Copernicus Climate Change

A Sustainable Asset Valuation of the Kakono Hydropower Plant in Tanzania

Assessing Climate Risks and Externalities of Hydropower and Energy Generation Alternatives

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Project Partners

The African Development Bank (AfDB) and the Green Growth Knowledge Partnership (GGKP) co-commissioned this Sustainable Asset Valuation (SAVi) assessment and the report under the framework of the Natural Capital for African Development Finance (NC4AF) program to demonstrate the value of the natural capital approach to infrastructure finance and green growth. Both institutions have joined together to mainstream natural capital in African development finance through institutional and political advocacy, co-created knowledge generation, convening regional stakeholders, capacity-building, and global communications.

The GGKP facilitated the SAVi assessment and the engagement with the AfDB. The AfDB set up a Technical Committee to share data and feedback relevant to the Kakono Hydropower Plant.

The International Institute for Sustainable Development (IISD) and KnowlEdge Srl have worked on integrating climate data from the Copernicus Climate Data Store (CDS) to improve the analysis of infrastructure projects performed with SAVi. The project serves to demonstrate the importance and usability of climate data generated through the CDS products in deploying sustainable infrastructure projects to contribute to a climate-resilient, low-carbon economy.

The assessment of the Kakono Hydropower Plant is one of the use cases for demonstrating the value of integrating climate data of the Copernicus database into SAVi.

About the Sustainable Asset Valuation (SAVi)

SAVi is a simulation service that helps governments and investors value the many risks and externalities that affect the performance of infrastructure projects.

The distinctive features of SAVi are:

- Valuation: SAVi values, in financial terms, the material environmental, social, and economic risks and externalities of infrastructure projects. These variables are ignored in traditional financial analyses.
- Simulation: SAVi combines the results of systems thinking and system dynamics simulation with project finance modelling. We engage with asset owners to identify the risks material to their infrastructure projects and then design appropriate simulation scenarios.
- Customization: SAVi is customized to individual infrastructure projects.

For more information on SAVi: www.iisd.org/savi

Authors

International Institute for Sustainable Development (IISD)

Laurin Wuennenberg

David Uzsoki

Andrea M. Bassi

KnowlEdge Srl

Andrea M. Bassi

Georg Pallaske

Marco Guzzetti

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- Edith Ofwona Adera: Principal Climate Change and Green Growth Officer, Climate Change and Green Growth Department
- Olufunso Adegbenga Somorin: Principal Climate Change and Green Growth Officer, Climate Change and Green Growth Department
- Andrew Muguwa: Principal Power Engineer, East Africa Regional Office - Task Manager for the Kakono Hydropower Project
- Mohammed Sauko Ally: Senior Energy Officer, Tanzania Country Office – Co-Task Manager for the Kakono Hydropower Project
- Robert Ochieng: Consultant - Climate Change and Green Growth, Climate Change and Green Growth Department
- Emmanuel Muligirwa: Principal Environmental and Social Safeguards Officer, Safeguards and Environmental Compliance Department
- Alemayehu Wubeshet-Zegeye: Chief Regional Power Systems Officer, East Africa Regional Office
- Tekalign Wendayehu Demissie: Senior Energy Specialist, Power and Energy Systems Development Department

The Disclosure & Access to Information (DAI) Team, with:

- Evon Wanishi, Chief Records Management, Classification & Archives Officer
- Houzanme Tibaut, Principal Documents and Records Management Officer
- Ulrich Innocent Beliby, Records Management and Archives Assistant
- Lazare Yves De Medeiros, Archiviste

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Abbreviations

AfDB	African Development Bank
BAU	business as usual
C3S	Copernicus Climate Change Service
CAPEX	capital expenditure
CBA	cost–benefit analysis
CF	cash flow
CLD	causal loop diagram
EIA	environmental impact assessment
ESIA	environmental and social impact assessment
GDP	gross domestic product
GGKP	Green Growth Knowledge Partnership
GHG	greenhouse gases
HPP	hydropower plant
IISD	International Institute for Sustainable Development
InVEST	Integrated Valuation of Ecosystem Services and Trade-offs
IRR	internal rate of return
LCOE	levelized cost of electricity
LULC	land use and land cover
MW	megawatt
MWh	megawatt-hours
NPV	net present value
O&M	operation and maintenance
OPEX	operation and maintenance expenditure
PV	photovoltaic
RCP	representative concentration pathway
SAVi	Sustainable Asset Valuation
SCC	social costs of carbon
TANESCO	Tanzania Electric Supply Company
UNEP	United Nations Environment Programme
WACC	weighted average cost of capital

Glossary

Causal loop diagram: A schematic representation of key indicators and variables of the system under evaluation that shows the causal connections between them and contributes to the identification of feedback loops and policy entry points.

Discounting: A finance process to determine the present value of a future cash value.

Externality: An externality is a negative or positive impact, often referred to as a cost or benefit, that affects a third party that did not play a role in determining such impact. The third party, who can be private (individual, organization) or society as a whole, did not choose to incur the cost or to receive the benefit. Hence, an externality is not reflected in the market price of a good or service (Kenton, 2019).

Feedback loop: "A process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts et al., 1983).

Indicator: Parameters of interest to one or several stakeholders that provide information about the development of key variables in the system over time and trends that unfold under specific conditions (United Nations Environment Programme [UNEP], 2014).

Internal rate of return (IRR): An indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Cash flows net of financing give us the equity IRR.

Methodology: The theoretical approach(es) used for the development of different types of analysis tools and simulation models. This body of knowledge describes both the underlying assumptions used as well as qualitative and quantitative instruments for data collection and parameter estimation (UNEP, 2014).

Model transparency: The degree to which model structure and equations are accessible and make it possible to directly relate model behaviour (i.e., numerical results) to specific structural components of the model (UNEP, 2014).

Model validation: The process of assessing the degree to which model behaviour (i.e., numerical results) is consistent with behaviour observed in reality (i.e., national statistics, established databases) and the evaluation of whether the developed model structure (i.e., equations) is acceptable for capturing the mechanisms underlying the system under study (UNEP, 2014).

Net present value (NPV): The difference between the present value of cash inflows net of financing costs and the present value of cash outflows. It is used to analyze the profitability of a projected investment or project.

Risk: A risk in the context of infrastructure finance refers to the chance that a factor outside the direct control of an asset owner or operator materializes as a cost for an asset. The materiality of a risk is considered in relation to the asset under assessment. Risks can be of social, environmental (physical), economic, or regulatory origin. An externality caused by the same asset under assessment may or may not turn into a risk.

Scenarios: Expectations about possible future events are used to analyze potential responses to these new and upcoming developments. Consequently, scenario analysis is a speculative exercise in which several future development alternatives are identified, explained, and analyzed for discussion on what may cause them and the consequences these future paths may have on our system (e.g., a country or a business).

Simulation model: Models can be regarded as systemic maps in that they are simplifications of reality that help to reduce complexity and describe, at their core, how the system works. Simulation models are quantitative by nature and can be built using one or several methodologies (UNEP, 2014).

Social cost of carbon: The economic cost caused by an additional tonne of carbon dioxide emissions or its equivalent through the carbon cycle (Nordhaus, 2017).

Stock and flow variables: "A stock variable represents accumulation and is measured at one specific time. A flow variable is the rate of change of the stock and is measured over an interval of time" (UNEP, 2014, p. 51)

System dynamics: A methodology developed by Forrester in the late 1950s (Forrester, 1961) to create descriptive models that represent the causal interconnections between key indicators and indicate their contribution to the dynamics exhibited by the system as well as to the issues being investigated. The core pillars of the system dynamics method are feedback loops, delays, and non-linearity emerging from the explicit capturing of stocks and flows (UNEP, 2014).

1 Introduction

The International Institute for Sustainable Development (IISD) and KnowlEdge are collaborating with the Copernicus Climate Change Service (C3S), one of the six thematic information services provided by the European Union's Copernicus Earth Observation Programme, to integrate world-class data on climate into the Sustainable Asset Valuation (SAVi) methodology and enhance its capacity for climate resiliency assessments of infrastructure projects.

The SAVi methodology quantifies and values the environmental, social, and economic externalities of infrastructure projects as well as financial performance implications caused by diverse risk factors faced by the same projects, such as those associated with climate change. The methodology can also be applied to conduct comparative assessments between alternative infrastructure solutions. More information on the SAVi methodology may be found in Appendix B and on this website: https://iisd.org/savi

One of the defined pilot applications of the enhanced SAVi methodology was conducted for the planned Kakono Hydropower Plant (HPP) in northwestern Tanzania. This pilot application was jointly developed and implemented with the African Development Bank (AfDB) and the Green Growth Knowledge Partnership (GGKP). The GGKP, with support from the MAVA Foundation, is facilitating this SAVi assessment and engagement with the AfDB to demonstrate the value of the natural capital approach to infrastructure finance and green growth in Africa. The AfDB set up a Technical Committee to share data and feedback relevant to the Kakono HPP and the Tanzanian government.

The SAVi tool was customized and applied to the Kakono HPP. The assessment explored the following:

(1) How the value and financial performance of the Kakono HPP are affected if environmental and socio-economic costs and co-benefits (externalities) are integrated into an asset valuation.
(2) If and how the Kakono HPP's conventional costs, revenues, and externalities are affected under different climate scenarios and, if they are, how the asset performance is altered under each climate scenario.
(3) How alternative energy generation options for Tanzania perform under (1) and (2) in comparison to the Kakono HPP.

Further, the results of this SAVi assessment and the drawn conclusions serve to inform the AfDB about important considerations for integrated, sustainability-aligned, and climate-resilient infrastructure investment decisions.

2 The Kakono Hydropower Plant and Alternative Energy Generation Solutions in Tanzania

The Government of Tanzania, through the Tanzania Electric Supply Company Limited (TANESCO), is proposing to build the Kakono HPP on the Kagera River in Karagwe District and construct a 220 kV transmission line from the planned Kakono HPP to Kyaka substation in Missenyi District. The overall project objective is to improve the power supply in northwestern Tanzania in addition to the increasing grid-connected generation capacity in order to foster economic growth.

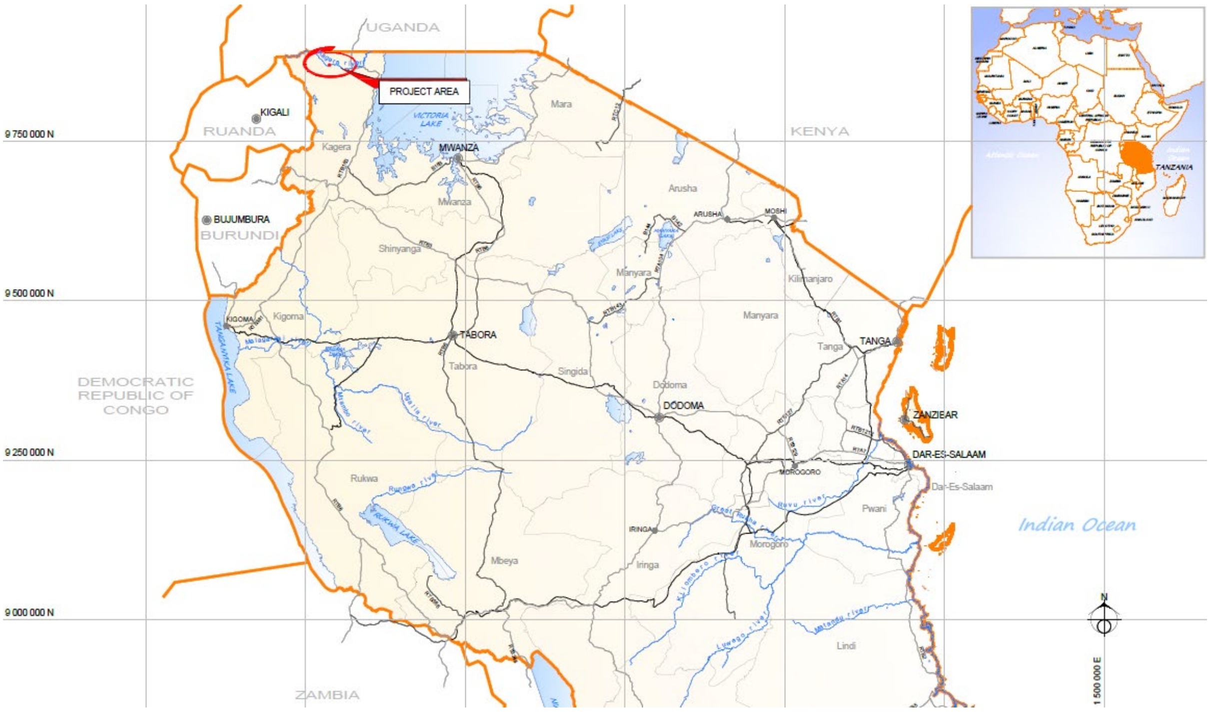
In an effort to implement this project, the Government of Tanzania is seeking funding from the AfDB and Agence Française de Développement (AFD). Both institutions have expressed interest in financing the proposed Kakono HPP and the associated transmission line project.

The Kakono HPP in Tanzania is in the design phase, and financing decisions by the AfDB and other multilateral and bilateral financial institutions are still pending.

The planned Kakono HPP is comprised of two key infrastructure components: a hydropower plant with an installed capacity of 87.8 MW and the construction of a transmission line from the plant to the Kyaka substation. The Kakono HPP would be characterized by a gravity dam in the Kagera riverbed, a concrete face rockfill dam on the left and right abutments, and an outdoor powerhouse at the dam toe. The Kakono HPP is envisioned to operate as a run-of-the-river plant with a reservoir (1,500 ha) for daily regulation of the river flows. The construction and operation of the plant also require the upgrade and building of access roads.

The SAVi assessment focused on the project location of the planned Kakono HPP in northwestern Tanzania, as indicated in Figure 1. The Kakono HPP would use the Kagera River, which runs eastward through the northern part of the Kagera region and enters Uganda shortly before flowing into Lake Victoria. The project area is about 200 km upstream from the lake. The catchment area of the Kagera River is more than 46,000 km², covering large parts of Burundi and Rwanda, as well as parts of Tanzania and Uganda.

Figure 1. Location of the Kakono HPP



Source: Studio Pietrangeli Consulting Engineers, 2019b.

In this SAVi assessment, asset performance of the Kakono HPP is evaluated by (1) integrating environmental and socio-economic costs and co-benefits (externalities) into the assessment, (2) evaluating the performance impacts of different climate scenarios, and (3) comparing it to the performance of two hypothetical energy generation alternatives. Technical parameters of both alternatives were defined to make them viable electricity supply alternatives for the Kakono HPP, which is to say, the electricity generation capacity of each alternative is the same under baseline conditions (524,000 MWh/year), and each alternative is capable of supplying baseload electricity, the anticipated primary use of the HPP. The two alternatives are:

1) A utility-scale diesel power plant: This technology alternative represents the status quo in Tanzania and a scenario of inaction concerning the Paris Agreement.

2) An energy portfolio solution consisting of a gas power plant (providing 70% of the electricity generation capacity) and a utility-scale solar photovoltaic (PV) system (providing 30% of the electricity generation capacity): This portfolio solution presents an energy transition scenario comprised of an alternative for fostering renewable energy use (solar PV) while addressing the intermittency issue and limited base-load potential of solar power by installing a complementary gas-fired power plant.

The following chapter provides details about the technical parameters of each energy generation alternative as well as the scope of this SAVi assessment.

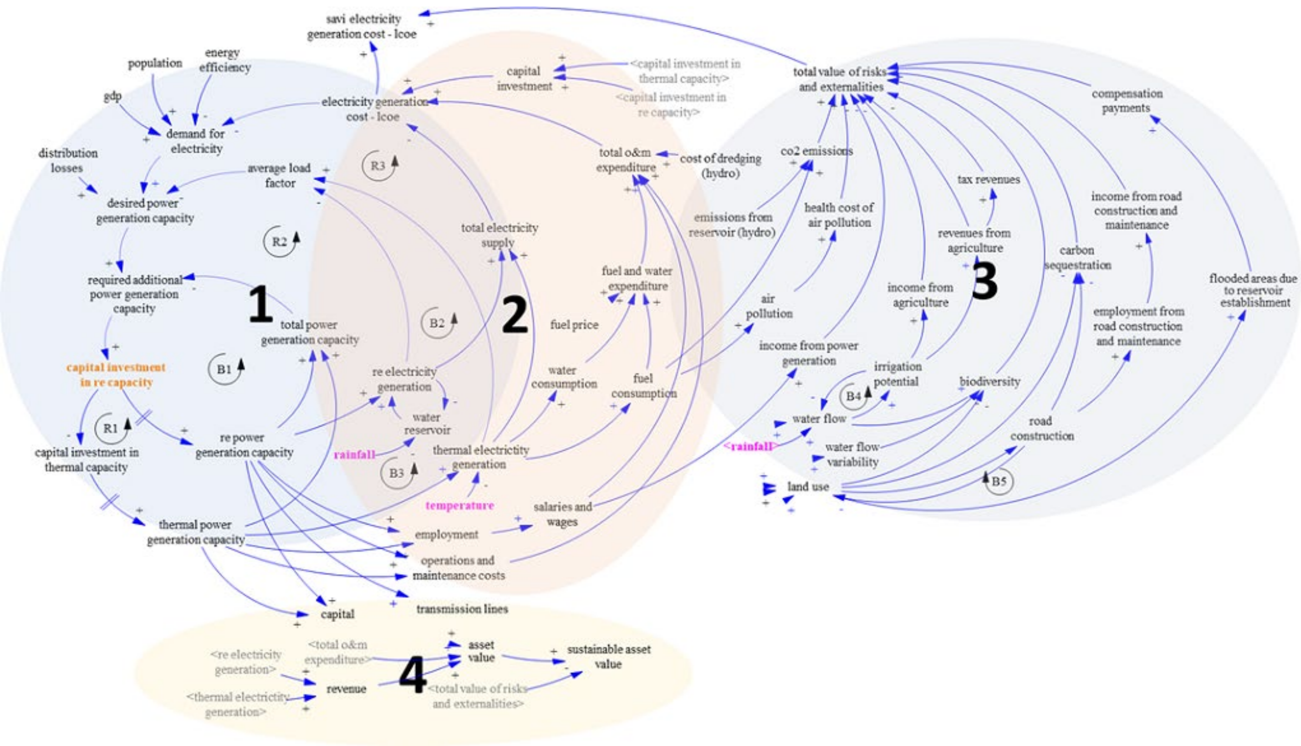
3 SAVi Modelling Approach, Assessment Scope, and Parameters

Figure 2 shows a generalized systems diagram presenting the systemic approach that this SAVi assessment uses to estimate 1) the societal contribution of electricity generation from hydropower, diesel power, gas power, and solar PV, and 2) how elements of the system affect the infrastructure assets under assessment. The diagram shows how the asset is embedded in the system (energy, in this case) and how it affects a variety of social, economic, and environmental indicators.

The system dynamics and project finance models used for this SAVi assessment (described in more detail in Appendix B) include indicators of capacity and generation, employment, and fuel consumption. Thus, conventional cost positions, revenues from power generation, and negative and positive externalities caused by the assets are estimated (see definitions for all estimated elements below).

Externalities affect a third party in the system that did not play a role in determining the effects of the energy-generating assets. Externalities are displayed on the right side in the systems diagram in Figure 2. Further, climate change impacts that will likely materialize as costs or reduced revenues for an energy asset are estimated. The climate-related variable considered for the assessment of climate change impacts on electricity generation capacity in this SAVi assessment is precipitation (which affects water flow and water availability in the Kagera River) and air temperature (which affects the efficiency of thermal power plants and solar panels, and loss of power during distribution—i.e., reduced efficiency of transmission lines). Future variations of precipitation and air temperature are externally defined (i.e., obtained from global circulation models, via the Copernicus Climate Data Store) and affect the load factor and efficiency of the different electricity generation technologies, which in turn affect both power generation costs and revenues.

Figure 2. Conceptual representation in a causal loop diagram of the systemic analysis performed with (i) a system dynamics and (ii) a project finance model



3.1 Costs, Revenues, and Externalities

The SAVi assessment includes the calculation and valuation of cost positions, revenue streams, selected externalities, and cost/revenue implications due to climate change impacts (variations of precipitation rates and air temperatures) for four energy generation technologies clustered into three energy generation assets: HPP, diesel power plant, and a combined portfolio consisting of a gas power plant and solar PV system.

While most parameters are calculated for all technologies, as applicable, the focus of this SAVi assessment is laid on the Kakono HPP. Available project-specific data for the HPP stem from various feasibility, appraisal, and impact studies. On the other hand, the other three technologies are hypothetical energy generation alternatives, which is why corresponding technological, cost, and externality assumptions are deduced from international data sources and scientific literature. Quantitative information per technology, data sources, assumptions, and respective references are presented in Appendix A. The main technical parameters and assumptions for the various energy generation alternatives are presented in Table 1.

Table 1. Main technical parameters and assumptions

Parameter	Unit	Kakono HPP	Diesel comparator	Portfolio comparator	
				Solar PV (30%)	Gas (70%)
Installed capacity *	MW	87.8	142.5	85.5	104.7
Load factor	%	68.1	42	21	40
Electricity generation (annual)	MWh/Year	524,000	524,000	524,000	
Transmission losses	%	17.7			
Construction time	Months	52	24	24	24
Operation time	Years	50	30	25	40
Price of electricity	USD/MWh	110			
Discount rate (based on weighted average cost of capital)	%	5.3			

** The scenarios have been formulated to ensure full comparability of the technologies considered. Specifically, we assume that all technologies will generate the same amount of electricity, so that revenues are comparable. It results that, given that different technologies have different load (or use) factor, the amount of power generation capacity required to produce the stated amount of electricity will be higher for those technologies characterized by lower load/use factor (e.g. solar power when compared to hydropower).*

This section provides brief explanations of the main performance parameters assessed in this SAVi assessment to ease the reading of quantitative results presented in several tables in Section 4.

The SAVi assessment includes the following conventional cost positions, revenues, and externalities for the assessed energy generation assets. Items 1–10 are also indicated with numbers in the cost–benefit analysis (CBA) and levelized cost of electricity (LCOE) tables to ease the finding of definitions presented below.

Cost positions

1. **Capital cost**
   1.1. Cost of capacity: includes expenditure for installing the energy generation capacity, such as the cost of planning, technical equipment, road construction, logistics, and labour. For the Kakono HPP, the capital cost also includes the cost for the transmission lines.
   1.2. Cost of fish path: includes estimated expenditures for installing a fish migratory solution to mitigate the potentially adverse impacts of the HPP on fish populations.

1.3. Replacement investment: cost to replace outdated technical equipment to extend the lifetime of the energy asset. This considers reinvestment in technologies that have a shorter lifetime than the proposed hydropower solution, to ensure comparability of investment throughout the lifetime of the hydropower dam.

2. **Operational and maintenance (O&M) cost**

   2.1. Regular annual O&M costs, including the cost of technical equipment and human resources.

   2.2. Fuel expenditure: applicable to the two fossil fuel-powered energy assets, the diesel power plant and gas power plant for power generation. The study does not consider the energy used to transport fossil fuels within the country to reach the power plant; it only considers direct use for power generation in thermal plants.

3. **Cost of sediment removal:** costs for the physical removal of sediment volumes (every 10 years) that accumulate in the hydropower reservoir over time. Only applicable for the Kakono HPP in order to keep the plant at full operational capacity.

4. **Cost of financing:** includes interest rate payments and financing fees charged by providers of debt and capital for the different life-cycle phases of the energy asset.

Revenues

5. **Electricity sales:** Revenues of each asset are based on electricity sold over the lifetime of the asset. Electricity price assumptions refer to the offtake electricity price (USD/MWh) that the producer receives in Tanzania (without adding further taxes and fees). The assumed price for the electricity generated and sold (generation minus 17.74% transmission and distribution losses according to National Audit Office Tanzania [2020]) received by all technologies is listed in Table 1 and was proposed in the Basic Design Report (Studio Pietrangeli Consulting Engineers, 2019a).

Externalities

6. **Discretionary spending from employment for energy capacity:** This positive externality refers to the amount of additional discretionary spending that flows into the Tanzanian economy from generated income by employing people for constructing and operating the energy asset. Discretionary spending describes expenses for non-essential consumer goods and services. The estimated additional spending by people employed for the construction and operation of each energy asset, compared to spending opportunities for unemployed people, is considered a benefit (positive externality) of the asset. It needs to be noted that this assessment does not differentiate between whether the employment generation and respective spending occurs in local communities or the country more broadly.

7. **Discretionary spending from employment for road construction:** This positive externality refers to the amount of additional discretionary spending that flows into the Tanzanian economy from generated income by employing people to construct and maintain the roads necessary for building and operating the energy asset. The spending explanations above also apply here.
8. **Social cost of carbon (SCC):** Various life-cycle phases of the different energy assets cause carbon emissions, which are considered a negative externality. The SCC is a top-down assessment of the economic cost of an additional tonne of carbon dioxide emissions or its equivalent through the carbon cycle. Several sources of carbon emissions are distinguished and estimated in this SAVi assessment:
    8.1. **SCC from commissioning and decommissioning of energy capacity**: emissions from material and energy use for establishing energy capacity. This component captures greenhouse gases (GHGs) that emerge from the use of materials (e.g., cement, steel) and energy during the commissioning and decommissioning phases of the power plant (based on Turconi et al., 2013).

    8.2. **SCC from land clearing for built infrastructure**: carbon emissions released during land clearing. This was only calculated for the Kakono HPP for the construction of the dam, required roads, and power transmission lines. The potential conversion of land cover for constructing the other energy alternatives is unknown. Locations were not determined; the footprint of thermal generation is comparatively smaller and plants can be located in already developed areas; solar panels could be roof mounted and elevated from the ground. Therefore, the SCC from land clearing for a diesel power plant, a gas-fired power plant, and a utility-scale solar PV system were not estimated.

    8.3. **SCC from biomass loss in flooded area (reservoir)**: carbon sequestration lost over the lifetime of the energy asset due to lost vegetation cover as a result of the inundation of the valley upstream of the dam. This was only calculated for the Kakono HPP, as the other technologies do not require the creation of an artificial reservoir.

    8.4. **SCC from reservoirs**: biological decomposition processes in reservoirs (as well as lakes and rivers) result in methane and carbon emissions. This only applies to the Kakono HPP.

    8.5. **SCC from fossil fuel use:** the combustion of fossil fuels causes carbon emissions. This only applies to the two fossil fuel-powered energy assets, the diesel power plant and the gas power plant.
9. **Habitat quality loss:** Land cover change, road construction, and the installation of transmission lines are threats to biodiversity, as they alter habitat. QGIS and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) model were used to generate a map of habitat quality before and after the construction of the dam (see Section 3.2). Results showed a reduction in habitat quality in the study area due to the construction and operation of the dam. We then calculated the forest area in which habitat quality would decline (e.g., the forest surrounding transmission lines) and multiplied that area by the average value of biodiversity per

hectare, as obtained from Turpie (2000). This negative externality was only estimated for the Kakono HPP because the location of the other energy asset alternatives is unknown.

10. **Foregone raw materials:** The area that is flooded for the creation of the reservoir is not accessible for the extraction of wood, sand, and other raw materials. As in the case of habitat quality loss, we estimate the currently forested area that would be flooded once the dam is constructed and then multiply these hectares by the monetary value of natural resources that can be extracted from the land cover available in the area. Given the limited number of people in the area and the type of land cover, the value used is small, in the range of USD 0.7/ha/year (Turpie 2000).

3.2 The Kakono HPP: Spatial analysis results of environmental externalities

The SAVi approach makes use of mixed modelling methods. Normally, a system dynamics model and a project finance model are used, where the former includes social, economic, and environmental indicators, and the latter performs a financial analysis for the project. On the other hand, projects where ecosystems play an important role—either as enablers of economic activity or systems being impacted by the construction and the use of built assets—require a more in-depth assessment of spatial dynamics related to the project. The system dynamics model is not spatially explicit and hence cannot estimate location-specific outcomes of the construction of the asset. However, location is critical for the estimation of ecosystem services as well as for their economic valuation. For this reason, the InVEST suite of models and QGIS were used in this assessment to complement the system dynamics and project finance models. Specifically, these spatially explicit models have been used to quantify the consequences of land-use changes for habitat quality and provide more accurate inputs to the calibration of ecosystem services in the system dynamics model. The integration of spatially explicit inputs for the estimation and economic valuation of ecosystem services into the system dynamics model supplements the spatial component of the analysis. It allows for the quantification of land-use-related impacts on ecosystem services provided.

An ecosystem services map simulation has been performed for the Kakono HPP to estimate material environmental externalities associated with this infrastructure project. The InVEST Software V.3.8.0[1] was used for this simulation. The input spatial data for the InVEST model have been prepared by utilizing QGIS-OSGeoW-3.4.2-1.

Two different scenarios have been considered to run different InVEST models in order to estimate the environmental externalities caused by the Kakono HPP:

- Business-as-usual (BAU) scenario: the land use and land cover (LULC) map used in InVEST does not consider the impacts created by the development of the Kakono HPP.

[1] https://naturalcapitalproject.stanford.edu/invest/

- DAM scenario: the LULC map includes a reservoir, a dam, a new built-up area, and, in the case of the Habitat Quality model, new roads and the installation of a transmission line.

Details about the data used and assumptions made to calculate the carbon storage variations and habitat quality variations for the two scenarios are provided in Appendix D.

3.2.1 Carbon Storage

Figures 3 and 4 show the amount of carbon stored in Megagrams (Mg) in the BAU and DAM scenarios. They are a sum of all the carbon pools of the various land-use types found in the study area, including the carbon above ground, the carbon below ground, carbon stored in organic matter, and the carbon stored in soil.

Figure 3. Carbon stored in the BAU scenario (the Kakono HPP is not built)

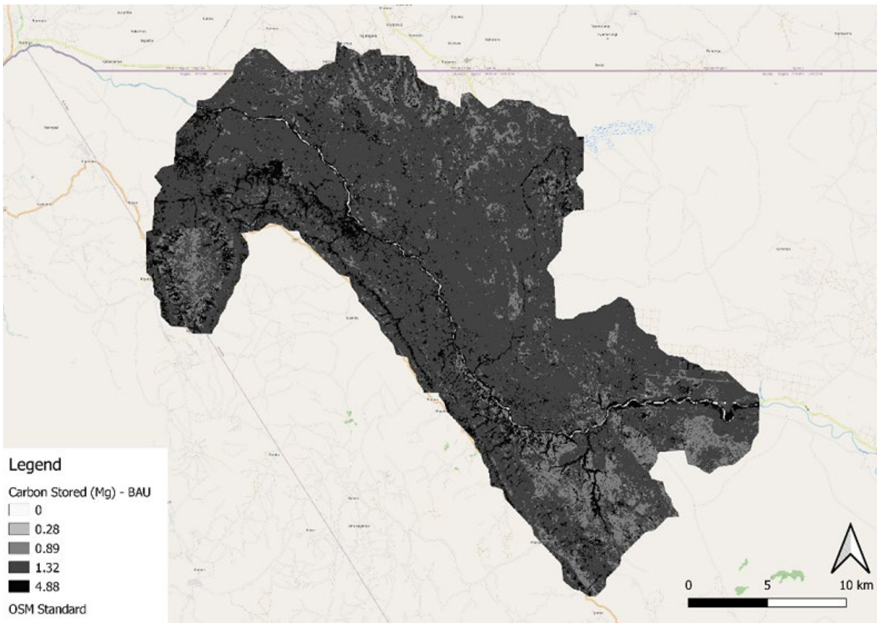
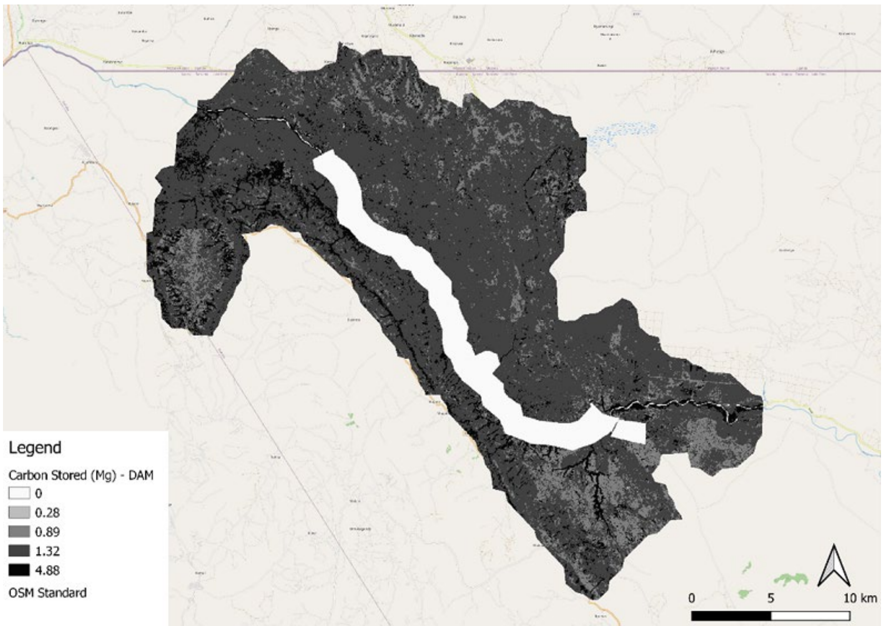


Figure 4. Carbon stored in the DAM scenario (the Kakono HPP is built)



In the BAU scenario, the landscape absorbs approximately 2.26 million Mt of carbon. In the DAM scenario, the study area would absorb 98,383 Mt of carbon less than the BAU scenario. In other words, the total carbon storage in the area affected by the construction of the Kakono HPP would decrease by more than 4%. On the other hand, this decline should be assessed in relation to the emissions that the hydropower project avoids when compared to alternative options for power generation, e.g. fossil fuel based plants.

3.2.2 Habitat Quality

Figures 3 and 4 show the relative level of habitat quality in the study area of the two scenarios. Higher numbers indicate better habitat quality vis-à-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat score values range from 0 to 1, where 1 indicates the highest habitat suitability.

Figure 5. BAU scenario – habitat quality score without the Kakono HPP

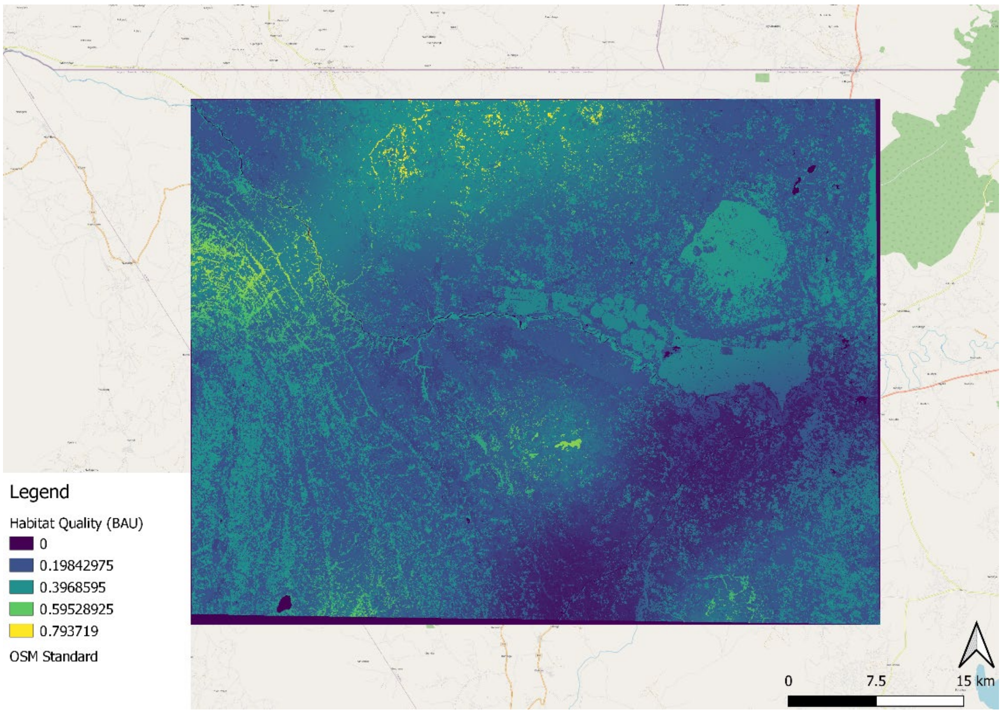
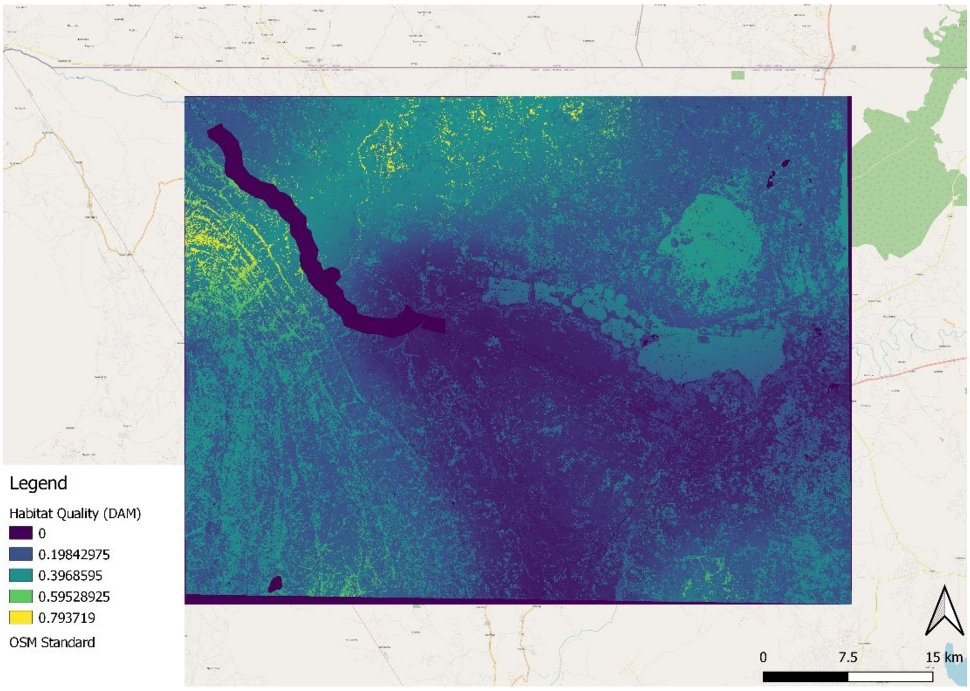


Figure 6. DAM scenario – habitat quality score when the HPP is built



Estimations yield a mean habitat quality in the study area for the BAU scenario of 0.26 and for the DAM scenario of 0.23. These results indicate that the value of habitat quality is low in both cases. Nevertheless, in the DAM scenario, the mean of the habitat quality would decrease by more than 10%, indicating that the development of the HPP would negatively impact the surrounding natural environments. The per cent reduction in habitat quality, together with the area affected and the average value of biodiversity per hectare (Turpie, 2000), is used for the economic valuation of habitat quality, as described above.

3.2.3 Foregone Raw Materials

The forecasted land-use changes obtained from the spatial assessment are used for the assessment of raw material losses. The loss of tropical forest and shrublands, obtained from the InVEST results, is used to estimate the foregone value of raw materials. This is based on the assumption that raw materials are sourced from this land-use class. The conversion of this land class hence leads to a reduction in available ecosystem services (provisioning services) as this land is used for different purposes. The average value of raw materials was obtained from Turpie (2000), and the approach used for the estimation is described above.

It should be noted that the InVEST analysis also investigated whether water flow and sediment retention in the Kagera River would be altered in the DAM scenario, that is, when the HPP is built and operated over time. The InVEST results show very small, irrelevant changes, which is why those factors were not defined as material externalities of the HPP and hence not further considered in the SAVi assessment. Water flow and sediment retention results are presented in Appendix D.

3.3 Climate Change Risk Scenarios for the Energy Generation Assets

A key endeavour of this SAVi assessment is to quantify the impact of physical climate change risks on the performance of the HPP and alternative energy generation assets. This section outlines the climate change parameters analyzed as well as the climate models and the scenarios applied to this assessment.

Data Sources

For this SAVi assessment, regional as well as location-specific precipitation and air temperature data and projections for the Kagera catchment area were sourced from the Copernicus Climate Data Store.[2] For both, historical data (from 2000) and future projections (until 2100) were analyzed. The historical and present-day data are sourced from the Copernicus ERA5 database and comprise mean monthly precipitation and air temperature data. The forecasts use CMIP5 data on mean monthly precipitation flux (more specifically, median projections were used) (C3S, 2017) and mean monthly air temperature. The results are bias-corrected for each month of the year. For this SAVi assessment, results were obtained from an ensemble of nine climate models to determine four climate scenarios associated with common Representative Concentration Pathways (RCPs).[3]

- RCP 4.5: This is defined as the BAU climate scenario for this SAVi assessment and often serves in the results section (Section 4) to compare the performance of the different energy generation assets. The RCP 4.5 scenario assumes international climate action, implying that carbon emissions peak by 2040.
- RCP 2.6: The RCP 2.6 scenario assumes strong international climate action, including negative emissions (i.e., additional carbon sequestration). In this climate scenario, future impacts of GHG emissions on temperature and precipitation are more contained compared to the RCP 4.5 scenario.
- RCP 6.0: Climate projections of the RCP 6.0 scenario assume some climate mitigation actions—however, fewer ambitions than in the RCP4.5 scenario. The RCP 6.0 scenario could be referred to as the middle ground between the RCP 4.5 and the RCP 8.5 scenarios in terms of future impacts of GHGs on precipitation and temperature.
- RCP 8.5: This is a climate scenario that assumes that fossil fuel use and emission-intensive energy generation continue to grow throughout the 21st century, according to the historical trajectory. The RCP 8.5 scenario is referred to as the BAU scenario of climate models, assuming no climate action is taken by governments.

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[2] The calculated climate change impacts in this SAVi assessment build on modified C3S (2020), making use on an ensemble of model forecasts from various global circulation models. These same models are used in IPCC assessments. Neither the European Commission nor the European Centre for Medium-Range Weather Forecasts is responsible for any use that may be made of the Copernicus information or data it contains.

[3] Representative Concentration Pathways (RCPs) describe four possible pathways of GHG emissions and atmospheric concentrations, air pollutant emissions and land use for the 21st century. These four RCPs serve as input for various climate model simulations and are adopted by the Intergovernmental Panel on Climate Change (IPCC).

The abovementioned climate scenarios are used to estimate the impacts of climate change variables on the performance of the energy assets considered. The precipitation parameters are proxies for river discharge changes of the Kagera River. Precipitation rates and flux influence hydropower generation potential by affecting the volume of water in the river system and hence water volumes arriving in the hydropower reservoirs. If precipitation decreases, water volume in the river may decrease and adversely affect the ability of HPPs to operate at full capacity. Therefore, electricity generation potential may be reduced, which has implications for the revenue streams of the HPP. We have analyzed both the precipitation trends for the location of the hydropower dam as well as for the area upstream of the dam, first to the north and then southwest. Precipitation is higher and more regular at the source of the Kagera River located in Lake Rweru in Rwanda. Consequently, lake Rweru is characterized by a regular supply of water, being at the edges of western watersheds of the country. The regular and abundant rainfall in this area also feeds Lake Sake and Lake Mugesera that, together with the Lake Rweru, also enjoy water inflows from the higher rainfall and higher altitudes of the Western Province of the country. Water flow data for the Kagera River confirm a stable flow throughout the year (Lake Victoria Basin Water Board, 2020), also guaranteed by the presence of wetlands between lakes Rweru and Kakono. The Kimisi Game Reserve, Akagera National Park and the Ibanda Game Reserve are all crossed by the Kagera River, which is therefore not heavily impacted by land cover change and water abstraction.

The air temperature parameters affect the efficiency of thermal power generation, the generation potential of solar capacity, and the degree of transmission losses. As temperature increases, the efficiency of thermal and solar generation declines. In the case of thermal (diesel and gas-based) generation, the decline in efficiency leads to higher fuel use (and hence more emissions and higher expenditures). For solar PV, the impacts of temperature directly affect the load factor and reduce generation. In addition to the efficiency impacts, higher temperatures lead to increased transmission losses, reducing the amount of electricity that can be sold on the market, which reduces revenues. The SAVi model assumes that transmission losses affect all generators equally. The described impacts are temperature-dependent and consequently vary depending on the forecasted temperature in the respective climate scenario.

Figure 7 illustrates the forecasted trajectory of transmission and distribution losses for the four climate scenarios, considering 17.74% of transmission and distribution losses as the baseline (National Audit Office Tanzania, 2020). It highlights the difference in climate impacts on transmission and distribution losses in the RCP 2.6 scenario (blue line), the RCP 6.0 scenario (yellow line) and the RCP 8.5 scenario (red line) compared to the BAU scenario (grey line, RCP 4.5). In the RCP 2.6 scenario, temperature increases less compared to the RCP 4.5 scenario, implying that transmission losses are comparatively lower over time, which increases the amount of electricity reaching the market and its revenues. Higher temperatures in the RCP 8.5 scenario (compared to the RCP 4.5 scenario) cause transmission losses to increase, leading to reduced electricity sales and foregone revenues compared to the BAU scenario.

Figure 7. Transmission and distribution losses under different climate scenarios

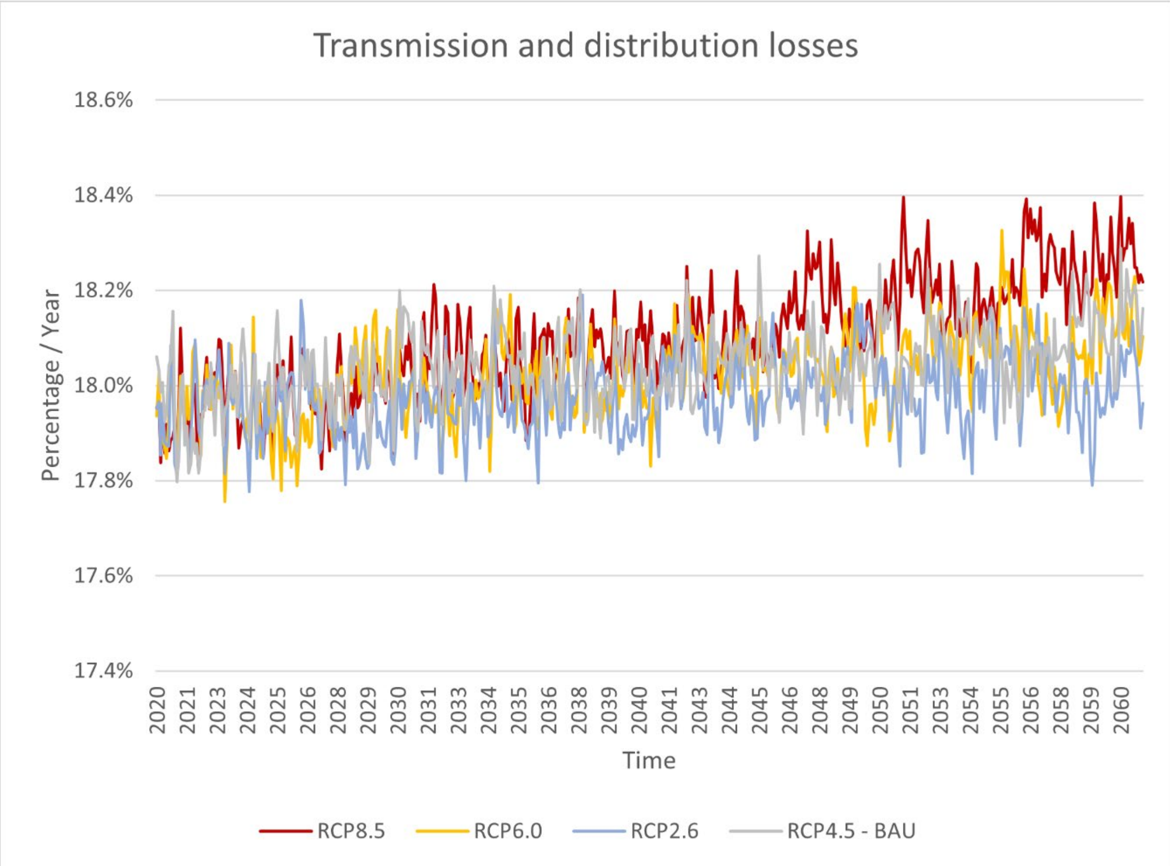
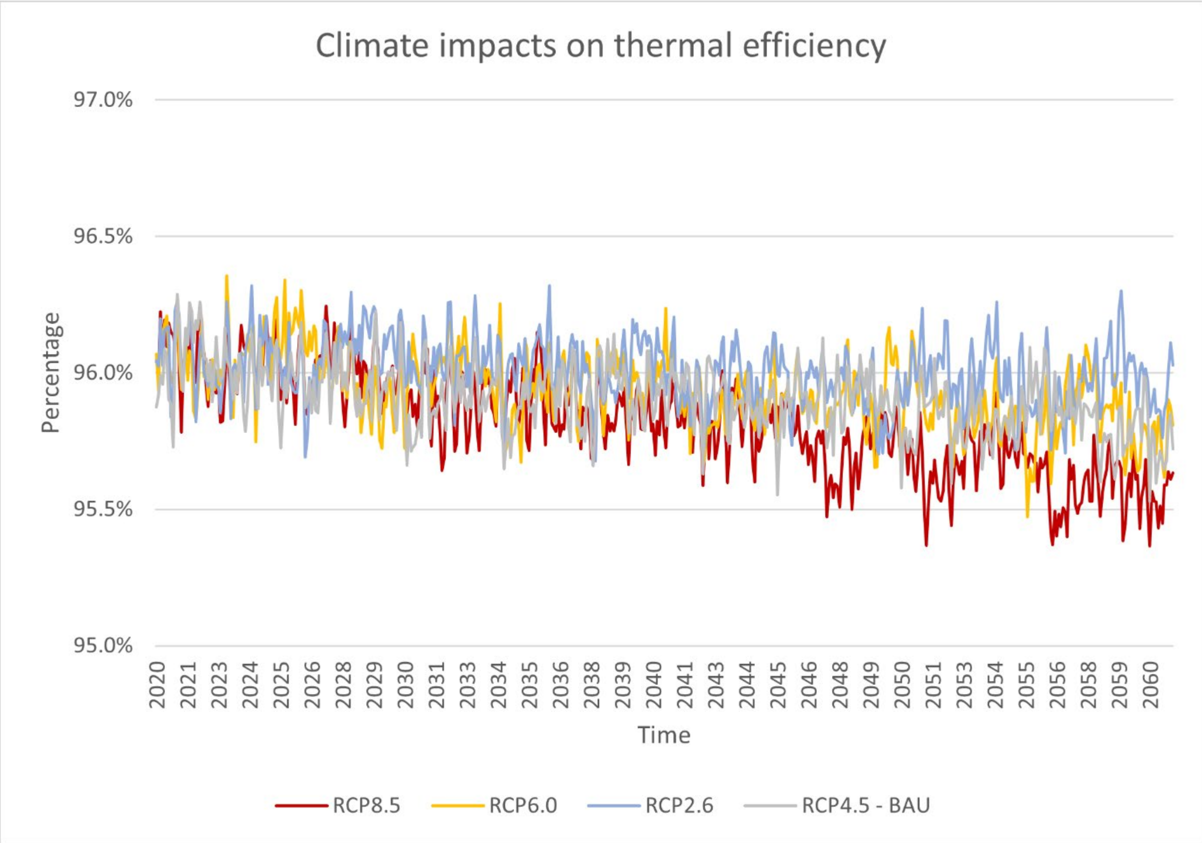


Figure 8 presents the forecasted climate impacts on the efficiency of thermal power generation capacity (e.g., diesel and natural gas). In the SAVi assessment, it is assumed that reductions in thermal efficiency lead to higher fuel use to maintain the same level of generation. The lower the value of this variable, the more fuel is required to maintain the desired generation. The results illustrate that the impacts of temperature on thermal generation efficiency are the highest in the RCP 8.5 scenario (red line) and the lowest in the RCP 2.6 scenario (blue line). Temperature-induced changes in thermal efficiency and related higher fuel use lead to respective changes in the fuel expenditure for thermal generators. In doing this, the use of climate data allows for estimating the financial implications of climate change (e.g., changes in temperature) for thermal generators.

Figure 8. Thermal efficiency variations under different climate scenarios



4 Results of the SAVi Assessment

This chapter presents the results of the integrated CBA, the LCOE, and the financial analysis conducted for the three assessed energy assets: the HPP, a utility-scale diesel power plant, and an energy portfolio solution consisting of a gas power plant and a utility-scale solar PV system. These three replaceable alternatives have been defined as serving the same energy supply purpose in Tanzania's electricity grid. Assumptions for the technical characteristics and capital requirements of the utility-scale diesel power plant and the energy portfolio solution are adjusted so that each of the installed alternatives could generate the same annual amount of electricity as the HPP, which amounts to approximately 524 GWh per year. This allows for a more appropriate comparison between the three alternatives, even though the lifetime of each asset varies. The latter issue is addressed by the LCOE calculation, given that the unit cost of electricity generation is calculated.

The calculations of the CBA results and the LCOE are based on system dynamics modelling. The financial analysis (internal rate of return [IRR] and net present value [NPV] calculations) is based on project finance modelling and incorporates valued externalities as cost factors, informed by results from the system dynamics modelling.

4.1 CBA

This section presents the results of the calculated CBA. First, the HPP is compared to the utility-scale diesel power plant and the gas-solar PV energy portfolio. For this purpose, environmental, social, and economic externalities caused by each respective alternative are integrated into the comparative CBA. As locations for the hypothetical diesel power plant and the gas-solar PV energy portfolio have not been defined, only technology-specific externalities were considered for these two alternatives; for the Kakono HPP, some location-specific externalities were also assessed (see sections 3.1 and 3.2). Second, the performance impacts of climate change parameters on costs, externalities, and revenues of the three alternatives are presented under four different climate scenarios.

4.1.1 Results of the Comparative CBA

Figure 9 presents an overview of the CBA results of the three energy asset alternatives under a BAU climate scenario (RCP 4.5). All conventional cost positions, revenues, and externalities that occur over time are discounted by 5.3% to calculate the NPV of each asset. The SAVi net results account for the monetary value of externalities. In this summary figure, externalities are separated into socio-economic externalities—which are positive for all three energy generation alternatives given their employment creation effects—and environmental externalities. The latter are negative for all three energy generation alternatives, while there are significant differences in magnitude. Figure 9 highlights that the Kakono HPP attains the highest net benefits with USD 124 million. The gas-solar PV portfolio yields approximately half of these benefits, while the diesel power plant yields significant negative net results over its lifetime, amounting to negative USD 1.265 million.

Figure 9. Costs and benefits of different energy assets under a 4.5 RCP climate scenario (discount rate: 5.3%)

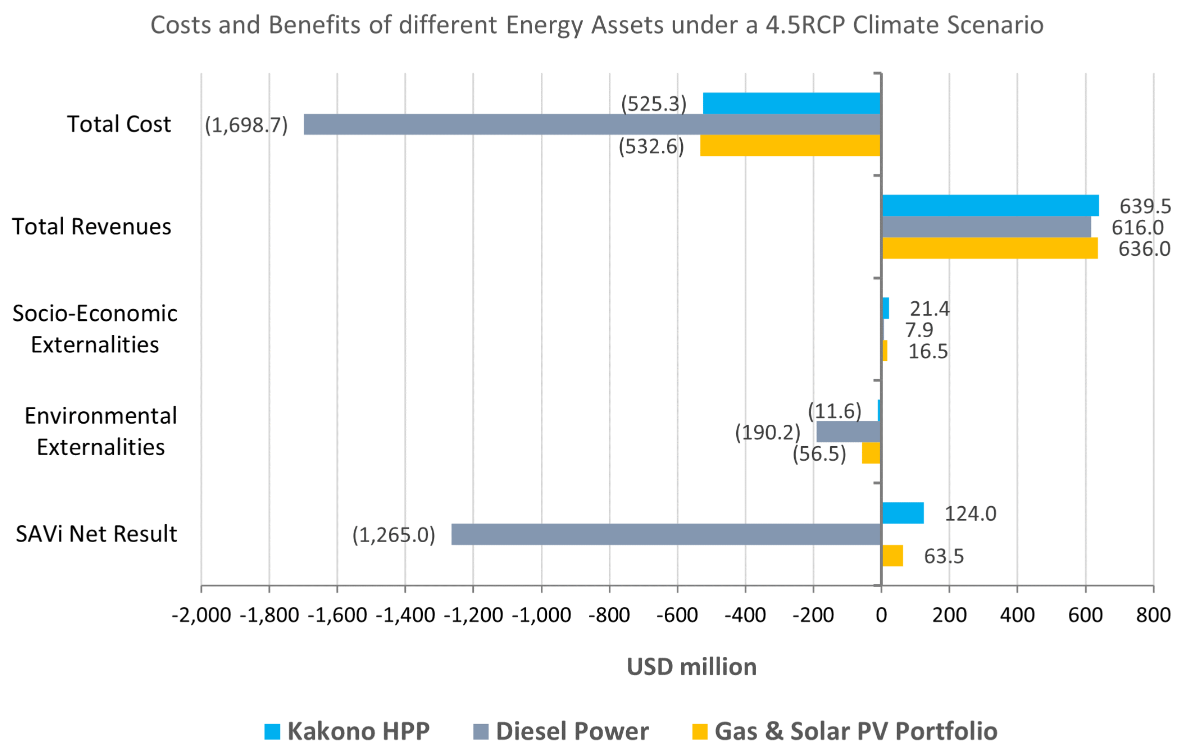


Table 2 presents the CBA results of the three energy asset alternatives in more detail. The Kakono HPP accounts for the highest capital cost of the three alternatives. Accordingly, it also accounts for the highest cost of financing. Given that the HPP is the only energy generation alternative without the need for fuel expenditures, it accounts for the lowest O&M costs. Revenue volumes are quite similar across the three alternatives despite the varying lifetimes. This is primarily caused by the effect of discounting future revenue streams. Revenue results would vary more among the alternatives when not using a discount factor—revenues would by far be the highest for the Kakono HPP due to the longest lifetime (see Table C1, Appendix C, for the undiscounted CBA results of the Kakono HPP).

The most significant negative externality across all energy alternatives is caused by their respective carbon emissions—carbon equivalent emissions were valued through the SCC approach. The highest emissions are caused by the diesel power plant, followed by the gas power plant (part of the solar PV and gas portfolio). The lowest emissions are caused by the Kakono HPP; however, it cannot be considered a zero-carbon energy asset. The largest emissions of the hydro asset are caused by carbon emissions related to the commissioning of the hydropower dam. Some carbon emissions are also associated with the operational phase of the HPP, including the direct carbon emissions from land clearing, the lost carbon sequestration due to destroyed biomass in the reservoir area, and carbon emissions caused by organic matter decomposition in the reservoir over the plant´s lifetime.

The Kakono HPP accounts for the highest job and income creation for energy capacity installation and operation across the three energy asset alternatives, which is why the associated positive externality "discretionary spending" is the highest. It overcompensates for the HPP's SCC, leading to an overall positive externality result. This is not the case for the other two energy generation alternatives.

Finally, Table 2 confirms that the Kakono HPP attains the highest positive net benefits when assessing the absolute cost and benefit figures over the lifetime of the asset. It is followed by the solar PV-gas energy portfolio, which yields slightly more than half of the net benefits compared to the Kakono HPP. The CBA table clarifies that the high negative SAVi net results of the diesel power plant are primarily caused by the high fuel expenditures and, to a lesser extent, by the caused SCC associated with the plant's fuel emissions.

Table 2. Comparative CBA for the BAU climate scenario RCP 4.5, discounted results (5.3%) in USD million

Cost and benefit categories (USD million)	**Kakono HPP**	**Diesel generation**	**Solar PV (30%) & gas (70%) portfolio**
Cost positions			
(1) Capital cost	264.1	83.5	111.0
(1.1) Cost of capacity	*257.7*	*83.5*	*111.0*
(1.2) Cost of fish passage	*5.6*	-	-
(1.3) Replacement investment	*0.8*	-	-
(2) Total O&M cost	34.1	1,551.9	324.0
(2.1) O&M cost	*34.1*	*27.9*	*41.0*
(2.2) Fuel expenditure	-	*1,524.1*	*282.9*
(3) Cost of sediment removal	0.1	-	-
(4) Cost of financing	226.9	63.3	97.7
Subtotal A: Total Cost	**525.3**	**1,698.7**	**532.6**
Revenues			
(5) Electricity sold	639.5	616.0	636.0
Subtotal B: Total Revenues	**639.5**	**616.0**	**636.0**

Subtotal C: Conventional Net Result (B-A)	**114.2**	**(1,082.7)**	**103.4**
Externalities			
(6) Discretionary spending: employment energy capacity	21.3	7.9	16.5
(7) Discretionary spending: employment roads	0.05	0.00	0.01
(8) Social cost of carbon (SCC)	(11.6)	(190.2)	(56.5)
(8.1) SCC from commissioning and decommissioning of energy capacity	*(7.3)*	*(3.2)*	*(3.4)*
(8.2) SCC from land clearing for built infrastructure	*(0.4)*	-	-
(8.3) SCC from biomass loss in inundated area	*(2.2)*	-	-
(8.4) SCC from reservoir GHG emissions	*(1.7)*	-	-
(8.5) SCC from fossil fuel use	-	*(187.0)*	*(53.1)*
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	(0.01)	-	-
(10) Foregone raw materials	(0.01)	-	-
Subtotal D: Value of Externalities	**9.8**	**(182.3)**	**(40.0)**
Subtotal E: SAVi Net Result (C+D)	**124.0**	**(1,265.0)**	**63.5**

4.1.2 Results of the CBA Under Different Climate Scenarios

For this SAVi assessment, regional as well as location-specific precipitation and air temperature data and projections for the Kagera catchment area were sourced from the Copernicus Climate Data Store. As introduced in Section 3.3, four climate scenarios were assessed for each of the three energy generation alternatives: RCP 4.5 (BAU), RCP 2.6, RCP 6.0, and RCP 8.5. This section summarizes the results for each energy generation alternative under the four climate scenarios. Tables that present detailed CBA results are included in Annex C.

Figure 10 presents the varying costs and benefits of the Kakono HPP under different climate scenarios. The variations are minimal, suggesting that irrespective of the climate scenario, the assessed climate parameters have hardly any impact on the performance of the hydro energy asset. Given the planned location of the Kakono HPP in the Kagera River, the asset can be considered climate resilient. A slight variation can be observed for the revenues from electricity sales because climate impacts affect distribution losses and hence the amount of electricity that can be sold. The adverse effect is the highest in the RCP 4.5 scenario. However, this negative climate impact rather concerns the transmission lines and not the HPP itself. Minimal variations across the climate scenarios can also be observed for the valued externalities of the HPP. This is due to varying GHG emissions from the hydropower reservoir during its lifetime operation. The highest emissions and hence the highest SCC from this externality occur in the RCP 8.5 scenario due to higher average air temperature, leading to higher water temperature in the reservoir and consequently higher decomposition rates.

Due to the small variations in revenues and externalities, the Kakono HPP would yield the highest net results under the RCP 6.5 scenario and the lowest net results in the RCP 4.5 scenario.

Figure 10. Costs and benefits of the Kakono HPP under different climate scenarios (discount rate: 5.3%)

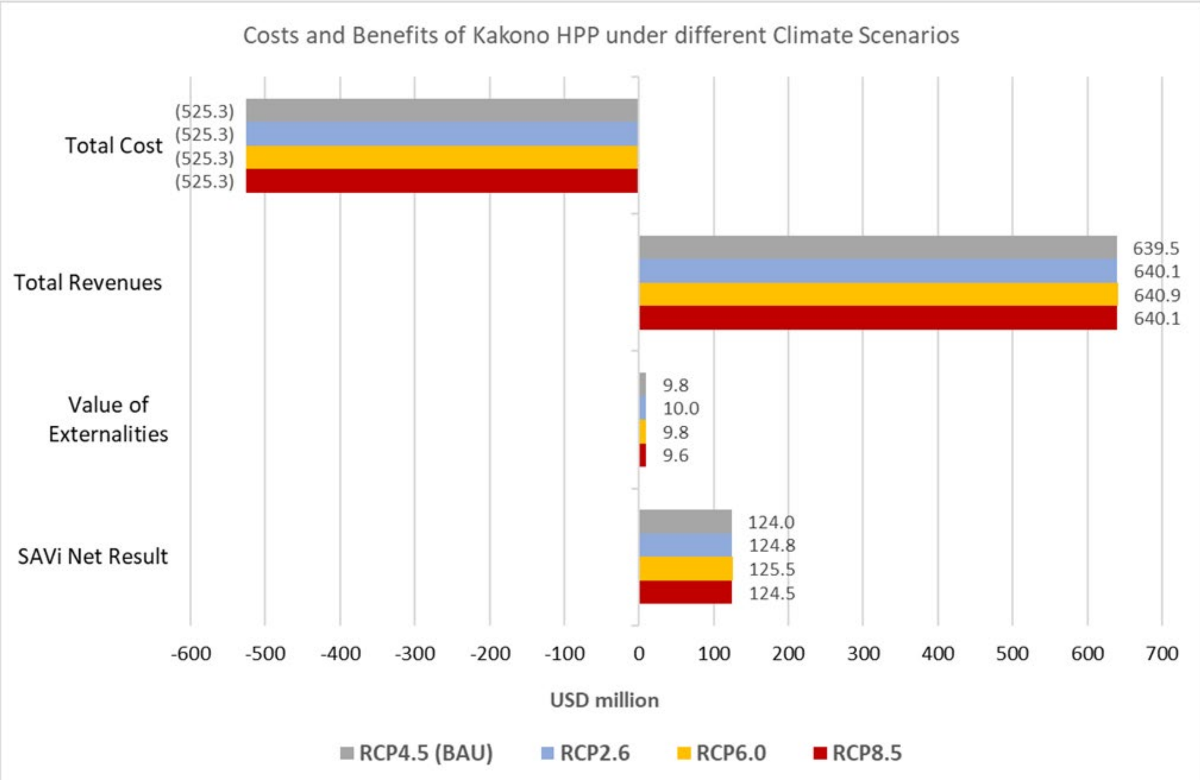


Figure 11 summarizes the costs and benefits of the utility-scale diesel power plant under the four climate scenarios. The strongest climate impacts can be observed for the costs of this power plant. Higher air temperatures decrease the thermal efficiency and hence require higher fuel consumption and corresponding expenditures to continue generating a stable amount of electricity. These cost increases are strongest in the RCP 4.5 and RCP 8.5 scenarios. Likewise, higher consumption of fuel implies higher carbon emissions and hence higher social cost of carbon, increasing the total value of negative externalities. Consequently, the RCP 4.5 and RCP 8.5 scenarios are associated with the highest negative externalities among the four climate scenarios. Finally, those two climate scenarios also yield the poorest performance results for the diesel power plant, while the SAVi net results under each climate scenario are negative.

Figure 11. Costs and benefits of a diesel power plant under different climate scenarios (discount rate: 5.3%)

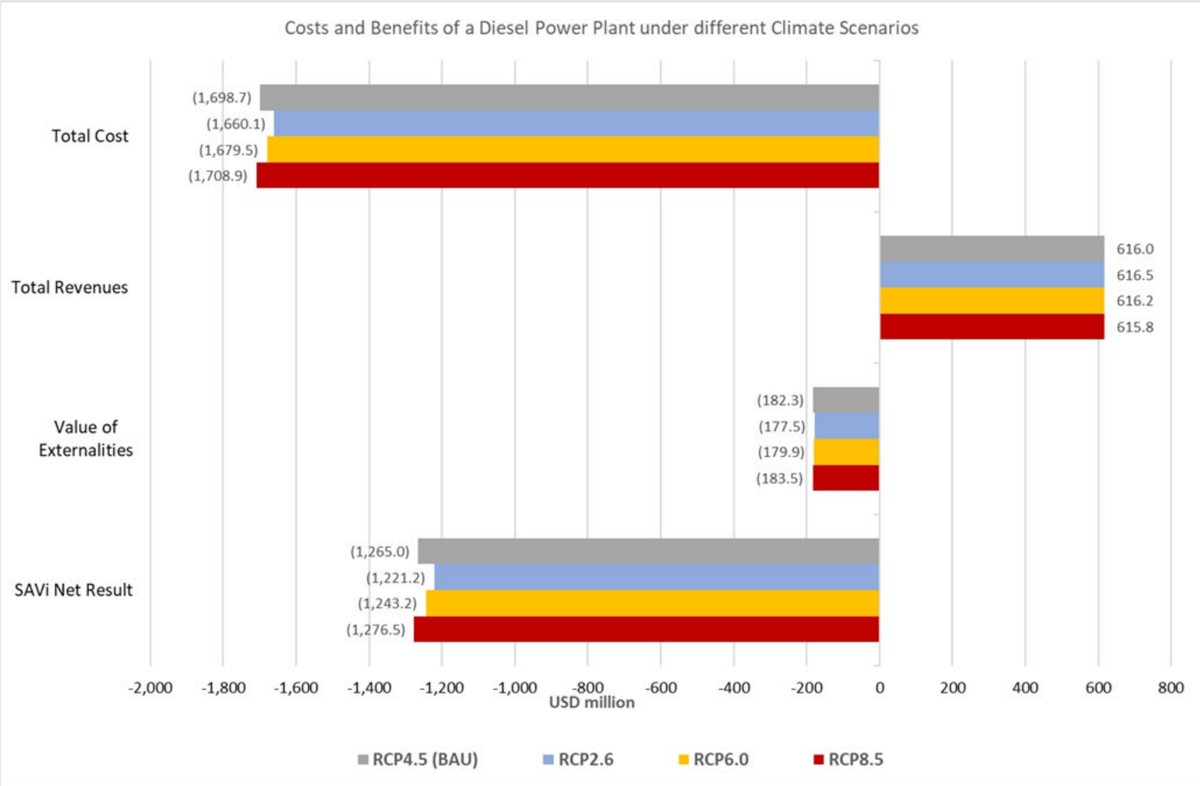
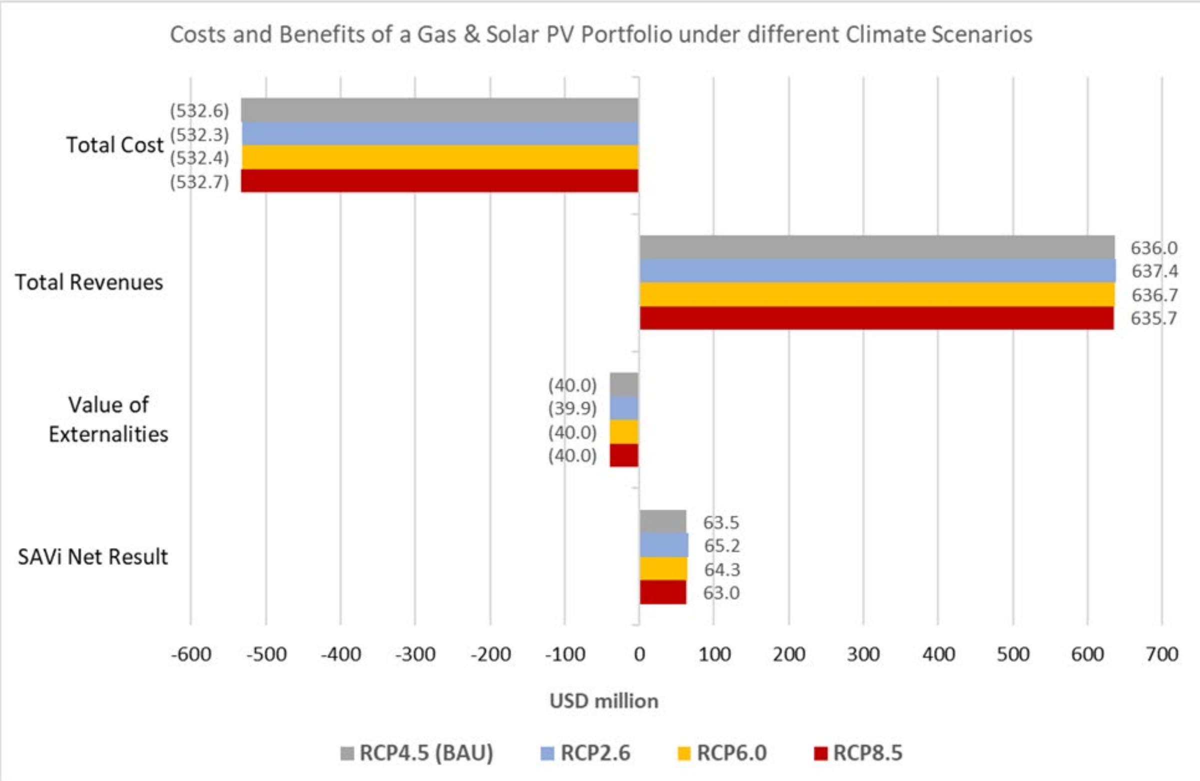


Figure 12 summarizes the costs and benefits of the energy generation portfolio under the four climate scenarios. The portfolio consists of a gas power plant (70% of energy generation) and a utility-scale solar PV system (30% of energy generation). The performance variations among the scenarios are minimal, suggesting that, irrespective of the climate scenario, the assessed climate parameters have hardly any impact on the performance of the portfolio. A climate impact concerns the thermal efficiency of the gas-fired power plant, which slightly decreases under rising air temperature conditions, as illustrated in the previous Section 3.3. Consequently, the increased fuel use leads to higher fuel expenditures, which slightly increases the total cost of the entire portfolio. The strongest impact, and hence cost increase, is forecasted for the RCP 8.5 scenario. Moreover, variations in transmission losses and thermal efficiency occur depending on the climate scenario used, affecting the amount of electricity sold from all energy assets considered. The strongest combined impact of efficiency reductions and transmission losses is observed in the RCP 8.5 scenario, causing the least amount of electricity to reach the markets and generating the lowest amount of revenues. The magnitude of monetized externalities is hardly affected by changes in climate variables. The main externality affected is the SCC, induced by changes in fuel use for gas-powered generation, which has consequences for the carbon footprint of generation.

The energy generation portfolio yields positive SAVi net results under each climate scenario. Corresponding to explanations above, the RCP 8.5 yields the lowest SAVi net results while the RCP 2.6 yields the highest positive SAVi net results. In either case, the positive net results of this portfolio remain lower than the net results of the Kakono HPP.

Figure 12. Costs and benefits of a gas and solar PV portfolio under different climate scenarios (discount rate: 5.3%)



In conclusion, the Kakono HPP is largely resilient to climate change. Its assessed cost and benefit components are hardly altered under different climate scenarios and varying projections for the climate parameters assessed. The highest climate impact can be observed for the revenues from electricity sales because air temperatures affect distribution losses and hence the amount of electricity that can be sold. However, this is not specific to hydropower: because it concerns electricity distribution infrastructure, it applies across centralized energy generation technologies.

Likewise, the energy generation portfolio can largely be considered climate resilient. This is not the case for the diesel power plant—it appears vulnerable to the impacts of climate change. Its performance suffers in particular in the RCP 2.6 climate scenario, given the 30-year time horizon that was assessed for this asset.

4.2 LCOE of the Three Energy Assets

This section presents the LCOE for the three energy assets. The environmental, social, and economic externalities caused by the HPP, the utility-scale diesel power plant and the gas and solar PV energy portfolio are integrated into the respective LCOE calculations. In a second step, the climate change impacts on the LCOE of both HPPs are also presented.

LCOE is a measure of the unit cost of electricity generation. It provides a full breakdown of cost components. LCOE is a useful indicator for comparing the unit cost of different technologies over their lifetimes (International Energy Agency & Nuclear Energy Agency, 2015). It is calculated by dividing the net present costs of generation over the lifetime of capacity by the net present generation. In other words, it is calculated by dividing cumulative discounted costs (i.e., USD) by cumulative discounted generation, typically indicated in MWh. See details for the LCOE calculation method in Appendix B.

Similar to the integrated CBA discussed in Section 4.1, externalities are integrated (as cost and benefit items) into the calculation of the LCOE in all tables of this section. The calculation of the integrated LCOE (SAVi LCOE) is done for the three energy generation alternatives to make the comparative analysis more comprehensive and disclose the "societal" cost of power generation by the respective asset type. Because the LCOE is a cost indicator, positive externalities are indicated with a minus sign (they reduce the LCOE) in the tables below, whereas negative externalities add to the LCOE.

4.2.1 Comparative LCOE Results

This section presents the LCOE results of the three energy generation alternatives under the BAU climate scenario (RCP 4.5). Table 3 presents the conventional LCOE (Subtotal A) as well as the SAVi LCOE (Subtotal C) that integrate the monetary value of environmental, social, and economic externalities caused by the respective assets. A discount rate of 5.3% is applied for the calculation of the LCOE. For the gas and solar PV energy portfolio, note that the weighted average results of the two technologies (gas-fired power plant and solar PV system) are presented. Compared to the CBA results for this portfolio, the results of the two technologies are not simply added up, but a weighted average factor is applied that takes into account the varying energy generation capacity and the varying lifetime of the two technologies (70/30). This is reasonable, as the LCOE does not present absolute monetary figures but figures per MWh.

The results indicate that the diesel power plant is by far the most expensive energy asset in both instances when considering the conventional LCOE as well as the SAVi LCOE. When comparing the conventional LCOE of the Kakono HPP and the gas and solar PV portfolio, the levelized costs of generating electricity are almost at par (71.36 USD/MWh vs. 74.17 USD/MWh).

A stronger discrepancy can be observed when comparing the SAVi LCOE of the two assets due to the effect of integrating externalities into the LCOE calculation. The total value of assessed externalities is positive for the Kakono HPP due to the employment generation and related discretionary spending effects. These overcompensate for the negative externalities, such as the SCC. As positive externalities are accounted for in the SAVi LCOE calculations (they reduce the LCOE), the integrated LCOE of the Kakono HPP is lower than the conventional LCOE (69.98 USD/MWh < 71.36 USD/MWh). Due to the high SCC caused by the fossil fuel use of the gas-fired power plant, the overall levelized value of externalities of the gas and solar PV energy portfolio is negative. Therefore, the SAVi LCOE of this energy portfolio is higher compared to the asset´s conventional LCOE (79.03 USD/MWh > 74.17 USD/MWh). The SAVi LCOE results highlight that electricity generated by the Kakono HPP is the most affordable solution for the Tanzanian people, followed by the gas and solar PV energy portfolio. Electricity generated by the diesel power plant cannot be considered cost competitive or beneficial from a societal point of view. It is almost four times as expensive compared to electricity from the Kakono HPP due to the high fuel expenditures for diesel and its significant negative externalities associated with high carbon emissions from fossil fuel use.

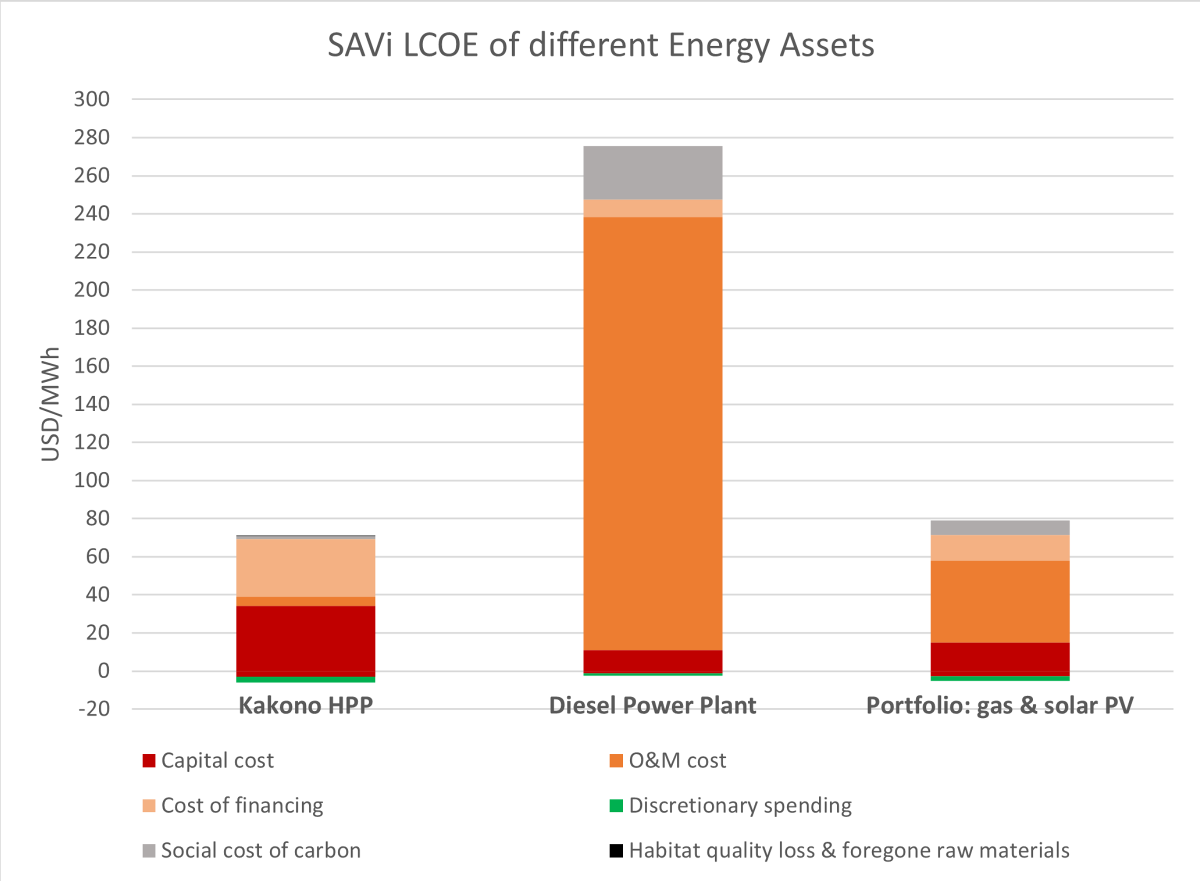
Table 3. Itemized LCOE (USD/MWh) by energy generation asset (discount rate 5.3%)

Cost positions (USD/MWh)	**Kakono HPP**	**Diesel generation**	**Solar PV (30%) and gas (70%) portfolio**
Conventional cost			
(1) Capital cost	37.12	12.22	17.52
(1.1) Cost of capacity	*36.21*	*12.22*	*17.52*
(1.2) Cost of fish passage	*0.79*	*0.00*	*0.00*
(1.3) Replacement investment	*0.11*	*0.00*	*0.00*
(2) Total O&M cost	4.81	227.18	43.19
(2.1) O&M cost	*4.81*	*4.08*	*5.84*
(2.2) Fuel expenditure	*0.00*	*223.10*	*37.35*
(3) Cost of sediment removal	0.02	0.00	0.00
(4) Cost of financing	30.32	9.37	13.45
Subtotal A: Conventional LCOE	**71.36**	**248.77**	**74.17**
Externalities[4]			
(6) Discretionary spending: employment energy capacity	-3.00	-1.16	-2.63
(7) Discretionary spending: employment roads	-0.01	0.00	0.00
(8) Social cost of carbon (SCC)	1.63	27.84	7.50
(8.1) SCC from commissioning and decommissioning of energy capacity	*1.02*	*0.47*	*0.49*
(8.2) SCC from land clearing for built infrastructure	*0.06*	*0.00*	*0.00*
(8.3) SCC from biomass loss in inundated area	*0.31*	*0.00*	*0.00*
(8.4) SCC from reservoir GHG emissions	*0.24*	*0.00*	*0.00*
(8.5) SCC from fossil fuel use	*0.00*	*27.37*	*7.01*
(9) Habitat quality loss from deforestation for road, reservoir, and transmission lines	0.002	0.000	0.000
(10) Foregone raw materials	0.001	0.000	0.000
Subtotal B: Value of Externalities	**-1.38**	**26.68**	**4.87**
Subtotal C: SAVi LCOE (A+B)	**69.98**	**275.45**	**79.03**

[4] As the LCOE is a cost indicator, positive externalities are indicated with a minus sign (they reduce the LCOE), whereas negative externalities are adding to the LCOE and are indicated as positive values.

Figure 13 summarizes the various cost components of the integrated SAVi LCOE of each assessed energy generation alternative. The vertical axis and the bar charts indicate values below zero (negative values) because the SAVi LCOE calculations integrate the monetary value of positive externalities. They reduce the total LCOE, and the bar charts account for that. The final (positive) LCOE value of each energy generation asset corresponds with the SAVi LCOE results indicated as Subtotal C in Table 3.

Figure 13. SAVi LCOE (USD/MWh) of the three energy generation assets (discount rate: 5.3%)



4.2.2 LCOE Results Under Different Climate Scenarios

This section summarizes the LCOE results of the three energy generation alternatives under various climate scenarios. As introduced in Section 3.3, four climate scenarios were considered in this SAVi assessment: RCP 4.5 (BAU), RCP 2.6, RCP 6.0, and RCP 8.5. Please refer to Tables C5, C6, and C7 in Appendix C for the detailed LCOE results of each energy generation asset under the various climate scenarios.

Figure 14 in this section presents the conventional LCOE as well as the SAVi LCOE of each energy generation alternative under the four climate scenarios. Explanations for cost positions and externalities included in the LCOE calculations correspond with Section 4.2.1.

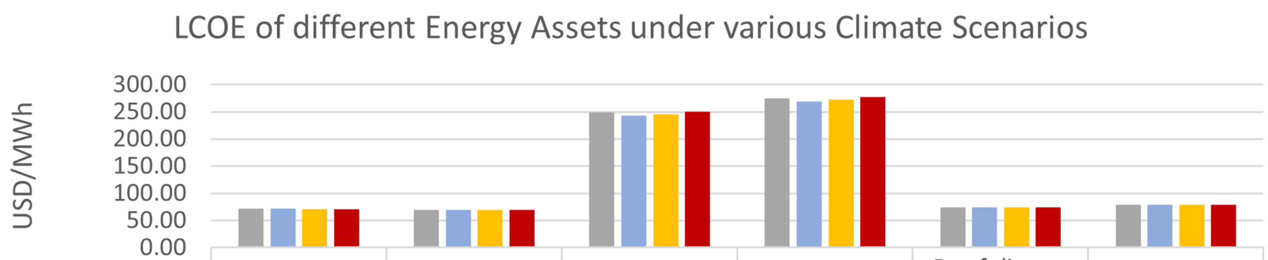
Figure 14 illustrates various conclusions that can be drawn about the impacts of climate parameters and varying climate projections.

First, the varying climate scenarios do not alter the performance ranking of the three energy generation alternatives: electricity generated by the Kakono HPP remains the most affordable, followed by the energy portfolio and the diesel power plant.

Second, the performance impact of varying climate projections on the LCOE of the Kakono HPP and the energy portfolio are insignificant. It means that variations of assessed climate parameters such as air temperature and precipitation across the four climate scenarios are not sufficiently strong on a local level to cause performance alterations (e.g., higher operational costs) that would increase the costs of generating energy by these two energy generation assets. Small variations can be observed for the LCOE of the diesel power plant when comparing the results of the four climate scenarios. If the RCP 8.5 climate scenario materializes (which is characterized by comparatively higher air temperatures and hence decreases thermal efficiency, see Figure 8), the LCOE of this energy asset will even further increase compared to the BAU climate scenario because additional fuel expenditures are needed for maintaining the same amount of energy output. If either the RCP 2.6 or the RCP 6.0 scenario materializes, the LCOE of the diesel power plant will slightly decrease compared to the BAU climate scenario.

Third, cost differences between the conventional LCOE and the SAVi LCOE can be observed across all three energy generation alternatives. Explanations raised in Section 4.2.1 also apply here. The largest discrepancy between the conventional LCOE and the SAVi LCOE applies to the diesel power plant. The large discrepancy stems from the high SCC caused by the diesel power plant due to its fossil fuel use. These costs are only accounted for in the SAVi LCOE and hence explain the increase compared to the conventional LCOE. Such an increase can be observed under each climate scenario, though it is the highest in the RCP 8.5 scenario. This is the case because the highest degree of air temperature increase is associated with this climate scenario, leading to a less efficient combustion process and the need to use more fuel to keep the electricity generation stable. This implies that the highest SCC is caused by the diesel power plant under the RCP 8.5 scenario. Consequently, the SAVi LCOE of this energy asset is the highest under this climate scenario, implying that generating electricity by a diesel power plant becomes most costly for society under the RCP 8.5 scenario. This also indirectly suggests that the more climate change is accelerated by fossil fuel use and triggers air temperature increases on a local level, the less cost-efficient fossil fuel-based energy generation assets will be and the more detrimental they will be for society (less combustion efficiency = more fossil fuel use for same energy output = higher carbon emissions = higher SCC).

Figure 14. Itemized LCOE (USD/MWh) of different energy assets under various climate scenarios (discount rate 5.3%)



	Kakono HPP: Conventional LCOE	Kakono HPP: SAVi LCOE	Diesel: Conventional LCOE	Diesel: SAVi LCOE	Portfolio gas & solar PV: Conventional LCOE	Portfolio gas & solar PV: SAVi LCOE
RCP4.5 (BAU)	71.36	69.98	248.77	275.45	74.17	79.03
RCP2.6	71.36	69.95	243.13	269.12	74.05	78.92
RCP6.0	71.28	69.90	245.97	272.30	74.11	78.98
RCP8.5	71.29	69.94	250.26	277.12	74.19	79.06

4.3 Financial Analysis of the Energy Generation Assets

This section presents the results of the financial analysis conducted for the Kakono HPP as well as the financial performance results of the hypothetical diesel power plant and the gas and solar PV energy portfolio. The financial analysis of this SAVi assessment incorporates the implications of externalities and climate parameters on the financial performance of each asset.

4.3.1 Internalization Methodology and Key Assumptions

A financial model was built for each of the three energy generation assets considered in this SAVi assessment. These financial models calculate the financial performance of the respective asset and generate results for a range of financial performance indicators. Results of the following two financial performance indicators are presented in the next sections under different scenarios analyzed: the Project NPV and the Project IRR. The NPV is a performance indicator that is used to analyze the profitability of a projected investment or project. The NPV result demonstrates the difference between the present value of cash inflows net of financing costs and the present value of cash outflows. The IRR is an important financial performance indicator that investors use to evaluate infrastructure projects. It serves as an indicator of the profitability prospects of a potential investment. The IRR is the discount rate that makes the NPV of all cash flows from a particular project equal to zero.

The assessed climate parameters of this SAVi application have implications for the magnitude of some costs as well as for the total electricity generation (and hence revenues) from electricity sales of the respective asset. In those two instances, climate change can have direct cash flow and financial performance implications. Moreover, variations in climate parameters can also have implications for the magnitude of externalities.

The cost and/or revenue implications of climate change-related risks can be internalized into the financial model of an energy-generating asset. The same can be done for the monetary value of externalities. While they have no immediate cash flow implications, the internalization of externalities allows for a more holistic view and presents financial performance indicators corrected by additional social, environmental, and economic dimensions. Accordingly, in this SAVi assessment, financial performance results have been assessed with and without internalizing the monetary values of externalities. In addition, the impact of the various climate change scenarios was assessed (RCP 4.5 [BAU], RCP 2.6, RCP 6.0, and RCP 8.5) for each of the three energy generation assets. In this section, the NPV and IRR results of each energy generation asset are presented under the various climate change scenarios as well as under the two varying cost and internalization assumptions:

- **i)** **Baseline scenario:** The financial model of each asset includes project-related costs, such as capital, operating expenditures, and cost of financing—these are the conventional cost positions. It also includes the revenues from electricity sales.
- **ii)** **Baseline + externalities:** In addition to the conventional revenues and cost items, this scenario considers the financial performance implications if the externalities are internalized into the financial model of each asset.

For this SAVi assessment, levelized values were calculated and internalized into the annual financial flows of the respective financial model. The levelized values for the financial analysis are calculated in a way similar to the calculation of the LCOE in Section 4.2 of this report. The total amount of undiscounted monetized externalities that emerge during the construction and operation of each asset is divided by the total electricity generation over the lifetime of each asset.

In order to integrate the levelized value of externalities and climate change impacts on levelized costs and levelized externalities into the financial model, these levelized values are then multiplied by the electricity generation for each year assessed. Therefore, this approach takes all externalities and climate change-related cost factors into account that occur during an asset's lifetime. While their monetary values are allocated to each operating year of the asset relative to the electricity being generated, the methodology does not reflect the real magnitude of externalities and climate change-related cost factors per year. Appendix B provides more details about the methodology of the project finance model of SAVi.

Table 4 lists the various assumptions that have been defined for each asset in conducting the financial analysis. For the Kakono HPP, the basic project design report (Studio Pietrangeli Consulting Engineers, 2019a) and feedback from the AfDB served to define reasonable assumptions for the debt-to-equity ratio and the weighted average cost of capital for the asset, including the cost of debt and the cost of equity. Due to lacking information and the hypothetical nature of the two energy generation alternatives, the same financing assumptions have been set for the diesel power plant and the mixed energy portfolio.

Table 4. Key assumptions for the financial analysis of each energy generation asset

Assumptions	**Unit**	**Kakono HPP**	**Diesel comparator**	**Portfolio comparator**	
				Solar PV	**Gas**
Installed capacity	MW	87.8	142.5	85.5	104.7
Electricity generation	MWh p.a.	524,000	524,000	524,000	
Construction time	Months	52	24	24	24
Operation time	Years	50	30	25	40
Construction cost (total)	USD million	308.39	92.61	34.18	99.45
Operation cost	USD/MWh	4.80	4.08	5.37	
Capital split (debt-to-equity ratio)	%	76% / 24%	76% / 24%	76% / 24%	
Discount rate/weighted average cost of capital	%	5.3	5.3	5.3	
Debt tenor	Years	25	25	25	
Cost of debt (average)	%	8.08	8.08	8.08	
Electricity price	USD/MWh	110	110	110	

4.3.2 Results of the Financial Analysis: Comparison of the energy generation assets

This section presents the NPV and IRR results of the conducted financial analysis for the three energy generation alternatives.

Table 5 presents the Project NPV results of the Kakono HPP in comparison to the diesel power plant and the combined energy portfolio under a BAU climate scenario (RCP 4.5). The Project NPV of the Kakono HPP and the combined energy portfolio are positive considering the lifetime of each asset and the electricity price of USD 110 per MWh. Therefore, both assets are attractive investment opportunities. One can observe that the Project NPV results of the Kakono HPP (USD 192 million) are almost twice as high under the baseline cost scenario compared to the combined energy portfolio (USD 98 million), making the former the more attractive investment opportunity. The superiority of the hydropower assets is further enhanced when considering a societal point of view by internalizing the monetary value of environmental, social, and economic externalities into the financial model of the assets. In that instance, the performance discrepancy of the two assets further increases as the Project NPV results of the Kakono HPP slightly rise (USD 195 million) while the results of the combined energy portfolio significantly decrease (USD 58 million). This is caused by the asset's relatively high negative externalities associated with carbon emissions from fossil fuel use.

The Project NPV results of the diesel power plant are negative in both cost scenarios (i.e., with and without externalities). This highlights that this fossil fuel-based energy asset is not an attractive investment opportunity and not at all competitive compared to the other two assets. On the other hand, the even more negative NPV result in the internalization scenario emphasizes that the asset can also not be considered beneficial from a societal point of view.

Table 5. Comparison of the Project NPV results of the different energy generation assets under the climate scenario RCP 4.5 (BAU)

	Project NPV (in USD million)		
	Kakono HPP	**Diesel power**	**Energy portfolio: Gas and solar PV**
(i) Baseline: Conventional results	191.92	(1,070.71)	97.66
(ii) Baseline + Externalities	194.92	(1,262.04)	57.94

Table 6 summarizes the Project IRR results of the Kakono HPP compared to the diesel power plant and the combined energy portfolio under a BAU climate scenario (RCP 4.5). The performance conclusions about the three assets are very similar to observations raised for the Project NPV results. The only exception is that, in the baseline cost scenario, the combined energy portfolio yields a better Project IRR (10.66%) compared to the Kakono HPP (8.93%). Both assets can be considered financially viable given the positive Project IRR results while the portfolio achieves a more convincing risk–return profile. However, the latter insight is reversed when considering a societal point of view and internalizing the valued externalities. In that instance, the Kakono HPP yields a slightly higher Project IRR compared to the combined energy portfolio (8.99% vs. 8.62%).

Again, the diesel power plant cannot be considered competitive in any event, as it attains a negative Project IRR. Due to the anticipated high fuel expenditures, the asset cannot be considered financially viable over time.

Table 6. Comparison of the Project IRR results of the different energy generation assets under the climate scenario RCP 4.5 (BAU)

	Project IRR		
	Kakono HPP	**Diesel power**	**Energy portfolio: Gas and solar PV**
(i) Baseline: Conventional results	8.93%	Negative	10.66%
(ii) Baseline + Externalities	8.99%	Negative	8.62%

4.3.3 Results of the Financial Analysis Under Different Climate Scenarios

This section presents the financial performance results of the three energy generation alternatives under various climate scenarios. As introduced in Section 3.3, four climate scenarios were considered in this SAVi assessment: RCP 4.5 (BAU), RCP 2.6, RCP 6.0, and RCP 8.5. Results of the BAU scenario were presented in the previous section and are indicated in the tables below again. The tables present the Project NPV and Project IRR results of each energy generation asset individually under the various climate scenarios instead of comparing the three energy assets. This distinction is useful because the various climate scenarios do not cause strong performance variations across the three assets, implying that the investment rationale and attractiveness concluded in the previous section are not being altered.

Table 7 presents the Project NPV and Project IRR results of the Kakono HPP under the different climate scenarios as well as for a baseline cost scenario and a scenario that assumes the internalization of externalities. Minimal performance variations can be observed when comparing the results under the various climate scenarios, implying that the variations of air temperatures and precipitation at the project locations under different climate projections will not largely affect the performance of the Kakono HPP. It can be considered a climate-resilient asset. The internalization scenario yields slightly better performance results, as the overall value of externalities of the Kakono HPP is positive (see Section 4.1.1). The improved Project NPV and Project IRR results reflect that the asset provides overall net benefits to society.

Table 7. Project NPV and Project IRR of the Kakono HPP under different climate scenarios

Kakono HPP	**Project NPV (in USD million)**				**Project IRR**			
Scenario	**RCP 4.5 (BAU)**	**RCP 2.6**	**RCP 6.0**	**RCP 8.5**	**RCP 4.5 (BAU)**	**RCP 6.0**	**RCP 6.0**	**RCP 8.5**
(i) Baseline: Conventional results	191.92	191.92	192.81	192.65	8.93%	8.94%	8.95%	8.95%
(ii) Baseline + Externalities	194.92	195.09	195.84	195.44	8.99%	8.99%	9.00%	8.99%

Table 8 presents the Project NPV and Project IRR results of the diesel power plant under the different climate scenarios, as well as corresponding results of a baseline cost scenario and a scenario that assumes the internalization of externalities. The Project NPV results vary when comparing the various climate scenarios, while the Project IRR results are negative under each scenario and are not further differentiated. As the Project NPV results are almost USD 65 million more negative in the RCP 8.5 scenario compared to the RCP 2.6 scenario, it can be concluded that variations in climate parameters, such as air temperature variations, have an impact on the asset´s performance. As was described in Section 4.1.2 (see explanations above Figure 11), higher air temperatures lead to combustion inefficiencies in the power plant and require more fuel consumption and a corresponding increase in expenses. Therefore, the asset appears vulnerable to a changing climate.

Irrespective of the climate scenario, the asset performs poorly and cannot be considered a worthwhile investment opportunity under any scenario. The investment case becomes even less compelling when adopting a societal point of view and internalizing the externalities into the financial model of the asset. In that case, the Project NPV results further decrease.

Table 8. Project NPV and Project IRR results of the diesel power plant under different climate scenarios

Diesel power plant	**Project NPV (in USD million)**				**Project IRR**			
Scenario	**RCP 4.5 (BAU)**	**RCP 2.6**	**RCP 6.0**	**RCP 8.5**	**RCP 4.5 (BAU)**	**RCP 6.0**	**RCP 6.0**	**RCP 8.5**
(i) Baseline: Conventional results	(1,070.71)	(1,030.79)	(1,054.80)	(1,095.23)	Negative	Negative	Negative	Negative
(ii) Baseline + Externalities	(1,262.04)	(1,217.23)	(1,244.19)	(1,289.57)	Negative	Negative	Negative	Negative

Table 9 presents the Project NPV and Project IRR results of the combined gas and solar PV energy portfolio under the different climate scenarios, as well as the corresponding results of a baseline cost scenario and a scenario that assumes the internalization of externalities. Both the Project NPV results and the Project IRR results vary to a minimal extent when comparing the various climate scenarios. Explanations for these variations were listed in Section 4.1.2 (see explanations above Figure 12). The most compelling results are attained under the RCP 2.6 scenario, which is associated with the lowest degree of air temperature increases across the four climate scenarios.

The positive and stable financial performance results of the combined energy generation asset suggest it to be an appealing investment opportunity. Its performance is only to a small degree vulnerable to climate change in the northern region of Tanzania. The results of both financial performance indicators decrease quite substantially when the monetary value of assessed externalities is internalized into the financial model of the combined portfolio. Hence, from a societal point of view, the investment case is less compelling, as the negative externalities caused by the portfolio are larger, in monetary terms, than the positive externalities. See the detailed results for the assessed externalities indicated, for example, in Table 2 and 3 of the previous sections. The Project NPV results decrease by around 40% when the externalities are internalized, and the Project IRR results are approximately 2% lower than under a baseline cost scenario. This discrepancy remains similar across all the climate scenarios.

Table 9. Project NPV and Project IRR results of a gas and solar PV portfolio under different climate scenarios

Gas and solar PV portfolio	**Project NPV (in USD million)**				**Project IRR**			
Scenario	**RCP 4.5 (BAU)**	**RCP 2.6**	**RCP 6.0**	**RCP 8.5**	**RCP 4.5 (BAU)**	**RCP 6.0**	**RCP 6.0**	**RCP 8.5**
(i) Baseline: Conventional results	97.66	98.18	97.93	97.58	10.66%	10.68%	10.67%	10.66%
(ii) Baseline + Externalities	57.94	58.43	58.20	57.86	8.62%	8.64%	8.63%	8.61%

In conclusion, the Project NPV and the Project IRR results of this financial analysis highlight that the Kakono HPP is a financially viable as well as an appealing investment opportunity both from financial and broader societal viewpoints. Moreover, these financial performance indicators are hardly altered under different climate scenarios, suggesting that it is also a climate-resilient investment opportunity.

Similar conclusions can be drawn for the energy portfolio alternative, though one key difference should be highlighted. The performance of both indicators decreases substantially when the monetary value of environmental and socio-economic externalities are internalized in the financial model. This suggests that, from a societal point of view, the asset is less appealing compared to when assuming a rather conventional investor’s perspective. As multilateral investors, such as the AfDB, also have a mandate to promote sustainable development, it is worthwhile to consider the financial performance when externalities are internalized and take this as a starting point for comparison between asset alternatives. In that instance, the Kakono HPP is the superior investment choice.

Finally, the diesel power plant is neither financially viable nor an appealing and climate-resilient investment opportunity under any consideration.

5 Conclusions and Recommendations

The SAVi methodology was customized and applied to the Kakono HPP. The assessment explored the following:

(1) How the value and financial performance of the Kakono HPP are affected if environmental and socio-economic costs and co-benefits (externalities) are integrated into an asset valuation.
(2) If and how conventional costs, revenues, and externalities of the Kakono HPP are affected under different climate scenarios and, if they are, how the asset performance is altered under each climate scenario.
(3) How alternative energy generation options for Tanzania perform under (1) and (2) in comparison to the Kakono HPP.

Further, the results of this SAVi assessment and the drawn conclusions serve to inform the AfDB about important considerations for integrated, sustainability-aligned, and climate-resilient infrastructure investment decisions.

5.1 Key Insights of this SAVi Assessment

The Kakono HPP performs well across all assessment components and related performance indicators evaluated in this SAVi assessment: CBA results, LCOE results, and financial analysis results (Project NPV, Project IRR). The good performance remains stable under all assessed climate scenarios, which provides evidence that the Kakono HPP is a climate-resilient energy asset and an appealing investment opportunity.

This is emphasized when comparing the hydro asset to a diesel power plant comparator, as well as a mixed energy portfolio consisting of a gas-fired power plant and a utility-scale solar PV system. In the BAU climate scenario and without accounting for externalities, the Kakono HPP performs better than the two comparators across all performance indicators with only one exception: the mixed energy portfolio yields a higher Project IRR (10.66%) than the Kakono HPP (8.93%). If the value of socio-economic and environmental externalities is accounted for, this exception does not hold anymore as the Project IRR of the portfolio (8.62%) decreases and remains below the sustainability-adjusted Project IRR of the Kakono HPP (8.99%). All other performance indicators of the Kakono HPP (absolute CBA results, LCOE value, and Project NPV results) become even more superior once the externalities are integrated into the assessment.

Given its location and when assuming no upstream land-use changes, the Kakono HPP is the most climate-resilient energy generation asset among the three energy generation alternatives assessed. The integration of climate projections under various climate models did hardly imply any performance changes—in fact, this insight was not anticipated, as hydropower assets can be vulnerable to the impacts of climate change. Therefore, it is an important insight that the location and intact natural ecosystems in which a hydropower asset is embedded both matter. An infrastructure assessment, especially when it is meant to capture climate risks posed to an asset, and associated preparations for investment decisions need to take this location specificity into account. Put differently, a climate risk assessment and the corresponding analysis of climate projections for natural capital and ecosystem services that enable the profitable operation of an envisioned energy infrastructure asset have to inform the siting of the same energy asset. Therefore, an ex-ante climate risk assessment prior to siting decisions is inevitable.

Further consideration has to be made regarding the changes that the presence of the hydropower dam, supporting infrastructure (e.g., better roads for better access for extractives, new developments, availability of water in the reservoir for irrigation), and further land-use changes will create for the area. While the dam is climate resilient under current land use, changes in land cover may undermine its sustainability. When an investment of this type (heavily reliant on natural capital) and size (with large power generation that could support thousands of families) is implemented, the ecological integrity of the area upstream has to be guaranteed to avoid reduced generation, revenues, and possibly turning the Kakono HPP into a stranded asset. A scenario analysis that assesses alternative projections for future land-use changes (and associated implications for natural capital) in relevant proximity to and over the lifetime of a planned energy infrastructure project will help identify how dependent the asset's performance is on respective land-use variations. Again, this will help to determine the most resilient location of an energy infrastructure project or might suggest the use of an alternative energy generation technology for an already prioritized location.

When assuming a similar location in northwestern Tanzania for siting the hypothetical energy portfolio (combination of a gas-fired power plant and utility-scale solar PV system), it can largely be considered a climate-resilient investment choice given the parameters that were assessed in this SAVi assessment. Further, the economic performance of this portfolio may improve if small-scale off-grid technology is considered, reducing transmission and distribution costs, as well as losses. The diesel power plant, on the other hand, appears vulnerable to climate change impacts—primarily due to decreased combustion efficiency under higher air temperatures and respectively higher fuel expenses to keep electricity generation stable.

The conventional LCOE of USD 71.36 per MWh and the even lower SAVi LCOE of approximately USD 70 per MWh highlight that electricity generated by the Kakono HPP is relatively affordable. Investing in this energy generation asset implies higher value for money for the Tanzanian people compared to investing in the energy asset alternatives, which are both characterized by higher LCOE and would hence imply higher electricity expenditures for the Tanzanian people. Likewise, the Project NPV results of more than USD 190 million and the Project IRR results of almost 9% underline that the Kakono HPP is a financially viable as well as an appealing investment opportunity from financial and broader societal viewpoints.

Therefore, based on the comprehensive SAVi assessment results, the Kakono HPP can be considered a worthwhile investment for a multilateral development bank such as the AfDB.

5.2 Implications of the SAVi Assessment for Improving the Sustainability Performance of the Kakono HPP

The SAVi assessment confirmed that the construction and operation of the Kakono HPP are causing several adverse environmental impacts. These impacts should ideally be mitigated or compensated if cost-efficient mitigation is not feasible and is not essential for the ecological balance of the project area in order to improve the overall sustainability performance of the hydro project.

In particular, even if considered a low-carbon energy technology, the SAVi assessment provided evidence that the Kakono HPP causes GHG emissions in various life-cycle phases from various sources, ranging from the manufacturing of construction materials and commissioning the plant to land clearing, loss of carbon sinks, and emissions from the reservoir throughout the operation phase of the Kakono HPP. In this assessment, costs associated with these emissions were valued by applying the SCC, a top-down assessment of the economic cost caused by an additional tonne of carbon dioxide emissions or its equivalent through the carbon cycle. While some of these GHG emissions could be mitigated to some extent (for example, by choosing concrete mixtures with a lower carbon footprint than conventional compositions), most of the emissions cannot be avoided.

Offsetting these unavoidable life-cycle GHG emissions could be an appropriate approach to improve the carbon balance of the Kakono HPP and ensure it is a net-zero carbon project. Investing in reforestation to offset the GHG emissions caused by the Kakono HPP could be one viable option. The (re)forestation could be planned in proximity to the Kakono HPP, as this could also offset some of the terrestrial habitat quality that will be lost due to land clearing and establishing the reservoir. Moreover, proper vegetation along the river course upstream of the Kakono could contribute to soil stability and avoid soil erosion and increased sediment volumes in the river, therefore preventing the need for increased sediment removal requirements in the reservoir. On the other hand, (re)forestation along the river course downstream of the Kakono could also be a meaningful choice, especially if it is a consideration to generate peak electricity at times (hydropeaking)—which would imply strong fluctuations of water flow and diverse threats for downstream ecosystems, including the risk of increased soil erosion.

Indeed, two areas of adverse environmental impacts that were not investigated through this SAVi assessment, given data gaps, are the downstream effects of the to-be-constructed dam (and changes to the natural water flow during different seasons) and the effects of different modes of operation (baseload vs. hydropeaking) on ecosystems and species. The effects on migratory fish species were indirectly accounted for in this assessment by assuming a cost component for investing in a technical fish migration solution, while it remains to be answered how this technical solution could effectively be designed to serve the purpose. Primary data collection and scenario analyses are required to adequately investigate and account for these potentially adverse ecosystem impacts of the Kakono HPP in order to develop effective mitigation solutions. Costs for such solutions need to be incorporated in investment proposals and asset valuations, such as those conducted with this SAVi assessment.

Finally, concerning investments in new hydropower projects, it is advisable to define and run risk scenarios in addition to the climate risk scenarios that were incorporated into this SAVi assessment. In this assessment, it was assumed that no upstream land-use changes or additional hydropower projects would occur throughout the life cycle of the Kakono HPP. However, it is likely that both will happen at some point during the HPP's operational life. Land-use changes, agriculture expansion and related irrigation activities, and additional hydropower projects might imply performance risks for the Kakono HPP. For example, reduced water availability in the Kagera River, stronger variations in water flow, and/or higher volumes of sediment transport in the river (leading to quicker sediment accumulation in the reservoir) imply either reduced electricity generation capacity or higher sediment removal costs. All these factors have adverse cost and revenue implications and could significantly alter the Project NPV and Project IRR. Therefore, investment decisions for a project at hand (the Kakono HPP) should take into account planned investments of the same (TANESCO) or other project proponents (e.g., Kagera Sugar) that affect the same key ecosystems (Kagera River) in which the project at hand (the Kakono HPP) is embedded.

Moreover, the cumulative effects of several infrastructure projects (the Kakono HPP being one of several in the future) and other larger-scale economic activities imply higher burdens to local ecosystems and might put the carrying capacity of (freshwater) ecosystems at risk. A multilateral development bank should have monitoring systems in place that avoid investment that could lead to irreversible natural capital depletion.

5.3 Policies and Protocols for Sustainable Infrastructure Investment Decision

Multilateral development banks, such as the AfDB, and other infrastructure investors could advance their project preparation, upstream planning and investment decision in favour of sustainable and resilient infrastructure options. This study shows that there are several advantages emerging from (i) developing a comprehensive framework of analysis that considers both external risks faced by infrastructure and the external cost and (co-)benefits implied by the infrastructure project; (ii) conducting a multi-disciplinary, integrated assessment of the investment; and (iii) comparing the proposed investment with alternative options to better assess its socio-economic, environmental, and financial performance. These three activities can be performed effectively if internal protocols are established to mandate pre-feasibility assessments that consider climate trends and social and environmental outcomes of the project, as well as if these assessments are carried out using a multi-stakeholder approach that is also multi-disciplinary. Specifically, planning for sustainable infrastructure could be advanced by implementing the following measures.

Adjust procedures and protocols

Adjusting procedures and protocols, including external multi-stakeholder consultation as well as stronger cross-departmental exchanges for project preparation within the AfDB to overcome planning silos and appreciate the diverse dimensions of sustainable infrastructure planning and investing across departments.

Conduct comparative assessments

Conducting comparative assessments with project alternatives to benchmark and put project performance into perspective, such as done in this assessment by comparing performance results of the Kakono HPP with two technologically viable energy generation alternatives. This should be advocated by multilateral development banks and other sustainable infrastructure investors and conducted in proactive collaboration with project proponents—for example, national governments or state-owned utilities—in order to have a scope for alternative infrastructure investments in early upstream planning stages.

Advance GHG accounting

Advancing the GHG accounting approach for infrastructure projects in order to account for multiple direct and indirect sources of GHG emissions, such as is done in this SAVi assessment by quantifying and monetizing GHG emission sources indicated as externalities 8.1 to 8.5 in the CBA and LCOE results tables and defined in Section 3.1. Advanced GHG accounting and carbon budgeting will allow for successfully implementing a carbon-neutral strategy for infrastructure projects and hence align investment decisions with the Paris Agreement.

Improve quantitative environmental and social impact assessments

Improving quantitative environmental and social impact assessments (e.g., integrated CBA) instead of exclusively using qualitative assessments and ranking exercises (e.g., multi-criteria analysis) in order to identify significant adverse impacts that would allow for a more informed decision on the approval or rejection of project proposals. An improved comparison and prioritization between viable project alternatives and an improved rationale for mitigation and/or offsetting pathways would reduce project and hence investment risks. The quantification and monetary valuation, as done in this SAVi assessment, allows for the calculation of sustainability-adjusted LCOE results as well as sustainability-adjusted Project NPV and Project IRR results. This can imply new insights about the societal value of an investment. See, for example, differences between conventional net results and SAVi net results of the CBA in Section 4.1; differences between conventional LCOE and SAVi LCOE in Section 4.2; and differences between baseline Project NPV and Project IRR results versus results that integrate the monetary value of externalities in Section 4.3.

Moreover, such sustainability-adjusted cost indicators and financial key performance indicators might speak more to (in-house) investment professionals and decision-makers at potential co-financing institutions than having to review lengthy reports operating with bio-physical indicators and non-monetary units unknown to investment professionals that make it difficult for them to compare the various performance dimensions of a project. For example, as raised above, once the value of socio-economic and environmental externalities are accounted for in this SAVi assessment, the Kakono HPP yields a higher Project IRR than the mixed energy generation portfolio compared to not accounting for these externalities. Certainly, one may criticize the valuation methodology used, but without accomplishing such valuation, comparing these investment alternatives on a common ground would be difficult.

Conduct comprehensive climate risk assessments

Conducting comprehensive climate risk assessments that entail various climate scenarios to properly evaluate the resilience of investment options: ensure that time-series data and projections of various climate scenarios are spatially explicit and identify how different climate parameters (e.g., air temperatures, precipitation, wind speed) affect cost and revenues of infrastructure projects. This SAVi assessment and the use of Copernicus Climate Data provides a prime example of how this could be approached. See Section 3.2 for the climate data integration approach and sections 4.1.2, 4.2.2, and 4.3.3 for the performance results of the three energy generation alternatives under various climate risk scenarios.

While the various climate scenarios did not imply significant performance alterations for the Kakono HPP, varying performance results were observed for the diesel power plant. For example, the conventional LCOE of this energy generation technology varies between USD 243.13 per MWh and USD 250.26 per MWh, depending on which climate scenario materializes. Likewise, variations can be observed when comparing the Project NP results under the different climate scenarios. These projected variations provide evidence that climate change can have an adverse effect on energy generation potential and distribution (i.e., decreased sales and revenues) and/or on the magnitude of operational expenditures. This could also apply to potential hydropower projects if they are located in riverbeds and natural surroundings that are more vulnerable to the impacts of climate change than in the case of the Kakono HPP. For example, in certain locations, precipitation variations may imply stronger adverse effects on water volume and water flow in a river, implying less energy generation potential. Moreover, precipitation variations might be more pronounced in other locations than is projected for northwestern Tanzania. Such sophisticated climate risk assessments are also in line with recommendations from the Task Force on Climate-related Financial Disclosures.

This assessment sheds light on the trade-offs for policy-makers and stakeholders when investing in economic development, and can be used to make a multitude of decisions by investors in large-scale infrastructure such as the African Development Bank. Specifically,

- This analysis could be used as a baseline to perform due diligence for grants, concessional lending, and organizing “pay-for-performance” financing solutions.
- It could inform decisions on infrastructure planning, sustainable agriculture, climate adaptation, and economic development.
- The AfDB and other funders of nature-based infrastructure projects can use such valuations to design conservation finance solutions, potentially raising capital from private investors.

In order to support the transition to green, low carbon and climate-resilient development in Africa, it is crucial to understand and integrate the economic values arising from nature. The results of the

SAVi analysis demonstrate how these values can be internalized into investment decision-making. The results also address a series of questions related to sustainable infrastructure that policy-makers investors and development finance institutions such as AfDB are challenged to understand and apply by the Dasgupta Review on the Economics of Biodiversity, and which can be framed as follows:

- How can sustainable infrastructure assets offer better financial returns and better value for money than their business-as-usual counterparts?
- How much additional capital is required to plan and build sustainable infrastructure projects and assets that are more resilient to changing climates?
- How does sustainable infrastructure make a better contribution towards achieving objectives such as enhanced GDP, employment, innovation, and productivity, as well as the UN Sustainable Development Goals overall? Additionally, how can these contributions be measured?

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Appendix A. Data Sources and Assumptions

Table A1. Technical data for Kakono HPP

Parameter	Unit	HPP Poçem	Data Source/Comment
Installed capacity	MW	87.8	SP, 2019 (1)
Construction time	Months	52	SP, 2019 (1)
Operation time	Years	50	SP, 2019 (1)
Electricity generation (annual)	GWh/ Year	524	SP, 2019 (1)
Assumed load factor	%	68.13	AfDB, 2020
Roads	km	28	SP, 2019 (1)
Employment from construction of energy capacity	FTE/MW	11.39	TANESCO, 2017
Employment from O&M of energy capacity	FTE/MW/Year	0.68	TANESCO, 2017
Employment from road construction	FTE/km	7.7883	CIDB, 2005
Employment from road maintenance	FTE/km/Year	0.6	Figures for labour-based methods and technologies for employment-intensive construction works (CIDB, 2005)
Average salary in Tanzania	USD/Person/Year	2,000	Assumption
Share of income discretionary	% of salary	23.7	Based on NUMBEO (2019) disaggregation of costs, the non-discretionary items are rent (25.2%), markets (30.8%), transportation (11.8%) and utilities (8.4%). Discretionary spending assumes restaurants (11.3%), sports and leisure (9.6%), and clothing and shoes (2.8%). The total share of assumed discretionary spending is hence 23.7%.

Table A2. Financial data for Kakono HPP

Parameter	Unit	Kakono HPP	Data Source/Comment
Capital cost	USD/MW	3,444,647	Based on total capital costs, including for the HPP; transmission lines, contingencies and legal costs as well as estimated compensation and resettlement costs. This amount to USD 302.44 million (SP, 2019 (1)).
Replacement investment	USD million	5	Cost in year 30 of operation to replace outdated technical equipment to extend the lifetime of the energy asset (SP, 2019 (1)).
Cost of fish passage	USD million	5.9	Includes expenditures for installing and maintaining a fish migratory solution to mitigate potentially adverse impacts of the HPP on fish population (TANESCO, 2017).
O&M cost	USD/MW/ Year	28,645	Assumption that the annual O&M cost are a 1% share of the investment cost for Kakono HPP and the transmission lines (USD 251.5 million), as also suggested in SP (2019 (1)).
Cost of sediment removal	USD	400,000	Assumption USD 100,000 need to be spent every 10 years for dredging the reservoir to remove accumulated sediments and keep the plant at full operational capacity, The last dredging occur in year 40 of operation.

Table A3. Cost of Financing for Kakono HPP and the other energy generation assets

Note: the cost of financing have been defined for Kakono HPP based on SP (2019), exchanges with the AfDB and relevant data research. Among others, below parameters served to calculate the weighted average cost of capital (WACC) amounting to 5.3%, which served as the discount rate in the system dynamics and project finance models. For simplicity, the same WACC and according financing conditions have been assumed for the other energy generation assets.

Parameter	Unit	Kakono HPP	Data Source/Comment
Financing instruments	% concessional loans % grants % equity	76% 18.7% 5.3%	Financing instruments based on SP (2019 (1)) and exchanges with the AfDB: • Share of concessional loans in USD: 41.8% • Share of concessional loans in EUR: 34.2% • Share of grants: 18.7% • Equity share (provided by TANESCO): 5.3%
Loan Tenor	Years	25	Assumption
Grace period	Years	8	Assumption
Concessional loan discount	%	1	Assumption
Equity financing premium	%	2	Assumption
Corporate Tax Rate in Tanzania	%	30	PKF International Limited, 2016
Risk premium on lending	%	9.26	World Bank, 2020
US Treasury 2-year rate	%	0.16	U.S. Department of the Treasury, 2020
Euro area government bond 2-year rate (EUR)	%	-0.61	ECB, 2020

Table A4. Data on GHG Emissions and Social Cost of Carbon of Kakono HPP

Purpose of collected data and assumptions: The figures below serve to calculate and value the different sources of greenhouse gas (GHG) emissions associated with the Kakono HPP, explained further in Section 3.

Parameter	**Unit**	**Kakono HPP**	**Data Source/Comment**
Direct land use for reservoir	ha/MW	20.31	The direct land use of the HPP comprises the area used for the technical facilities as well as the area inundated for setting up the reservoir which covers an area of approximately 15 km^2 (SP, 2019 (1)). The land use approximation has been complemented by the spatial analysis done with the InVEST analysis.
GHG emissions caused by hydropower reservoirs	ton/ha/ Year	3	Emissions are operationalized based on InVEST results on carbon losses (loss of carbon from reservoir establishment) and the assumption that 30% of emission occur from deforestation and 67% of emissions over time from the reservoir.
GHG from land clearing for built infrastructure	Ton C	78,280	Carbon emissions released during land clearing are operationalized based on InVEST results on carbon losses (loss of carbon from reservoir establishment) and the assumption that 30% of emission occur from deforestation and 67% of emissions over time from the reservoir.
Biomass loss in flooded area (reservoir) for GHG calculation	Ton C	156,55 9	Carbon sequestration lost over the lifetime of the energy asset due to lost vegetation cover, as a result of deforestation and the inundation of valley upstream of the dam. This was calculated with the InVEST model.
$CO_{2eq.}$ emissions from commissioning and decommissioning of energy capacity per MW capacity	Ton/MW	3,514	Estimated based on data on lifecycle emissions by capacity type obtained from Turconi et al., 2013. Assuming 0.0098 ton/MWh for hydropower.

Social cost of carbon	USD/ MWh	31	The social costs of carbon (SCCs) are the economic cost caused by an additional ton of carbon dioxide emission or its equivalent through the carbon cycle. This is a top-down assessment of the cost of carbon. The BAU valuation for the SCC is USD 31 (constant) as indicated in Nordhaus (2017). This cost is used to value the carbon dioxide equivalent emissions caused by the Kakono HPP.

Table A5. Data on other environmental externalities of Kakono HPP

Purpose of collected data and assumptions: The figures below served to calculate and value environmental externalities of Kakono HPP. Part of the data are obtained from the InVEST assessment, see Appendix D.

Parameter	Unit	Kakono HPP	Data Source/Comment
Reduction in habitat quality	%	2020: 0% 2025: 10.25% 2080: 10.25%	Obtained from InVEST assessment; assumed that after establishment of roads and reservoir, no further degradation occurs (hence 10.25% constant)
Natural area considered affected	Ha	8,799	Forest area within 5.5km proximity of roads is assumed accessible and vulnerable for habitat degradation. Based on InVEST analysis, Habit-Quality model.
Share of land tropical woods and shrublands	%	31.3	Obtained from InVEST assessment and used for estimating the foregone value of raw materials.
Average value of biodiversity	USD/Ha/ year	0.89	Based on Turpie, 2000. Can range from 0.89 USD/Ha/Year to 4.52 USD/Ha/Year. Calculation of the total value of biodiversity is based on the area within a 5.5km radius around existing roads.
Average value of raw materials per hectare	USD/Ha/yea r	0.707	Turpie, 2000

Table A6. Technical data for diesel power plant, solar PV and gas-fired power plant

Parameter	Unit	Diesel	Solar PV	Gas	Data Source/Comment
Installed capacity	MW	142.48	85.5	104.7	The installed capacity of solar and wind is estimated to match the electricity production of Kakono HPP.
Construction time	Months	24	24	24	Assumption
Operation time	Years	30	25	40	Assumption
Electricity generation (annual)	MWh/ Year	524,200			Electricity generation for wind and solar is assumed to be the sum of annual electricity generated by the two hydropower assets.
Assumed load factor	%	42	21	40	(IRENA, 2018)
Direct land use per MW of capacity	Ha/MW	0.70	0.05	2.33	Diesel and gas based on U.S. NRC (2020) Solar based on NREL (2013)
Employment from construction of energy capacity	FTE/MW	2.522	13.8	3.2	(Rutovitz & Atherton, 2009) & (Wei et al., 2010)
Employment from O&M	FTE/MW/Year	0.553	0.3081	0.2782	(Rutovitz & Atherton, 2009) & (Wei et al., 2010)
Employment from road maintenance	FTE/km	0.6			CIDB, 2005
Average salary in Tanzania	USD/Person/Year	2,000			Assumption
Share of income discretionary	% of salary	23.7			Based on NUMBEO (2019) disaggregation of costs, the non-discretionary items are rent (25.2%), markets (30.8%), transportation (11.8%) and utilities (8.4%). Discretionary spending assumes restaurants (11.3%), sports and leisure (9.6%), and clothing and shoes (2.8%). The total share of assumed discretionary spending is hence 23.7%.

Table A7. Financial data for diesel power plant, solar PV and gas-fired power plant

Parameter	Unit	Diesel	Solar PV	Gas	Data Source/Comment
Capital cost	USD/MW	650,000	400,000	950,000	Diesel: Baurzhan & Jenkins (2017) Gas: IEA (2017) Solar (utility scale): Lazard's (2019)
O&M cost	EUR/ MW/ Year	15,000	20,000	10,500	Diesel and Solar (utility scale): Baurzhan & Jenkins (2017) Gas: World Bank (2015)

Table A8. Data on GHG emissions and social cost of carbon for diesel power plant, solar PV and gas-fired power plant

Purpose of collected data and assumptions: The figures below served to calculate and value environmental externalities of Kakono HPP. Part of the data are obtained from the InVEST assessment, see Appendix D.

Parameter	Unit	Diesel	Solar PV	Gas	Data Source/Comment
Fuel price	USD/MMBTU	20	0	6	Diesel: based on World Bank (2015) Gas: based on Open Data Africa (2020)
$CO_{2eq.}$ emissions from commissioning and decommissioning of energy capacity per MW capacity	Ton/MW	850	800	501	Estimated based on data on lifecycle emissions by capacity type obtained from Turconi et al., 2013

Appendix B. Modelling Components of SAVi and Customization for the Kakono HPP Assessment

Systems Thinking and System Dynamics

The SAVi model is developed using the system dynamics methodology. Its core pillars are feedback loops, delays, and non-linearity. These are explicitly represented in the model using stocks and flows, which are solved with differential equations. The SAVi model has been developed based on global literature, customized with local stakeholder input and parametrized with local, accessible data. The model simulates the period 2000 to 2082. There are two main reasons for using this specific timeframe: (i) being causal-descriptive, SAVi needs to be validated against historical data (hence the simulation of the model from 2000 onwards), (ii) being focused on infrastructure and long-term interventions (and their costs and outcomes) SAVi needs to forecast the impacts of interventions after they have been implemented and are fully operational. The HPP assessed in this SAVi assessment has a lifetime of 50 years and are assumed to start operating in year 2025—this is why the model simulates until the end of 2074.

IISD used and customized the SAVi energy model for the analysis of the HPPs Kalivaç and Poçem and the alternative energy generating assets, solar PV, and onshore wind. The assessment monetizes the impacts climate change has on the HPPs, as well as the environmental, social, and economic externalities caused by each of the assessed energy generating assets.

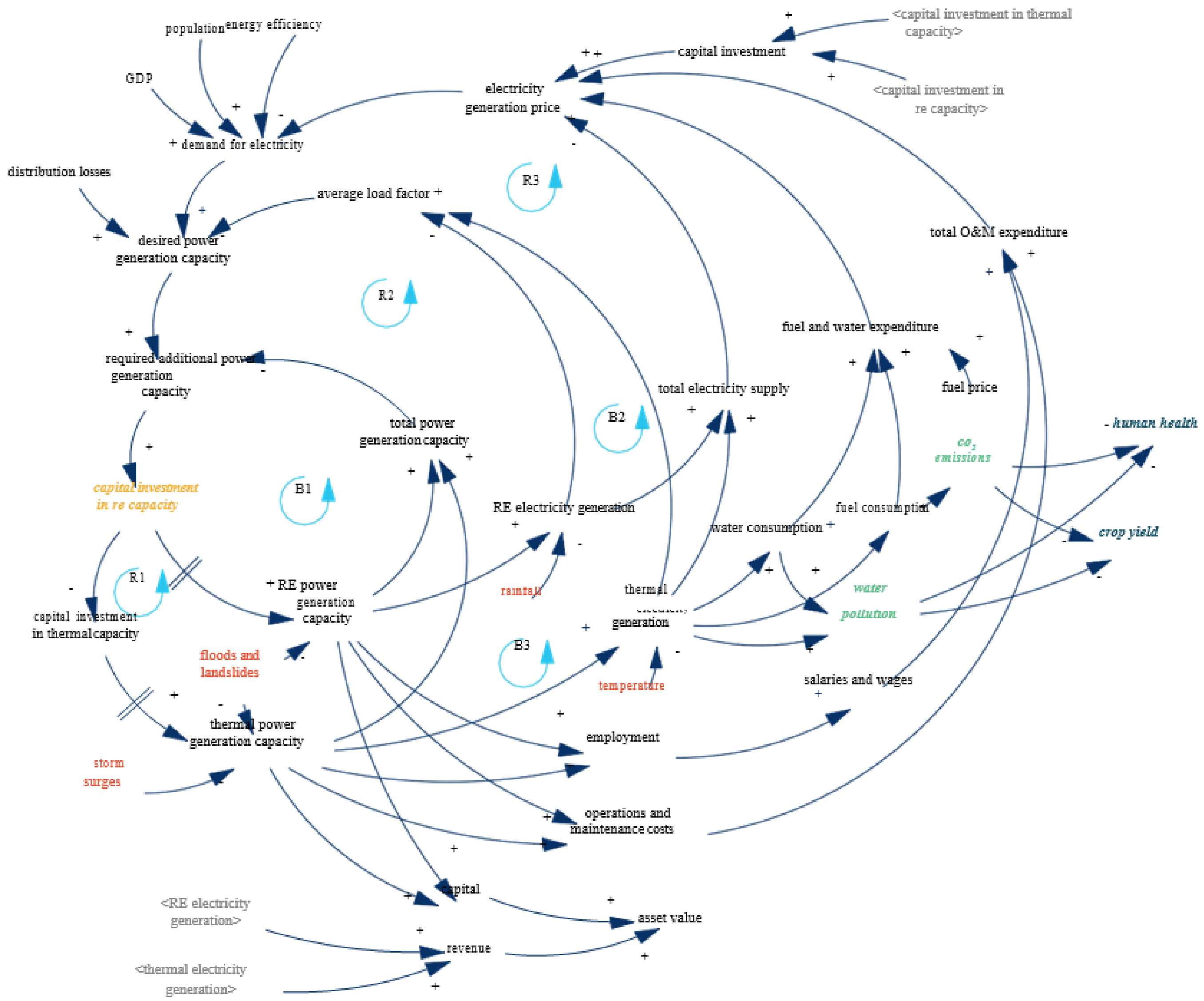
System Dynamics Model Overview

The CLD of the generic SAVi energy model is displayed in Figure B1. Note that elements that were customized in the SAVi energy model for this particular assessment and that are captured by the quantitative system dynamics model (such as concession payments and cost of dredging to be paid by HPPs or the range of technology- and location-specific externalities) are not displayed in this Figure B1. The customized CLD is displayed in Figure 2 in the main body of this report. Most dynamics of the generic CLD shown in the below figure are relevant for this study, aside from the macroeconomic drivers of change (e.g., population and GDP affecting electricity demand). There are four major feedback loops that drive the dynamics of the energy sector, loops (R1), (R2) and (B1), (B2). The character (R) represents a reinforcing loop and the character (B) represents a balancing loop; detailed definitions of these feedback loops and explanations how to design and read a CLD are described below Table B1.

- Loops (R1) and (B1) represent the adjustment of power generation capacity. The current amount of capacity, renewable and non-renewable, is compared to the required amount of capacity to provide the desired electricity supply. The gap between current and desired capacity determines the required investments in the respective technology types.

- The desired capacity level depends on the average effectiveness, also called average load factor, of the current energy technology mix. If the load factor of newly added energy generation infrastructure is higher than the load factors of the current energy technology mix, it will increase the average load factor, which is captured by loop (R2). Renewable energy technologies are less efficient compared to thermal technologies due to their dependency on, for example, sunlight and wind speed, captured by loop (B2). Consequently, a transition toward more renewables likely requires the installation of higher capacity than an energy system primarily based on thermal technologies. For this specific SAVi application, the difference in load factor of the three considered renewable energy assets is taken into account, and the corresponding capacity is calculated.
- The price of electricity is the third major driver affecting the demand for power generation capacity (via demand for electricity). On the other hand, the impact of price on demand (and hence sales) is not considered when a single asset is analyzed. The underlying assumption is that all electricity generated is sold.

Figure B1. Causal Loop Diagram SAVi energy model



Designing a CLD for a project helps to combine and integrate a team's knowledge, ideas, and concepts. Moreover, an interactive CLD design and verification process with key stakeholders of a project ensures that these stakeholders have a common understanding of the analysis being undertaken, both in terms of its overarching scope and its underlying factors. This will then enable these stakeholders to later appreciate and make use of analysis results (TEEB, 2018; Pittock et al., 2016). In this regard, CLDs highlight the root causes of a problem, as well as the variables of a system that could, with the appropriate technical or policy interventions, be targeted to develop solutions (UNECA, 2018).

To design solution-oriented and effective interventions, CLDs need to capture causal relations of a system correctly. Therefore, CLDs establish causal links between variables by linking them with arrows and attributing a sign to the arrow (either + or −) that indicates whether a change in one variable generates a positive or negative change in the other.

As noted by Bassi et al.:

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction" (Bassi, 2009).

Table B1. Causal relations and polarity

Variable A	Variable B	Sign
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Moreover, these causal interactions can form what is known as a positive or negative "feedback loop" (Forrester, 1961). In other words, an intervention made in that system can either support the tendency toward an equilibrium within the overarching system, in which case this negative feedback loop is called a balancing loop. Alternatively, an intervention can reinforce the intervention's impact and hence create a positive feedback loop, which is called a reinforcing loop (Bassi, 2009; Forrester, 1961). What makes CLDs especially useful for decision-makers and other stakeholders is this feedback component, showing how the different elements within a system interact with each other and either exacerbate or ameliorate a given situation (TEEB, 2018). These mapped relationships may not necessarily indicate linear behaviour, and potential impacts may occur delayed, which is why a CLD that captures the extent and complexity of this system is important. The interaction of "feedback loops" may also be where the source of a given policy problem lies, and therefore where decision- makers will need to direct their efforts for finding a solution—along with being aware of how this solution will affect the rest of the system (WWF-Greater Mekong, 2014).

LCOE Calculation Method

The LCOE serves as the key indicator for each of the energy-generating technologies. It is a useful indicator for comparing the unit cost of different technologies over their lifetime (IEA & NEA, 2015). It is calculated by dividing the net present costs of generation over the lifetime of capacity by the net present generation. In other words, it is calculated by dividing cumulative discounted costs (i.e., USD) by cumulative discounted generation, typically indicated in MWh.

To fully account for the impact of power generation capacity, it is necessary to regard capacity as part of the system rather than in isolation. A system dynamics model assesses and monetizes asset-related externalities and risks, such as climate impacts on generation efficiency, transitional risks (e.g., carbon tax) and health impacts from particle and other emissions. This information is used to complement the traditional LCOE assessment and to determine the "real social, economic and environmental costs" of power-generation technologies. In addition to the conventional LCOE, including cost parameters such as capital investment, O&M, and fuel costs, an integrated LCOE is presented that considers the monetized externalities and risks related to each technology. This approach allows a full account of asset-related impacts and provides a holistic picture of capacity-related advantages and disadvantages.

The LCOE of power generation options depends on a variety of factors, such as upfront capital intensity, O&M costs, total generation, and the lifetime of the asset. The traditional LCOE is calculated using the following equation:

$$LCOE = \frac{\sum[(CAPEX_t + OPEX_t + Fuel_t) * (1 + r)^{-t})]}{\sum MWh * (1 + r)^{-t}}$$

where the different parameters indicate:

- LCOE = the levelized costs of generating one MWh of electricity over the lifetime of the asset MWh = the amount of electricity generated by the asset in megawatt-hours
- $(1+r)^{-t}$ = the discount factor for year t to discount capital and O&M costs and generation equally
- r = the discount rate applied for the discounting of costs and generation $CAPEX_t$ = the capital cost in year t
- $OPEX_t$ = the operation and maintenance costs in year t
- $Fuel_t$ = the fuel costs in year t

To convey a more holistic assessment, the SAVi assessment includes transitional risks (e.g., carbon tax), climate risks, and various externalities in the calculation in addition to the conventional assessment. The additional parameters considered in this analysis are presented in Section 3. These parameters have been identified in collaboration with local stakeholders and project owners, and belong to one of the three different categories: expenditure, avoided costs, and added benefits.

Financial Analysis: Project Finance Model Overview

The main purposes of a project finance model are: (i) to identify the optimal capital structure, (ii) to assess the financial viability of the project, and (iii) to calculate the expected return on investment under different operational and risk scenarios.

I. Project sponsors use financial models to determine what the optimal debt-equity split used in the financing of the project should be. This largely depends on the project's revenue and cost profile: the timing and size of incoming cash flows during operations and the associated costs in each period. Most infrastructure projects follow a so-called "J-curve": having high upfront costs and relatively small but steady revenue streams. The "J" represents a certain number of years before the project breaks even and generates a return on investment.

II. Project finance models can also calculate whether the cash flows generated by the project will be sufficient to service the debt and generate an attractive risk-adjusted return for both equity and debt investors. This assessment includes the calculation of key performance indicators such as the IRR and the NPV. The definition of these indicators can be found in the glossary.

III. Project finance models are also well placed to stress test projects and assess how the expected return changes under certain operational and risk scenarios.This is calculated by a so-called "scenario table," which modifies key project assumptions and shows how key financial indicators react to these changes. Scenarios could be simple operational events, such as an increase in the price of feedstock, disruption in operation, or more complex climate events, such as heatwaves, sea-level rise, or carbon tax.

The project finance model used in SAVi is built in Microsoft Excel and follows Corality SMART best practices in order to improve the readability and auditability of the model by a third party. The outputs of the system dynamics model in SAVi are used as inputs in the project finance model and vice versa. The system dynamics model quantifies and monetizes the relevant environmental, social, and economic externalities associated with the project. It also helps identify the scenarios used in the scenario table. Depending on the purpose of the assessment and the target audience, some of the externalities are included as costs or benefits in the scenario table. Outputs of the system dynamics model can also change some of the key assumptions of the project finance model.

The main outputs of the project finance model are the financial indicators mentioned earlier. During the customization of the model, the list of indicators can be changed or extended as needed. Project-specific data, such as cost of financing, can also be extracted from the project finance model and fed back into the system dynamics model.

Appendix C. Complementary SAVi Results

Table C1. Comparative CBA for the BAU climate scenario RCP 4.5, undiscounted results in USD million

Cost and benefit categories (USD million)	**Kakono HPP**	**Diesel generation**	**Solar PV (30%) & Gas (70%) Portfolio**
Cost positions			
(1) Capital cost	313.4	92.6	123.1
(1.1) Cost of capacity	*302.4*	*92.6*	*123.1*
(1.2) Cost of fish passage	*5.9*	-	-
(1.3) Replacement investment	*5.0*	-	-
(2) Total O&M cost	125.7	3,584.8	889.3
(2.1) O&M cost	*125.7*	*64.1*	*106.2*
(2.2) Fuel expenditure	-	*3,520.7*	*783.2*
(3) Cost of sediment removal	0.4	-	-
(4) Cost of financing	384.5	109.0	161.2
Subtotal A: Total Cost	**813.0**	**3,786.4**	**1,173.6**
Revenues			
(5) Electricity sold	2,357.3	1,417.3	1,651.5
Subtotal B: Total Revenues	**2,357.3**	**1,417.3**	**1,651.5**
Subtotal C: Conventional Net Result (B-A)	**1,544.2**	**(2,369.1)**	**477.9**
Externalities			
(6) Discretionary spending: employment energy capacity	34.8	14.6	23.1
(7) Discretionary spending: employment roads	0.1	0.0	0.0
(8) Social cost of carbon (SCC)	(19.8)	(435.7)	(151.0)
(8.1) SCC from commissioning and decommissioning of energy capacity	*(9.6)*	*(3.8)*	*(3.9)*
(8.2) SCC from land clearing for built infrastructure	*(0.6)*	-	-
(8.3) SCC from biomass loss in inundated area	*(3.0)*	-	-

(8.4) SCC from reservoir GHG emissions	*(6.6)*	-	-
(8.5) SCC from fossil fuel use	-	*(432.0)*	*(147.0)*
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	(0.04)	-	-
(10) Foregone raw materials	(0.01)	-	-
Subtotal D: Value of Externalities	**15.1**	**(421.1)**	**(127.9)**
Subtotal E: SAVi Net Result (C+D)	**1,559.3**	**(2,790.2)**	**350.0**

Table C2. CBA for Kakono HPP under different climate scenarios, discounted results (5.3%) in USD million

	Kakono HPP			
Cost and benefit categories (USD million)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Cost positions				
(1) Capital cost	264.1	264.1	264.1	264.1
(1.1) Cost of capacity	257.7	257.7	257.7	257.7
(1.2) Cost of fish passage	5.6	5.6	5.6	5.6
(1.3) Replacement investment	0.8	0.8	0.8	0.8
(2) Total O&M cost	34.1	34.1	34.1	34.1
(2.1) O&M cost	34.1	34.1	34.1	34.1
(2.2) Fuel expenditure	-	-	-	-
(3) Cost of sediment removal	0.1	0.1	0.1	0.1
(4) Cost of financing	226.9	226.9	226.9	226.9
Subtotal A: Total Cost	**525.3**	**525.3**	**525.3**	**525.3**
Revenues				
(5) Electricity sold	639.5	640.1	640.9	640.1
Subtotal B: Total Revenues	**639.5**	**640.1**	**640.9**	**640.1**
Subtotal C: Conventional Net Result (B-A)	**114.2**	**114.8**	**115.6**	**114.8**
Externalities				

(6) Discretionary spending: employment energy capacity	21.3	21.3	21.3	21.3
(7) Discretionary spending: employment roads	0.0	0.0	0.0	0.0
(8) Social cost of carbon (SCC)	(11.6)	(11.4)	(11.5)	(11.7)
(8.1) SCC from commissioning and decommissioning of energy capacity	(7.3)	(7.3)	(7.3)	(7.3)
(8.2) SCC from land clearing for built infrastructure	(0.4)	(0.4)	(0.4)	(0.4)
(8.3) SCC from biomass loss in inundated area	(2.2)	(2.2)	(2.2)	(2.2)
(8.4) SCC from reservoir GHG emissions	(1.7)	(1.5)	(1.6)	(1.8)
(8.5) SCC from fossil fuel use	-	-	-	-
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	(0.01)	(0.01)	(0.01)	(0.01)
(10) Foregone raw materials	(0.01)	(0.01)	(0.01)	(0.01)
Subtotal D: Value of Externalities	**9.8**	**10.0**	**9.8**	**9.6**
Subtotal E: SAVi Net Result (C+D)	**124.0**	**124.8**	**125.5**	**124.5**

Table C3. CBA for a hypothetical, utility-scale diesel power plant under different climate scenarios, discounted results (5.3%) in USD million

	Diesel power plant			
Cost and benefit categories (USD million)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Cost positions				
(1) Capital cost	83.5	83.5	83.5	83.5
(1.1) Cost of capacity	83.5	83.5	83.5	83.5
(1.2) Cost of fish passage	-	-	-	-
(1.3) Replacement investment	-	-	-	-
(2) Total O&M cost	1,551.9	1,513.4	1,532.8	1,562.1
(2.1) O&M cost	27.9	27.9	27.9	27.9

(2.2) Fuel expenditure	1,524.1	1,485.5	1,504.9	1,534.2
(3) Cost of sediment removal	-	-	-	-
(4) Cost of financing	63.3	63.3	63.3	63.3
Subtotal A: Total Cost	**1,698.7**	**1,660.1**	**1,679.5**	**1,708.9**
Revenues				
(5) Electricity sold	616.0	616.5	616.2	615.8
Subtotal B: Total Revenues	**616.0**	**616.5**	**616.2**	**615.8**
Subtotal C: Conventional Net Result (B-A)	**(1,082.7)**	**(1,043.7)**	**(1,063.3)**	**(1,093.0)**
Externalities				
(6) Discretionary spending: employment energy capacity	7.9	7.9	7.9	7.9
(7) Discretionary spending: employment roads	0.0	0.0	0.0	0.0
(8) Social cost of carbon (SCC)	(190.2)	(185.5)	(187.9)	(191.5)
(8.1) SCC from commissioning and decommissioning of energy capacity	(3.2)	(3.2)	(3.2)	(3.2)
(8.2) SCC from land clearing for built infrastructure	-	-	-	-
(8.3) SCC from biomass loss in inundated area	-	-	-	-
(8.4) SCC from reservoir GHG emissions	-	-	-	-
(8.5) SCC from fossil fuel use	(187.0)	(182.3)	(184.6)	(188.2)
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	-	-	-	-
(10) Foregone raw materials	-	-	-	-
Subtotal D: Value of Externalities	(182.3)	(177.5)	(179.9)	(183.5)
Subtotal E: SAVi Net Result (C+D)	**(1,265.0)**	**(1,221.2)**	**(1,243.2)**	**(1,276.5)**

Table C4. CBA for a hypothetical energy portfolio (30% solar PV, 70% gas power) under different climate scenarios, discounted results (5.3%) in USD million

	Solar PV (30%) & Gas (70%) Portfolio			
Cost and benefit categories (USD million)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Cost positions				
(1) Capital cost	111.0	111.0	111.0	111.0
(1.1) Cost of capacity	111.0	111.0	111.0	111.0
(1.2) Cost of fish passage	-	-	-	-
(1.3) Replacement investment	-	-	-	-
(2) Total O&M cost	324.0	323.6	323.8	324.1
(2.1) O&M cost	41.0	41.0	41.0	41.0
(2.2) Fuel expenditure	282.9	282.6	282.8	283.1
(3) Cost of sediment removal	-	-	-	-
(4) Cost of financing	97.7	97.7	97.7	97.7
Subtotal A: Total Cost	**532.6**	**532.3**	**532.4**	**532.7**
Revenues				
(5) Electricity sold	636.0	637.4	636.7	635.7
Subtotal B: Total Revenues	**636.0**	**637.4**	**636.7**	**635.7**
Subtotal C: Conventional Net Result (B-A)	**103.4**	**105.1**	**104.3**	**103.0**
Externalities				
(6) Discretionary spending: employment energy capacity	16.5	16.5	16.5	16.5
(7) Discretionary spending: employment roads	0.0	0.0	0.0	0.0
(8) Social cost of carbon (SCC)	(56.5)	(56.4)	(56.5)	(56.5)
(8.1) SCC from commissioning and decommissioning of energy capacity	(3.4)	(3.4)	(3.4)	(3.4)
(8.2) SCC from land clearing for built infrastructure	-	-	-	-

(8.3) SCC from biomass loss in inundated area	-	-	-	-
(8.4) SCC from reservoir GHG emissions	-	-	-	-
(8.5) SCC from fossil fuel use	(53.1)	(53.1)	(53.1)	(53.1)
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	-	-	-	-
(10) Foregone raw materials	-	-	-	-
Subtotal D: Value of Externalities	**(40.0)**	**(39.9)**	**(40.0)**	**(40.0)**
Subtotal E: SAVi Net Result (C+D)	**63.5**	**65.2**	**64.3**	**63.0**

Table C5. Itemized LCOE (USD/MWh) of Kakono HPP under different climate scenarios; Discount rate 5.3%

	Kakono HPP			
Cost positions (USD/MWh)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Conventional cost				
(1) Capital cost	37.12	37.12	37.04	37.05
(1.1) Cost of capacity	*36.21*	*36.21*	*36.14*	*36.15*
(1.2) Cost of fish passage	*0.79*	*0.79*	*0.79*	*0.79*
(1.3) Replacement investment	*0.11*	*0.11*	*0.11*	*0.11*
(2) Total O&M cost	4.81	4.81	4.80	4.80
(2.1) O&M cost	*4.81*	*4.81*	*4.80*	*4.80*
(2.2) Fuel expenditure	*0.00*	*0.00*	*0.00*	*0.00*
(3) Cost of sediment removal	0.02	0.02	0.02	0.02
(4) Cost of financing	30.32	30.32	30.32	30.32
Subtotal A: Conventional LCOE	**71.36**	**71.36**	**71.28**	**71.29**
Externalities				
(6) Discretionary spending: employment energy capacity	-3.00	-3.00	-3.00	-3.00
(7) Discretionary spending: employment roads	-0.01	-0.01	-0.01	-0.01
(8) Social cost of carbon (SCC)	1.63	1.60	1.62	1.65

(8.1) SCC from commissioning and decommissioning of energy capacity	*1.02*	*1.02*	*1.02*	*1.02*
(8.2) SCC from land clearing for built infrastructure	*0.06*	*0.06*	*0.06*	*0.06*
(8.3) SCC from biomass loss in inundated area	*0.31*	*0.31*	*0.31*	*0.31*
(8.4) SCC from reservoir GHG emissions	*0.24*	*0.21*	*0.23*	*0.26*
(8.5) SCC from fossil fuel use	*0.00*	*0.00*	*0.00*	*0.00*
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	0.002	0.002	0.002	0.002
(10) Foregone raw materials	0.001	0.001	0.001	0.001
Subtotal B: Value of Externalities	**-1.38**	**-1.41**	**-1.38**	**-1.36**
Subtotal C: SAVi LCOE (A+B)	**69.98**	**69.95**	**69.90**	**69.94**

Table C6. Itemized LCOE (USD/MWh) of a hypothetical, utility scale Diesel Power Plant under different climate scenarios; Discount rate 5.3%

	Diesel Power Plant			
Cost positions (USD/MWh)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Conventional cost				
(1) Capital cost	12.22	12.22	12.22	12.22
(1.1) Cost of capacity	*12.22*	*12.22*	*12.22*	*12.22*
(1.2) Cost of fish passage	*0.00*	*0.00*	*0.00*	*0.00*
(1.3) Replacement investment	*0.00*	*0.00*	*0.00*	*0.00*
(2) Total O&M cost	227.18	221.54	224.37	228.67
(2.1) O&M cost	*4.08*	*4.08*	*4.08*	*4.08*
(2.2) Fuel expenditure	*223.10*	*217.46*	*220.30*	*224.59*
(3) Cost of sediment removal	0.00	0.00	0.00	0.00
(4) Cost of financing	9.37	9.37	9.37	9.37
Subtotal A: Conventional LCOE	**248.77**	**243.13**	**245.97**	**250.26**
Externalities				

(6) Discretionary spending: employment energy capacity	-1.16	-1.16	-1.16	-1.16
(7) Discretionary spending: employment roads	0.00	0.00	0.00	0.00
(8) Social cost of carbon (SCC)	27.84	27.15	27.50	28.03
(8.1) SCC from commissioning and decommissioning of energy capacity	*0.47*	*0.47*	*0.47*	*0.47*
(8.2) SCC from land clearing for built infrastructure	*0.00*	*0.00*	*0.00*	*0.00*
(8.3) SCC from biomass loss in inundated area	*0.00*	*0.00*	*0.00*	*0.00*
(8.4) SCC from reservoir GHG emissions	*0.00*	*0.00*	*0.00*	*0.00*
(8.5) SCC from fossil fuel use	*27.37*	*26.68*	*27.03*	*27.56*
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	0.000	0.000	0.000	0.000
(10) Foregone raw materials	0.000	0.000	0.000	0.000
Subtotal B: Value of Externalities	**26.68**	**25.99**	**26.34**	**26.86**
Subtotal C: SAVi LCOE (A+B)	**275.45**	**269.12**	**272.30**	**277.12**

Table C7. Itemized LCOE (USD/MWh) of a hypothetical energy portfolio (30% solar PV, 70% gas power) under different climate scenarios; Discount rate 5.3%

	Solar PV (30%) & Gas (70%) Portfolio			
Cost positions (USD/MWh)	**RCP4.5 (BAU)**	**RCP2.6**	**RCP6.0**	**RCP8.5**
Conventional cost				
(1) Capital cost	12.22	12.22	12.22	12.22
(1.1) Cost of capacity	*12.22*	*12.22*	*12.22*	*12.22*
(1.2) Cost of fish passage	*0.00*	*0.00*	*0.00*	*0.00*
(1.3) Replacement investment	*0.00*	*0.00*	*0.00*	*0.00*
(2) Total O&M cost	227.18	221.54	224.37	228.67
(2.1) O&M cost	*4.08*	*4.08*	*4.08*	*4.08*
(2.2) Fuel expenditure	*223.10*	*217.46*	*220.30*	*224.59*
(3) Cost of sediment removal	0.00	0.00	0.00	0.00

(4) Cost of financing	9.37	9.37	9.37	9.37
Subtotal A: Conventional LCOE	**248.77**	**243.13**	**245.97**	**250.26**
Externalities				
(6) Discretionary spending: employment energy capacity	-1.16	-1.16	-1.16	-1.16
(7) Discretionary spending: employment roads	0.00	0.00	0.00	0.00
(8) Social cost of carbon (SCC)	27.84	27.15	27.50	28.03
(8.1) SCC from commissioning and decommissioning of energy capacity	*0.47*	*0.47*	*0.47*	*0.47*
(8.2) SCC from land clearing for built infrastructure	*0.00*	*0.00*	*0.00*	*0.00*
(8.3) SCC from biomass loss in inundated area	*0.00*	*0.00*	*0.00*	*0.00*
(8.4) SCC from reservoir GHG emissions	*0.00*	*0.00*	*0.00*	*0.00*
(8.5) SCC from fossil fuel use	*27.37*	*26.68*	*27.03*	*27.56*
(9) Habitat quality loss from deforestation for road, reservoir and transmission lines	0.000	0.000	0.000	0.000
(10) Foregone raw materials	0.000	0.000	0.000	0.000
Subtotal B: Value of Externalities	**26.68**	**25.99**	**26.34**	**26.86**
Subtotal C: SAVi LCOE (A+B)	**275.45**	**269.12**	**272.30**	**277.12**

Appendix D. Assessing Ecosystem Services Supply under a Hydropower Scenario in Tanzania by Applying the InVEST Tool

1. Model set up

1.1. Study area

This analysis has focused on the area surrounding the Kakono hydropower project, located in north-western Tanzania (see Figure 1 in Chapter 2).

1.2. Coordination system

Based on world project coordinate system called "V WGS 84 / Pseudo-Mercator -- Spherical Mercator – ESPG: 3857"

The detail of the coordinate system are:

```
PROJCS["WGS 84 / Pseudo-Mercator",
 GEOGCS["WGS 84",
 DATUM["WGS_1984",
 SPHEROID["WGS 84",6378137,298.257223563,
 AUTHORITY["EPSG","7030"]],
 AUTHORITY["EPSG","6326"]],
 PRIMEM["Greenwich",0,
 AUTHORITY["EPSG","8901"]],
 UNIT["degree",0.0174532925199433,
 AUTHORITY["EPSG","9122"]],
 AUTHORITY["EPSG","4326"]],
 PROJECTION["Mercator_1SP"],
 PARAMETER["central_meridian",0],
 PARAMETER["scale_factor",1],
 PARAMETER["false_easting",0],
 PARAMETER["false_northing",0],
 UNIT["metre",1,
 AUTHORITY["EPSG","9001"]],
 AXIS["X",EAST],
 AXIS["Y",NORTH],
 EXTENSION["PROJ4","+proj=merc +a=6378137 +b=6378137 +lat_ts=0.0 +lon_0=0.0 +x_0=0.0 +y_0=0 +k=1.0 +units=m +nadgrids=@null
+wktext +no_defs"],
 AUTHORITY["EPSG","3857"]]
```

1.3. Scenarios

Two different scenarios have been considered to run different InVEST models:

- Business-as-Usual (BAU) scenario: the lulc map used in InVEST do not considers the impacts created by the development of the Kakono Hydropower Project.
- DAM scenario: the lulc map includes a reservoir, a dam, a new built-up area, and in the case of the Habitat Quality model, new roads and the installation of a transmission line.

1.4. Maps used

A land cover map at 20 m spatial resolution developed in 2016 by ESA/CCI-LC has been used in this study.

The dataset (Figure D1) has originally 10 land cover classes and it can be downloaded from: http://2016africalandcover20m.esrin.esa.int/. The product technical report and the descriptions of the land classes can be found on the same website.

Figure D2 shows the study area defined by four watersheds using the land cover map produced by ESA/CCI (BAU scenario). The same figure also illustrates the same location including a dam, a built-up area, and a reservoir (DAM scenario). These two maps have been used in all models except the Habitat Quality model, where a larger area has been considered as well as roads and transmission lines.

Figure D1. Land cover classes of the LULC map developed in 2016 by ESA/CCI-LC

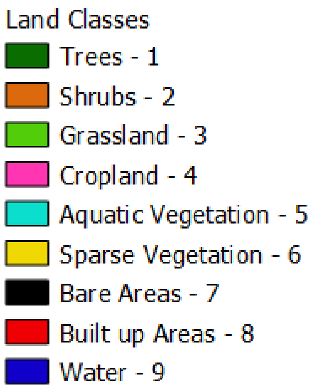
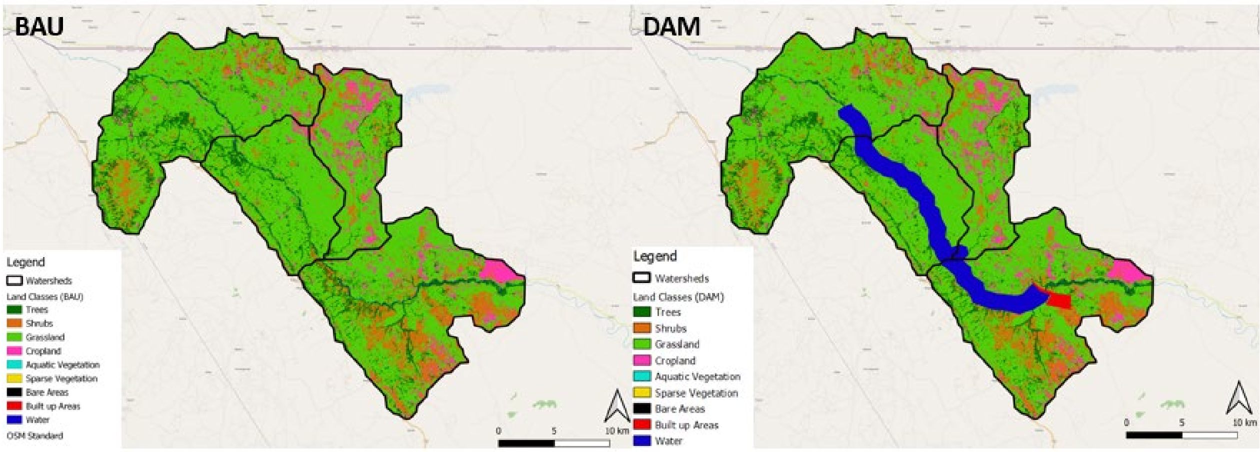


Figure D2. Land-use map BAU and DAM scenarios



1.5. Software and Simulation

Please note that the size of the reservoir, although approximate, considers an average depth of 10 meters. The size of the dam and of the built-up areas (both considered as "built up areas") have been also created from raw data.

The ecosystem services map simulation has been performed using InVEST Software V.3.8.0 (https://naturalcapitalproject.stanford.edu/invest/). The inputs spatial data for the InVEST model have been prepared by utilizing QGIS-OSGeoW-3.4.2-1 (qgis.org/downloads/). The tabulated data will be managed and prepared in Ms. Excel V. 2016.

2. Carbon Storage

2.1. Input data preparation and processing

1. Current land use/land cover – The LULC map developed by ESA/CCI in 2016 was used for both the BAU and DAM scenarios. For the DAM scenario, the LULC also showed the reservoir, the dam, and a built-up area.

2. Carbon Pools - Table of LULC classes, containing data on carbon stored in each of the four fundamental pools for each LULC class

- Carbon above ground: The values of carbon density in aboveground mass (Mg/ha or Tons/ha) of each land-use type are shown in Table D1.
- Carbon below ground: The values of carbon density in belowground mass (Mg/ha) of each land use-type are shown in Table D1.
- Carbon stored in organic matter: The values of carbon density in dead mass (Mg/ha) of each land-use type are shown in Table D1.

- Carbon stored in soil: The values of carbon density in dead mass (Mg/ha) of each land-use type are shown in Table D1.

The unit of measurement for these coefficients is Mg/ha. Average carbon coefficients values have been found in the “2006 IPCC Guidelines for National Greenhouse Gas Inventories” report, chapter 4 “Agriculture, Forestry and Other Land Use” (IPCC, 2006).

Table D1. Carbon pools

lucode	LULC_Name	C_above	C_below	C_soil	C_dead
1	lc_1	89.3	24.11	1.36	0
2	lc_2	15.46	4.18	1.36	0
3	lc_3	23.5	6.35	1.36	0
4	lc_4	23.5	6.35	1.36	0
5	lc_5	84.6	22.84	1.36	0
6	lc_6	4.23	1.14	1.36	0
7	lc_7	0	0	0	0
8	lc_8	0	0	0	0
10	lc_10	0	0	0	0

2.2. Results

Figure D3 and Figure D4 show the amount of carbon stored in Megagrams (Mg) in each pixel for the BAU and DAM scenarios. They are a sum of all the carbon pools provided by the biophysical table.

Figure D3. Carbon stored (BAU scenario)

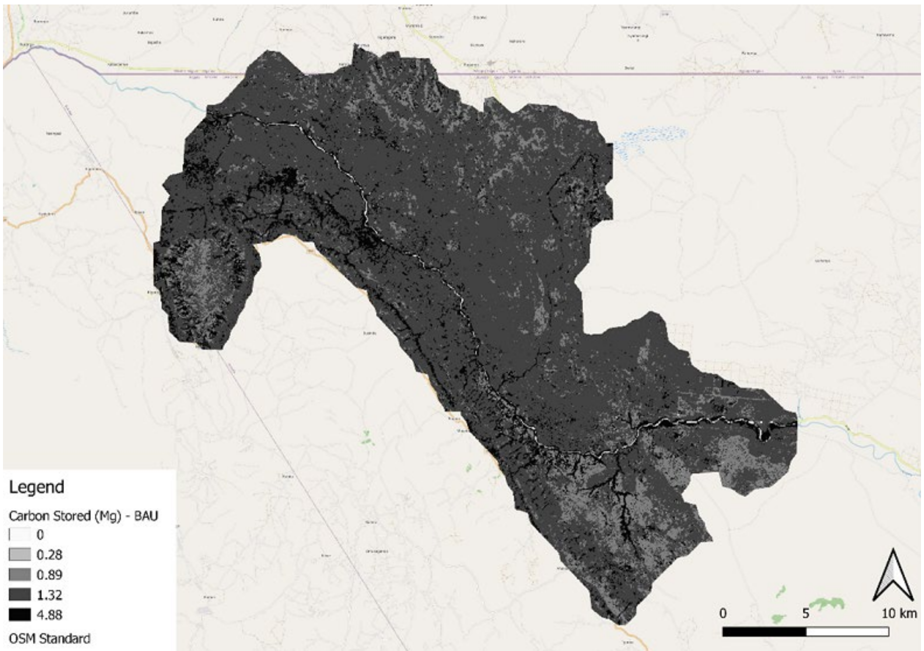


Figure D4. Carbon stored (DAM scenario)

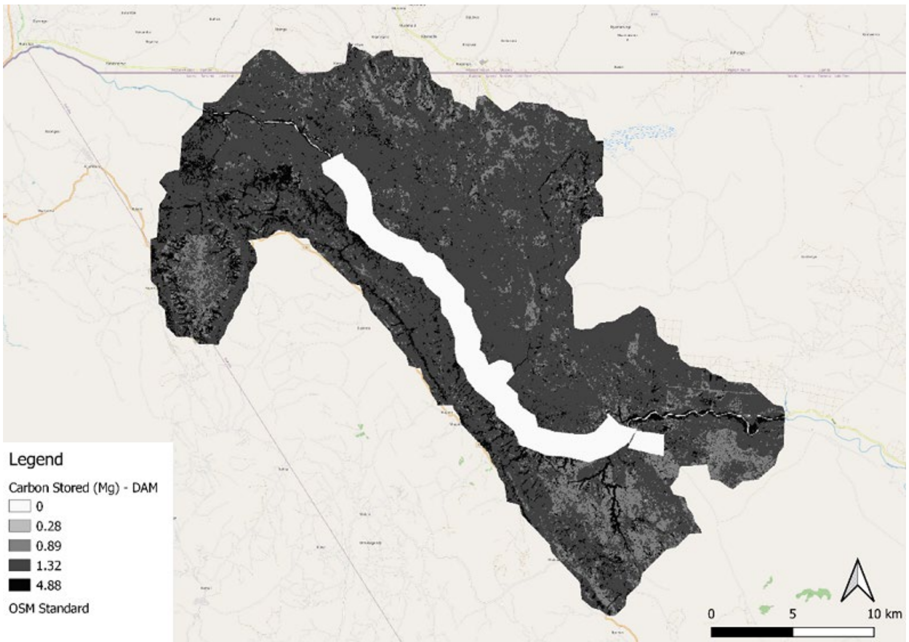


Table D2. Carbon pool statistics

	BAU	DAM	Change (%)
Sum (Mg)	2,257,461.59	2,159,078.38	-4.36

As Table D2 shows, in the BAU scenario the landscape would sequester approximately 2,26 million megatonnes of carbon. On the other hand, in the DAM scenario the study area would not be able to sequester approximately 98,383 megatonnes of carbon compared to the BAU scenario. In other words, the total carbon storage in the area affected by the completion of the Kakono hydropower project would decrease by more than 4% from the BAU scenario to the DAM scenario.

3. Habitat Quality

3.1. Input data preparation and processing

1. **Current Land cover map** – The LULC map developed by ESA/CCI in 2016 was used for both the BAU and DAM scenarios. For the BAU scenario, the LULC also showed an existing road. For the DAM scenario, the LULC also showed the reservoir, the dam, a built-up area, the existing road, an upgraded road, and a transmission line (for more information please check figure 3 of the environmental impact assessment for Kakono hydropower plant (2017)). Please note that the roads and the transmission line are represented by the lucode "9". Besides, the transmission line has also been considered a road, since we assume that one will be built to install the required infrastructure to transport the electricity generated by the hydropower plant. Figure D5 and Figure D6 show the land cover maps used to run the Habitat Quality InVEST model.

Figure D5. Land-cover map (BAU)

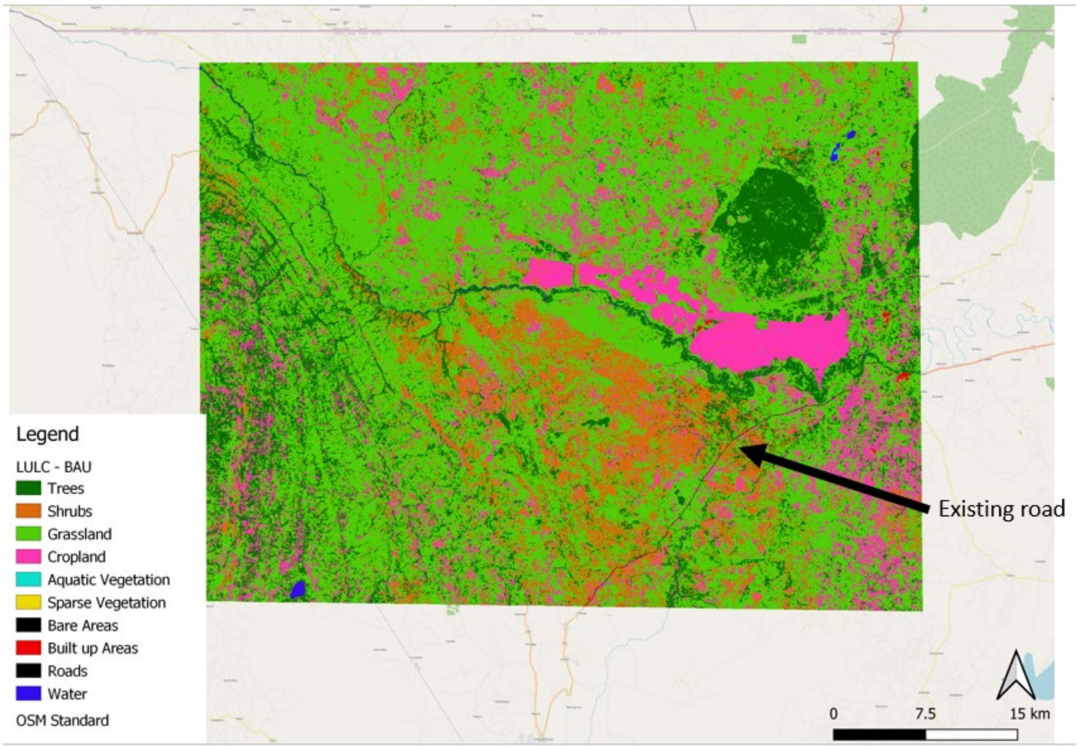
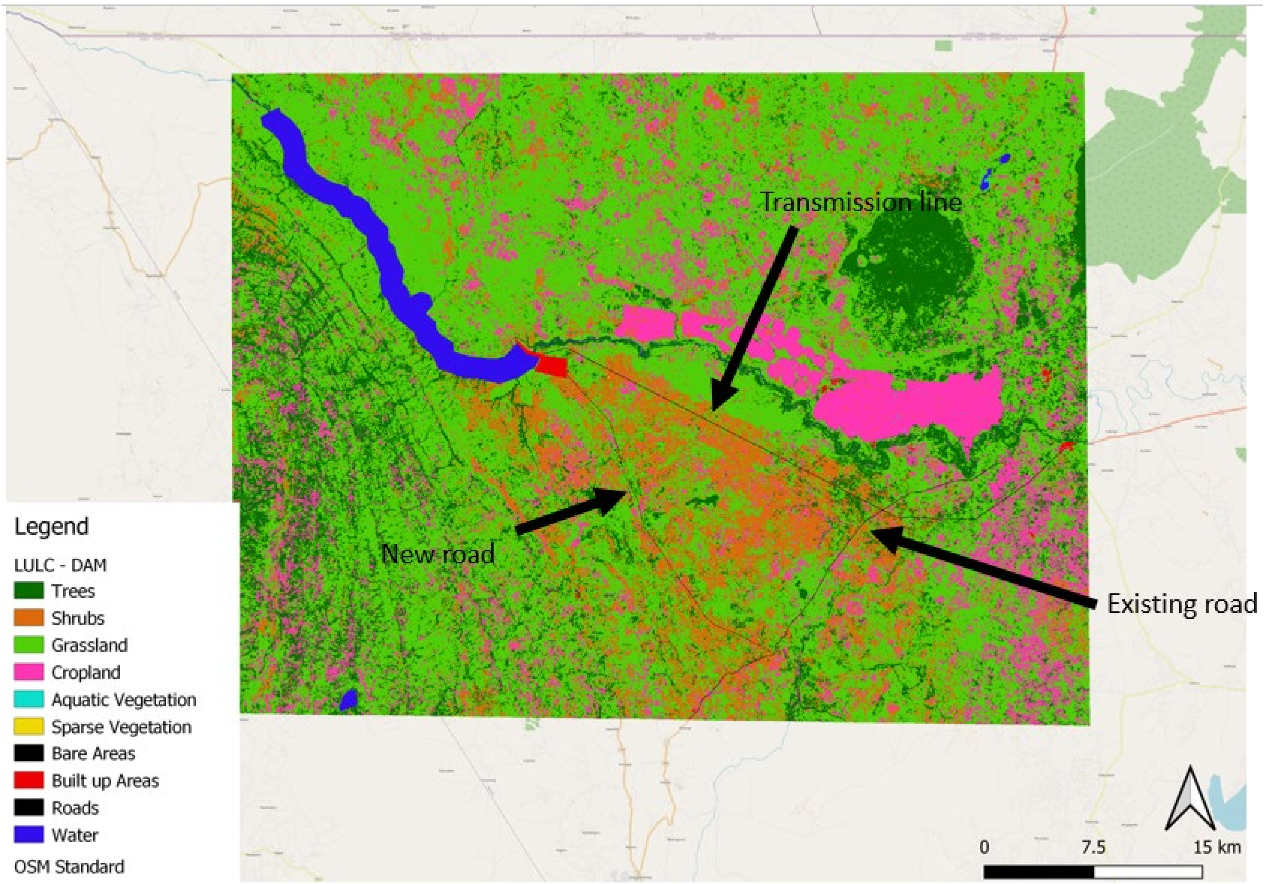


Figure D6. Land-cover map (DAM)



2. **Threat Data** - several major threats such as cropland areas, urban areas, and primary road networks have been identified as the threat sources to the natural habitat and biodiversity – see Table D3 below. See Table D12 for data sources.

Table D3. Table of threat (maximum distance, weighted value, and decay function) for InVEST simulation

N°	Threat name	MAX_DIST (Km)	WEIGHT	DECAY
4	Cropland	4.0	0.7	linear
8	Built-up Areas	7.1	0.7	linear
9	Roads	5.5	1.0	linear

3. **Sensitivity of land cover types to each threat:** Table D4 is characterizing each LULC type to be habitat or non-habitat and the type's sensitivity to the threats (see Table D13). The table contains the following fields:

   3.1 LULC – codes identify each LULC class

   3.2 Name – abbreviation of each LULC class

3.3 Habitat – score characterizing each LULC as habitat or non-habitat. The values of 0 and 1 are used for the purpose, in which 0 for non-habitat class and 1 for habitat class of LULC.

L_crop_4, L_urb_8, L_rd_9, – these are columns for the relative sensitivity of LULC classes to the threat. In this case, L_crop_4 contains the value for the sensitivity of each LULC class to "Cropland". L_urb_8 refers to "urban areas", and L_rd_9 refers to "roads", including transmission lines.

Table D4. Table of Sensitivity of land cover types to each threat for InVEST simulation

LULC	**NAME**	**HABITAT**	**L_crop_10**	**L_crop_11**	**L_mosa_30**	**L_urb_190**	**L_mo_280**
LULC	NAME	HABITAT	L_crop_4	L_urb_8	L_rd_9	LULC	NAME
1	lc_1	1	1	1	1	1	lc_1
2	lc_2	0.4	1	1	1	2	lc_2
3	lc_3	0.5	1	1	1	3	lc_3
4	lc_4	0.4	0.03	0.69	0.59	4	lc_4
5	lc_5	1	1	1	1	5	lc_5
6	lc_6	0.5	1	1	0.8	6	lc_6
7	lc_7	0	0	0	0	7	lc_7
8	lc_8	0	0	0	0	8	lc_8
9	lc_9	0	0	0	0	9	lc_9
10	lc_10	0	0	0	0	10	lc_10

4. **Half-saturation constraint** – the default value of 0.5 was used

3.2. Results

Figure D7and Figure D8 show the relative level of habitat quality in the study area considering both burned scenarios. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. The habitat score values range from 0 to 1, where 1 indicates the highest habitat suitability.

Figure D7. Scores of habitat quality (BAU)

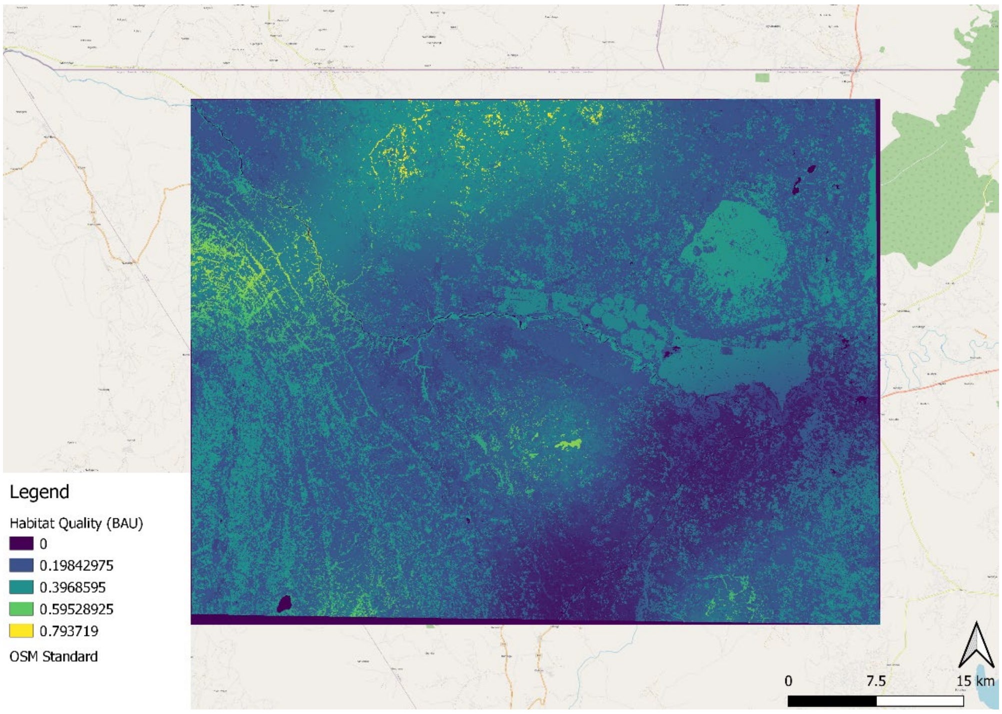


Figure D8. Scores of habitat quality (DAM)

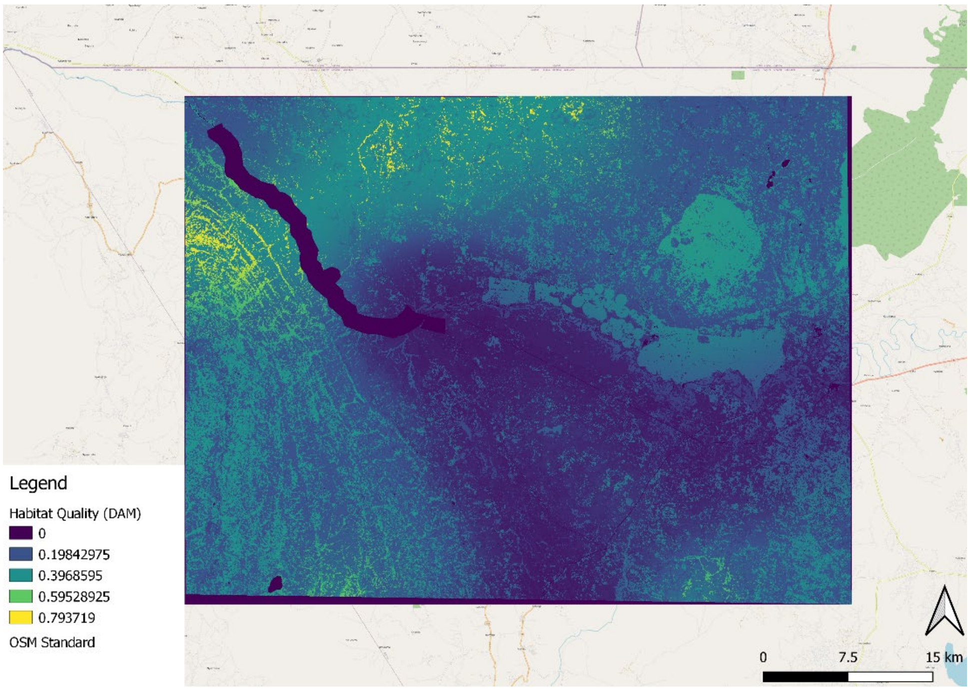


Table D5. Habitat quality statistics

	BAU	DAM	Change (%)
Mean	0.26	0.24	-8.52

As Table D5 shows, the mean of habitat quality in the study area considering the BAU and DAM scenarios is 0.26 and 0.23 respectively, which indicates that the value of habitat conservation is low in both cases. Nevertheless, in the DAM scenario the mean of the habitat quality would decrease by more than 8%, indicating that the development of the Kakono hydropower plant would negatively impact the surrounding natural environments.

4. Annual Water Yield

4.1. Input data preparation and processing

1. **Precipitation**– *A GIS raster dataset with a non-zero value for average annual precipitation for each cell. Its value is expressed in millimeters.* The average precipitation (in mm) from 1970 to 2000 downloaded from WorldClim version 2 (www.worldclim.com) was used for this study. The dataset was released on the first of June 2016. The original spatial resolution of the data is 30 seconds x 30 seconds (which is approximately 1 km^2). Besides, future precipitation data for the period 2061-2080 produced by calculating the average of nine global climate models (GCMs) have been downloaded from the same website and used in this model to compare current and future impacts of precipitation on water availability. Here, we considered the SSP585, SSP370, SSP245, SSP126 scenarios. In addition, we run this model using the average monthly precipitation for the dry and wet months that have been recorded from 2010 to 2018 to understand their contribution to the annual water yield.

2. ***Average annual reference evapotranspiration (ET0)*** – *A GIS raster dataset with an annual average evapotranspiration value for each cell in millimeters.* Reference evapotranspiration is the potential loss of water from the soil by both evaporation from the soil and transpiration by healthy alfalfa (or grass) if sufficient water is available. Its value is in millimeters. In this study, the global evapotranspiration of reference crops was adopted from "Global Aridity Index and Potential Evapotranspiration (ET0) Climate Database v2". The spatial resolution of the data is 30 arc-seconds (approximately 1km at the equator). Note: for the simulations using monthly precipitation data we used average monthly reference evapotranspiration data. The dataset can be found here:

   (https://figshare.com/articles/Global_Aridity_Index_and_Potential_Evapotranspiration_ET0_Climate_Database_v2/7504448/3)

3. **Root restricting layer depth -** These terms were defined as an average root restricting layer depth value for each cell. It is the soil depth at which root penetration is strangler inhibited because of physical or chemical characteristics. Root restricting layer depth may be obtained from some soil maps. If a root restricting layer depth is not available, soil depth can be used as a proxy. If several soil horizons are detailed, the root restricting layer depth is the sum of the depths of non-restrictive soil horizons. Its value is in millimeters. In this study, the absolute depth to bedrock downloaded from soilgrid.org stored in cm was used to present for root restricting layer depth

4. **Plant Available Water Content -** Plant Available Water Content (PAWC) is the fraction of water that can be stored in the soil profile that is available for plants' use. PAWC can be measured from 0 to 1. The format of PAWC for the model is a GIS raster dataset.

   Plant available water content is a fraction obtained from some standard soil maps. It is defined as the difference between the fraction of volumetric field capacity and permanent wilting point. The plant available water content is often available as a volumetric value (mm). To obtain the fraction it is necessary to divide it by soil depth. Soil characteristic layers are estimated by performing a weighted average from all horizons within a soil component. If PAWC is not available, raster grids obtained from polygon shapefiles of weight average soil texture (%clay, %sand, %silt) and soil porosity will be needed. In this study, the average calculation of available soil water capacity of the volumetric fraction of 2.0 (pF 2.0) from 0 to 2 m was used to represent the plant available water contents for water yield model simulation.

5. **Land cover map** - The LULC map developed by ESA/CCI in 2016 was used for both the BAU and DAM scenarios. For the DAM scenario, the LULC also showed the reservoir, the dam, and a built-up area.

6. **Watersheds -** This is the polygon shapefile representing the watersheds. The watersheds used for this study were downloaded from https://www.hydrosheds.org/ on October 24th, 2020. We used sub watershed level 11 for this simulation.

7. **Biophysical Table -** A table of land use/land cover (LULC) classes, containing data on biophysical coefficients used in this tool. These data are attributes of each LULC class rather than attributes of individual cells in the raster map. This table contains 5 variables included: [1] *lucode (Land use code)*, [2] *LULC_desc*, [3] *LULC_veg*, [4] *root_depth,* and [5] K_c. Table D 6 shows the biophysical table used in this study. Values have been derived from Hoy et al. (2015).

   7.1 Lucode (Land use code): Unique integer for each LULC class (e.g., 1 for trees, 4 for cropland, etc.), must match the LULC raster above.

   7.2 LULC_desc: Descriptive name of land use/land cover class (optional).

7.3 LULC_veg: Values must be 1 for vegetated land use except for wetlands, and 0 for all other land uses, including wetlands, urban, water bodies, etc.

7.4 root_depth: The maximum root depth for vegetated land use classes, given in integer millimeters. This is often given as the depth at which 95% of a vegetation type's root biomass occurs. For land uses where the generic Budyko curve is not utilized (i.e. where evapotranspiration is calculated based on the equation below, rooting depth is not needed). In these cases, the rooting depth should be set to NA. The equation can be found here in:

$$AET(x)=Min(Kc(\ell x)\cdot ET_0(x),P(x))$$

where

$ET_0(x)$ is the reference evapotranspiration,

$Kc(\ell x)$ is the evaporation factor for each land use and land cover.

Kc factor is the plant evapotranspiration coefficient for each LULC class. It is used to convert from reference evaporation to potential evaporation for each land use.

7.5 Kc: The plant evapotranspiration coefficient for each LULC class, used to obtain potential evapotranspiration by using plant physiological characteristics to modify the reference evapotranspiration, which is based on alfalfa. The evapotranspiration coefficient is thus a decimal in the range of 0 to 1.5 (some crops evapotranspire more than alfalfa in some very wet tropical regions and where water is always available).

Table D6. Biophysical table used in this study

lucode	LULC_desc	LULC_veg	root_depth	Kc
1	lc_1	1	7300	1.3
2	lc_2	1	5100	0.4
3	lc_3	1	2600	1
4	lc_4	1	2100	0.65
5	lc_5	1	7300	1.2
6	lc_6	1	7000	0.9
7	lc_7	1	5100	0.8
8	lc_8	1	5100	0.8
10	lc_10	1	5100	0.8

Z parameter - Z is an empirical constant that captures the local precipitation pattern and hydrogeological characteristics, with typical values ranging from 1 to 30. It is corresponding to the seasonal distribution of precipitation. This parameter is mainly used for model calibration, however, in this study, there is no observed data for the model calibration. Therefore, the recommended default value of the Z parameter equals to 5 was used.

4.2. Results

The main output is a table containing biophysical output values per watershed, with the following attribute: *wyield_vol* (m^3) - Volume of water yield in the watershed. Figure D9 shows the watersheds that have been considered.

Study area

Figure D9. Watersheds ID in the study area

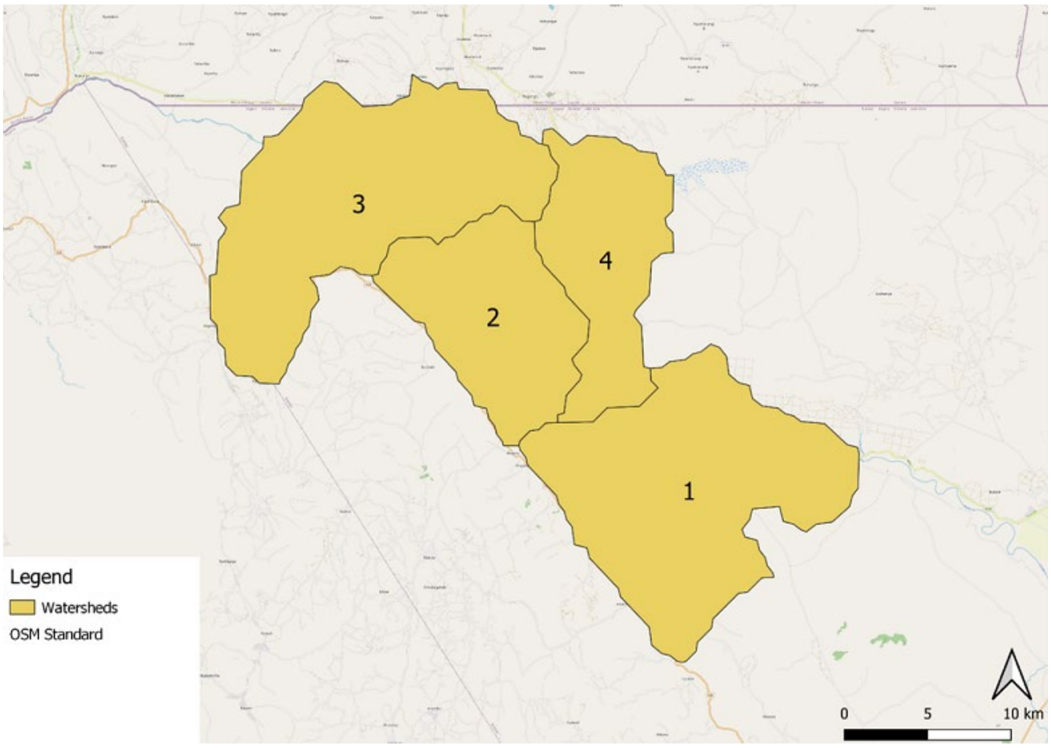


Table D7 shows that the reservoir created from the construction of the Kakono hydropower plant will increase water yield in almost all watersheds. In particular, the second one will experience a large increase in water availability (+14.51%), while in the third and fourth watersheds water volume will increase by 0.37/1.37%. The only exception is represented by the first watershed, where the volume of water yield will decrease by around 3%.

Table D7. Difference in water yield volume (m3) between BAU and DAM scenarios (1970-2000)

Watershed ID	BAU	DAM	Change (%)
1	20,815,752.70	20,147,121.97	-3.21
2	3,702,419.87	4,239,473.77	14.51
3	10,499,056.30	10,643,292.38	1.37
4	6,960,330.01	6,986,275.23	0.37

Table D8 shows the difference (in %) between the water yields calculated using average annual precipitation forecasts (2061-2080) under different climate scenarios and the values of water yield showed in Table 7, which have been calculated average annual precipitation records (1970-2000). In other words, Table 8 shows that under different climate scenarios, it is likely that water yield in the study area will increase between 10% and 50%, depending on the watershed and on the land-use scenario (BAU or DAM).

Table D8. Changes in water yield using annual average precipitation forecasts (2061-2080) for different climate change scenarios compared to Table D7

SSP585		
	BAU	DAM
Watershed ID		
1	28.53%	29.40%
2	45.88%	48.10%
3	44.04%	44.44%
4	33.09%	33.30%
SSP370		
	BAU	DAM
Watershed ID		
1	17.22%	17.54%
2	28.61%	29.96%
3	29.64%	29.93%
4	19.78%	19.93%
SSP245		
	BAU	DAM
Watershed ID		
1	24.95%	25.63%
2	38.82%	40.68%
3	37.24%	37.59%
4	27.98%	28.17%
SSP126		

	BAU	DAM
Watershed ID		
1	11.57%	11.62%
2	19.09%	19.98%
3	20.92%	21.15%
4	12.72%	12.83%

It is worth noting that the results above do not show if the water yield will remain constant during a certain year or if other causes, such as stronger and shorter rainfall events, will impact monthly water availability.

Table D9 shows that wet months (March, April, May, November, and December) contribute to more than 98% of the annual water yield in both the BAU and DAM scenario. On the other hand, dry months (January, February, June, July, August, September, and October) contribute by around 1% of the total annual water yield in the study area.

Table D9. Contribution of dry and wet months to the annual water yield (%)

	Watershed	**Dry months**	**Wet Months**
BAU	1	0.98%	99.02%
	2	0.37%	99.63%
	3	1.13%	98.87%
	4	1.11%	98.89%
	Watershed	**Dry months**	**Wet Months**
DAM	1	0.91%	99.09%
	2	0.40%	99.60%
	3	1.14%	98.86%
	4	1.11%	98.89%

5. Sediment Retention

5.1. Input data preparation and processing

1. **Digital Elevation Model (DEM) Raster** – DEM: the hydrologically conditioned elevation dataset which is distributed by HydroSHEDS (https://www.hydrosheds.org/) was downloaded on October 24, 2020. The original spatial resolution of the dataset is 3 arc-second (approximately 90 m at the equator). Its elevation values are in meters. The HydroSHEDS's data technical report can be found in:

   Technical report:
   https://www.hydrosheds.org/images/inpages/HydroSHEDS_TechDoc_v1_2.pdf

Technical page: https://www.hydrosheds.org/page/development

2. **Rainfall Erosivity Index (R) Raster** – A GIS raster dataset containing erosivity index for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rain storm, the higher the erosion potential. The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data. It value is $MJ*mm*(ha*h*yr)^{-1}$. The R factor dataset in spatial resolution of 25 km downloaded from https://www.nature.com/articles/s41467-017-02142-7 was employed for this study. The technical report of the data also can be found here: https://static-content.springer.com/esm/art%3A10.1038%2Fs41467-017-02142-7/MediaObjects/41467_2017_2142_MOESM1_ESM.pdf

3. **Soil Erodibility (K) Raster** – A raster dataset of soil erodibility. It is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. It value is in $T.ha.h.(ha.MJ.mm)^{-1}$. The spatial resolution of 25 km of soil erodibility download from https://www.nature.com/articles/s41467-017-02142-7 was used in this study.

4. **Land cover map** - The LULC map developed by ESA/CCI in 2016 was used for both the BAU and DAM scenarios. For the DAM scenario, the LULC also showed the reservoir, the dam, and a built-up area.

5. **Watersheds -** This is the polygon shapefile representing the watersheds. The watersheds used for this study were downloaded from https://www.hydrosheds.org/ on October 24th, 2020. We used sub watershed level 11 for this simulation

6. **Biophysical table** - A .csv (Comma Separated Value) table containing model information corresponding to each of the land use classes in the LULC raster. All LULC classes in the LULC raster MUST have corresponding values in this table (see Table D10 for the table used in this study and Table 14 for data sources). Each row is a land use/land cover class and columns must be named and defined as follows:

   - lucode: Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.) Every value in the LULC map MUST have a corresponding lucode value in the biophysical table.
   - usle_c: Cover-management factor for the USLE, a floating-point value between 0 and 1.
   - usle_p: Support practice factor for the USLE, a floating-point value between 0 and 1.

Table D10. Biophysical table used in this study

lucode	usle_c	usle_p
0	0	0
1	0.01	0.05
2	0.15	0.15
3	0.2	0.17
4	0.5	0.4
5	0.013	0.07
6	0.1	0.15
7	0.8	0.25
8	0.8	0.25
10	0	0.01

7. **Threshold flow accumulation** – The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM. This threshold directly affects the expression of hydrologic connectivity and the sediment export result: when a flow path reaches the stream, sediment deposition stops, and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully, so modeled streams come as close to reality as possible. The default value of 1000 was used in this simulation.

8. **Borseli K parameter (kb) and Borseli IC0 parameter (IC_0)** – two calibration parameters that determine the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream). The default values of kb=2 and IC_0=0.5 were used in the simulation.

9. **Max SDR value (SDRmax)** – the maximum SDR that a pixel can reach, which is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse sand (1000 µm; Vigiak et al. 2012). This parameter can be used for calibration in advanced studies. Its default value of 0.8 was used.

5.2. Results

Figure D30. Sediment deposition (tons/pixel) in the BAU scenario

Figure D41. Sediment deposition (tons/pixel) in the DAM scenario

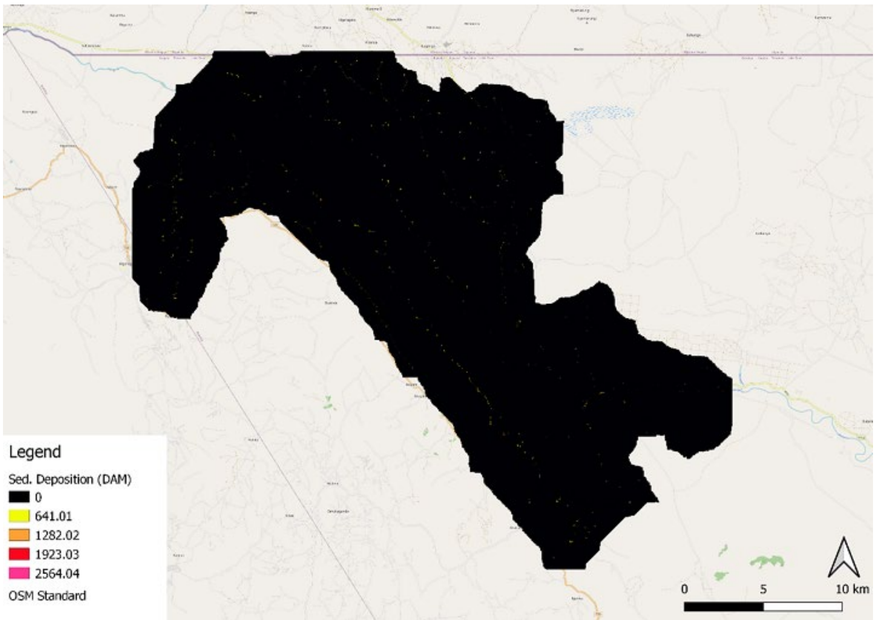


Table D11. Sediment deposition statistics

	BAU	DAM	Change (%)
Total (tons/pixels)	2,034,332.04	2,069,754.87	1.74
Mean (tons/pixels)	8.75	8.76	0.06

Table D11 shows the amount of sediments deposited on each pixel due to retention from upstream sources in the BAU and DAM scenario (Figure D10 and Figure D11 respectively). As the table illustrates, the difference in the sum of sediment deposition, as well as in the mean per pixel, is not significant between the two scenarios, and it is possible to assume that the Kakono HPP will not produce serious consequences on the sediment deposition dynamics in the study area.

6. Additional Resources

Table D12. Habitat Quality model – references "threat table"

Threat	Max_ Distance	Max_ Distance adopted sources	Weighted value	Weight value adopted sources	Decay function	Decay func. adopted sources
Cropland	4.0 km	(Terrado, et al., 2016)	0.7	(Bhagabati, et al., 2012)	Linear	(Bhagabati, et al., 2012)
Urban areas	7.1 km	(Terrado, et al., 2016)	0.7	(Bhagabati, et al., 2012)	Linear	(Bhagabati, et al., 2012)
Roads	5.5 km	(Barber, Cochrane, Souza Jr, & Laurance, 2014)	0.7	(Bhagabati, et al., 2012)	Linear	(Bhagabati, et al., 2012)

Table D13. Habitat Quality model – references “threat sensitivity table”

Value	Habitat	Habitat adopted sources	Sensitivity to Agricultural source	Sensitivity to Agri source adopted sources	Sensitivity to Urban Areas Sources	Sensitivity to Urban Area adopted sources	Sensitivity to Paved Road	Sensitivity to Paved Road adopted sources
1	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
2	0.4	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
3	0.5	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
4	0.4	(Terrado, et al., 2016)	0.03	(Terrado, et al., 2016)	0.69	(Terrado, et al., 2016)	0.59	(Terrado, et al., 2016)
5	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)
6	0.5	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	1	(Bhagabati, et al., 2012)	0.8	(Bhagabati, et al., 2012)
7	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
8	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)
9	0	Assumed	0	Assumed	0	Assumed	0	Assumed
10	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)	0	(Sulistyawan, et al., 2017)

Table D14. Biophysical table – sediment retention model

lucode	usle_c	usle_c adopted sources	usle_p	usle_p adopted sources
1	0.01	(Bhagabati, et al., 2012)	0.05	(Bhagabati, et al., 2012)
2	0.15	(Bhagabati, et al., 2012)	0.15	(Bhagabati, et al., 2012)
3	0.2	(Bhagabati, et al., 2012)	0.17	(Bhagabati, et al., 2012)
4	0.5	(Udayakumara & Gunawardena, 2016)	0.4	(Udayakumara & Gunawardena, 2016)
5	0.013	(Bhagabati, et al., 2012)	0.07	(Bhagabati, et al., 2012)
6	0.1	(Bhagabati, et al., 2012)	0.15	(Bhagabati, et al., 2012)
7	0.8	(Bhagabati, et al., 2012)	0.25	(Bhagabati, et al., 2012)
8	0.8	(Bhagabati, et al., 2012)	0.25	(Bhagabati, et al., 2012)
9	0.8	(Bhagabati, et al., 2012)	0.25	(Bhagabati, et al., 2012)
10	0	(Bhagabati, et al., 2012)	0.01	(Bhagabati, et al., 2012)