due to the expansion of the road network due to the construction of the hydropower dam and related infrastructure (e.g. transmission lines). The total road network is 952 Km in 2010 and 1,255 Km in 2030, which is 7.9% higher than under the BAU scenario. Consequently, habitat quality is 1.2% lower compared to the BAU scenario with a yearly percentage decrease of 0.2% in the period 2010-2030. However, road construction is not the only threat affecting habitat quality, which also accounts for cropland, power distribution lines and urban areas.

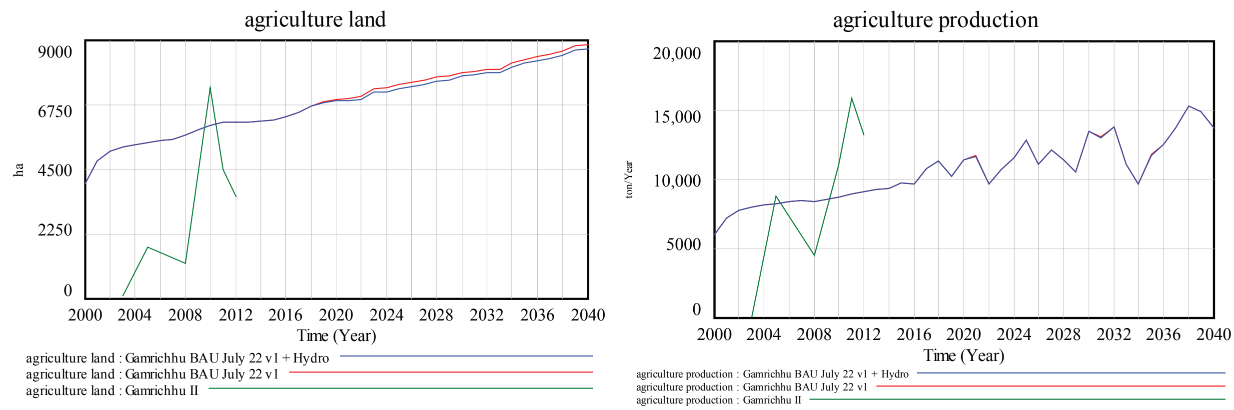

Figure 24. Agriculture land and production, BAU and Hydropower scenarios; 2000 – 2040

Emissions from forest fires are expected to be 2.6% higher under this scenario in 2030 because of the construction of transmission and distribution lines. Total emissions are projected to be between 0.05% and 0.21% higher under this scenario (when using the lower and upper range for carbon sequestration) than under the BAU scenario. The average amount of emissions during the same period is 137,615 ton/year when using the lower range and 164,868 ton/year when using the upper range. The same trend is forecasted for annual emissions from land use change (including both deforestation and forest fires) which is expected to be 1.98% and 2% higher under this scenario than under the BAU scenario. Consequently, total carbon sequestration is expected to be 0.12% lower under this scenario than under the BAU scenario, reaching 8 and 37.1 million ton in 2030.

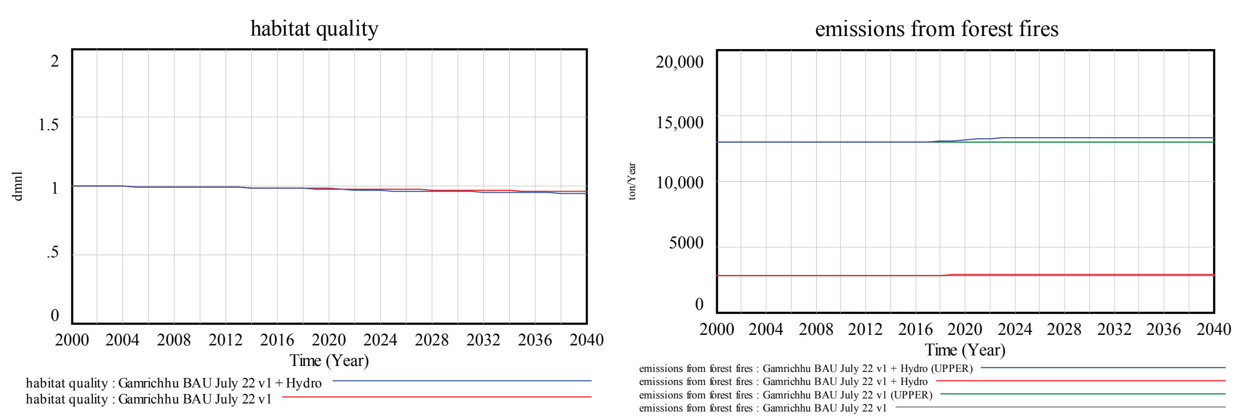

Figure 25. Habitat quality and missions from forest fires (upper and lower carbon sequestration), BAU and Hydro-power scenarios; 2000 – 2040

Mitigation scenario

Under this scenario, forest cover is expected to be 0.16% and 0.19% higher than under the BAU and the Hydropower scenarios respectively. Reforestation would start in 2018 and increase to reach on average 25.4 ha/year once the hydropower dam is complete and operational. Watershed conservation investment would follow the trend of revenue from hydropower generation, reaching approximately 25,430 US$/year.

Due to the expansion of forest cover, total carbon sequestration is expected to be 0.16% and 0.07% higher under this scenario than under the BAU scenario (for the lower and upper ranges of carbon sequestration), reaching 8 and 37.1 million ton in 2030.

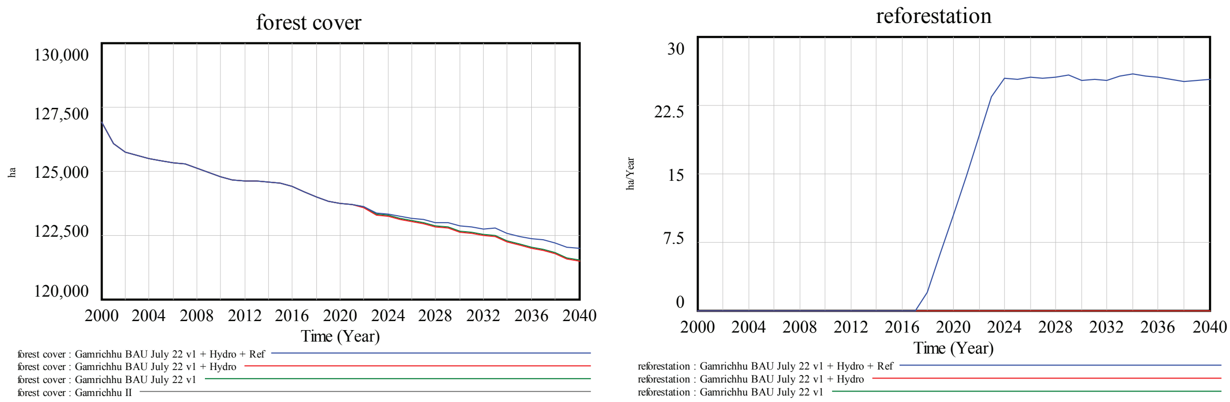

Figure 26. Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

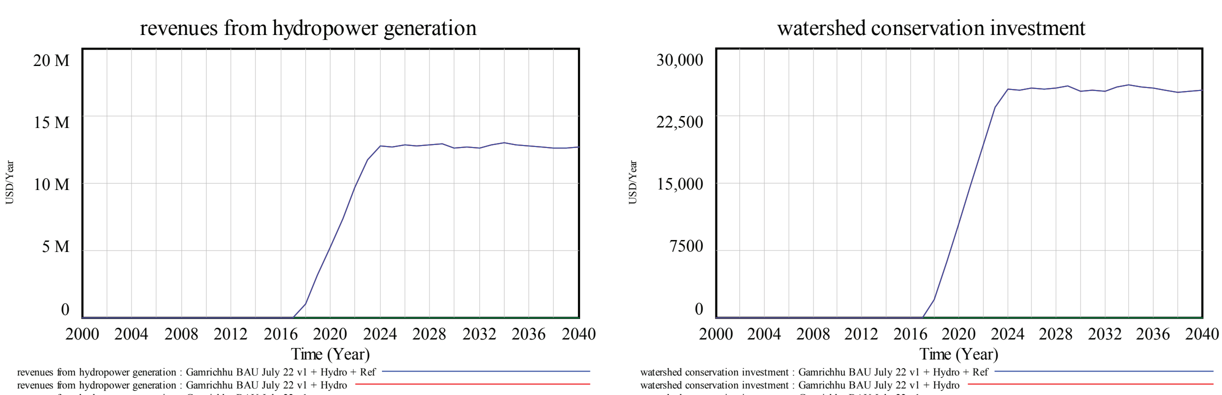

Figure 27. Revenues from hydropower generation and watershed conservation investment, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

ES	Estimation			Biophysical change (2010-2030): BAU	Hydro vs BAU	ES vs BAU	Economic value per unit	Economic valuation (year 2030)		Comments
	In-VEST	SD	Benefit transfer					Hydro vs BAU	ES vs BAU	
Provision of food		X		4,773 ton	-21	-23	514 US$/ton	-$21,777	-$22,960	Systemic approach, with endogenous changes to population and land use
					208	202		$145,869	$142,167	Sectoral approach with no change to land use, only yield
Sedimentation	X			3.41 mm3/km2	14.1%	3.3%	862.75 $/hour of hydropower dam operation	-$153,583	-$35,698	Only considers impact on sedimentation from land use
Provision of freshwater (quality) - nitrogen		X		0.0047 mg/l	-0.56%	-0.55%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Provision of freshwater (quality) - phosphorus		X		0.0047 mg/l	-0.74%	-0.74%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Habitat for species			X	2,093 ha	-46	193	5,192 US$/Ha	-$237,615	$1,002,948	Economic value per unit obtained from Kubiszewski et al. (2010)
		X		1,396 persons	-11	-11	34,730 US$/person	-$378,918	-$371,592	Assumes that a reduction in habitat quality has a proportional impact on tourism visits (it could also be assumed that expenditure per visit might change)
Regulation of carbon sequestration and storage	X	X		-395,328 ton	-26,343	15,553	43 US$/ton	-$1,132,749	$668,779	Upper values of carbon coefficients from IPCC Report 2006
	X	X		-22,914 ton	-1,838	7,758	43 US$/ton	-$79,034	$333,594	Lower values of carbon coefficients from IPCC Report 2006
Genetic resources			X	2,093 ha	-46	193	19 $US/ha/year	-$870	$3,670	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Timber			X	2,093 ha	-46	193	44 $US/ha/year	-$2,014	$8,500	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Biological control			X	1,697 ha	-28	-26	28 $US/ha/year	-$771	-$724	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	2,093 ha	-46	193	9 $US/ha/year	-$412	$1,739	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Pollination			X	1,697 ha	-28	-26	19 $US/ha/year	-$523	-$491	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	2,093 ha	-46	193	376 $US/ha/year	-$17,208	$72,633	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)

Table 3. Ecosystem service valuation, Gamrichhu II, year 2030

BUNAKHA RESERVOIR

BAU scenario

Socio-economic trends

The geographical area that may likely be affected by the construction of the Bunakha Reservoir Hydro Power is comprised of Chukha dzongkhag. Within these districts population is expected to increase from 22,776 people in 2010 to 29,577 people in 2030, with an overall percentage increase of 29.9% and with an average yearly increase of 1.31% in the BAU scenario between 2010 and 2030. Food demand, which is driven by population change and calories consumption -estimated at a steady value of 3,403 kcal/day per capita- (see Nutrition Main Report), is estimated to increase from 28.3 billion kcal/year in 2010 to 36.7 billion kcal/year in 2030 with an overall increase and an average yearly increase matching the percentage of population growth.

In this scenario, desired agricultural land is expected to increase from 2,100 ha in 2010 to 2,901 ha in 2030, with an overall percentage increase of 38.1%. Desired pasture land, which is determined by livestock density and local livestock production, is estimated to increase from 99 ha in 2010 to 129 ha in 2030, with an overall percentage increase of 1.3% and with an average yearly increase of 1.3%.

Tourism, in addition to population growth and agriculture production, is expected to influence economic growth and employment creation. Tourism arrivals, which in the model are primarily determined by habitat quality and by the historical growth rate of visitors, is expected to rise from 92,113 person/year in 2010 to 183,746 person/year in 2030 marking an overall percentage increase of 99.5% and with an average yearly increase of 3.5%.

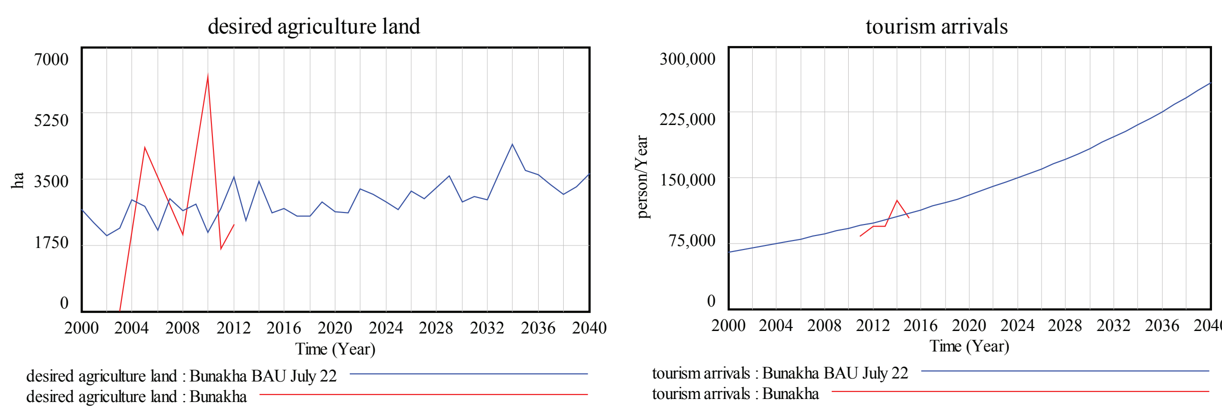

Figure 28. Desired agriculture land and tourism arrivals, BAU scenario; 2000 – 2040

Land use changes and ecosystem services

In the BAU scenario forest cover, which is determined by deforestation for agricultural land, infrastructure, pasture land, and settlements, is expected to decrease from 182,678 ha in 2010 to 181,876 ha in 2030 with an overall percentage decrease of 0.4% and with an average yearly decrease of 0.02%.

Agricultural production, which is determined by agricultural land and average yield, is expected to increase from 9,619 tons in 2010 to 10,938 tons in 2030 with an overall percentage increase of 13.7% and with an average yearly increase of 2.4%. The projected change in agricultural land amounts to 21% from 2010 to 2030 with an average yearly change of 0.97%; concerning yield the change is 6% from 2010 to 2030 with an average yearly change of 1.4%.

Runoff -which is determined by surface water inflow, and surface water use (for residential/urban use and irrigation)- is expected to oscillate around 3.6 and 3.2 billion m^3/year (based on rainfall variability) and is projected to be 3.6 billion m^3/year in 2010 and at 3.5 billion m^3/year in 2030. While climate scenarios are not simulated (i.e. variations in the underlying trend of precipitation and modifications in rainfall variability), the historical trend of variability is embedded in the model and evaporation and evapotranspiration, as well water retention by vegetation are taken into account.

The total loadings of nitrogen and phosphorus in this area -which is the sum of the nutrients contribution from all LULC types without filtering from the landscape- is expected to increase for the former from 578,359 kg/year in 2010 to 620,059 kg/year, representing an overall increase of 7.2%, and for the latter from 2 million kg/year in 2010 to 2.3 million kg/year, representing an overall increase of 11.6%. On the other hand, total nutrients export from this area is expected to decrease from 326,802 kg/year in 2010 to 164,236 kg/year in 2030, representing an overall decrease of 49.7%.

Finally, total emissions -which are determined by emission from energy use and land use change- are expected to change based on deforestation and the occurrence of forest fires. Two values for carbon sequestration are used (and two simulations have been created), considering an upper (maximum 394.74 ton/ha, including carbon in biomass and soil) and a lower value (78.82 ton/ha) for forest. The annual amount of emissions (not the net amount, which compensates for increase carbon storage in biomass) is higher in 2030, being at 93,657 ton/year in 2010 and 120,980 ton/year in 2030 (+29.2%) when using the lower range for carbon sequestration; being at 102,938 ton/year in 2010 and 130,552 ton/year in 2030 (+26.8%) when using the upper range for carbon sequestration. The difference in the % change is to be attributed to the fact that energy emissions do not change under both scenarios, while the carbon sequestration does. On the other hand, the average amount of emissions during the same period is 109,201 ton/year when using the lower range and 125,279 ton/year when using the upper range.

When considering carbon sequestration in the area affected by the construction of Bunakha Reservoir with the boundaries set at the watershed level, instead than at the district level, the change in the period 2010-2030 amounts to -123,059 ton in the lower range and to -2,211,105 ton in the upper range.

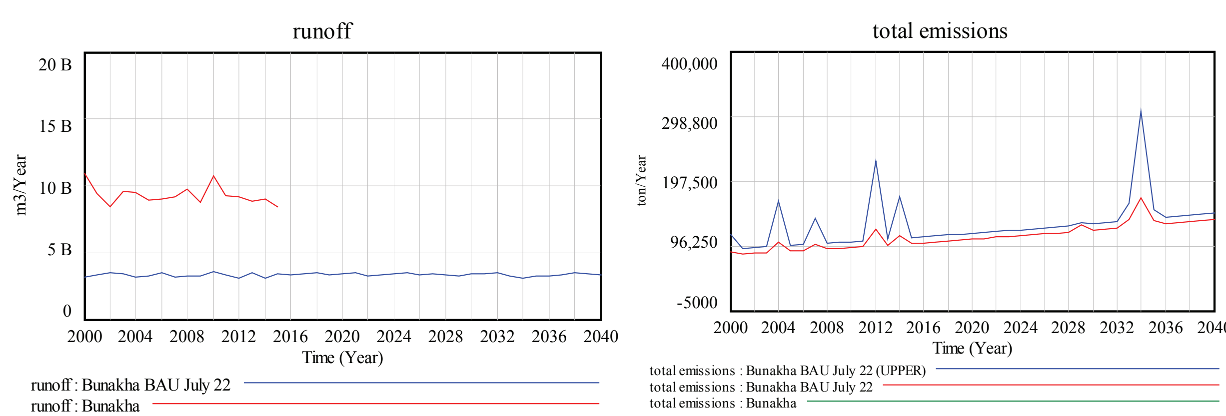

Figure 29: Runoff and total emissions, BAU scenario; 2000 – 2040

Hydropower scenario

In this scenario, hydropower construction and capacity starts increasing as of 2014 and it reaches 180 Mw/year in 2022 and it remains constant afterwards. Hydroelectric power generation reaches 925,677 Mwh/year in 2024 and it remains fairly constant afterwards, oscillating due to rainfall variability and slightly declining over time due to sedimentation.

From an economic perspective, the value of the hydropower dam (reaching close to $450 million in 2022) slowly declines over time (due to depreciation). It is also projected that costs (including both capital and operation and management costs) will likely outweigh revenues throughout the simulation period, unless the capacity factor can reach above 70-75% and the selling price increases above the current national average.

Total dam employment increases substantially in the period 2015-2021 reaching a maximum level of 493 people (due to construction employment), it then decreases and reaches 213 people for activities related to operation and management. Employment wages follows the same trend as total dam employment and peak at 1.2 million US$/year in 2023 to then decline to 511,920 US$/year for the operation and management of the hydropower dam (with the assumption that a full time job will be compensated on average $2,400 per year).

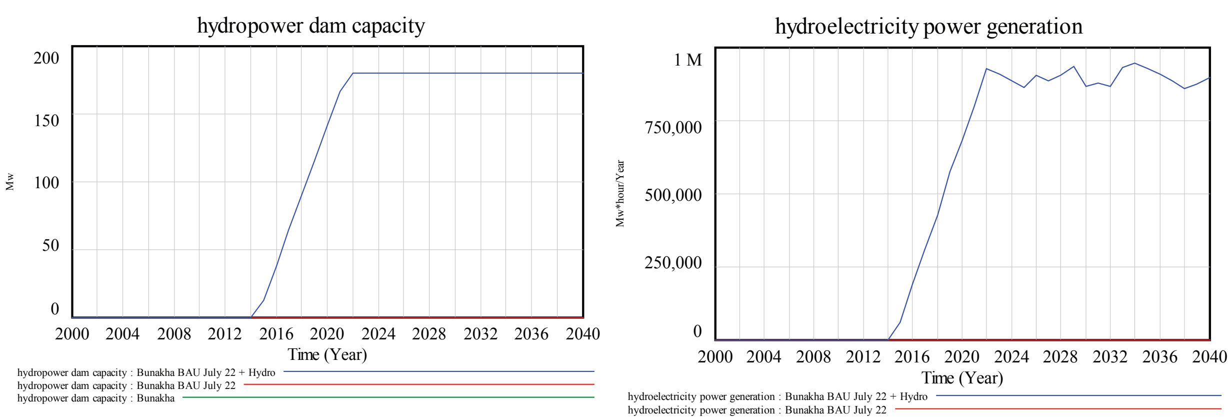

Figure 30. Hydropower dam capacity and electricity generation, Hydropower scenario; 2000 – 2040

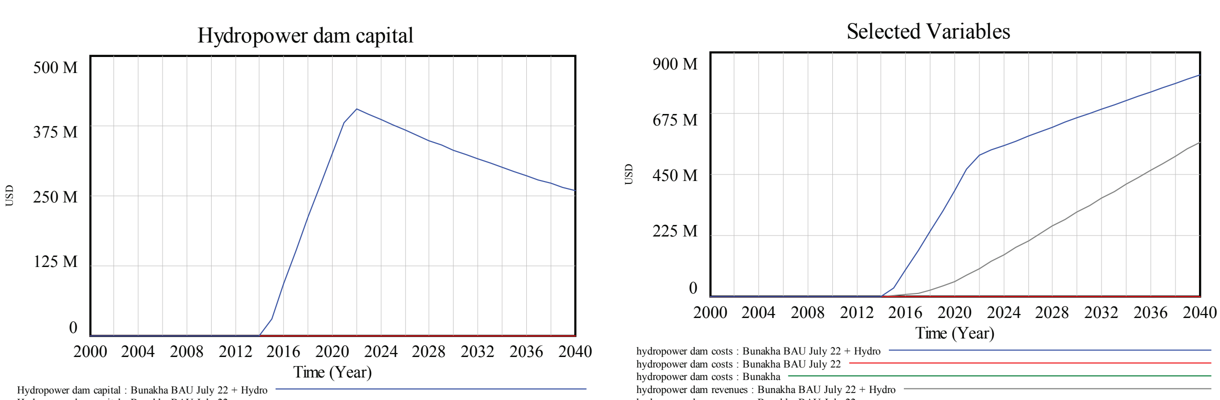

Figure 31. Hydropower dam capital and cash flow (investment and costs, and revenues), Hydropower scenario; 2000 – 2040

With the projections on population, food demand, as well as of the land that would be used by the hydropower dam and related infrastructure, forest cover is expected to be 0.01% lower than under the BAU scenario in 2030 with an yearly average decrease of 0.02% in the period 2010-2030. Agricultural land is also expected to be 10.2% lower than under the BAU scenario in 2030 with a yearly average decrease of 0.4% in the period 2010-2030. Agricultural production is also expected to be 0.7% lower than under the BAU scenario in 2030 with a yearly average decrease of 2.4% in the period 2010-2030.

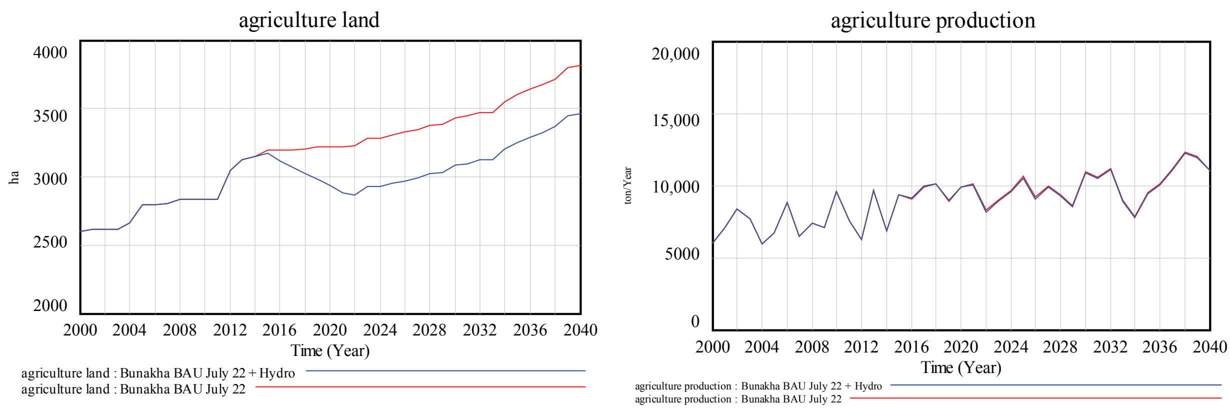

Figure 32. Agriculture land and production, BAU and Hydropower scenarios; 2000 – 2040

Under the Hydropower scenario, the road construction budget has a considerable increase in the period 2015-2021 when it reaches a maximum of 7 million US$/year and then it levels out to the same level as in the BAU scenario. This is due to the expansion of the road network due to the construction of the hydropower dam and related infrastructure (e.g. transmission lines). The total road network is 719 Km in 2010 and 1,470 Km in 2030, which is 65.4% higher than under the BAU scenario. Consequently, habitat quality is 4.7% lower compared to the BAU scenario with a yearly percentage decrease of 0.3% in the period 2010-2030. However, road construction is not the only threat affecting habitat quality, which also accounts for cropland, power distribution lines and urban areas.

Emissions from forest fires are expected to be 5.4% higher under this scenario in 2030 because of the construction of transmission and distribution lines. Total emissions are projected to be between 10% and 0.43% higher under this scenario (when using the lower and upper range for carbon sequestration) than under the BAU scenario. The average amount of emissions during the same period is 109,394 ton/year when using the lower range and 128,489 ton/year when using the upper range. The same trend is forecasted for annual emissions from land use change (including both deforestation and forest fires) which is expected to be 4.4% higher under this scenario than under the BAU scenario. Consequently, total carbon sequestration is expected to be 0.01% lower under this scenario than under the BAU scenario, reaching 9.1 and 42.6 million ton in 2030.

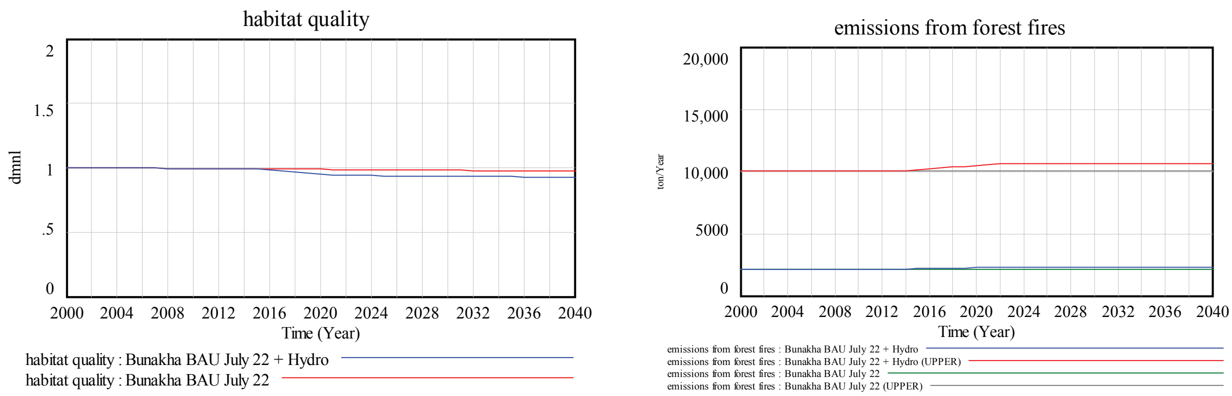

Figure 33. Habitat quality and emissions from forest fires (upper and lower carbon sequestration), BAU and Hydropower scenarios; 2000 – 2040

Mitigation scenario

Under this scenario, forest cover is expected to be 0.32% and 0.34% higher than under the BAU and the Hydropower scenarios respectively. Reforestation would start in 2014 and increase to reach on average 53.7 ha/year once the hydropower dam is complete and operational. Watershed conservation investment would follow the trend of revenue from hydropower generation, reaching approximately 51,972 US$/year.

Due to the expansion of forest cover, total carbon sequestration is expected to be 0.32% and 0.22% higher under this scenario than under the BAU scenario (for the lower and upper ranges of carbon sequestration), reaching 9.2 and 42.7 million ton in 2030.

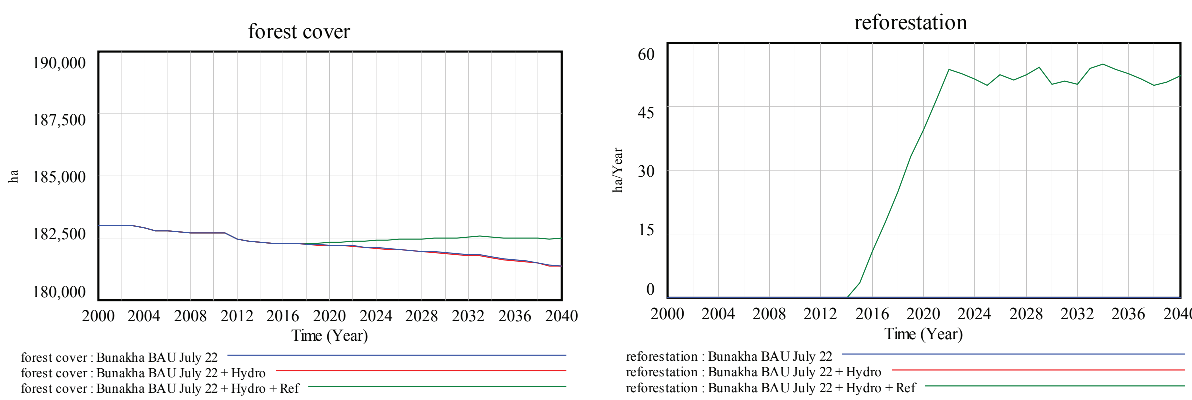

Figure 34. Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

ES	Estimation			Biophysical change (2010-2030): BAU	Hydro vs BAU	ES vs BAU	Economic value per unit	Economic valuation (year 2030)		Comments
	InVEST	SD	Benefit transfer					Hydro vs BAU	ES vs BAU	
Provision of food		X		1,319 ton	-76	-80	739.86 US$/ton	-$421,692	-$424,088	Systemic approach, with endogenous changes to population and land use
					1,159	1,151		$814,442	$808,675	Sectoral approach with no change to land use, only yield
Sedimentation	X			0.02 mm3/km2	2.0%	1.4%	1,827 $/hour of hydropower dam operation	-$8,594	-$5,969	Only considers impact on sedimentation from land use
Provision of freshwater (quality) - nitrogen		X		0.0410 mg/l	-1.96%	-1.92%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Provision of freshwater (quality) - phosphorus		X		0.0435 mg/l	-3.69%	-3.67%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Habitat for species			X	802 ha	-26	590	5,192 US$/Ha	-$133,045	$3,065,470	Economic value per unit obtained from Kubiszewski et al. (2010)
		X		91,633 persons	-3,535	-3,511	576 US$/person	-$2,036,106	-$2,022,201	Assumes that a reduction in habitat quality has a proportional impact on tourism visits (it could also be assumed that expenditure per visit might change)
Regulation of carbon sequestration and storage	X	X		-2,211,105 ton	-81,350	154,884	43 US$/ton	-$3,498,050	$6,660,012	Upper values of carbon coefficients from IPCC Report 2006
	X	X		-123,059 ton	-2,292	52,794	43 US$/ton	-$98,556	$2,270,142	Lower values of carbon coefficients from IPCC Report 2006
Genetic resources			X	802 ha	-26	590	19 $US/ha/year	-$487	$11,218	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Timber			X	802 ha	-26	590	44 $US/ha/year	-$1,128	$25,979	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Biological control			X	406 ha	-164	-163	28 $US/ha/year	-$4,599	-$4,566	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	802 ha	-26	590	9 $US/ha/year	-$231	$5,314	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Pollination			X	406 ha	-164	-163	19 $US/ha/year	-$3,121	-$3,099	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	802 ha	-26	590	376 $US/ha/year	-$9,635	$221,999	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)

Table 4. Ecosystem service valuation, Bunakha Reservoir, year 2030

NIKACHHU II HYDROPOWER PLANT

BAU scenario

Socio-economic trends

The geographical area which will likely be affected by the construction of the Nikachhu II Hydro Power is comprised of Trongsa and Zhemgang dzongkhags. Within these districts population is expected to increase from 34,512 people in 2010 to 44,079 people in 2030, with an overall percentage increase of 27.7% and with an average yearly increase of 1.23% in the BAU scenario between 2010 and 2030. Food demand, which is driven by population change and calories consumption is estimated to increase from 42.9 billion kcal/year in 2010 to 54.6 billion kcal/year in 2030 with an overall increase and an average yearly increase matching the percentage of population growth.

In the BAU scenario desired agricultural land is expected to decrease from 4,078 ha in 2010 to 3,889 ha in 2030, with an overall percentage decrease of 4.4%. Desired pasture land, which is determined by livestock density and local livestock production, is estimated to increase from 150 ha in 2010 to 191 ha in 2030, with an overall percentage increase of 27.7% and with an average yearly increase of 1.23%.

Tourism, in addition to population growth and agriculture production, is expected to influence economic growth and employment creation. Tourism arrivals, which in the model are primarily determined by habitat quality and by the historical growth rate of visitors, is expected to rise from 21,255 person/year in 2010 to 42,365 person/year in 2030 marking an overall percentage increase of 99.3% and with an average yearly increase of 3.5%.

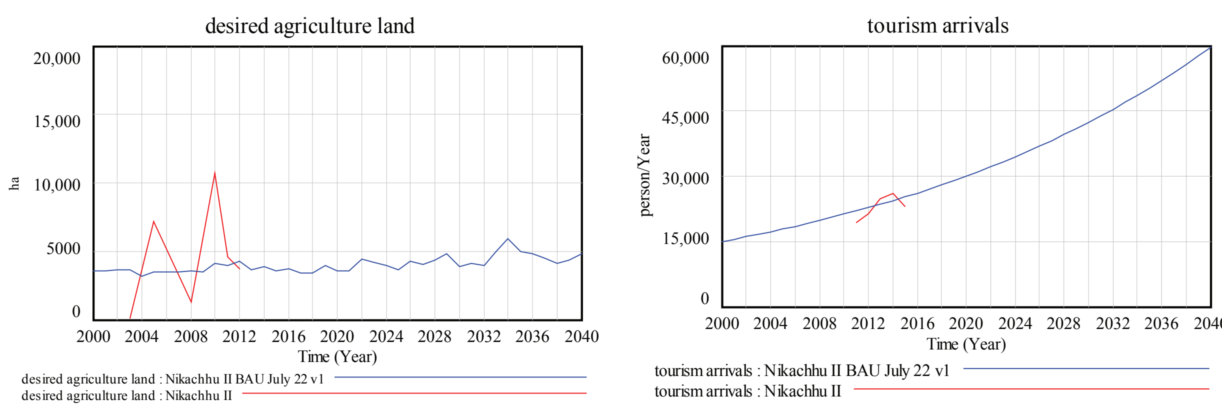

Figure 35. Desired agriculture land and tourism arrivals, BAU scenario; 2000 – 2040

Land use changes and ecosystem services

In the BAU scenario forest cover, which is determined by deforestation for agricultural land, infrastructure, pasture land, and settlements, is expected to decrease from 260,456 ha in 2010 to 259,318 ha in 2030 with an overall percentage decrease of 0.4% and with an average yearly decrease of 0.02%.

Agricultural production, which is determined by agricultural land and average yield, is expected to increase from 9,923 tons in 2010 to 16,251 tons in 2030 with an overall percentage increase of 63.8% and with an average yearly increase of 3.1%. The projected change in agricultural land amounts to 22.6% from 2010 to 2030 with an average yearly change of 1.03%; concerning yield the change is 33.6% from 2010 to 2030 with an average yearly change of 2.03%.

Runoff -which is determined by surface water inflow, and surface water use (for residential/urban use and irrigation)- is expected to oscillate around 9.8 and 6.9 billion m^3/year (based on rainfall variability) and is projected to be 7.8 billion m^3/year in 2010 and at 9.6 billion m^3/year in 2030. While climate scenarios are not simulated (i.e. variations in the underlying trend of precipitation and modifications in rainfall variability), the historical trend of variability is embedded in the model and evaporation and evapotranspiration, as well water retention by vegetation are taken into account.

The total loadings of nitrogen and phosphorus in this area -which is the sum of the nutrients contribution from all LULC types without filtering from the landscape- is expected to increase for the former from 843,109 kg/year in 2010 to 904,772 kg/year, representing an overall increase of 7.3%, and for the latter from 1.8 million kg/year in 2010 to 2.2 million kg/year, representing an overall increase of 19.2%. On the other hand, total nutrients export from this area is expected to increase from 273,449 kg/year in 2010 to 330,938 kg/year in 2030, representing an overall increase of 21%.

Finally, total emissions -which are determined by emission from energy use and land use change- are expected to change based on deforestation and the occurrence of forest fires. Two values for carbon sequestration are used (and two simulations have been created), considering an upper (maximum 394.74 ton/ha, including carbon in biomass and soil) and a lower value (78.82 ton/ha) for forest. The annual amount of emissions (not the net amount, which compensates for increase carbon storage in biomass) is generally constant. On the other hand, we project occurrences of forest fires in 2010 and not in the year 2030, making so that emissions would be lower in 2030, being at 26,794 ton/year in 2010 and 4,251 ton/year in 2030 (-84.1%) when using the lower range for carbon sequestration; being at 123,456 ton/year in 2010 and 18,786 ton/year in 2030 (-84.8%) when using the upper range for carbon sequestration. The average amount of emissions during the same period is 7,554 ton/year when using the lower range and 31,785 ton/year when using the upper range.

When considering carbon sequestration in the area affected by the construction of Nikachhu II with the boundaries set at the watershed level, instead than at the district level, the change in the period 2010-2030 amounts to -57,195 ton in the lower range and to -1,030,861 ton in the upper range.

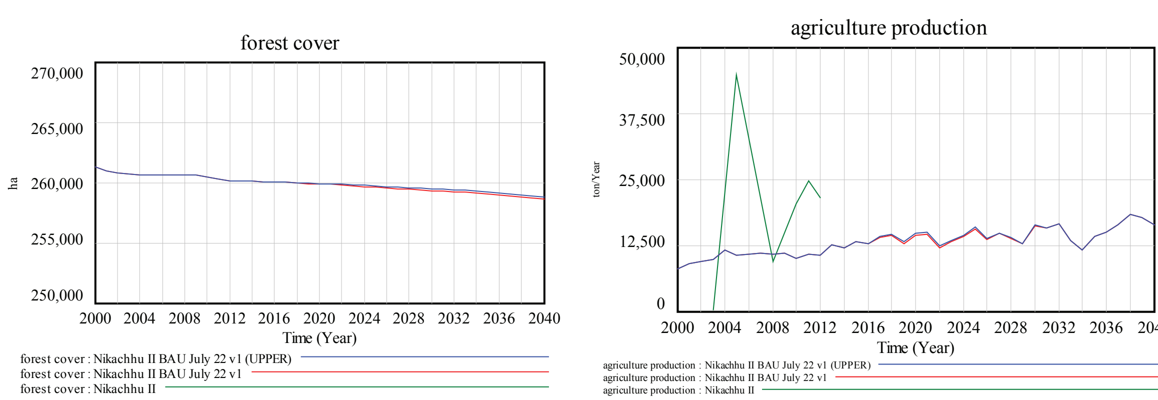

Figure 36. Forest cover and agriculture production, BAU scenario; 2000 – 2040

Hydropower scenario

In this scenario, hydropower construction and capacity starts increasing as of 2016 and it reaches 118 Mw/year in 2021 and it remains constant afterwards. Hydroelectric power generation reaches 602,186 Mwh/year in 2021 and it remains fairly constant afterwards, oscillating due to rainfall variability and slightly declining over time due to sedimentation.

From an economic perspective, the value of the hydropower dam (exceeding $160 million in 2022) slowly declines over time (due to depreciation). It is also projected that costs (including both capital and operation and management costs) will outweigh revenues until 2040 (unless the capacity utilization factor or selling prices could be higher), while the annual cash flow (without considering capital costs) will be positive as soon as electricity generation starts.

Total dam employment increases substantially in the period 2015-2020 reaching a maximum level of 396 people (due to construction employment), it then decreases and reaches 140 people for activities related to operation and management. Employment wages follows the same trend as total dam employment and peak at 949,596 US$/year in 2020 to then decline to 335,592 US$/year for the operation and management of the hydropower dam (with the assumption that a full time job will be compensated on average $2,400 per year).

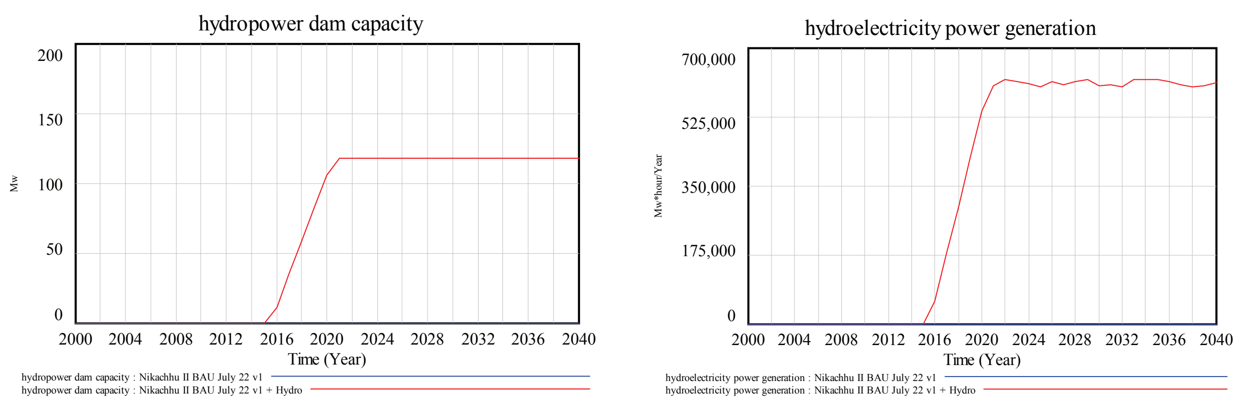

Figure 37. Hydropower dam capacity and electricity generation, Hydropower scenario; 2000 – 2040

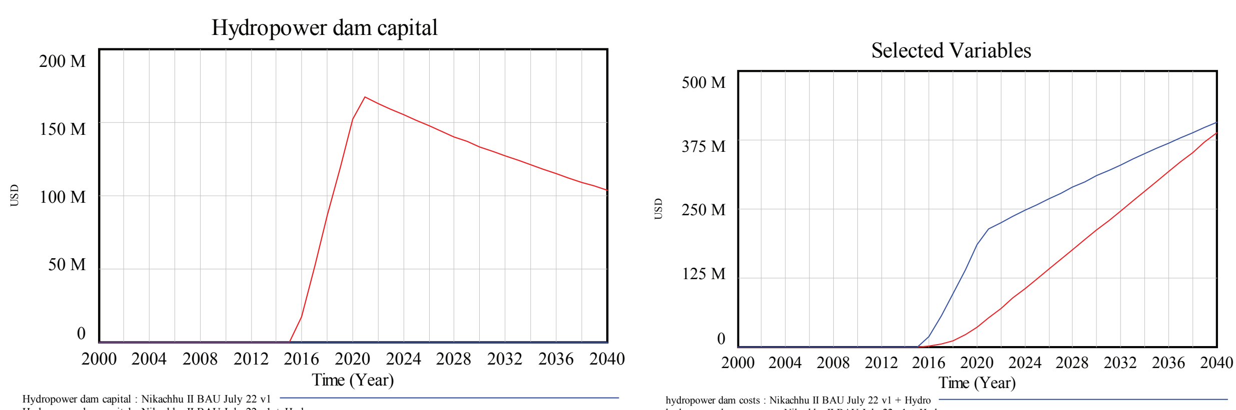

Figure 38. Hydropower dam capital and cash flow (investment and costs, and revenues), Hydropower scenario; 2000 – 2040

With the projections on population, food demand, as well as of the land that would be used by the hydropower dam and related infrastructure, forest cover is expected to be 0.02% lower than under the BAU scenario in 2030 with an yearly average decrease of 0.02% in the period 2010-2030. Agricultural land is also expected to be 4% lower than under the BAU scenario in 2030 with a yearly average decrease of 0.83% in the period 2010-2030. Similarly, agricultural production is expected to be 0.38% higher than under the BAU scenario in 2030 with a yearly average increase of 3.1% in the period 2010-2030.

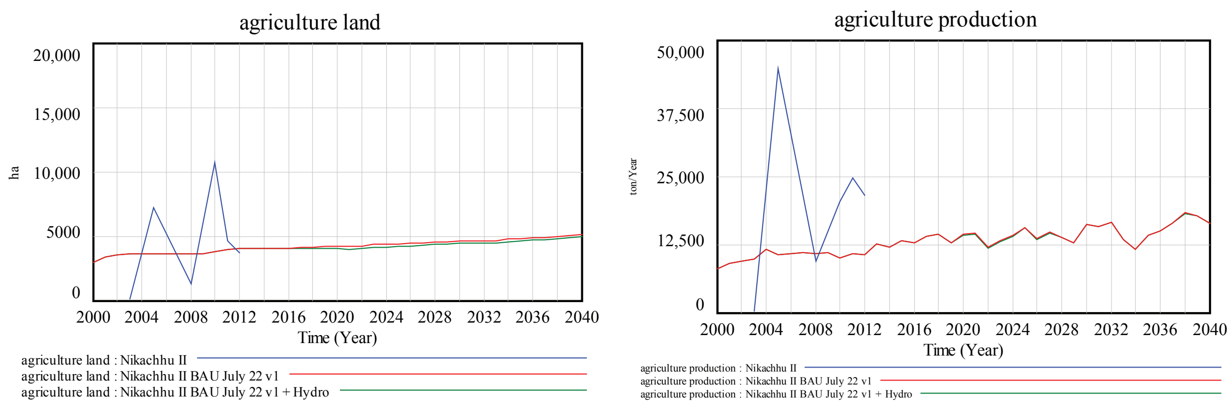

Figure 39. Agriculture land and production, BAU and Hydropower scenarios; 2000 – 2040

Under the Hydropower scenario, the road construction budget has a considerable increase in the period 2015-2020 when it reaches a maximum of 4.6 million US$/year and then it levels out to the same level as in the BAU scenario. This is due to the expansion of the road network due to the construction of the hydropower dam and related infrastructure (e.g. transmission lines). The total road network is 906 Km in 2010 and 1,394 Km in 2030, which is 20.2% higher than under the BAU scenario. Consequently, habitat quality is 1.5% lower compared to the BAU scenario with a yearly percentage decrease of 0.2% in the period 2010-2030. However, road construction is not the only threat affecting habitat quality, which also accounts for cropland, power distribution lines and urban areas.

Emissions from forest fires are expected to be 3.5% higher under this scenario in 2030 because of the construction of transmission and distribution lines. Total emissions are projected to be between 2.5% and 2.6% higher under this scenario (when using the lower and upper range for carbon sequestration) than under the BAU scenario. The average amount of emissions during the same period is 7,822 ton/year when using the lower range and 35,440 ton/year when using the upper range. The same trend is forecasted for annual emissions from land use change (including both deforestation and forest fires) which is expected to be 2.7% higher under this scenario than under the BAU scenario. Consequently, total carbon sequestration is expected to be 0.02% lower under this scenario than under the BAU scenario, reaching 18.2 and 84.3 million ton in 2030.

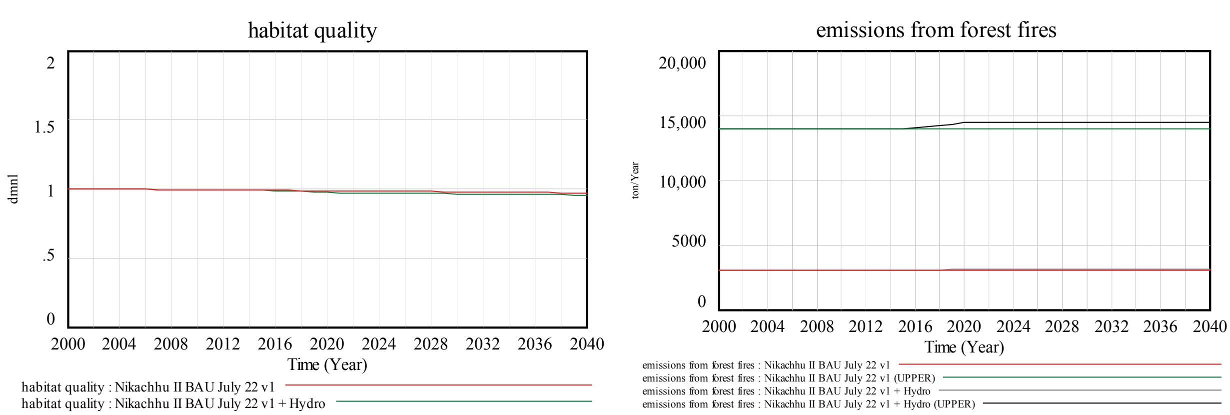

Figure 40: Habitat quality and emissions from forest fires (upper and lower carbon sequestration), BAU and Hydropower scenarios; 2000 – 2040

Mitigation scenario

Under this scenario, forest cover is expected to be 0.14% and 0.16% higher than under the BAU and the Hydropower scenarios respectively. Reforestation would start in 2016 and increase to reach on average 35.4 ha/year once the hydropower dam is complete and operational. Watershed conservation investment would follow the trend of revenue from hydropower generation, reaching approximately 35,972 US$/year.

Due to the expansion of forest cover, total carbon sequestration is expected to be 0.14% and 0.08% higher under this scenario than under the BAU scenario (for the lower and upper ranges of carbon sequestration), reaching 18.2 and 84.4 million ton in 2030.

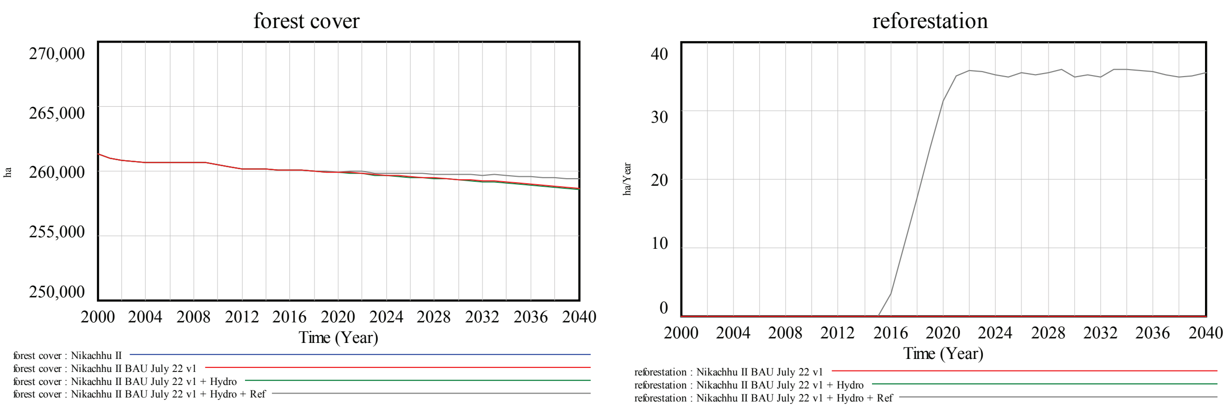

Figure 41: Forest cover and reforestation, BAU, Hydropower and Mitigation scenarios; 2000 – 2040

ES	Estimation			Biophysical change (2010-2030): BAU	Hydro vs BAU	ES vs BAU	Economic value per unit	Economic valuation (year 2030)		Comments
	InVEST	SD	Benefit transfer					Hydro vs BAU	ES vs BAU	
Provision of food		X		6,328 ton	-62	-64	536.28 US$/ton	-$70,933	-$72,039	Systemic approach, with endogenous changes to population and land use
					611	606		$429,432	$425,584	Sectoral approach with no change to land use, only yield
Sedimentation	X			0.13 mm3/km2	3.7%	-0.3%	1,197 $/hour of hydropower dam operation	-$32,628	$2,507	Only considers impact on sedimentation from land use
Provision of freshwater (quality) - nitrogen		X		0.0161 mg/l	-0.76%	-0.73%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Provision of freshwater (quality) - phosphorus		X		0.0202 mg/l	-1.50%	-1.48%	-	Below health threshold	Below health threshold	Assumes that all the land-related N loadings take place in 20% of the area (concerning the estimation of concentration)
Habitat for species			X	1,138 ha	-63	357	5,192 US$/Ha	-$329,286	$1,855,572	Economic value per unit obtained from Kubiszewski et al. (2010)
		X		21,111 persons	-262	-260	2,456 US$/person	-$644,566	-$639,481	Assumes that a reduction in habitat quality has a proportional impact on tourism visits (it could also be assumed that expenditure per visit might change)
Regulation of carbon sequestration and storage	X	X		-1,030,861 ton	-28,793	28,989	43 US$/ton	-$1,238,099	$1,246,527	Upper values of carbon coefficients from IPCC Report 2006
	X	X		-57,195 ton	-1,965	11,072	43 US$/ton	-$84,495	$476,096	Lower values of carbon coefficients from IPCC Report 2006
Genetic resources			X	1,138 ha	-63	357	19 $US/ha/year	-$1,205	$6,790	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Timber			X	1,138 ha	-63	357	44 $US/ha/year	-$2,791	$15,725	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Biological control			X	701 ha	-38	-37	28 $US/ha/year	-$1,057	-$1,033	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	1,138 ha	-63	357	9 $US/ha/year	-$571	$3,217	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)
Pollination			X	701 ha	-38	-37	19 $US/ha/year	-$717	-$701	Economic value per unit for cropland obtained from Kubiszewski et al. (2010)
			X	1,138 ha	-63	357	376 $US/ha/year	-$23,847	$134,379	Economic value per unit for temperate forest obtained from Kubiszewski et al. (2010)

Table 5. Ecosystem service valuation, Nikachhu II, year 2030

Confluence of Kuri – Gongri chhu. Note the difference in the color of water.

CONCLUSIONS

The modeling exercise has shown that there are both potential benefits and drawbacks of expanding hydropower generation. Benefits include revenues from the generation and export of electricity, depending on the price and the resulting revenue generated. Side effects include the potential increase in sedimentation which would reduce the electricity generation and increase dredging costs. Also, negative impacts could be expected in the reduction of agriculture land in the proximity of the dams (depending on the topography of the area) and fires may increase due to deforestation and the expansion of transmission lines. In addition to the impacts directly driven by the construction of the dam, the growth of population of the economic development of the country by 2030 may create challenges, both in terms of electricity demand and land use changes.

Ecosystem restoration interventions could be implemented to curb and offset some of these emerging environmental pressures and side effects. The analysis shows that reallocating part of the revenues to local environmental preservation can avoid most of the negative impacts forecasted. Investments in reforestation, among other options, would avoid the reduction of forest cover, thereby reducing sediment export and increasing carbon sequestration, providing habitat for species and genetic resources, as well as supporting economic activities (e.g. timber production).

The results of this exercise highlight both challenges and opportunities, across sectors and economic actors. Action is required to ensure that the required economic benefits are accrued, while undesirable environmental impacts are avoided. The results from the three scenarios, we can clearly see marked effect on the sediment load; habitat quality and carbon sequestration by adopting hydropower development with up-stream land use management. Since the model was linked on number of tourism to carbon sequestration and habitat quality, our models show that tourist entering the country may likely increase if the third scenario was followed by 2030.

The marked inference we could make out from this study was on the importance of initiating targeted up-stream land use management programs through the introduction of PES and to undertake sustainable developmental activities with minimum destruction to forest cover. While we are certain that there is a plough back mechanism – whereby 1% of the revenue generated from the energy sector is paid back to government exchequer, even if it is not in the form of monetary benefits but in the form of energy subsidy to the rural communities. Our model suggests that even if only 20% of the 1% plough back revenue could be spent on instituting PES, it could mean increase in economy and environmental benefits and this could help in the development of model hydro-power plant for the country. Though, there could be marked ecosystem destruction at the construction sites during the initial phase of development, in the longer run our model suggests that following the mitigation scenario would in-fact prove beneficial to carbon sequestration and land management. However, this in no way is a statement suggesting to dam more rivers as our model didn't look at the aquatic fauna since it forms the important ecosystem affected by hydropower. This couldn't be undertaken due to lack of aquatic data.

We believe that, similar studies should be pursued in future but looking at the scale of hydro-power and how it is affecting the ecosystem services within specific watershed level and also look at how downstream ecosystems are affected. Studies should also be pursued to look from both economy and ecosystem services aspects to obtain holistic understanding on hydro-power construction; de-commissioning of dams; and also the ecosystem services which are affected at earlier stage of development and at later stage of commissioning the hydropower.

The study demonstrated the importance of considering the study of watershed level during the DPR or ESIA study for any hydropower developmental works unlike the current trend of focusing within the project sites. The study showed the need to undertake broader level of study to clearly project the problems and to suggest mitigation meaures for betterment of both the power plants and environment.

Keys Results

- Sediment control and carbon sequestration stands out to be the most significant ecosystem services that will bring significant shifts by adopting scenario III;
- Five drainage basins [Wangchhu; Punatsangchhu; Nikachhu; Kurichhu; and Gamrichhu] may contribute ecosystem services [Sediment; Habitat; Biological control; Carbon; and Timber] worth USD 5 millions in 2030 if scenario III is followed;
- If only scenario II is followed, these five drainage basins may lose USD 34 millions worth of ecosystem services by 2030;
- Since the model directly linked forest cover to number of tourists visiting Bhutan, our model suggests that number of tourists visiting Bhutan shall increase helping in revenue generation

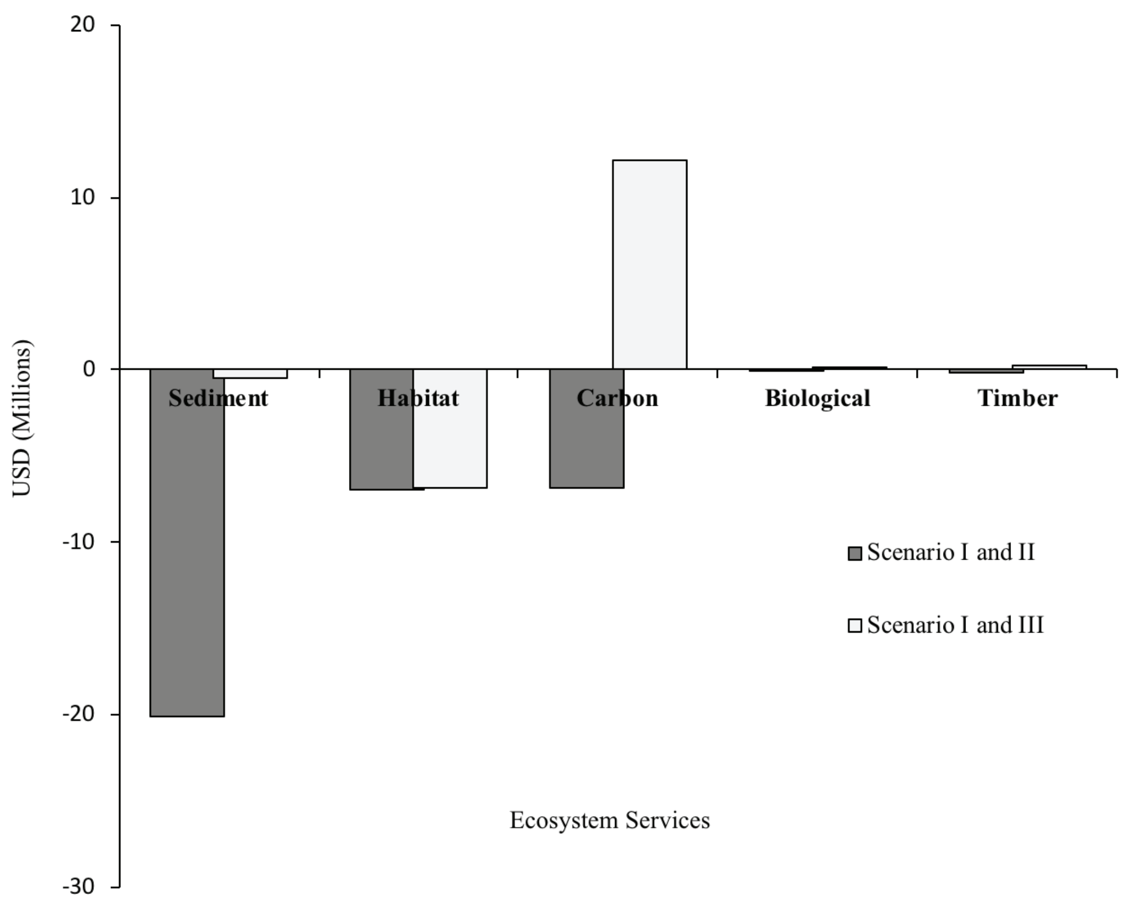

Figure 42: Ecosystem Services that will be affected in all drainage basins of study area

	PHP		Kuri I		Gamri II		Bunakha		Nikachhu	
ES	**Economic valuation (year 2030)**		**Economic valuation (year 2030)**		**Economic valuation (year 2030)**		**Economic valuation (year 2030)**		**Economic valuation (year 2030)**	
	Hydro vs BAU	**ES vs BAU**	**Hydro vs BAU**	**ES vs BAU**	**Hydro vs BAU**	**ES vs BAU**	**Hydro vs BAU**	**ES vs BAU**	**Hydro vs BAU**	**ES vs BAU**
Provision of food	-$2,936,798	-$2,973,203	-$407,898	-$416,954	-$21,777	-$22,960	-$421,692	-$424,088	-$70,933	-$72,039
	$2,446,579	$2,179,229	$2,259,158	$2,207,937	$145,869	$142,167	$814,442	$808,675	$429,432	$425,584
Sedimentation	-$1,725,787	-$721,468	-$18,211,679	$281,590	-$153,583	-$35,698	-$8,594	-$5,969	-$32,628	$2,507
Provision of fresh-water (quality) - ni-trogen	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold
Provision of fresh-water (quality) - phosphorus	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold	Below health threshold
Habitat for species	-$9,068,964	$15,714,075	-$7,981,483	$7,334,511	-$237,615	$1,002,948	-$133,045	$3,065,470	-$329,286	$1,855,572
	-$1,158,773	-$1,109,511	-$2,760,841	-$2,719,680	-$378,918	-$371,592	-$2,036,106	-$2,022,201	-$644,566	-$639,481
Regulation of carbon sequestration and storage	-$22,767,769	$39,450,479	-$3,062,288	$2,813,705	-$1,132,749	$668,779	-$3,498,050	$6,660,012	-$1,238,099	$1,246,527
	-$5,919,724	$8,439,051	-$677,981	$623,027	-$79,034	$333,594	-$98,556	$2,270,142	-$84,495	$476,096
Genetic resources	-$33,188	$57,505	-$29,208	$26,840	-$870	$3,670	-$487	$11,218	-$1,205	$6,790
Timber	-$76,856	$133,170	-$67,640	$62,157	-$2,014	$8,500	-$1,128	$25,979	-$2,791	$15,725
Biological control	-$14,139	-$13,320	-$29,006	-$28,665	-$771	-$724	-$4,599	-$4,566	-$1,057	-$1,033
	-$15,720	$27,239	-$13,835	$12,714	-$412	$1,739	-$231	$5,314	-$571	$3,217
Pollination	-$9,594	-$9,039	-$19,683	-$19,451	-$523	-$491	-$3,121	-$3,099	-$717	-$701
	-$656,766	$1,137,999	-$578,012	$531,159	-$17,208	$72,633	-$9,635	$221,999	-$23,847	$134,379

Table 5. Comparative ecosystem service valuation of five hydropower plants, year 2030

RECOMMENDATIONS

The study draws four recommendations revolving around human resource development in the field of valuation and in implementing watershed management strategies besides suggesting some future studies. Following recommendations were arrived after considering the need to have sustainable funding mechanisms to pursue targeted up-stream land use management activities. This may be achieved only upon institutionalizing mechanisms to integrate such programs within the framework of Royal Government of Bhutan's Five Year Plans (FYPs).

- Acknowledging the possible benefits that the study might bring to environment and hydropower generation capacity in Bhutan, the study recommends a follow-up study to determine the source of sediments loads that is flowing in the river systems of Bhutan so that targeted management programs could be initiated.
    - Recommendation 1:
        - Strengthening implementation of Integrated Watershed Management through programming in the FYPs
        - Evaluate and strengthen watershed management plans that affect or are affected by hydropower installations, and integrate with EMPs
        - Institutionalize sustainable funding mechanisms, and better target spending of these funds at the watershed level
- Implementation, monitoring and evaluation of these plans should be included in the mandate of the existing river basin management committees
    - Recommendation 2:
- A follow up study to identify the source of sediments (mines, quarries, transmission lines, roads, agriculture etc.) and targets for its management should be undertaken
    - Recommendation 3:
- Water Commission or any appropriate body should be tasked with carrying out valuation studies of down-stream ecosystem services
    - Recommendation 4:
- Develop/Enhance technical capacity in conducting ecosystem services valuation studies (InVEST, System Dynamics, Hydrological Modeling, etc.)

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Putting up of transmission line

APPENDIX I

InVEST data inventory

Habitat Quality	Carbon	Annual Water Yield (Hydro-power)	Nutrient Retention (Water Purification)	Sediment Retention (Erosion Control)	InVEST (v3.3.0) Data Inventory	
Models					**Data requirements**	**Type**
X	X	X	X	X	Land use/land cover (LULC)	map
			X	X	DEM (topography)	map
X					Threat impact distance	table
X					Threat impact weights	table
X					Form of decay function	table
X					Threat maps	map
X					Habitat sensitivity to threats	table
X					Half saturation constant	table
	X				Carbon in aboveground biomass	table
	X				Carbon in belowground biomass	table
	X				Carbon in dead organic matter	table
	X				Carbon in soil	table
		X	X	X	Annual average precipitation	map
		X	X		Annual average reference evapotranspiration	map
		X	X		Plant available water content	map
		X	X		Etk/Crop Coefficient (by LULC)	table
		X	X		Root depth (by LULC)	table
		X	X		Effective soil depth	map
		X	X		Zhang coefficient	single value
		X	X		Consumptive use (by LULC)	table
		X	X	X	Watersheds above points of interest	shapefile
		X	X	X	Subwatersheds above points of interest	shapefile
			X		Water yield	map
			X		Nutrient export/load coefficient	table
			X		Nutrient filtration efficiency	table
			X	X	Threshold flow accumulation	single value
			X		Allowed level of nutrient pollution	table
				x	Rainfall erosivity	map
				x	Soil erodability	map
				X	Management Factor USLE (by LULC)	table
				X	Crop Factor USLE (by LULC)	table
				X	Sediment retention efficiency	table
				X	Slope threshold	single value
				X	Reservoir dead volume (reservoir points of interest, by watershed)	table
				X	Allowed sediments load in rivers (TMDL, etc., by watershed)	table
	X				Future land use/land cover	
	X				Value of sequestered carbon	
	X				Discount rate	
	X				Timespan	

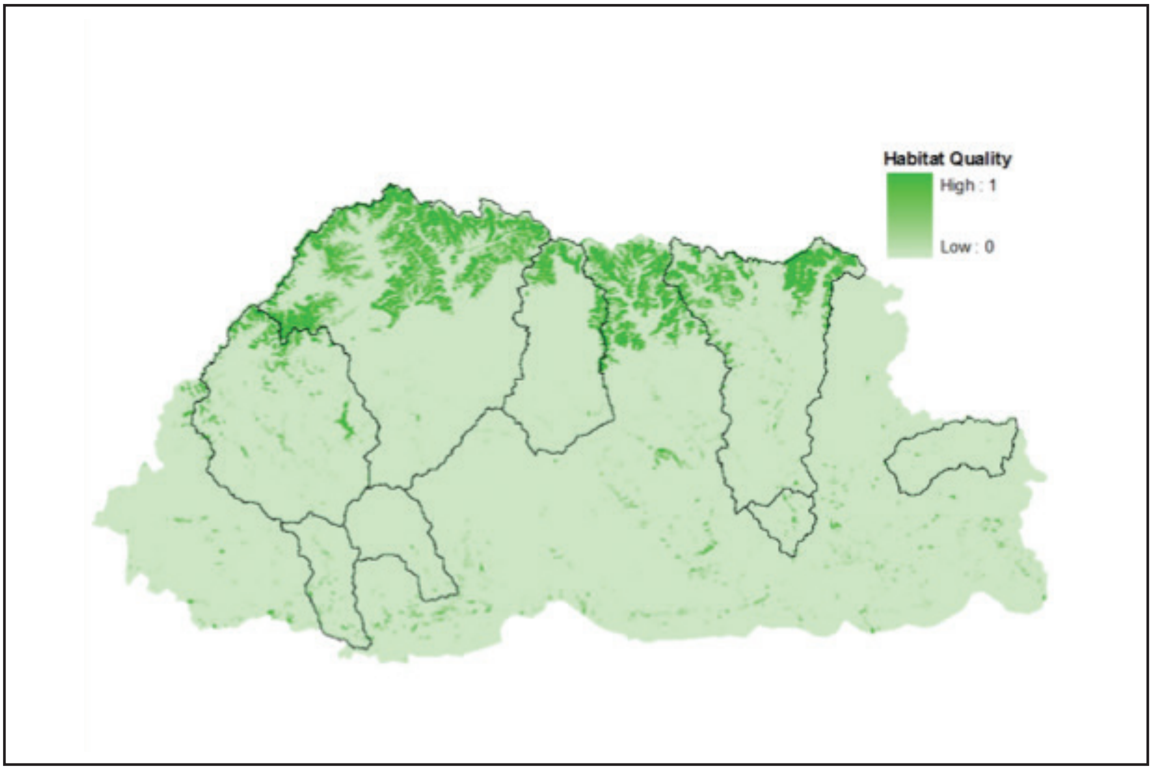
APPENDIX II:
Data inventory for SD model

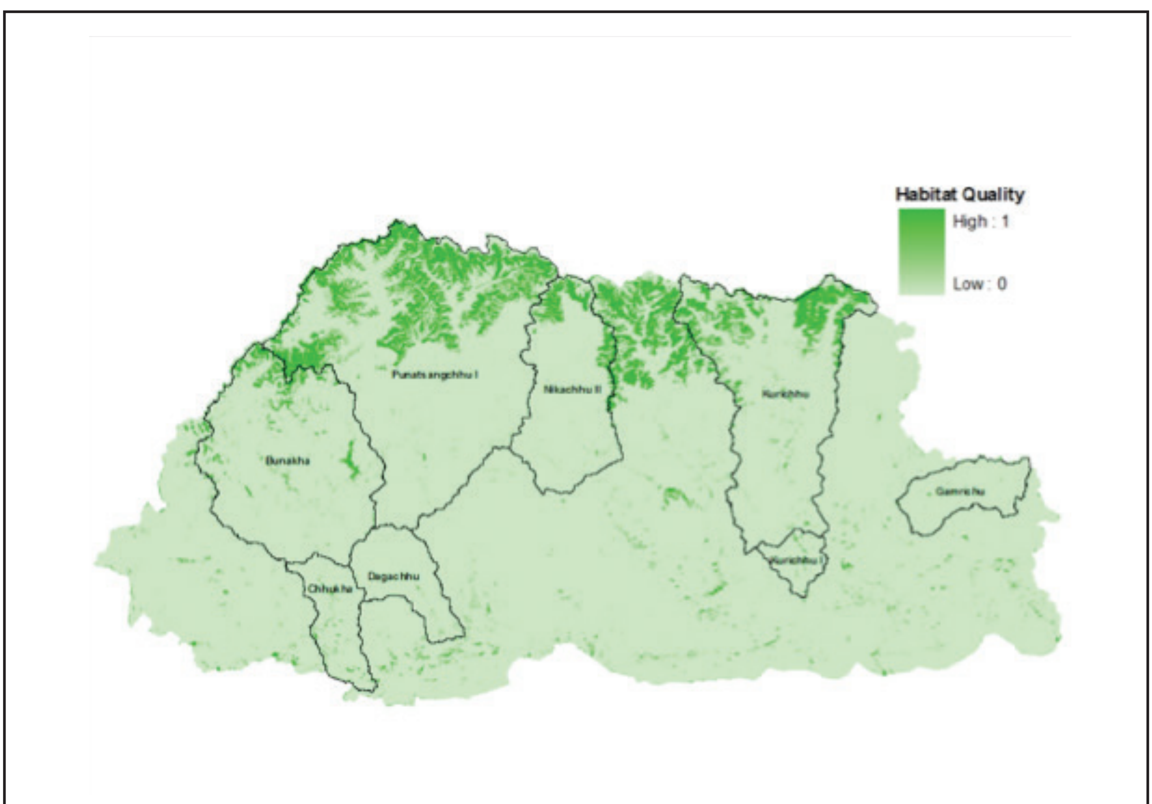
Category	Indicator	Unit of measure	Notes	Data file
Agriculture	**Annual Price of Agricultural Commodities by Type**		These commodities were chosen on the basis of their share of the total production	
	Paddy	Nu./ Kg	Only national data available, no breakdown by Dzongkhag	Table 5.13: Annual Average Price of Agricultural Commodities by Type, Bhutan (2003-2012)
	Maize	Nu./ Kg	Prices for mainland China	FAOSTAT
	Wheat	Nu./ Kg	Only national data available, no breakdown by Dzongkhag	Table 5.13: Annual Average Price of Agricultural Commodities by Type, Bhutan (2003-2012)
	Annual Average Price of Agricultural Commodities	Nu./ Kg	The weighted average of the annual price of these three commodities was calculated based on their share of the total production	
	Agriculture Production (total)		Ranking based on crop national production, not at the Dzongkhag level	
	Paddy	Million ton/year	Sum of crop production across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Maize	Million ton/year	Sum of crop production across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Wheat	Million ton/year	Sum of crop production across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	share of paddy		Estimated	
	share of maize		Estimated	
	share of wheat		Estimated	
	Agricultural Yield	ton/ha	Agricultural yield of the three main crops of agricultural production	
	Paddy	ton/ha	Sum of crop yield across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Maize	ton/ha	Sum of crop yield across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Wheat	ton/ha	Sum of crop yield across relevant Dzongkhag affected by plant	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Quantity of Chemical Fertilizers Distribution to Farmers	Kg/liter	National data	Table 5.4: Quantity of Chemical Fertilizers Distribution to Farmers, Bhutan
	Cultivated Land (total)	Ha	Cultivated land of the three main crops of agricultural production	
	Paddy	Ha	Breakdown by Dzongkhag	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Maize	Ha	Breakdown by Dzongkhag	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan
	Wheat	Ha	Breakdown by Dzongkhag	Cultivated Area, Production and Yield of Major Crops by Dzongkhag, Bhutan

Category	Indicator	Unit of measure	Notes	Data file
Livestock	Fish production	Metric Tones	Only national data available, no breakdown by Dzongkhag	Table 5.8: Livestock Production
	Number of animals	Metric Tones	Only national data available, no breakdown by Dzongkhag	Table 5.8: Livestock Production
	Meat produced	Metric Tones	Only national data available, no breakdown by Dzongkhag	Table 5.8: Livestock Production
Nutrition	Food demand	kcal/person/day	Only national data available, no breakdown by Dzongkhag	Nutrition Main Report (UWICE)
	Consumption of fish, crops, and meat (% of diet)		Share of food demand	
	Share of diet that is livestock	%	Estimated	
	Share of diet that is cereals	%	Estimated	
	Share of diet that is fruits	%	Estimated	
	Share of diet that is vegetables	%	Estimated	
Forest	Fuelwood extraction	m3/year	Sum of fuelwood collected from Dzongkhag affected by plant	Department of Renewable Energy
	Fuelwood extraction per capita	m3/year	Estimated	
	Forestland	Ha	Sum of forest area of relevant Dzongkhag affected by plant	Table 6.4: Forest Area Under Tree Cover by Dzongkhags
	Royalty realized	Nu. Millions	Sum of royalties of relevant Dzongkhag affected by plant	Department of Forests and Park Services
	Logging (timber harvest)	m3/year	Sum of timber harvest of relevant Dzongkhag affected by plant	Table 6.10: Quantity of Timber Supplied and Royalties Realized by Dzongkhag
	Forest fires (occurrences)	number/year	Sum of forest fires of relevant Dzongkhag affected by plant	BHUTAN RNR STATISTICS 2015 (Table 60)
	Forest fires (area affected)	ha/year	Sum of forest fires of relevant Dzongkhag affected by plant	BHUTAN RNR STATISTICS 2015 (Table 60)
	Materials extraction from stone quarries	kg/year	Sum of timber harvest of relevant Dzongkhag affected by plant	Dataset "Yearwise production from stone quarries"
Water	Precipitation	mm/year	Sum of precipitation of relevant Dzongkhag affected by plant	Department of Hydro-met Services
	Estimated total sediment load for record period	tonnes	Data at the watershed level	Department of Hydro-met Services
	Estimated specific sediment yield for record period	tonnes/km2	Data at the watershed level	Department of Hydro-met Services
	Estimated total runoff for record period	mill m3	Data at the watershed level	
	Evaporation and evapotranspiration	m3/year	Sum of evaporation of relevant Dzongkhag affected by plant	
Natural hazards	Population density	people/ha	Estimated	
	Average value of housing units (rural)	BTN/house	Data at national level	Royal Insurance Corporation of Bhutan

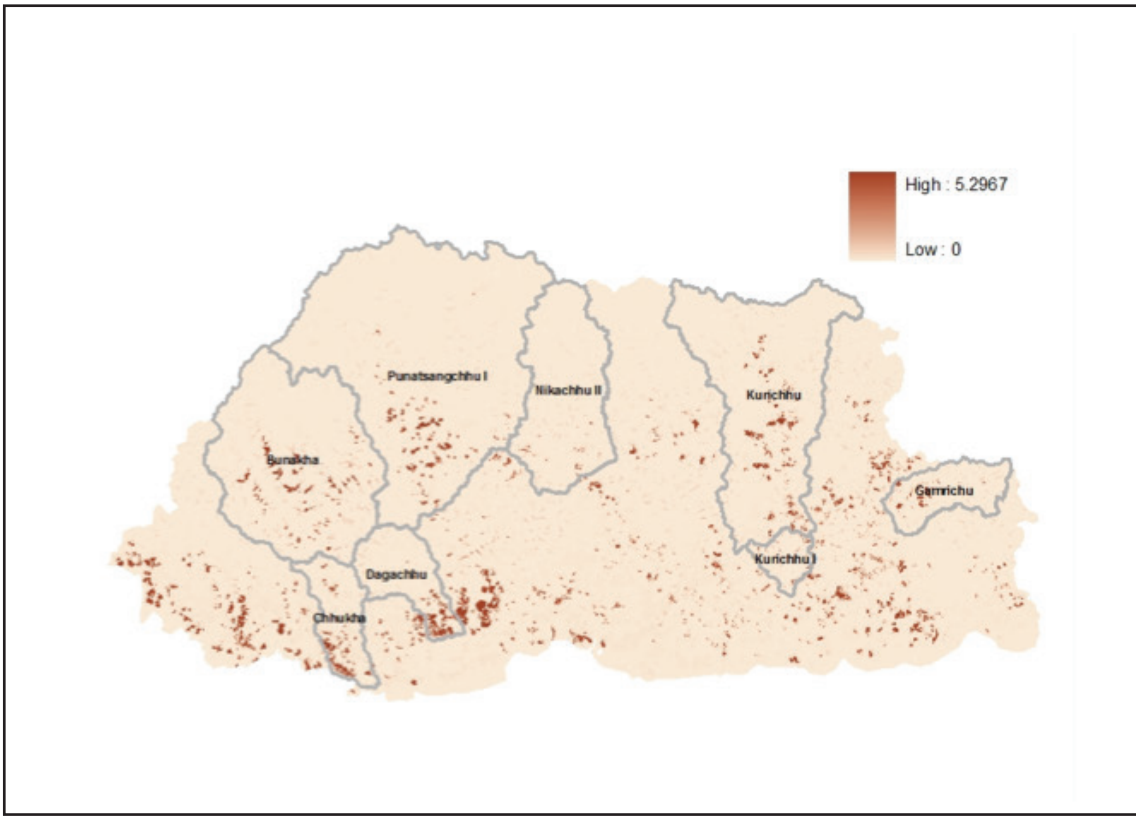
Category	Indicator	Unit of measure	Notes	Data file
Tourism	Hotels	number	Sum of hotels of relevant Dzongkhag affected by plant	Tourism Council of Bhutan
	Rooms	number	Sum of rooms of relevant Dzongkhag affected by plant	Tourism Council of Bhutan
	Roads (total)	km	Sum of length of roads of relevant Dzongkhag affected by plant	Table 6.15: Length of Roads by Type and Dzongkhag
	Number of tourists - arrivals (people/year)	people/year	Data at the national level	Tourism Council of Bhutan
	Number of religious and cultural sites	number	Sum of temples of relevant Dzongkhag affected by plant	Department of Culture
	Year Arrivals Gross Earnings	USD	Only national data available, no breakdown by Dzongkhag	Tourism Council of Bhutan
Economy	Population birth rate	%	Average birth rate across relevant Dzongkhag affected by plant	Crude Birth Rate by Area and Dzongkhag
	Population death rate	%	Average birth rate across relevant Dzongkhag affected by plant	Crude Birth Rate by Area and Dzongkhag
	Settlement land	ha	Only national data available, no breakdown by Dzongkhag	Table 6.1: Area of Land-Use and Vegetation by Types
	Agriculture, Livestock & Forestry	Million BTN/year	Only national data available, no breakdown by Dzongkhag	GDP by Economic Activity at Current Prices
	Construction	Million BTN/year	Only national data available, no breakdown by Dzongkhag	GDP by Economic Activity at Current Prices
	Electricity & Water Supply	Million BTN/year	Only national data available, no breakdown by Dzongkhag	GDP by Economic Activity at Current Prices
	Employment		Ranking of sectors by GDP production, not by employment	
	Agriculture, Livestock & Forestry	people	Only national data available, no breakdown by Dzongkhag	Total Employed Persons by Major Economic Activity and Nature of Employment
	Construction	people	Only national data available, no breakdown by /Dzongkhag	Total Employed Persons by Major Economic Activity and Nature of Employment
	Electricity & Water Supply	people	Only national data available, no breakdown by Dzongkhag	Total Employed Persons by Major Economic Activity and Nature of Employment
	Total employment	people	National Data	
	Per capita energy consumption	KWh	National Data	DGPC

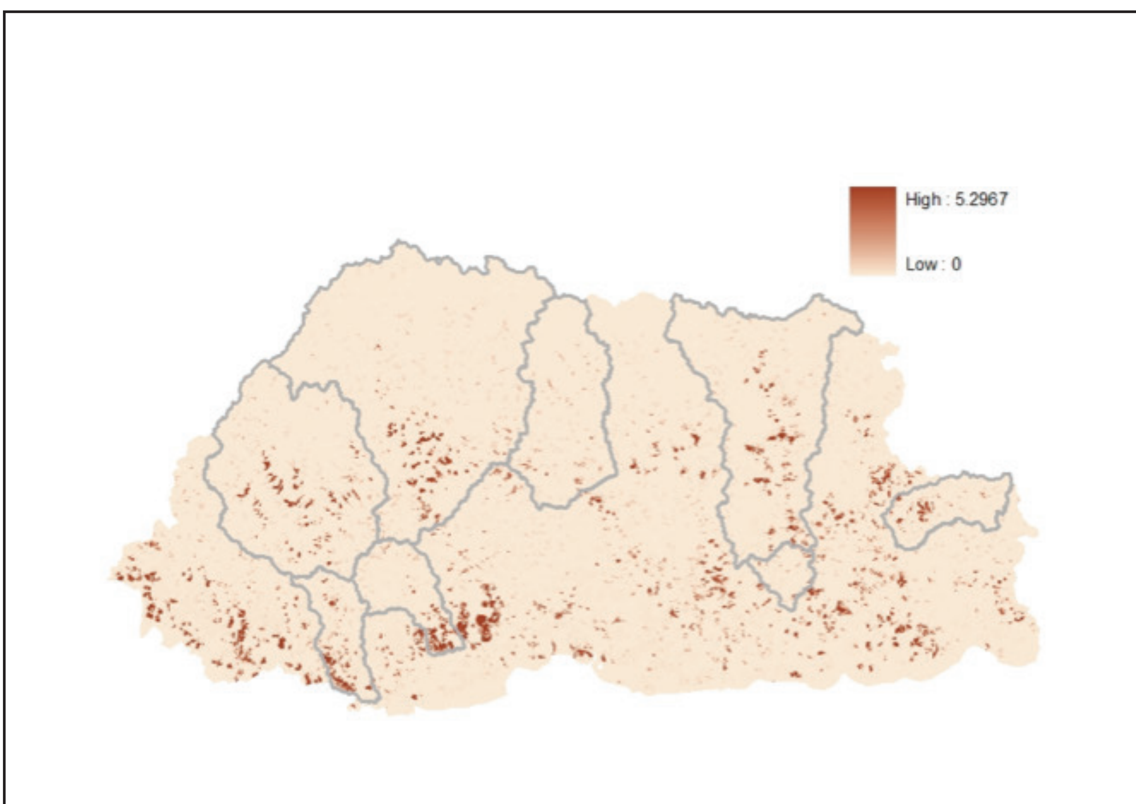
APPENDIX III:
Maps of Bhutan showing changes in ES from 2010 - 2030



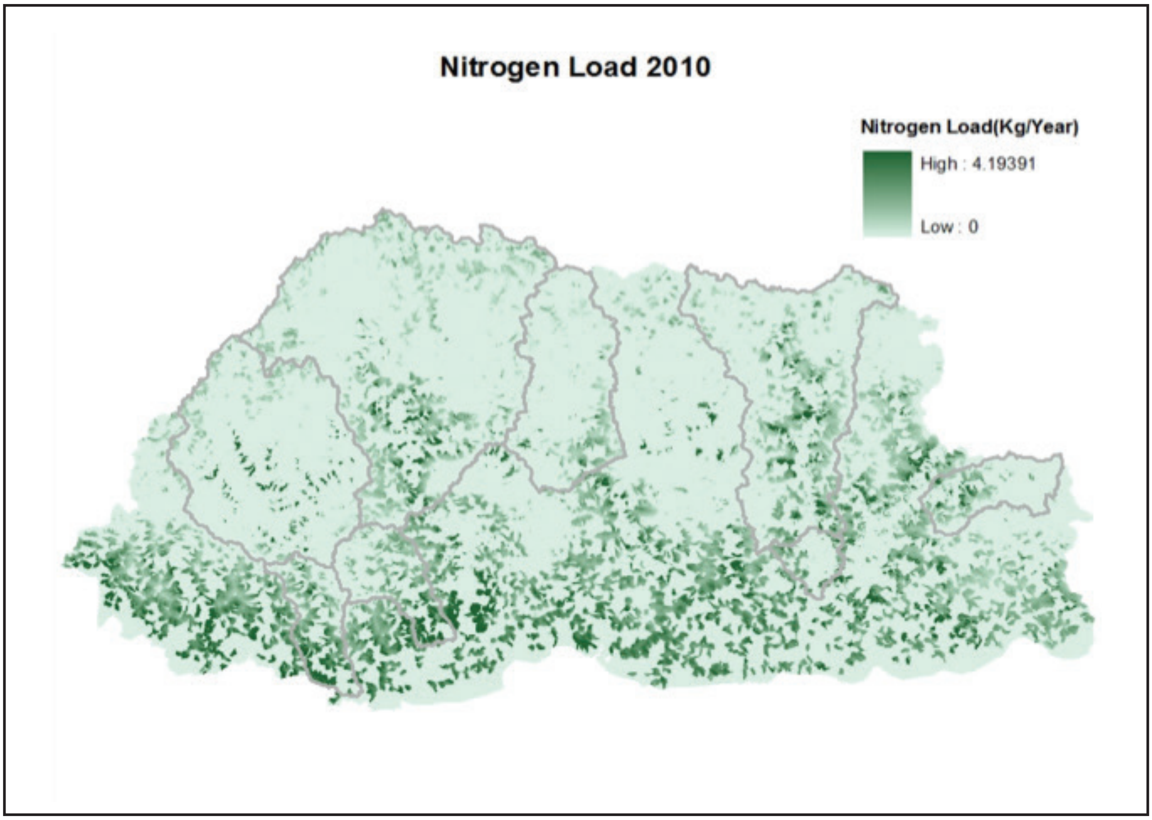


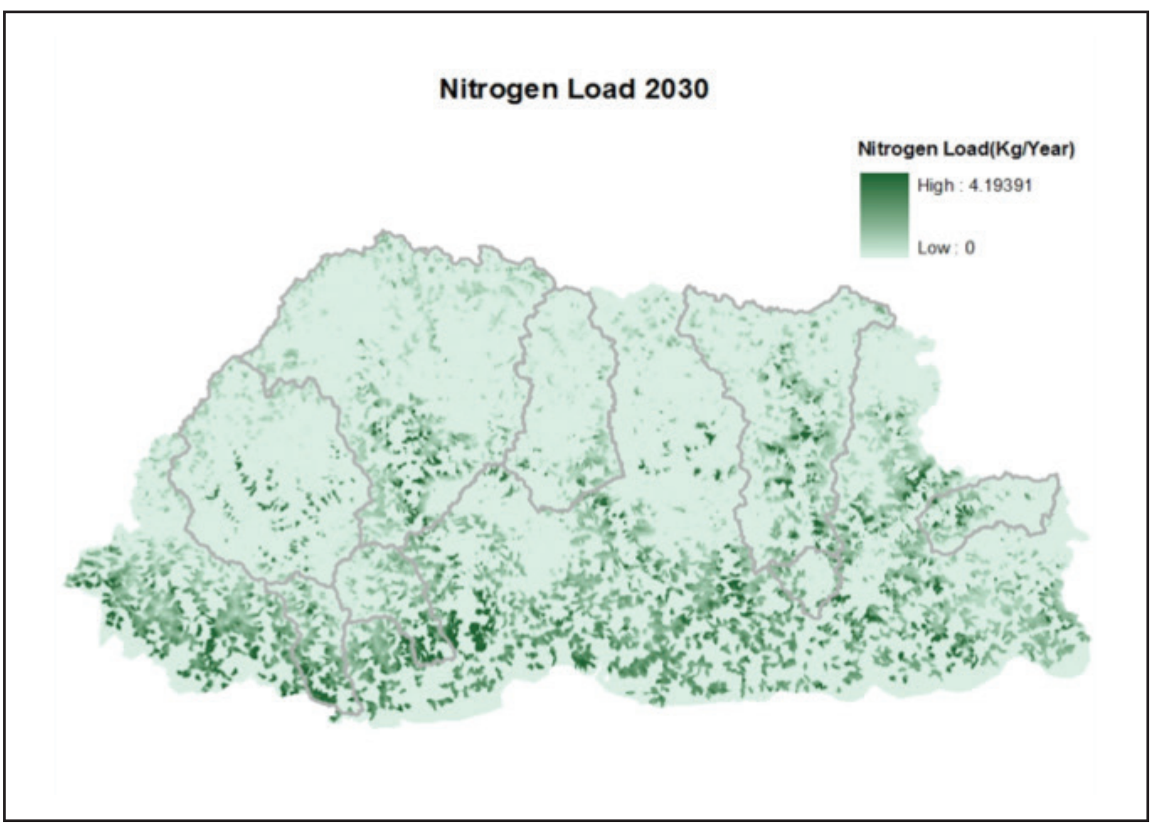
A. Habitat Quality



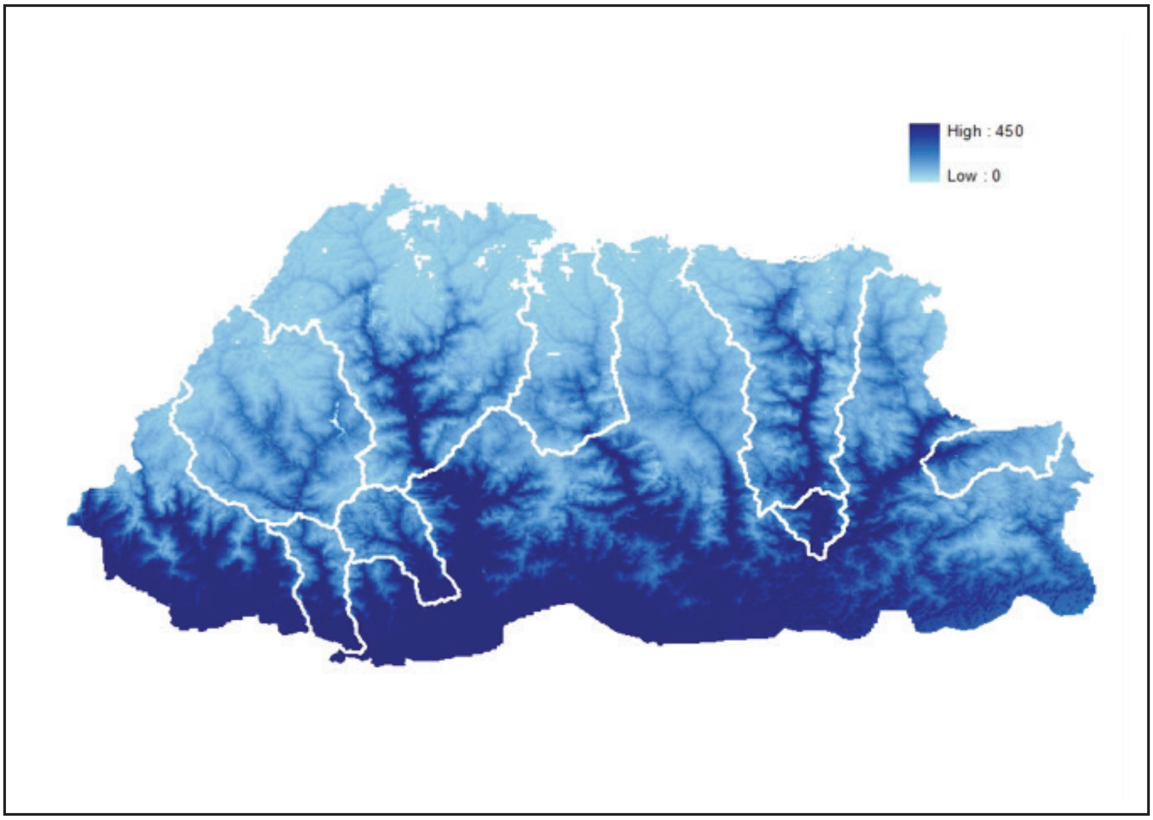


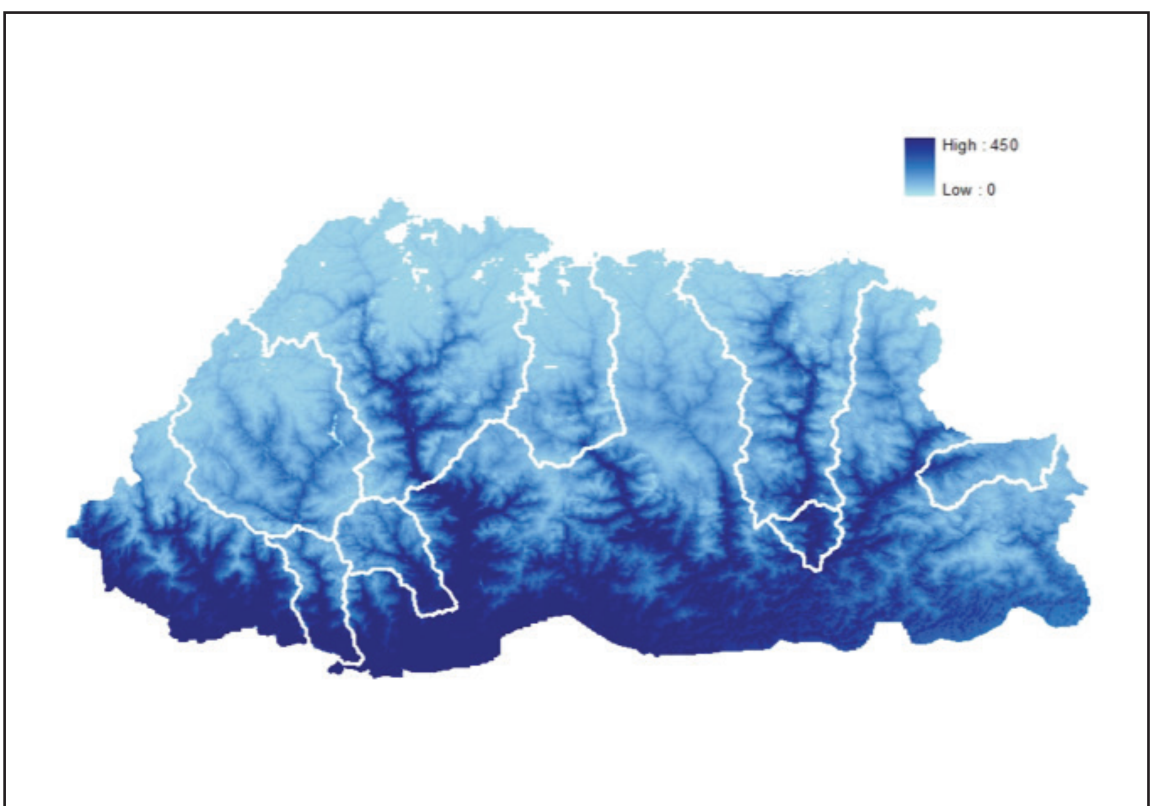
B: P load in 2010 and in 2030



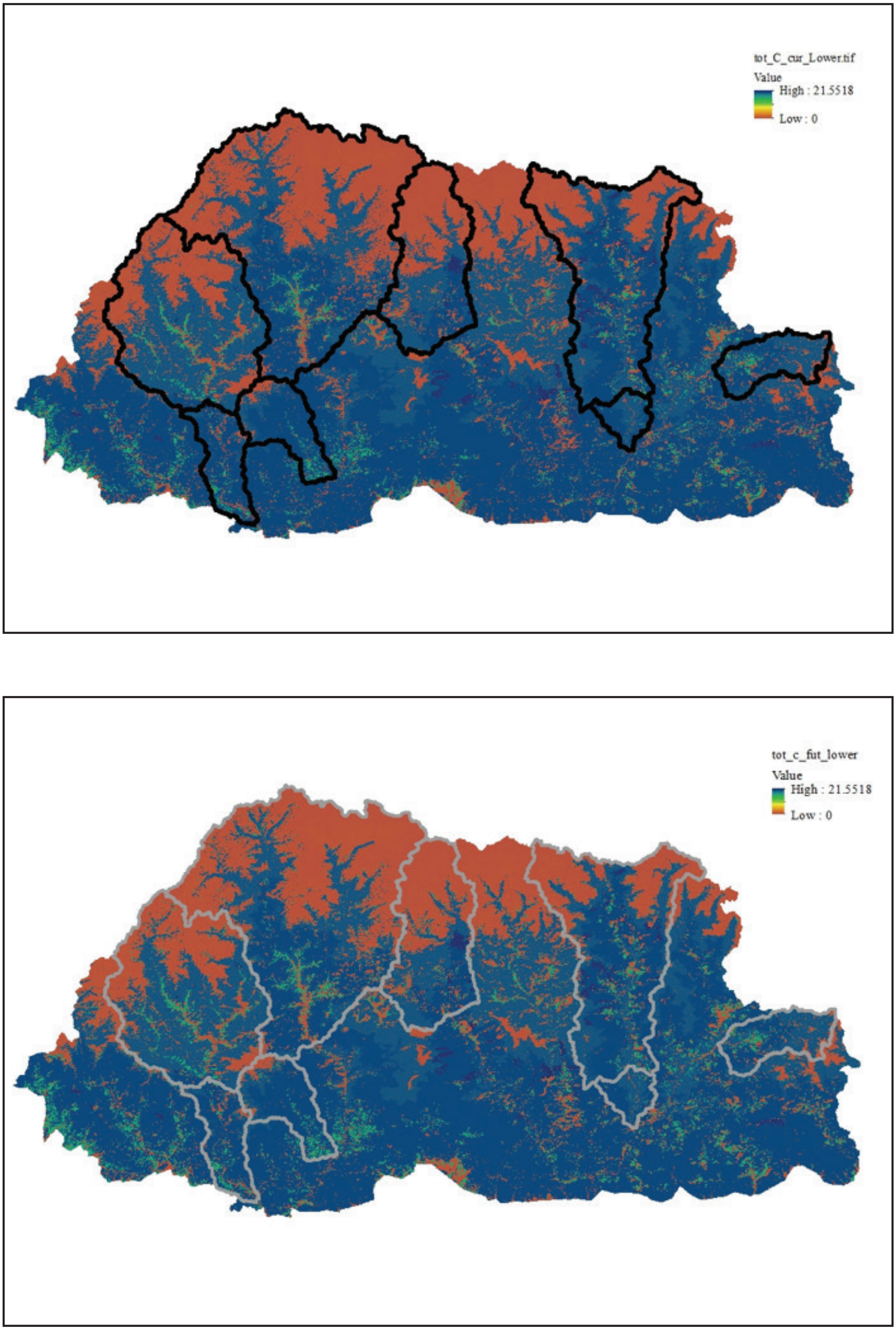


C: N load in 2010 and in 2030

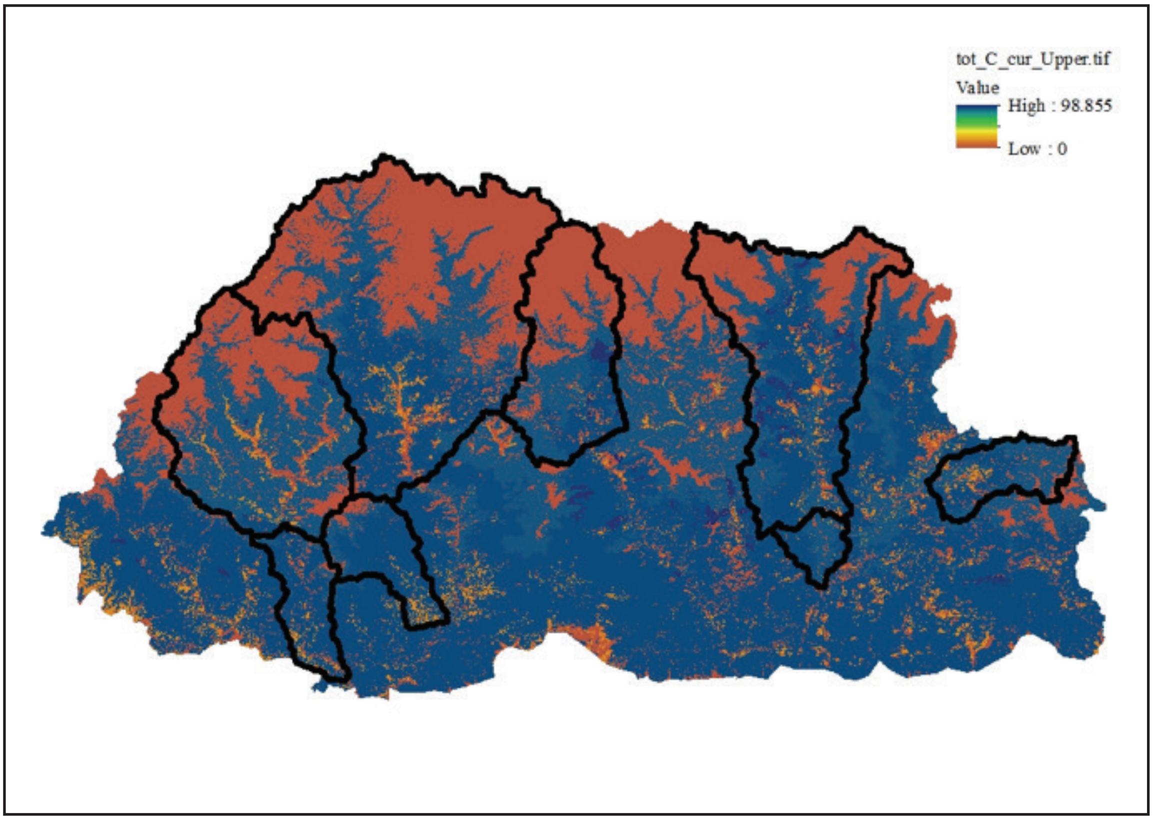


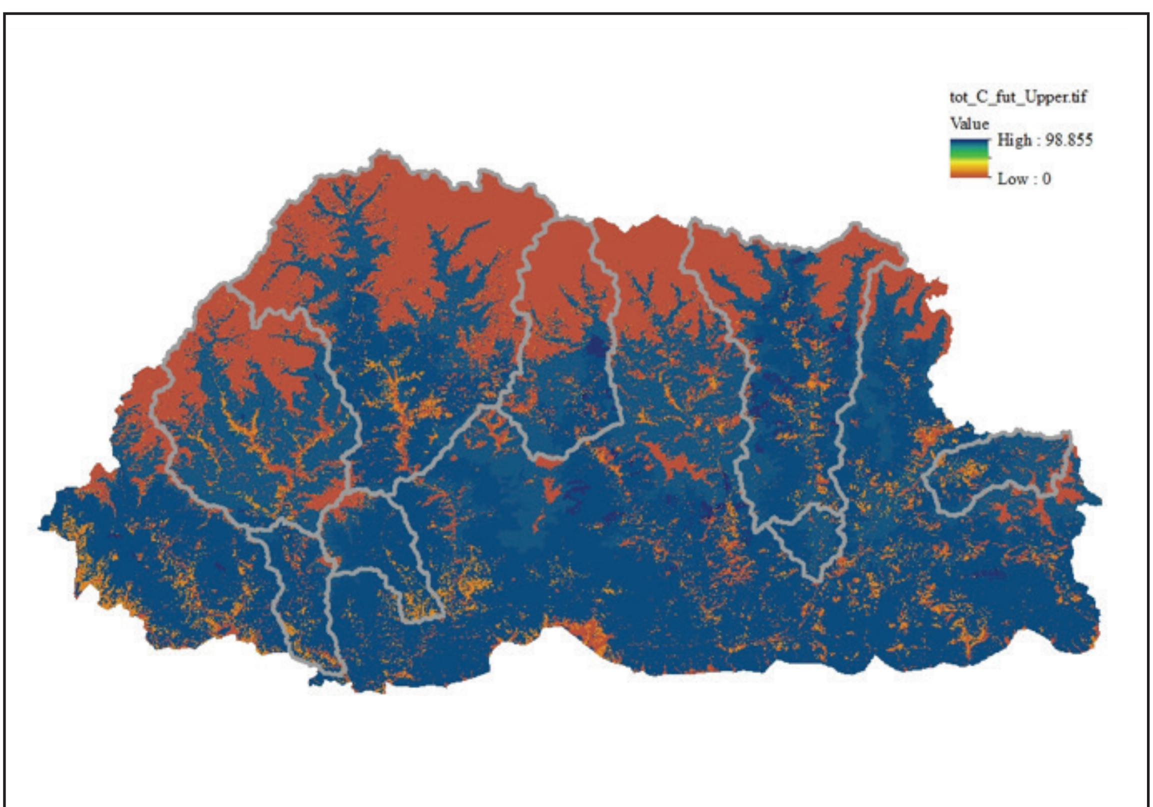


D: Water yield 2010 and 2030



E: Carbon sequestration 2010-2030 (lower)





F: Carbon sequestration 2010 and 2030 (upper)