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Environmental and societal effects and impacts of hydro floating solar power plants

Photo: SN Aboitiz Power

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Abstract

Floating solar (FPV) energy production represents an innovative technology with the potential to increase renewable power production, meeting both rising consumption and the need to replace fossil-based energy. The HydroSun Competence project, led by the Institute for Energy Technology (IFE) and funded by the Norwegian Research Council, aims to support the rapid, cost-efficient, and sustainable development of renewable energy. This report, a deliverable of the work package led by NIVA, addresses the environmental and societal impacts of FPV on hydropower or multi-purpose reservoirs. Using the Magat reservoir in the Philippines as a case study, it investigates the effects of different FPV scenarios on environmental variables such as evaporation, water temperature, oxygen levels, and greenhouse gas emissions, as well as economic and socio-cultural factors. The study compares baseline, low cover, and high cover FPV scenarios, suggesting measures to enhance benefits and mitigate adverse impacts. The findings emphasize the importance of context-specific assessments and provide recommendations for optimizing FPV design and deployment to optimize benefits.

Keywords: Floating photovoltaic, ex-ante environmental impact assessments, hydrodynamic modelling, greenhouse gas emissions
Emneord: Flytende solcelleanlegg, konsekvensutredning av miljøkonsekvenser, hydrodynamisk modellering, klimagassutslipp

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Preface

Hybrid hydro – floating solar (FPV) energy production represents an innovative technology and a potential for increased renewable power production meeting both the increased consumption and the need to replace fossil-based energy. Hybrid hydro-FPV installations combine hydropower generation with FPV. The Hydrosun Competence project led by Institute for Energy Technology (IFE) aims to contribute to rapid, cost-efficient and sustainable development and deployment of renewable energy. The project, funded by the Norwegian Research Council, include five research institutions, IFE, Norwegian Institute for Water Research (NIVA), Norwegian University of Science and Technology (NTNU), SINTEF Energy Research and six companies, Hydro REIN, Multiconsult, Ocean Sun, Scatec, Statkraft and TGS-Prediktor. The competence project is part of the Hydrosun Green Platform Project lead by Scatec.

This report is a deliverable of the work package led by NIVA addressing environmental and societal considerations of FPV on hydropower or multi-purpose reservoirs. It presents results from a study investigating environmental and social effects of placing FPV systems on a reservoir based on primary data collection and including hydro dynamic reservoir modelling. The assessment refers to a conceptual framework for a structured process to the ex-ante assessment which includes verifiable indicators to predict the impacts of FPV for beneficiaries. The Magat reservoir in the Philippines is the case study reference for addressing effects on indicators, impacts on water use functions and the sustainable development goals with respect to a baseline scenario, as well as a low and high FPV cover scenario. Effects of different FPV scenarios on environmental variables such as evaporation, water temperature, oxygen concentrations, and greenhouse gas (GHG) emissions, and on economic and socio-cultural factors are presented. Measures for addressing adverse impacts and to enhance co-benefits are suggested and discussed. The report includes a chapter discussing the generic relevance of the results from the Magat case study, and a chapter addressing the effects of FPV on GHG emissions in two additional case studies.

The report has been prepared by Ingrid Nesheim and François Clayer at NIVA, with inputs from Atle Harby (SINTEF) and Josefine Selj (IFE). NIVA has primarily been responsible for the chapters 1 to 4 presenting the conceptual framework for the impact assessment, and the Magat case study results. Atle Harby (SINTEF) has been writing Chapter 5 on GHG emissions, and Harby has contributed to the general editing of the report. Josefine Selj (IFE) has been contributing to general editing as well as to the parts on current knowledge and studies of FPV power generation. We would also like to acknowledge the contributions from Enrico Laluan, Albert Corpuz, and Celeste Frayna from the local energy company SNAP. Enrico Laluan and Albert Corpuz have joined and facilitated all data collection activities and provided feedback on the report. Enrico Laluan has been the main contact person at SNAP, taking part in the planning of each field work campaign. Jørn Stave at Multiconsult has provided feedback and input to the work. At NIVA, Johnny Håll (field work and data analysis) and Laurence Carvalho (discussion on the project approach) have also contributed.

The Green Platform Project has provided a valuable arena for discussion with other research institutes and industry partners and their affiliated companies such as SNAP. This collaboration has enabled us to gather valuable insights and feedback on the assessment approach. We hope the report will be a useful contribution for sustainable development and deployment of FPV, and fill important gaps regarding the effect of covering a hydropower reservoir with FPV for environmental impacts, as well as possible impacts on different beneficiaries in society.

Abbreviations

CC	Climate change
BFAR	Bureau Fisheries and Aquatic Resources
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DENR	Department of Environmental Resources
DOA	Department of Agriculture
DOE	Department of Energy
DOH	Department of Health
EIA	Environmental impact assessment
EMB	Environmental Management Bureau
FGD	Focus Group Discussion
FPV	Floating photo voltaics
GHG	Green House Gas Emissions
GPV	Ground mounted photo voltaics
HEPP	Hydroelectric power plants
HyPPs	Hybrid power plants
IP	Indigenous people
LGU	Local Government Units
MASL	Meter Above Sea Level
NEDA	National Economic and Development Authority
NIA	National Irrigation Administration
NIPC	National Commission on Indigenous Peoples
NPC	National Power Corporation
NWRB	National Water Resources Board
PAGASA	Philippine Atmospheric Geophysical and Astronomical Administration
SIA	Social impact assessments
WFD	Water Framework Directive
WESM	Wholesale Electricity Spot market
WGI	Worldwide Governance Indicators
WHO	World Health Organization
WUFs	Water Use Functions

Summary

The report presents results from a study investigating effects of hydro-FPV on the environment and society based on primary data collection and hydrodynamic reservoir modelling. Effects of different FPV scenarios on environmental parameters such as evaporation, water temperature, oxygen concentrations, and greenhouse gas (GHG) emissions, and on economic and socio-cultural factors, are presented. Moreover, measures to enhance co-benefits and mitigate adverse impacts are suggested.

Chapter 1 provides the purpose of the report and gives a brief overview of the current trends in FPV projects as well as the current knowledge on expected environmental and social impacts. The need for methodological guidance on structured impact assessments is emphasized.

Chapter 2 presents the conceptual framework for the ex-ante sustainability impact assessment (SIA), comprising three phases. The pre-modelling phase describes the system, defines scenarios, and select indicators. The modelling phase assess the effects of FPV on multiple indicators by means of modelling and other quantitative and or qualitative approaches. The post-modelling phase analyse the impacts on identified beneficiaries, possible responses to the predicted impacts and measures to enhance co-benefits and mitigate adverse impacts. Stakeholder involvement takes an essential part in the three generic phases of the framework. The aim of the conceptual framework described here is to provide a structured process that includes approaches and tools for undertaking an ex-ante impact assessment based on verifiable indicators that predicts the impact of FPV scenarios on the environment and society.

Chapter 3 presents results from the study addressing impacts on the environment, economy and social-cultural issues of installing FPV on hydropower or multi-purpose reservoirs. The Magat reservoir located in the Cagayan Valley Region in the Philippines used for hydropower, irrigation, and aquaculture was used as reference case. The reservoir includes a 360 MW hydropower plant in operation since 1983, and a 220 kWp FPV pilot constructed in 2019. Both primary data and secondary environmental, economic and socio-cultural data were collected for the study. The assessment addressed impacts of a baseline scenario, a low cover FPV scenario, and a high FPV cover scenario. The baseline scenario refers to current conditions without additional FPV installations, the low cover FPV scenario refers to Installation of FPV covering 3-6 per cent of the reservoir surface and the high cover FPV scenario with FPV covering 9-24 per cent of the reservoir surface. The assessment of environmental conditions used models to predict quantitative effects. Knowledge rules are used to analyse and predict the influence of the baseline and FPV scenarios on 15 Water Use Functions (WUFs) characterised by selected indicators. The predicted impact on the environmental, economic and socio-cultural WUFs refers to the respective indicator values and considers both the groups of beneficiaries and SDGs.

The impacts are described by comparing the low and the high FPV cover with the baseline scenario. For the baseline scenario, potential changes in provision of WUFs are expected to have an insignificant impact on the scales of magnitude and importance. For the *low cover FPV scenario*, mainly insignificant changes on WUFs are predicted for national and reginal levels. For environmental impacts, the low cover scenario only shows some small impacts during extreme dry periods with low water level, low oxygen levels and high temperatures, negatively affecting water quality for recreational use and ecological status. For the high FPV cover scenario, impacts are more substantial and more frequent. FPV can reduce surface emissions of CO_2 and CH_4 by blocking gas exchanges. The production of additional renewable energy through FPV can offset some of the GHG emissions caused otherwise by non-renewable electricity generation in the region. For economic impacts, the low FPV cover scenario has minor negative impacts on aquaculture due to reduced space for fish cages, while the high FPV cover scenario significantly reduces fish production and employment. Both scenarios increase renewable energy production, with the high cover scenario boosting annual electricity generation by 42-46 per cent. Regarding socio-cultural impacts, FPV deployment affects local communities by altering navigation routes and reducing recreational opportunities. The high cover scenario has more pronounced negative impacts on social cohesion and cultural practices. The chapter also includes a discussion of measures suggested for enhancing co-benefits and mitigating adverse impacts. If more water is retained in the reservoir during the dry season, when there is high production of solar power, higher reservoir levels will mean better water quality and more water for irrigation.

Chapter 4 discusses the broader applicability of the findings from the Magat case study. It compares the environmental and socio-economic impacts of traditional hydropower production with hybrid hydro-FPV systems. The chapter highlights the potential benefits of FPV, such as reduced GHG emissions and improved water management, while also addressing possible negative impacts on local ecosystems and communities. It emphasizes the importance of context-specific assessments and suggests that the conceptual framework and findings from the Magat case study can inform FPV projects in other regions, promoting sustainable development and renewable energy integration. It is important to acknowledge that storage hydropower with reservoir have the ability to enhance the output of FPV by making total electricity output more adaptable to the consumption compared to FPV without a hybrid solution.

Chapter 5 focuses on the impact of FPV systems on GHG emissions from hydropower reservoirs. It describes the modelling of GHG emissions released through diffusive emissions from the reservoir surface, bubbling emissions from shallow areas in the reservoir and degassing downstream the hydropower turbines. Environmental factors impacting GHG emissions like water temperature, oxygen levels, retention time, water depth and inflow of organic matter are briefly described. The chapter presents findings from the Magat reservoir, showing that FPV can reduce surface emissions of CO_2 and CH_4 by blocking gas exchanges. The chapter also briefly shows results from two other studies in Albania and Guinea. These studies show the potential of reducing GHG emissions with FPV on reservoir depending on local conditions and what the important emissions pathways are. If emissions are dominate by bubbling, FPV will have small impact on GHG emissions. The chapter concludes with recommendations for optimizing FPV design and operation to maximize GHG reduction benefits.

Sammendrag

Rapporten presenterer resultater fra en studie av påvirkningen av flytende solkraftverk (FPV) på miljø og samfunn. Magat-magasinet i Filippinene er brukt som casestudium for å analysere effekten av flytende solkraftverk med ulik dekningsgrad på miljøparametere som fordampning, vanntemperatur, oksygenkonsentrasjon og klimagassutslipp, og på økonomiske og sosiokulturelle faktorer. Rapporten foreslår også mulige tiltak for å redusere uønskede virkninger og øke flerbruksnytten.

Kapittel 1 introduserer rapportens formål og gir en kort oversikt over flytende solkraft og utviklingstrender, samt kunnskapsstatus om konsekvenser for miljø og samfunn. I kapittel 2 presenteres rammeverk og metodikk for konsekvensvurderingen. Dette inkluderer en forberedende fase for å identifisere status for naturmiljø, økonomiske og sosiokulturelle faktorer, definering av scenarier og valg av indikatorer, en modelleringsfase for analyse av effekter av FPV på indikatorer, og en vurderingsfase for evaluering av konsekvenser for nyttehavere og for bærekraftsmål. I vurderingsfasen identifiseres også tiltak for å redusere skadevirkninger og øke flerbruksnytten. Involvering av interessenter har en vesentlig rolle i de ulike delene av rammeverket.

Kapittel 3 presenterer resultater fra effektstudien av ulike flytende solkraftverk med ulike dekningsgrader på Magat-magasinet. Analysen er basert på innsamling av miljøparametere, økonomiske, og sosiokulturelle data og faktorer og utvikling av en hydro-biogeokjemisk modell for beregning av kvantitative effekter. Evalueringen vurderer et referansescenario, et scenario med lav dekning av FPV, og et -scenario med høy-FPV dekning. Referansescenarioet vurderer effekter av forventet klimaendring, og av utviklingstrender og policies - uten kommersiell FPV produksjon, og her forventes kun mindre, og ubetydelig endringer. For scenarioet med lav FPV-dekning, ble det for kortere perioder beregnet lavt oksygennivå og høyere temperatur i forbindelse med lav vannstand og tørr sesong, samt noe negativ effekt av FPV-systemet for båttransport. Det vurderes at negative effekter kan dempes helt med tiltak. For høy FPV-dekning ble det beregnet lavt oksygennivå, høyere temperatur for lengre perioder, med negativ effekt for blant annet fisk, og vannkvalitet, akvakultur, salg av fisk, vanskelige forhold for båttransport, rekreasjon og kulturarv. Positive effekter ble beregnet for elektrisitetsproduksjon og fleksibilitet og for redusert GHG. For høy FPV dekning kan negative effekter kun dempes i noen grad. Flerbruksnytten av flytende solkraft kan økes ved å endre manøvreringsregimet. Hvis mer vann holdes tilbake i magasinet i tørrsesongen, når det er høy produksjon av solkraft, vil høyre magasinnivå innebære bedre vannkvalitet og mer vann til irrigasjon.

Kapittel 4 diskuterer resultater fra Magat-studien og sammenligner de miljømessige og sosioøkonomiske konsekvensene av tradisjonelle vannkraftverk med hybride hydro-FPV-systemer. Kapittelet understreker viktigheten av kontekstspesifikke vurderinger og foreslår at det konseptuelle rammeverket og funn fra Magat-studien kan informere FPV-prosjekter i andre regioner, og fremme bærekraftig utvikling og fornybar energiintegrasjon. Samlokasjon av flytende solkraft og vannkraft vil gi større muligheter til å tilpasse strømproduksjonen til forbruk og behov.

Kapittel 5 adresserer effekten av FPV-systemer på klimagassutslipp. Modelleringen av klimagassutslipp fra overflateutslipp i magasinet, fra utslipp nedstrøms kraftverket beskrives. Modellberegninger fra Magat-magasinet og fra to andre case i Albania og Guinea, viser at FPV kan redusere overflateutslipp av klimagasser ved å blokkere gassutvekslinger. Studiene viser at hvorvidt FPV kan redusere klimagassutslipp avhenger av lokale forhold og hva som er den dominerende utslippsformen for klimagasser. Dersom utslippene domineres av metanbobling fra grunne områder, vil FPV ha liten innvirkning på klimagassutslipp. Kapittelet avsluttes med anbefalinger for optimalisering av FPV-design og drift for å maksimere fordelene for redusert klimagassutslipp.

1 Introduction

Hybridization of hydroelectric and floating solar photovoltaic (FPV) systems represents a promising approach to increase renewable power production by leveraging dual use of area and infrastructure (World Bank 2019). The growing demand for renewable energy is driven by the need to replace fossil-fuel-based power sources and meet rising global energy consumption (Essak and Ghosh 2022; Scatec 2022a). However, as deployment rates accelerate, land scarcity is becoming a critical challenge, increasing the importance of technologies that enable dual use of land. In 2023, the total installed global capacity of FPV installations reached 7 GW (Lee et al. 2020; Masson et al. 2024) and more than 50 GW is expected for the next decade e.g., (Arnold, Giuliani and Castelletti 2024).

While dual land use is a key advantage of hybrid hydro-FPV installations, integrating solar power generation with hydropower - and potentially battery storage – can (Ikitde et al. 2023) offer additional benefits. The flexible use of multiple energy sources can help mitigate power production intermittency and increase annual productions (Solomin et al. 2021). Furthermore, the hybridization may support enhanced water management regimes, benefiting both upstream and downstream water users (Essak and Ghosh 2022). In addition to the benefits related to the hybridization, FPV installations have been reported to contribute to reductions in water evaporation from reservoirs (Exley et al. 2021; Scavo et al. 2021; Essak and Ghosh 2022; Exley et al. 2022).

The reported benefits, however, often lack reference to analysis of impacts of FPV systems on environmental, economic and socio-cultural aspects that are based on primary data (Bax et al. 2022; Pouran et al. 2022)￼. Besides, the effects of covering water bodies with floating solar panels on biodiversity and water quality are uncertain. Regarding GHG emissions, lakes and reservoirs are often net sources of both CO_2 and CH_4 (Tranvik et al. 2009; Deemer et al. 2016; Prairie et al. 2018). Considering social issues, water reservoirs are often unique resources for transportation, (Ho and Goethals 2021), fishing and aquaculture (Sarkar et al. 2018), for irrigating agriculture (Biemans et al. 2011), for domestic uses, for recreation and as part of rituals and ceremonies (Pande et al. 2020). There is hence a need to better understand impacts on different stakeholders and beneficiaries in society and to enhance potential co-benefits and address adverse impacts.

This report aims to fill gaps by providing results from a study investigating effects of hydro-FPV hybrid power plants (HyPPs) on the environment and society based on primary data collection and including hydrodynamic reservoir modelling. Effects of different FPV scenarios on environmental parameters such as evaporation, water temperature, oxygen concentrations, and greenhouse gas (GHG) emissions, and on economic and socio-cultural factors are presented. Further, measures, activities to enhance co-benefits and enhance adverse impacts are discussed. Three FPV scenarios were explored, (i) a baseline scenario including the FPV pilot and climate change, (ii) a low cover FPV intervention, and (ii) a high cover FPV intervention. Quantitative results from modelling are provided for environmental variables. Only approaches and qualitative and semi-quantitative estimations are provided for economic and socio-cultural issues and for indicators. The study does not address potential impacts of the construction phase and anchoring and mooring of the FPV, nor the necessary infrastructure to connect FPV to the substation or feed-in point to the grid.

The study was undertaken during 2021 – 2024 as part of the KSP Hydrosun (RCN 328640) project aiming for sustainable development of society by knowledge development for efficient design and operation of hydro and FPV-hydro HyPPs, and, investigating FPV impacts and possible co-benefits (Scatec 2022a). The project involves both research institutions and industry partners, a collaboration that has been essential for accessing historical data, collecting primary data beneath the floating structures, fostering interdisciplinary discussion among partners and enabling valuable feedback from industry partners.

While national states have frameworks for environmental impact assessments, such frameworks rarely specify a structured approach that implies that results can be easily verified by others in retrospect. The systematic approach for the assessment and methods and tools are often decided by consultants hired to do the impact assessment. This report contributes with a conceptual framework approach that facilitates a systematic, transparent, and verifiable impact assessment that addresses the effect and the contribution of FPV to environment and society. Subsequently, this framework is used to guide the assessment of a case study of FPV on the Magat reservoir, including the primary data collection and modelling efforts to assess the possible effects of covering the water surface with floats and solar panels, (i) on the natural environment, and (ii) the direct and (iii) the indirect effects on economic and socio-cultural values. Measures to enhance co-benefits and to reduce adverse impacts considering costs and feasibility issues are suggested. For the environmental impacts, the report presents results comparing the impact of hydropower installation with the impact of hydro-FPV HyPPs, given the same targeted total energy production.

The Magat dam in the Philippines was selected as the case study for this project because it offered important opportunities to use empirical field and operational data to support modelling of FPV impact on water level, temperature, evaporation, water quality and greenhouse gas emissions. The Magat dam located in the Ifugao and Isabela provinces was constructed between 1975-82 for irrigation, flood control and hydropower generation, with policy priority for irrigation purposes (IFC, accessed August 2024). In 2019, a 280 kWp FPV pilot was installed on the reservoir for further studies, and there are plans for the construction of a commercial 10 to 12 MW FPV as a first phase. Originally owned and operated by the government of the Philippines through the National Power Corporation (NPC), the 360 MW Magat powerplant was acquired by SN Aboitiz Power (SNAP) in 2007 through a privatization program[1]. The construction of the dam at the time caused some local conflicts (Elazegui and Combalicer 2004), while in recent decade, the conflict situation has been low and stable (Personal communication with local actors, 2021 – 2024). The existence of hydropower production, the pilot FPV system, and the low conflict level in the area were all important criteria for selection of the case study area.

Subsection 1.1 of the report presents a short introduction to, and review of FPV. Chapter 2 presents the conceptual approach guiding the ex-ante sustainable impact assessment which include: (i) a pre-modelling phase to identify the system addressed, selection of scenarios and indicators, (ii) a modelling phase to assess the impacts on indicators and (iii) a post-modelling phase to analyse the impacts on society based on selected indicators, and to identify activities to enhance co-benefits and reduce adverse impacts. Chapter 3 presents the Magat case including methods for data collection, the context description, the selected indicators, indicator values, and the integrated impact evaluation. This chapter also discusses possible policy responses for enhancing co-benefits and reducing adverse impacts. Chapter 4 discusses the project approach to ex-ante impact assessment and generic relevance. Chapter 5 presents the main pathways of GHG emissions from hydropower reservoir, the standard empirical tool to estimate these emissions and how FPV is expected to affect GHG emissions from hydropower reservoirs.

1.1 Presenting current knowledge and studies of FPV power generation

FPV implementation on existing hydropower reservoirs is subject to significant positive opinions given the expected benefits on energy provision, water savings, other potential positive environmental

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[1] SNAP (SN Aboitiz Power) is a joint venture between Scatec (Norway) and Group of the Philippines (Scatec, 2022).

impacts, and limited social negative impacts. Hydropower reservoirs also offer a new location for installing solar power which is important in countries, regions and sies with competition for land use – either between energy generation and agriculture, forestry, industry or settlements. However, very few studies focusing on the impacts of FPV have been based on field data collection including social aspects. Below we provide a summary of the current trends in deployment of FPV power plants as well as the current knowledge on expected environmental and social impacts.

FPV development over the past two decades and potential:

The first commercial FPV installations ranging between 4 and 1600 kW were installed between 2007 and 2013 in Japan, USA, Southern Europe, South Korea and Singapore (Trapani and Santafé 2015). The main purposes of these floating installations in addition to providing additional energy include evaporation reduction from irrigation ponds and availability of additional space where land is valuable for growth of crops. FPV is a relatively small, but growing niche within solar PV. The cumulative installed capacity grew from 10 MW in 2014 to 2.6 GW by August 2020, with 73% of the market in China and 94% in Asia, and most of the remaining accredited to Europe (Rocio et al. 2021). The growth has continued reaching 7 GW in 2023 (Lee et al. 2020; Masson et al. 2024), and although 2023 saw a decrease in installation rates compared to 2022, a strong growth is expected over the next decade (Rocio et al. 2021).

It has been estimated that covering only 1% of all the man-made reservoirs in the world, the potential capacity could reach 400 GWp (World Bank Group 2019; Amer et al. 2023). Man-made reservoirs, 17 percent which are for hydropower purpose according to ICOLD[2], present a substantial opportunity for the deployment of FPV, leveraging existing water surfaces to enhance renewable energy generation. Hybridization of existing HPP by covering 2.4% of their basin surfaces at the global scale would result in an increase in energy production from these power plants by 35.9% (Cazzaniga et al., 2019).

The vast majority of the existing FPV installations are based on float technology from Sungrow and Ciel & Terre, both of whom make use of a HDPE pontoon design (so-called “pure floats”) with low tilt angles. In the European market, the ZIM Float design developed by Zimmermann PV-Steel Group is currently the most widely deployed, while Sungrow and Ciel & Terre are still the leading technologies in Asia (Rocio et al. 2021). Other notable FPV technologies include the South-Korean company Scotra, and several different Chinese providers of HDPE pure floats. A very different design where PV panels are mounted directly on a floating membrane, is developed and patented by the Norwegian company Ocean Sun (used on Magat reservoir). There are also many FPV technologies currently under development, particularly for rougher sea conditions.

Expected benefits and negative impacts:

Beyond generating energy from a renewable source, FPV is an attractive option because of its perceived co-benefits—benefits beyond renewable energy generation (Gadzanku et al. 2021). Benefits have been reported in the literature when comparing FPV systems to both ground-mounted PV installations and uncovered waterbodies. It has also been reported that the overall environmental impact of FPV is expected to be much smaller than ground-based PV (Da Silva and Branco 2018). However, there is still a lack of robust validation for these suggested co-benefits, and comprehensive knowledge of FPV's environmental impact on local ecosystems remains limited. Existing literature on local environmental

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[2] *ICOLD keep a register of all dams with their purpose, The statistics refers to 62 000 dams, among the single purpose dams, 48 % are for irrigation, 17% for hydropower (production of electricity), 13% for water supply, 10% for flood control, 5% for recreation and less than 1% for navigation and fish farming (ICOLD retrieved November 2024 https://www.icold-cigb.org/).*

impacts of FPV systems is often suggestive with unsupported findings and significant methodological limitations.

In the pre-construction phase, FPV avoid some of the potential challenges of ground-based PV, including land allocation, deforestation and/or loss of terrestrial habitat, necessary runoff infrastructure and associated land-cover requirements. However, some of these constraints for ground-mounted PV have slightly different counterparts for FPV where legal restrictions can be present related to protection for drinking water, fish sanctuaries, or other water uses (Da Silva and Branco 2018).

During the construction phase of FPV plants there may be detrimental impacts on the bottom due to the anchoring, cabling structure, and trenching on soil (on land) used for grid connection. Water quality, the aquatic flora and fauna as well as the surrounding soils might be impacted due to soil and sediment disturbance with machinery as well as accidental oil and lubricants spillage and emission from machinery.

During the operational phase, impacts on the local radiation balance, which can induce “local climate effect” for ground-mounted PV (GPV) because of the strong albedo difference between PV modules and natural land, is expected to be insignificant for FPV since the water albedo is on average about 5%, approximately equal to the PV modules albedo (Cazzaniga et al., 2019).

FPV also present several other environmental concerns or expected benefits such as leakage of toxic chemicals from the panels, pollution from cleaning reagents applied on the panels, impact on water temperature, shading with effects on algal growth and food web, fish kills, competitive advantage for cyanobacteria versus other phytoplankton, hypoxia and anoxia with effects on fish and other aquatic life, release of reduced substances from the sediment (CH_4, H_2S, NH_4) with consequences on water quality or GHG emissions (Exley et al. 2021; Gadzanku et al. 2021).

FPV systems are commonly believed to operate at lower temperatures than their GPV counterparts. However, recent literature indicates that the cooling effect attributed to FPV systems may be less pronounced than earlier studies suggested (Kjeldstad et al. 2021; Dörenkämper et al. 2023), with some cases demonstrating that FPV installations can have similar or even higher operating temperatures than GPV systems (Peters and Nobre 2020). To date, most FPV panels have been installed at tilt angles greater than zero, meaning that the panels do not come into direct contact with the water; their only ambient medium is air. In this configuration, the thermal behaviour of the FPV system is influenced by the same factors that affect GPV systems: irradiance, air temperature, wind speed, humidity, and mounting design. Such FPV systems primarily rely on wind for cooling, while water temperature plays a minimal role in affecting cell temperature. Consequently, the mounting structure and local wind conditions are critical in determining the cooling efficiency of air-cooled FPV systems.

There are also FPV designs that allow modules to be mounted in thermal contact with water. In such systems, the water temperature becomes the principal factor influencing cell temperature, and water-cooled FPV systems are likely to operate at lower temperatures compared to air-cooled installations. Thus, while improved thermal performance may be observed in some FPV systems, it is not an inherent advantage across all installations and depends critically on system design and local climatic conditions.

Covering the water surface with a floating structure and PV panels will reduce water loss from evaporation yielding water savings. However, also evaporation reduction will depend significantly on the FPV design. In the case where the solar panels are fixed on pure floats that fully cover the water surface, the solar irradiation transmitted to the water is almost zero, achieving the highest water savings, while limiting the cooling effect to only conduction through the plastic floats. Hence, the convective cooling by wind will be much more important for these systems. On the other hand, the water-cooled design, where FPV panels are mounted directly on a soft floating membrane in direct contact with water (Ocean Sun), will maximize the cooling effect (Kjeldstad et al. 2021), but have an uncertain impact on water savings. The membrane is expected to physically reduce evaporation, but significant quantities of heat will be transmitted to the water in agreement with efficient cooling (Kjeldstad et al. 2021), locally increasing the water temperature. The membrane and modules are however expected to reduce convective and radiative cooling of the water surface leading to enhanced evaporation in the vicinity of the FPV.

It has been suggested that the glare caused by optical reflection of sunlight on the surface of the panels may also be a source of discomfort to the fauna or residents near the solar facility (Rose and Wollert 2015). However, more recent research on the subject demonstrates that PV modules exhibit less glare than windows and water (NREL 2018). Solar PV modules are designed to reduce reflection, as any reflected light cannot be converted into electricity.

Installing FPV with subsequent anchoring, mooring and necessary infrastructure such as maintenance platforms, power transformation and transmission, represents an additional hazard risk to the dam. It is possible that during a storm, the FPV and associated infrastructure may lose their anchoring and drift to block the spillway or harm the dam body and other installations, potentially causing dam failure in the extreme consequence.

Environmental impact assessments:

Despite the expected large environmental and technical benefits of FPV non-occupation of usable land areas, water savings and improved water security, potentially reducing algal bloom and higher solar production efficiency, comprehensive impact assessments are rare in the literature.

Recent studies underscore the importance of comprehensive environmental impact assessments and ongoing monitoring to address potential risks and maximize the benefits of FPV technology (Benjamins et al. 2024). Environmental impacts of FPV systems are expected to scale with the fraction of the water body's surface area they occupy (Exley, et al. 2021).

Key priorities for monitoring include:

- water quality sampling (e.g., dissolved oxygen, temperature) at various depths and locations beneath the FPV structures to understand small-scale heterogeneity.
- condition of light-dependent species such as phytoplankton, macrophytes, and macroalgae.
- scale and distribution of emitted polarized light levels and their attractiveness and conservation risk to flying polarotactic species.
- presence and usage of FPV structures by mobile species (fish, birds, mammals) using a combination of methods such as remotely operated in-air cameras, periodic visual surveys, underwater active acoustic surveys (for fish), passive acoustic monitoring (for cetaceans), and eDNA surveys (for benthic and pelagic communities).
- impacts of activities surrounding FPV installation, including power cables and maintenance vessels.

Socio-economic and socio-cultural impacts:

Most of the large waterbodies provide extensive ecosystem services to local communities including fishery (commercial and artisanal fish harvesting and aquaculture), irrigation water, recreation and tourism, cultural heritage sites as well as transportation. While it is often claimed that installing floating solar panels instead of ground mounted PV will reduce the level of conflict for space, there is currently no study assessing this potential benefit for inland waterbodies, including multi-purpose hydropower reservoirs. More attention is also being given to the assessment of potential ecological impacts of placing solar panels on water bodies rather than social impacts (Haas et al. 2020; Exley et al. 2021; Gadzanku et al. 2021).

On the other hand, the lack of knowledge on FPV environmental impacts, in particular, as well as other impacts, could be a reason for some stakeholders to have a negative opinion about a FPV project (Bax et al. 2022).

Hence regarding social aspects, there is very little knowledge on the real social impacts of FPV, especially on existing multi-purpose hydropower reservoirs. Based on one study, the deteriorated aesthetic of the natural environment could be one of the strongest barriers while trust in the authorities could be one the best way to raise support for a FPV project. FPV might pollute the scenery and reduce recreational activities, with negative impact on local property prices and associated negative considerations from nearby landowners. In this context, it seems important to provide information early about the social benefits and impacts of the FPV project to all local communities and stakeholders and to take their perspective into account during the project development phase.

Summary:

Some co-benefits of FPV, such as improved panel efficiency and reduced land usage, have been validated by a large number of studies, whereas others, such as water quality impacts, lack empirical evidence. The social impacts are the least understood so far and require a deep understanding of the local context.

The current and first version of recommended practice for design, development and operation of FPV systems provide recommendations to assess the impacts on flora and fauna, natural habitats, noise, visual value, soil, water quality and human health are provided in DNV guidelines (2021). While some of these impacts might have indirect effects on social values, the direct and holistic social impacts are currently ignored.

2 The conceptual approach to FPV ex-ante impact assessment

The study applied a conceptual framework for the ex-ante sustainability impact assessment (SIA) adapted from the approach deployed in the LUPIS project (Reidsma et al. 2011; McNeill et al. 2012). Ex-ante impact approaches[3] imply modelling and calibration of data to make projections for the future for different variables under defined scenarios. The framework (Figure 2.1) includes three generic phases, (i) a pre-modelling phase to describe the system, define scenarios, and select indicators, (ii) a modelling phase to assess the effects of FPV on multiple indicators by means of modelling and other quantitative and or qualitative approaches, and (iii) a post-modelling phase to analyse the impacts on water use functions (WUFs) and the Sustainable Development Goals (SDGs)[4]. WUFs are defined as the functions provided by direct or indirect use of a water body e.g. lake, reservoir, river for the benefit of biodiversity, society and people (Adapted from Perez-Soba et al. 2008). The WUFs selected for the impact assessment of the Magat case study (Chapter 3) are presented in Table 8. The post-modelling phase also involves addressing possible responses, i.e. measures to enhance co-benefits and reduce adverse impacts. The approach described allows a focus on stakeholders as beneficiaries, land and water use sectors, different governance levels, and multiple dimensions of sustainability.

Stakeholder involvement takes an essential part in all three phases of the framework. We understand stakeholder involvement as activities that enable stakeholders, that is groups who can affect, or are affected by an intervention, to comment and provide input into the development of decisions that affect them (Jeffery 2009; Freeman et al. 2018). Moreover, involvement should be based on stakeholder mapping referring to the process of identifying key stakeholders to engage with, across the full stakeholder spectrum, and determining the basis for engaging these stakeholders (Blázquez et al. 2021; van den Brink et al. 2022). During the pre-modelling phase, stakeholders from local, regional, and national levels need to be identified and consulted for input to the system description. Typical categories of stakeholders are, farmers using irrigation, aquaculture farmers, fisherfolk, boaters, people enjoying an area for recreation, or as part of cultural rituals, sector authorities, public authorities and sectors with mandate and responsibility in the area. Involvement is important for targeting data collection, for selecting relevant indictors and for including the relevant information in the developed scenarios (Hughes 1998). In the modelling phase, in addition to literature as source of information, input from stakeholders is important for adopting appropriate knowledge rules for predicting future impact, and for feedback on model results. For the post-modelling phase stakeholder involvement allows feedback on feasibility and convenience of possible measures for enhancing co-benefits and reducing adverse impacts.

The conceptual framework for the ex-ante impact assessment of FPV described below has been presented to the different partners, including industry partners in the Hydrosun project for their feedback. The purpose of these discussions has been to make the conceptual framework as relevant as possible for industry actors when considering the effects of FPV. It has not been the aim for this work to provide a framework for an EIA, defined by the IAIA (1980, 2009) as cited by Partal and Dunphy (2016) ‘the process of identifying, predicting, evaluating and mitigating the biophysical, social, and others relevant effects of development proposals prior to major decisions being taken and commitments made. States adopt legislation that specifies the national EIA requirements including such as procedures for

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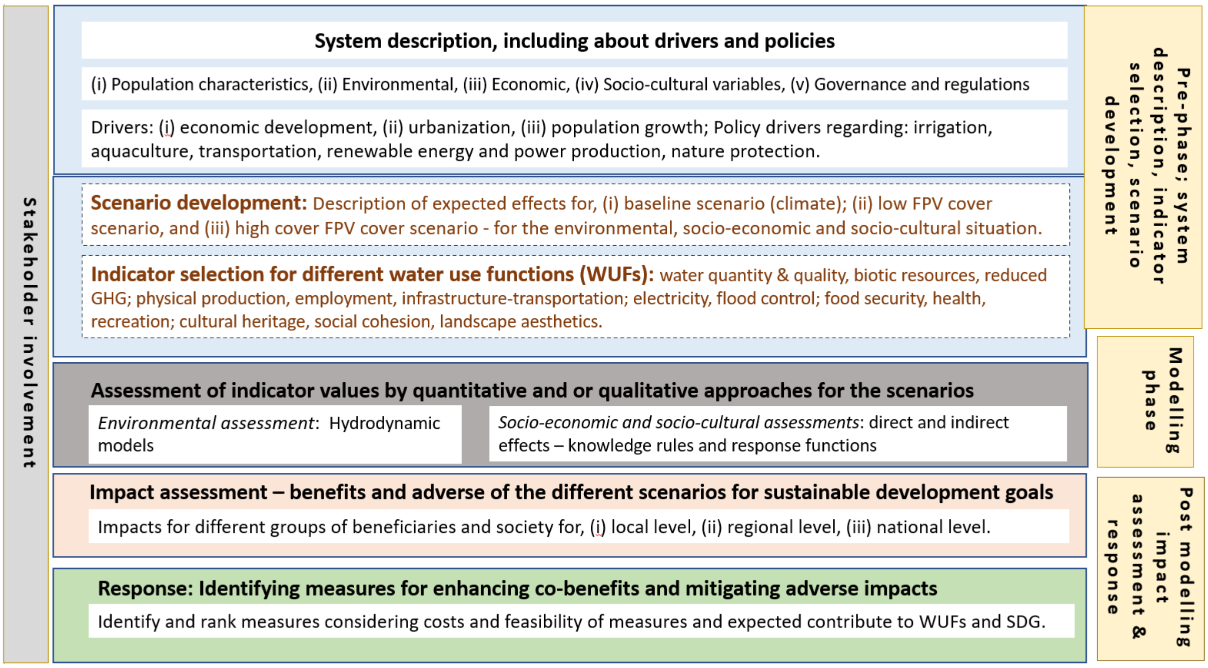
[3] *Ex-ante as contrast to ex-post approaches which analyses historical / empirical data to assess driver- impact relationships (Percoco, 2014).*

[4] *The members of the United Nations have adopted 17 Sustainable Development Goals (SDGs) (https://sdgs.un.org/goals).*

notification and hearing procedures, time scales, institutions with mandate to undertake decision (e.g. Regulations on impact assessments in Norway[5], and in the Philippines the Aministrative Order 03-30 or the Implementing Rules and Regulation of Presidential Decree No. 1586 (Annex 7.1). The aim of the conceptual framework described here is to provide a structured process that includes approaches and tools for undertaking an ex-ante impact assessment based on verifiable indicators that predicts the impact of FPV scenarios on the environment and society.



System description, including about drivers and policies

(i) Population characteristics, (ii) Environmental, (iii) Economic, (iv) Socio-cultural variables, (v) Governance and regulations

Drivers: (i) economic development, (ii) urbanization, (iii) population growth; Policy drivers regarding: irrigation, aquaculture, transportation, renewable energy and power production, nature protection.

Scenario development: Description of expected effects for, (i) baseline scenario (climate); (ii) low FPV cover scenario, and (iii) high cover FPV cover scenario - for the environmental, socio-economic and socio-cultural situation.

Indicator selection for different water use functions (WUFs): water quantity & quality, biotic resources, reduced GHG; physical production, employment, infrastructure-transportation; electricity, flood control; food security, health, recreation; cultural heritage, social cohesion, landscape aesthetics.

Assessment of indicator values by quantitative and or qualitative approaches for the scenarios

Environmental assessment: Hydrodynamic models

Socio-economic and socio-cultural assessments: direct and indirect effects – knowledge rules and response functions

Impact assessment – benefits and adverse of the different scenarios for sustainable development goals

Impacts for different groups of beneficiaries and society for, (i) local level, (ii) regional level, (iii) national level.

Response: Identifying measures for enhancing co-benefits and mitigating adverse impacts

Identify and rank measures considering costs and feasibility of measures and expected contribute to WUFs and SDG.

***Figure 2.1**. The conceptual framework for the ex-ante sustainable impact assessment (adapted from Reidsma et al. 2012)*

2.1 The pre-modelling phase: system description and scenarios development

The main purpose of the pre-modelling phase is to define and describe the system that will be influenced by the FPV intervention, including its stakeholders, the main issues and features. Identification of beneficiaries in the system, where a beneficiary is defined as a group or actors who experiences benefits from goods and activities in the context of a regulated watercourse, needs to be specified (García-Nieto et al. 2013; Nesheim and Barkved 2019; Garau et al. 2021). Taking the perspective of "beneficiaries" enables a contextualized approach by linking informants' perceptions of benefits to time and place; perceptions of benefits may differ, depending on whether the scale is local, regional or national. The identified beneficiaries may be positively or negatively affected by the FPV system.

In the following sub-sections, we will present the three elements of the pre-modelling phase: the system description, the scenario definition and the indicator framework.

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[5] *Regulations on impact assessments / Forskrift om konsekvensutredninger (2014)* FOR-2014-12-19-1758.

It is relevant to describe the pressure situation of the topics addressed, where pressure refers to influence of human activities e.g. excessive use of environmental resources, changes in land and water use, emissions to air water and soil on the environment because of production or consumption processes (Kristensen 2004).

2.1.1. Describing the system

The geographic area that will influence or be influenced by the FPV intervention as described in the FPV scenarios, represents the boundaries of the system description. The system description represents a description of the status and is the basis for selecting appropriate indicators for the impact assessment. It needs to address, **(i)** the environmental situation, **(ii)** population characteristics, (**iii**) the economic and **(iv)** socio-cultural situation, (**v**) governance features, and **(vi)** trends and policy drivers. Table 2.1 lists relevant variables for the system description. Both primary and secondary information data collection should be undertaken. Primary data collection complements existing literature and provides information on the local context. Interviews with local and regional authorities, and focus group discussions in local communities will provide useful information (see sub-section 3.2). Secondary information about the local environmental and socio-economic situation is often available from national and regional agencies. Also, scientific and grey literature can include useful information.

Below, drawing from EIA frameworks in Norway (vegvesen 2014) and in the Philippines the Administrative Order 03-30 or the Implementing Rules and Regulation of Presidential Decree No. 1586 (Annex 7.1), and from the document, "International Principles for Social Impact assessment (Vanclay 2003), we suggest topics for the system description.

(i) environmental parameters and factors – Identify the geographic area that are influenced by, or that will influence the FPV for a delimitation of the system description. The abiotic variables can include solar irradiance, air and water temperature, wind patterns, geologic aspects, surface area of reservoirs / lake, bathymetry of reservoir, hydrological dynamics (flow patterns, water levels fluctuations Inflow / outflow), thermal regime (pattern and dynamics of temperature distribution within the lake over time including stratification) of the lake / reservoir. Water quality variables include nutrient concentrations (e.g., nitrogen, phosphorus), color, turbidity, suspended sediments as well as dissolved greenhouse gas concentrations. Biotic variables include factors related to aquatic ecology – fish, zooplankton, phytoplankton diversity, bird migration patterns, protected species or species which have a local significance. Also, information on deforestation and erosion dynamics should be included. These variables help determine the essential processes that can lead to adverse environmental impacts and highlight specific factors of risks for the studied system.

(ii) Population characteristics - Describe population characteristics, as population density, including indigenous people and other minorities (Vanclay 2003). The existence or non-existence of current and previous conflicts and vulnerabilities are important features that need to be considered in the assessment of the effect of the FPV on economic and socio-cultural indicators.

(iii) The economic situation – Refers to the description of socio-economic groups and actors, economic activities, including the revenue of main economic activities. It also includes inequality patterns between groups of people, and employment and unemployment status. A description of the urbanisation, the urban / rural interrelations, and the infrastructure situation regarding access to electricity and transportation is also relevant to describe the economic situation

(iv) Social and cultural practices - Refers to recreation activities and the cultural heritage situation including such as presence of cultural/sacred sites (consider onshore and offshore). It also includes potential local environmental and or social pressures that may influencing social cohesions and health, as poor water quality, drought or conflicts between groups of people.

(v) Governance and institutions – Policy makers and decision makers responsible for adoption and implementation of policies need to be identified. An understanding of coherence and possible inconsistencies in legislation should be gained. The effect of policies and legislation depends on enforcement which is associated with the governance situation. The World Bank (Kaufmann et al. 2010) defines Governance as “the traditions and institutions by which authority in a country is exercised”. Characteristics of weak, poor or good governance are described with reference to the following dimensions, voice and accountability, political stability and absence of violence and terrorism, government effectiveness, regulatory quality rule of law and control of corruption (Kaufmann et al. 2010). Characteristics of weak versus strong governance should be considered in the system description to draw attention to the degree that public sector management is perceived as being transparent, accountable, allowing for the voice of actors, and being efficient and effective.

For the Magat case study, institutions, policies and legislation with influence on the Magat reservoir situation are presented in Table 3.2)

(vi) Trends and policies – This include identification and analysis of trends and policies to understand their influence on the system; knowledge that is important for an analysis of the baseline scenario (Table 2.1). Particularly relevant are economic and technological development trends, population growth, and urbanization. Regarding policies, minimum conditions to be considered in impact assessments include strategies and plans for renewable energy, irrigation, aquaculture, and legislation on nature protection and indigenous people. Legislation and policies set the decision space for FPV scenarios, and what determine the possible measures to enhance co-benefits or to reduce adverse impacts of FPV.

Assessing effects of policies often refers to a causal chain analysis, however, unidirectional causalities between factors are rare (Niemeijer and de Groot 2008). An assessment of policies and trends needs to acknowledge the complex interrelationships between actors, different variables and features. In subtropical and tropical areas, the use of reservoirs for subsistence, economic income, transportation and energy production is common. Hence, the system description should allow for an understanding of the interrelationship of the water – food – energy nexus in the area (Finley and Seiber 2014; Fayiah et al. 2020), including the related interplay of interests and values, power dynamics and conflicts in the area (Sianipar 2023).

***Table 2.1**. Variables of the system description.*

Relevant factors / variables	
Population characteristics	
Population numbers considering the lowest administrative levels	
Population growth, densities and demography	
Indigenous peoples and minorities	
Urban / rural situation	
Environmental variables	
Climate zone; regional weather patterns, climate variables including historical typhoon path	
Solar irradiance levels	
Temperature variations	
Wind patterns	
Geological aspect rim stability	
Surface area of reservoirs / lake	
Bathymetry of reservoir	
Depth of reservoir lake	
Hydrological dynamics (flow patterns, water levels fluctuations Inflow / outflow)	
Water quality variables, Dissolved Oxygen, Total Nitrogen, Total Phosphorus (NIA) were collected. Other variables as BOD, heavy metals or any relevant pollutant in the Priority Substances from the WFD (Directive 2000/ (European Commission 2000).	
Terrestrial ecology - KBAs, RAMSAR, bird migration, presence threatened species	
Land degradation, deforestation, erosion	
Aquatic ecology - fish biodiversity, zooplankton, phytoplankton, presence threatened species	
Ecological status	
Economic variables	
Socio-economic classes including poverty index situation	
Economic growth, drivers	
Employment situation, sectors	
Use of water for economic purposes	
Infrastructure and Accessibility - navigational routes, location of fish landing and ports	
Food security situation	
Health situation i.e. Water borne disease; WASH associated diseases	
Social and cultural variables	
Recreation activities	
Cultural heritage and traditional practices	
Social cohesion variables, including on conflicts among groups	
Landscape and identities	
Institutions, mandate, main rules and regulatory documents	
Administrative governance levels	Province & municipal strategies plans, strategies
Boundary and administrative/political jurisdiction over the reservoir	Watershed management plan
Information weak strong governance	Voice and Accountability, Political Stability and Absence of Violence, Government Effectiveness, Regulatory Quality, Rule of Law-
Environmental authorities and agencies	Environmental protection legislation, rules. Existence of National parks, reserve, sanctuaries.
	Land use & water use regulations, rights
	EIA rules
Agriculture & irrigation sector authorities	Area with irrigation and plans
Fishery sector authorities	Fishing rights, policies for expansions, aquaculture etc.
Energy sector authorities	Current situation and plans for expansion, GHG reduction goals
Cultural heritage responsibilities	Situation protection in case area
Authorities responsible for ethnic minorities, Indigenous people.	IP regulations
Local associations, unions – information about purpose, membership situation, association with sectors	
NGOs: information about purpose, membership.	

2.1.1. Scenario definition and selection of indicators

A scenario refers to the description of possible actions or events in the future with references to the current status. It is a useful tool for visualizing alternative images of the future for decision makers and other groups in society (Alcamo and Ribeiro 2001; Duinker and Greig 2007). A useful scenario structures information on driving forces, and other features characteristics of the system, as a narrative on relationships that seem plausible by experts and policy makers (Alcamo and Ribeiro 2001). Driving forces are trends that are assumed to influence future events. Values defining the driving forces can be quantitative or qualitative, and their assumed influence needs to refer to available data and publications.

Multiple scenarios, with different probabilities, are often developed to represent different trends or contrasting futures (See climate change scenarios, IPCC 2000). For environmental (EIA) and social impact assessments (SIAs), the construction of a baseline scenario is useful to present a narrative of the future without the project intervention, in addition to one or more FPV scenarios. Different FPV scenarios motivate to explore effects of different scales, and placement of the intervention. However, as developing scenarios requires extensive effort and expense, the number of scenarios are often limited. The current status description (the system description), the narratives of the baseline and the FPV scenarios serve to identify the indicators that will be assessed in the modelling phase (Section 2.2 this chapter). Below different types of scenarios are described, and then the indicator approach is presented.

The baseline scenario – The baseline scenario is a ‘do nothing’ scenario (Rathi 2017) being an assessment of the future situation without FPV enabling a comparison of the relative impact of the FPV. Assumptions need to be made and specified with respect to the extent of changes in relevant trends and policy drivers in a future situation and the environmental pressures, including the impact of climate change. Informed predictions of pressures and other trends can be gained from scientific publications, reports published by local and regional government institutions, and from interviews with actors. It is important to present uncertainties in the narrative on relationships between variables and features. The data for the system description, including data about existing policies and other drivers, and pressures are used to construct the baseline scenario.

The **FPV intervention scenario** includes a description of the FPV intervention; the size of the installation, the total influenced area, the FPV system technology, the mooring and the anchoring, the period of the installation etc. The handbook developed by the World Bank, “Where Sun Meets Water Floating solar handbook for practitioners” (2019), provides useful information about parameters that is relevant in FPV scenario definition. It may be relevant to define FPV scenarios that represent different scales of the FPV intervention, and it may be useful to construct an FPV intervention that includes measures to mitigate adverse impact and/or enhance benefits (Rowan and Streather 2011). The FPV scenario makes use of the narratives of the baseline scenario to produce a new narrative of the future which includes the FPV intervention. The FPV intervention scenario(s) considers the same drivers and pressures as the baseline scenario in addition to the effects of the FPV intervention on society. Uncertainties, data limitation, and assumptions regarding relationships between factors, and features must be clearly stated.

Selected indicators to assess the effects of identified scenarios.

The narratives of the different constructed scenarios are explored by indicators to describe the situation. The use of indicators can promote transparency and trust in the reliability of the undertaken assessment when combined with information on the data collection the analysis. Further, indicators are useful tools for communication between science, politics and stakeholders (McCool and Stankey 2004; Lehtonen 2015).

It is suggested to use an indicator framework to guide the selection process to ensure a harmonized and holistic approach, i.e. that all important issues are addressed in the impact assessment. As indicator framework for the conceptual assessment of FPV, we adopt and refer to Water Use Functions (WUFs) defined as the functions provided by direct or indirect use of a water body e.g. lake, reservoir, river by people or sectors, hence being beneficiaries in society. The WUF concepts is an adaptation of the Land Use Function (LUF) concept which is defined as types of goods and services provided by the different land uses in the area (Pérez-Soba et al. 2008; Reidsma et al. 2011). The WUF indictor framework presented allows us to highlight the link between the water body with important functions such as, provision of energy, employment, food security, transportation, recreation, and cultural heritage.

Indicators that represent direct and indirect water uses are used to characterize the WUFs, and the environmental pressures in the study area. Other relevant indicator selection criteria include scientific soundness (availability of data and models to assess changes in indicators), feasibility, usefulness (responsiveness; non-redundancy) (Czúcz et al. 2021). Because each indicator implies monitoring, evaluation, and reporting costs, redundant indicators should be avoided (Rice and Rochet 2005). Selecting appropriate indicators is often an iterative process considering input from stakeholders, experts, and competence and data availability. As biogeography, actors, and history differ between sites, suitable indicators need to be identified for the specific site. Lists of indicators, however, can represent valuable examples for inspiration (OECD indicators (retrieved 2024); Kaufmann et al. 2010). Selecting a single indicator per WUF allows for a straightforward communication with stakeholders, experts and other scientists. Selecting several indicators per WUF is more holistic, but also more complex (Paracchini et al. 2011).

Based on internal discussions, the study identified 15 relevant WUFs to represent the situation and enable assessment of environmental, economic and socio-cultural issues (Table 2.2). The WUFs, grouped according to the environmental, economic and socio-cultural sustainable development dimensions, are described below. Table 2.3 presents examples of possible indicators characterizing the WUFs, including information on the unit of their assessment, and the parameters. Table 3.5 in Chapter 3 presents the indicators being assessed for the Magat dam.

Environmental WUFs - The water body provides abiotic and biotic resources for the environment and for society.

The functioning of the abiotic and biotic resources is addressed by assessing the effects on: "*Available freshwater*" (WUF 1) defined as the sufficient freshwater for ecosystem functioning, human consumption and domestic and industrial usage; "*Provision of good water quality*" (WUF2) defined as existence of healthy and safe water quality for domestic and sector usage, swimming and ecosystem functioning; "*Provision of biotic resources"* (WUF3) defined as the role of water systems in supporting and supplying living organisms (fauna and flora) that are used for various human and ecological purposes and characterized by their abundance and diversity; and, "Reduced GHG emissions" (WUF4) defined as management for the reduction of GHG emissions.

Economic and socio-economic WUFs – the water body provides space and resource functions for a diverse range of economic activities. Economic WUFs refers to functions that involve costs for the actors, or functions / activities that lead to production processes and output of products (goods or services).

The following seven WUFs were identified: “*Physical production*” (WUF 5) defined as the function of water for agricultural and or aquaculture products, fishing yields etc. that will ultimately be sold or retailed; “*Provision of employment*” (WUF6) defined as the situation where water is resource that is basis for employment or income; “*Access to transportation*” (WUF7) defined as the degree that the waterbody provides efficient and feasible means of transportation; “*Provision of electricity*” (WUF8) refers to the use of water body as a function for generating affordable, and flexible energy for the state; “*Enabling flood control*” (WUF9) defined as the management function reducing damage by flooding. “Provision of food security” (WUF10) defined as the situation that there is reliable access to a sufficient quantity of affordable, nutritious food. “Contribution to good health” (WUF11) situation that the water uses provides for *“a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity*.

Social and cultural WUFs –The international principles for SIA conceptualize culture as subsidiary to the social domain, where social impacts are considered to include changes to ‘people’s culture – that is, their shared beliefs, customs, values and languages or dialect’ (Vanclay 2003). Socio-cultural impact assessment is less common (Alomoto et al. 2022), yet the effect on social and cultural situation often implies significant impacts and as a result reduced social acceptance (Partal and Dunphy 2016; Liao 2023). Water is known to be important for people for recreation, wellbeing, identity and rituals (UNESCO 2003).

Four social – and cultural WUFs were defined.; “*Recreation opportunities*” (WUF12) defined as qualities provided by different direct and indirect water uses, as appreciation of scenery, associated with recreational use for different groups in society and providing opportunities for education. ; “*Protection of cultural heritage* (WUF13) Water usage is managed in accordance with the aim of protecting cultural heritage where cultural heritage comprises cultural tradition and practices, rituals, artefacts, monuments, sites, that have symbolic, ethnological significance. “Existence of s*ocial cohesion*” (WUF14) defined as the extent of connectedness and solidarity among groups in society. WUF 15 *Provision of landscape* aesthetics and the effect that landscape / waterscape features this may have on the wellbeing of that people.

Table 2.2. Definition of the water use functions (WUFs).

Water Use Functions	Definitions
Available fresh water	Provision of sufficient freshwater for ecosystem functioning, human consumption, domestic use and for industries.
Good water quality	The waterbody is characterized by healthy and safe water quality for domestic usage, swimming, and ecosystem functioning.
Available biotic resources	Biotic resources include flora and fauna of different ecosystems used for various human and ecological purposes and characterized by their abundance and diversity.
Reduced GHG emissions	Water usage is managed for the reduction of GHG emissions.
Provision of physical production	Water usage provides for physical production, this can refer to direct harvest from the water body, or the use of water for physical production on land e.g. irrigation agriculture.
Provision of employment	Water usage - directly (for ex. as irrigation water) or indirectly (for ex. by representing an ecosystem where fishing can occur), is a function for employment and income.
Provision of transportation	Water represents a means, a function for navigation and transportation.
Provision of electricity	Water usage enables energy production.
Flood control management	Water use infrastructure and management can contribute to flood control.
Provision of food security	The World Food Summit (1996) defined food security as the physical, social and economic access to sufficient, safe and nutritious food, at all times, to meet dietary needs and food preferences for an active and healthy life. Here the focus is on a potential change in food security due to the FPV intervention.
Contribution to Good health	WHO (1948) defines health as *"a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity"*. The focus is on change in health status due to changes in water body environmental variables; water quality, quantity, or biotic resources.
Recreation opportunities	Qualities provided by different direct and indirect water uses, as appreciation of scenery, associated with recreational use for different groups in society and providing opportunities for education.
Protection cultural heritage	Water usage is managed in accordance with the aim of protecting cultural heritage.
Existence social cohesion	The extent of connectedness and solidarity among groups in society (Manca, 2014). OECD defines social cohesion as social inclusion, social capital and social mobility (OECD 2011).
Provision of landscape aesthetics	Landscapes and waterscapes affect nearby residents in terms of wellbeing that people gain from seeing, visiting, or even knowing of the existence of certain landscape features (Abraham, Sommerhalder and Abel 2010). FPV project operations and the FPV panels may change the character of the surrounding landscape / seascape and provide intense reflectivity "glare" (Anurag et al. 2017). Here the focus is on the degree that nearby residents experience that the change reduces their recreation activities, and that glare is disturbing.

Table 2.3. *Indicator examples for characterizing the WUFs. Annex includes more examples of relevant indicators).*

Water Use Functions (WUFs)		Indicator examples	Quantitative / qualitative units	Relevant parameters for the indicator assessment
Environmental WUFs	**Provision of water availability**	*Area irrigated & no. months w. access to irrigation water*	*Number*	Water temperature (impacts GHG emissions) Drought: water level below a threshold upstream Hydropower production: average head height, number of days for which head height below/above a threshold Dissolved oxygen concentrations (for fisheries) Nutrients
		No. of months w. access to irrigation of domestic garden.	*Number*	
		No. of days with reduced water availability in the reservoir, water level below estimated threshold to avoid risk of affecting ecosystem integrity	*Number and qualitative risk assessment*	
		Water flow downstream is acceptable for fishponds	*Qualitive categories w. ref. to infor. on water level thresholds*	
		No. months water for efficient hydropower production.	*Number*	
	Provision of good water quality	*No. month with acceptable ecological status situation of water*	*Number & qualitative assessment of situation.*	
		No. days when water quality status for domestic usage is unacceptable		
		No. days when water quality status for swimming, recreation is unacceptable.		
		No days with unacceptable abundance of algae and cyanobacteria.		
	Available biotic resources	*Mortality fingerlings / young / adult fish*	*Number of events*	Data from local fish cage owners. Fish species and thresholds oxygen concentration, temperature (literature). Reports sector authorities.
		Fish diversity (change in species number)	*Diversity index*	
		Change of fish body mass and size.	*Statistics*	
	Reduced GHG emissions	*Water Temperature change (impacts GHG emissions)*	*Number*	Greenhouse gas emission fluxes
		Avoided emissions of CO2 eq. per KWh due to renewable energy production		
Economic WUFs	**Provision of physical production**	*Sale of fish local fish market (weight)*	*Number, semi-quantitative qualitative indication of change.*	Available fish and boat landing area, Navigation constraints, dissolved oxygen concentrations, temperature.
		Weight aquaculture production (weight)		
		Sale of aquaculture production (weight)		
		Sale of irrigated agricultural production (weight)		Available irrigation water, area receiving irrigation water, statistics on sale.
		Fishpond production downstream (weight)		
	Provision of employment	*Pproporiton households (upstream) income from fishing, from aquaculture, from fishponds, from irrigation agriculture.*	*Number/ percentage within admin. area*	Statistics on current situation from local authorities, predicted effect of direct n ,
		Number of people employed associated with the FPV intervention and due to FPV ripple effects	*Qualitative assessment*	Plans, strategies to employ local people.
	Access to transportation	*Access to port*	*Binary / qualitative assessment*	Mean time spent on navigation per unit distance, area planned for FPV panels, main current navigation routes, gas prizes.
		% households where boating is the main mode of transportation	*% within area*	
		Increased navigation time to main port & increased costs for fuel	*Number*	
		Navigation time to fishing areas on lake		

	Provision of electricity	*Breaches of power-contracts (increased reduced)*	*Number Qualitative assessment Number*	Statistics on power cuts, analysis of reasons for power cuts, reported incidents where risks for energy rationing and curtailment of power production Ancillary services to keep grid stability.
		Tot. annual HEPP generation		
		Tot. annual electricity produced by hybrid hydro-FPV plants		
		Number of events for energy rationing		
		Number of events when power generation is curtailed	*Number*	
		Grid stability – how often the hybrid hydropower-FPV plant can deliver ancillary services	*Number*	
	Provision of flood control	*Estimated averted damage costs*	*Number (costs)*	Official statistics.
		/ Expected reduced nr. of households being impacted by flooding	*Number; %*	
	Good health situation	*Occurrence of water borne diseases*	*Number and predicted % change*	Abundance algae and cyanobacteria, dissolved oxygen levels
		Occurrence of WSH related diseases		
	Provision of food security	*Level of food security support needed by residents from local authorities.*	*Number and predicted % change*	Poverty index, information on marginalised groups, indicator values for the WUFs biotic resources, employment and transportation.
		% households that fish to contribute to own consumption		
Socio-cultural WUFs	**Provision of recreation activities**	*Proportion that uses boating for recreation*	*No. occurrences, qualitative assessments*	Primary data collection, statistics from local authorities, analysis of satellite images, planned area placement of FPV panels, area where recreation activity is compromised.
		Proportion that uses the area around the reservoir for picknicks		
		Number of days with unsafe swimming conditions due to spring flow(downstream)		
		Plans for excursion and field trips for schools developed by local authorities, energy company		Policy plans, education plans.
	Protection of cultural heritage and traditional practices	*Rates of occurrence of traditional practices villages / households*	*Qualitative assessment.*	Information on current situation, and of trend. Primary data collection.
		Protection sacred area, ancestral rites	*Presence of sites and assessment of protection*	Current situation protection. *Policies, strategies rules legislation, qualitative assessment of degree protection.*
		Presence ancestral domains		
	Existence of social cohesion	*Occurrence / change of conflicts among people associated with water use*		History or reported conflicts considering who / groups of people involved, infor. On marginalised groups, change economic and social cultural WUFs.
	Provision landscape aesthetics	*% residents who* are disturbed by this and from glare from FPV panels) in een in relation to the proportion of the waterscape occupied by FPV panels. Assessment of visual impact on recreation activities, and on cultural heritage and on everyday VISUAL impact	*Semi-quantitative / qualitative values.*	*Preferably primary data undertaking. Parallel studies from similar contexts are useful, but may not be representative as landscape and identity are associated with place (Howley 2011)*

2.2 The modelling phase: approaches for assessing effects on indicator values

Modelling in this framework refers to assessing the effects of the scenarios on selected indicators. The assessment of the effects of FPV needs to integrate in the analysis the effect of policy drivers and trends (see on 2.2 on scenarios). Indicator values can be expressed quantitatively and/or qualitatively. Effects of FPV on economic and socio-cultural issues can occur directly as part of competition for space, and indirectly by means of change in environmental factors caused by FPV. FPV installation may also drive other aspects of society, the so-called ripple effects (Bredesen and Aass 2016).

Both expected positive and negative effects of FPV on indicators should be investigated in the modelling. It is recommended to include the degree of uncertainty and information needed to verify the indicator values in the model assessment.

Below we briefly describe three main types of assessment approaches, (i) qualitative knowledge rules, (ii) quantitative empirical models, and (iii) advanced mechanistic quantitative approaches. The appropriate approach for assessing the indicator values depends on the available data, the competences, the available time, and the topics or indicators in question.

2.2.1. Qualitative and semi quantitative knowledge rules and response function

The use of qualitative knowledge rules refers to the expected relations between variables or situations, when this is supported by other cases, described and documented in scientific literature or other documents, that verify the relation (Sieber et al. 2008). An example of a situation of a knowledge rule could be, that the installation of an FPV system will cover an area excluding the use of the same area for other purposes. This could be verified by referring to official documents. Similarly, the relationship that the FPV installation will lead to increased employment rates, can be supported by referring to scientific literature, and or documents where this relationship is established. Knowledge rules are typically relevant for economic and socio-cultural issues and indicators where the level of transferability and knowledge is often too low to construct precise quantitative models. Qualitative information, based on previous experience can be used and typically depends on logical reasoning of cause and effect behind diverse aspects of behavior. In some cases (particularly for the socio-cultural aspects) tangible data is often lacking and it is not possible to define the expected response based on scientific literature. In these cases, when scientific knowledge is lacking, information gathered through expert opinion, experience, and intuition, can be used to reach an agreement between experts, stakeholders, and decision makers on certain behavior of a causal chain to predict impacts.

In contrast, environmental issues and indicators can often be directly quantified through either empirical or advanced mechanistic or dynamic models.

2.2.2. Quantitative empirical models

Empirical models are built from many previous assessments from similar cases which include a wider range of conditions than those applicable to the study case. They provide an established quantitative relationship between site-specific variables and indicators. A correlation or other statistical relationship between factors and variables can be identified to provide quantitative effects on indicators drawing on historic events and past assessment. Historic events are an important source of knowledge for estimating or assessing the likely impact on a function for a specific beneficiary /stakeholder.

The empirical models require site-specific input data, but these are usually readily available, and account for some uncertainty based on the model error where it has been validated previously. In other words, the uncertainty is transferred from a set of analogous previous cases. A good example of an empirical model is the G-res tool (Prairie et al., 2021) which is widely used during the planning phase of a new hydropower reservoir to predict the carbon footprint of reservoirs over its entire lifetime. The G-res tool is built on an extensive meta-analysis of published statistically robust empirical models developed over more than three decades.

Empirical models directly estimate the quantitative effects on indicators, including the associated uncertainty. The results can be used directly or be translated on a relative magnitude scale as for the knowledge rules above. Empirical models can also be referred to as response functions. For each indicator to be assessed the response function, and the underlying assumptions, needs to be described. The causal chains described in the pre-modeling phase, specifying policy drivers and pressures in the system, can be described using mathematics and statistics.

While empirical models play a vital role in impact assessments due to their simplicity and reliance on observed data, their limitations must be carefully considered. Issues such as dependency on historical data, lack of causal understanding, static nature, scale and transferability problems, uncertainty and sensitivity, and ethical and social considerations highlight the need for more advanced modeling approaches. Integrating mechanistic models, Bayesian networks, and fuzzy logic can help address these limitations by providing a more comprehensive, dynamic, and nuanced understanding of complex systems and their impacts.

2.2.3. Advanced mechanistic quantitative approaches

Advanced mechanistic quantitative approaches have become increasingly pivotal in enhancing the accuracy, reliability, and comprehensiveness of impact assessments. These approaches leverage detailed mechanistic models that represent the underlying processes and interactions within a system, providing deeper insights and more robust predictions.

Mechanistic models are based on the fundamental principles governing the behavior of systems, such as physical, chemical, biological, and socio-economic processes. Unlike empirical models that rely on observational data to establish correlations, mechanistic models use theoretical frameworks to simulate how systems respond to various inputs. This allows for a more nuanced understanding of causal relationships and the potential impacts of different scenarios.

When enough knowledge has been gained from previous applications, mechanistic models do not necessarily need to be applied to new cases since the impact can be assessed with this newly established “knowledge rule”.

Despite their advantages, mechanistic models face several challenges. Mechanistic models can be computationally intensive, requiring significant resources to run detailed simulations. High-quality, detailed data are essential for accurate mechanistic modeling. Incomplete or inaccurate data can lead to unreliable predictions. Efforts to improve data collection and integration are critical for the advancement of these models. Mechanistic models are sensitive to the assumptions and parameters used. Quantifying and communicating uncertainty are crucial for their effective use in decision-making. Techniques like sensitivity analysis and uncertainty quantification are important tools for model validation and reliability assessment. Impact assessments often require integrating knowledge from various disciplines. Effective communication and collaboration among experts in different fields are essential for developing comprehensive mechanistic models.

Dynamic systems modeling, such as hydrological reservoir modelling, involves simulating the time-dependent behavior of complex systems. This approach is crucial for assessing impacts that unfold over time or vary with season or specific climate events, such as the effects of extended droughts. Techniques like differential equations and agent-based modeling are often used to represent the dynamic interactions within the system (Norling et al. 2021).

Bayesian networks (BNs) are probabilistic graphical models that represent a set of variables and their conditional dependencies via a directed acyclic graph. They are particularly useful for their ability to handle uncertainty and incorporate expert knowledge (Jackson-Blake et al. 2022). They consist of nodes representing variables and edges denoting conditional dependencies. The relationships are quantified using conditional probability tables (CPTs), which capture the likelihood of each variable given its parent nodes. BNs effectively manage and propagate uncertainty through the network, providing probabilistic outcomes that reflect real-world complexities. They allow for the incorporation of expert knowledge, which is crucial when empirical data are limited.

Fuzzy logic is an approach that handles the concept of partial truth, where truth values range between completely true and completely false. This is particularly advantageous in impact assessments dealing with imprecise or ambiguous information. Fuzzy logic systems consist of fuzzy sets, membership functions, and rules. Inputs are fuzzified into degrees of membership across various sets, processed through a rule-based system, and then de-fuzzified into crisp outputs (Fayek and Flores 2010). Fuzzy logic excels in scenarios where information is vague or incomplete, providing more flexible and realistic assessments. It mimics human decision-making processes, making it suitable for assessments that require subjective judgments.

2.3 The post-modelling phase: Impact assessment of scenarios and responses

The post-modelling phase of the conceptual framework (Figure 2.1) comprises an assessment of the impact of the FPV intervention and the identification of possible responses to the predicted impacts, that is measures to enhance co-benefits and mitigate adverse impacts (Rowan and Streather 2011).

2.3.1. The impact assessment of the development intervention

The impact analysis considers the effects of the scenarios on the WUFs as characterized by the indicators being assessed (Figure 2.2). For some WUFs, more than one indicator is identified. The assessment addresses impact on the, (i) the beneficiaries affected by the interventions, and (ii) on the impact of society regarding the SDGs.

The impact analysis is presented with reference to the “magnitude” of the impact, and the “significance” of the impact as considered by society. The magnitude scale is defined, with reference to the increased or reduced provision of WUFs (Table 2.3a) for distinct groups of beneficiaries, according to the following categories: Highly severe reduction, Severe reduction, Intermediate reduction, No change, Minor positive increase, Intermediate positive increase, Substantial increase, Highly substantial increase. The scale of “significance” reflect societal norms and values as can be seen in adopted laws or policies as for example, nature protection laws addressing areas or species, laws protecting indigenous people, but also political objectives as increased energy provision. The five following categories are suggested: (i) Low significance, (ii) some significance, (iii) intermediate significant, (iv) high significance, (v) very high significance.

The impact analysis and the ranking exercise will be influenced by the perspective of actors involved (Amalanathan and Anouncia 2016). It is therefore essential that the analysis is transparent regarding the actors involved in ranking, which indicator values are being considered, consideration of literature etc. It is relevant to specify the beneficiaries, the actors that will experience effects, and effects on vulnerable groups. If the impact values are not recognized by the actors in the FPV influence area, the impact assessment will have little value. In such cases the FPV intervention may cause conflicts and low social acceptance (See also, Klæboe and Sundfør 2016).

The impact of the baseline and the FPV scenarios are analyzed focusing on beneficiaries (Figure 2.2). The perspective enables a holistic approach by taking an inclusive perspective to distinct types of actors as beneficiaries. The beneficiaries in the system are identified during the system description (pre-modeling phase); the modelling provides results on which beneficiaries will be affected negatively or positively by the intervention. It is relevant for a study to define a particular age group as youth or elderly people or based on ethnicity as target beneficiaries. Depending on whether the scale is local, regional, or national perceptions of benefits are likely to differ (Nesheim and Barkved 2019).

An alternative to the focus on different groups of beneficiaries for the impact assessment is a focus on the Sustainable Development Goals (SDGs). There are 17 SDGs, each with a number of specified sub-targets targets and associated indicators (UN 2024 retreieved September 2024). SDGs that may be affected by a FPV intervention are listed in Table 2.4. While both the SDGs and the WUFs explore overlapping themes, their methodologies and applications diverge. The SDGs are aspirational targets designed to guide global, national, or regional progress, often focusing on large-scale societal outcomes. In contrast, WUFs take a more operational perspective, emphasizing specific, functional aspects of how water resources are utilized or managed within the context of the reservoir. The SDG approach aligns with broader policy objectives, whereas the WUF framework is more localized, emphasizing practical resource allocation and immediate stakeholder impacts. Together, these perspectives offer complementary insights for assessing and understanding the broader implications of FPV implementation.

__Table 2.3a__. Magnitude of impact, definition of different categories

Magnitude of impact on WUFs	Definition / explanation
Highly severe reduction	The reduction of the WUF represents a complete disruption for most groups of beneficiaries, for the environment and the society.
Severe reduction	The WUF will be severely reduced for several group of beneficiaries. The change does no longer allow continuation of the same type of activities for these people.
Intermediate reduction	The WUF will be reduced for some beneficiaries, the ability to undertake the activity will be challenged in particular for vulnerable people.
Minor /minimal reduction	There is minor reduced provision of the WUF for beneficiaries, adaptation to the new system is feasible for most groups.
No change	There may be change but the change may be cause by other drivers in the system.
Minor positive increase	The increased provision of the WUF is experienced by a few beneficiaries, the increased provision does not imply ripple effects.
Intermediate positive increase	The increased provision of the WUF is experienced by some beneficiaries, and the increased provision increases the ability to undertake the activities / increases to some degree commitment to policy objectives.
Substantial positive increase	The increased provision of the WUF enhances the ability to undertake the activities for several beneficiaries / the commitment to policy objectives is recognized among actors / referred to in documents.
Highly substantial positive increase	The increased provision of the WUF enhances the ability to undertake activities for most beneficiaries / the commitment to policy objectives is significant compared to other situations / referred to in documents.

Table 2.3b. Significance of the of the impact, definition of different categories

Level of significance	Definition.
Insignificant importance / value: no symbol	The change that occurs caused by the intervention does not have any importance for stakeholders or beneficiaries. The variable, issue is not identified as a relevant variable for consideration in local, national or international (e.g. SDGs) policy documents.
Some significance: *	The change that occurs caused by the intervention has some importance for a few stakeholder categories or beneficiaries. The variable, issue is identified as a relevant variable for consideration in local, national or international (e.g. SDGs) policy documents.
Intermediate significance: **	The change that occurs caused by the intervention has medium importance for stakeholders or beneficiaries. The variable, issue is identified in local, and or regional / national policy documents as policy objective, it may either reduce a known pressure in the watershed or mitigate the pressure.
High significance: ***	The change that occurs caused by the intervention has high importance for stakeholders or beneficiaries. The aspect /issue is regulated in local, and or regional / national legislation policy documents. It may either reduce a known pressure in the watershed or mitigate the pressure. Not respecting this rule will cause conflicts in the local area.
Very high significance: ****	The change that occurs caused by the intervention has high importance for stakeholders or beneficiaries. The aspect /issue is regulated and enforced in local, and or regional / national legislation policy documents. It may either reduce a known pressure in the watershed or mitigate the pressure. Not respecting this rule will lead to high conflict levels between groups of stakeholders.

Table 2.4. List of Sustainable Development Goals (SDGs) that may be affected by FPV.

SDGs	Definition SDGs (UN 2024)
1.: No poverty:	End poverty in all its forms everywhere.
2: Zero hunger	End hunger, achieve food security and improved nutrition and promote sustainable agriculture. (8 specified targets)
3. Good health and well-being	Ensure healthy lives and promote wellbeing for all at all ages.
6, Clean water and sanitation	Ensure availability and sustainable management of water and sanitation for all; it includes 6 targets. Among relevant targets are addressing drinking water, increase water use efficiency and ensure freshwater supplies (6.4), water related ecosystems, and IWRM. Indicators: Level of water stress: freshwater withdrawal as a proportion of available freshwater resources.
7: Affordable and clean energy	Ensure access to affordable and clean energy for all. (5 specified targets)
8 Decent work and econ. growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. (8 targets)
9. Industry innovation infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
11. Sust. cities and communities	Make cities and human settlements inclusive safe, resilient and sustainable: target "protect the world's cultural and natural heritage.
13. Climate action	Take urgent action to combat climate change and its impacts.
15. Life on Land (incl. freshwater)	Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

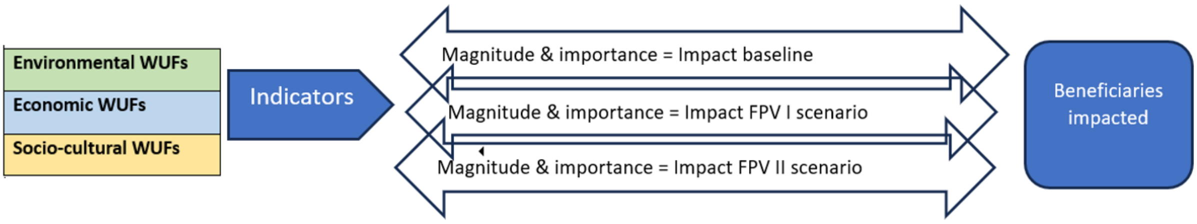

Figure 2.2 The figure illustrates that the WUFs and the associated indicators are used as reference for assessing the impact of scenarios on beneficiaries, and SDGs

2.3.1. Response to enhance co-benefits and reduce or mitigate adverse impacts

Considering the effects of the FPV intervention on the different WFUs and beneficiaries assessed in the modelling phase, potential measures to enhance co-benefits and reduce identified adverse impacts can be identified. As the final element of the conceptual framework for ex-ante sustainable impact assessment, this sub-section addresses response measures to enhance co-benefits and to mitigate or reduce adverse effects of the FPV intervention. *Co-benefits* refers to the positive effects of an intervention for beneficiaries and society, beyond the intervention's main objective. Examples includes such as increased employment, stimulation of investments, and the multiplier effects of employees spending some of their wages in their communities (Esteves and Barclay 2011; Kjærland et al. 2012). Mitigation measures are implemented to avoid or minimize negative environmental effects. The aim of such measures may also be compensation for negative social impacts resulting from the inequitable distribution of benefits and costs associated with an intervention (Macintosh et al. 2010; Walker 2010). Mitigation measures are important elements in licensing processes and are typically included in criteria for licence (Sánchez and Gallardo 2005).

The discussion of possible measures to address risks of adverse effects and to enhance co-benefits may be initiated already in the pre-modelling phase. Identifying potential measures in an early stage can enable the developer/owner to adapt the planning accordingly. As suitable measures for co-benefits and mitigations actions differ depending on context, involvement of stakeholders in identifying measures increase chances of success. Identifying measures to increase the positive impact of FPV for local communities can contribute to social acceptance (Esteves and Barclay 2011; Rowan and Streather 2011). Social acceptance refers to, as cited in Ellis and Feraro (2016) "a favorable or positive response (including attitude, intention, behavior and — where appropriate — use) relating to proposed or in situ technology or social technical system by members of a given social unit (country or region, community or town and household, organization)' (Upham, 2015, p. 107). Social acceptance, or the lack of acceptance of renewable energy projects, is recognized as a key challenge (Rosso-Cerón and Kafarov 2015). Social acceptance is influenced by peoples' perception of the distribution of costs and benefits, impacts on landscape, health, and biodiversity, the degree of public participation, and trust in the government and institutions (Ellis and Ferraro 2016)[6].

Costs effective and feasible measures to enhance co-benefits and mitigate adverse impacts - Measures for either enhancing co-benefits or mitigating adverse impacts can be addressed in an iterative process, starting with a suggestion of measures that includes both technological, social, and engineering solutions by the industry partners. Steps for considering suggested measures are suggested

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[6] *Regarding wind energy projects, Ellis and Ferraro (2016) argue that projects' neglect of broader social implications, is likely to have been a contributing factor to decreasing levels of social acceptance.*

(Figure 2.3). suggests steps for reviewing suggested measures, including (i) costs, (ii) convenience, (iii) mitigation effect, (iv) weighing by considering local, regional policy priorities, (v) evaluation.

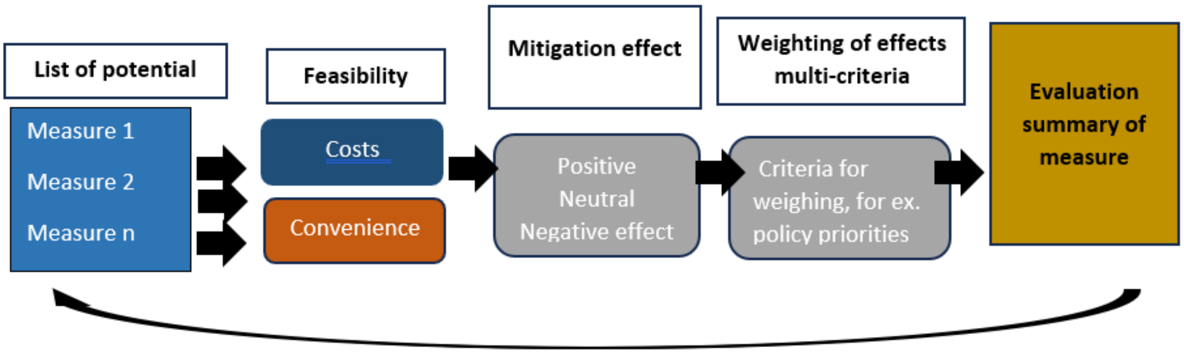


Figure 2.3 *Steps for considering suggested measures to address adverse impacts and enhance co-benefits.*

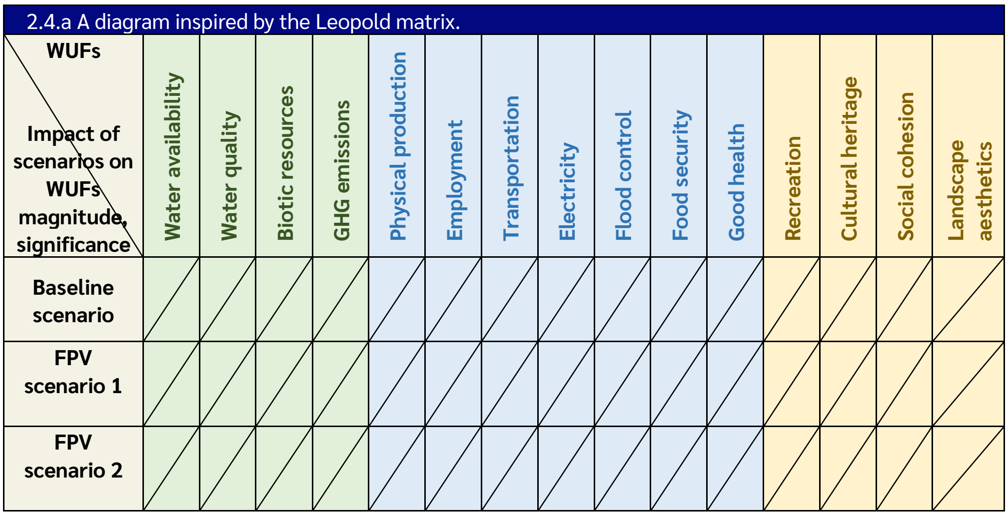
2.3.1. Visualization of results

Effective communication of results and outcomes from impact assessments by experts to stakeholders and decision-makers is essential for informed decision-making and successful project implementation. It is of primary importance to place the findings within the broader context of the project and its goals and to explain how the impacts relate to stakeholders' values and priorities (Cash et al. 2003). Visual tools as graphs, charts, maps can enhance understanding and retention of complex information (Tufte 1985). The information needs to be presented in a clear and concise manner in a form that is easily understood by stakeholders and decision makers. Tools like the Leopold matrix (Leopold 1971) and spider diagrams (e.g., McManamay et al. 2020) are particularly effective in summarizing and comparing impacts visually with the main indicators related to WUFs.

The Leopold matrix is a grid that cross-references the project actions, e.g., operations of FPV on the Magat reservoir, with environmental, social, and economic factors such as the WUFs, displaying the magnitude and significance of impacts on each of the factors. The various project actions are displayed along one axis while the WUFs are shown on the other axis (Figure 3.9). Each cell in the matrix can be filled with numerical values indicating the magnitude and significance of the impact of each action on a given WUFs.

Spider diagrams are used to display multiple variables/indicators/WUFs on a single chart, showing performance or impact levels across different categories. The spider diagram might include axes for each WUF (see, Figure 3.9 in Chapter 3). Each axis is scaled from low to high impact or benefit. The project’s performance in each area is plotted, and the points are connected to form a shape, illustrating the project's overall profile and highlighting strengths and weaknesses.

In addition, within a comprehensive assessment and to ensure its transparency and reproducibility, it is important to display underlying results (raw data) from the modelling phase that are used in the post-modelling to calculate the indicators. In this context, the experts need to adapt to the stakeholders’ best practices regarding visualization. Within the hydropower sector, for example, it is common to display water level and other water related variables along a yearly cycle (see Figure, 3.7 in Chapter 3). Additional visualization products can also include summary tables displaying absolute and relative changes of key parameters according to different scenarios.



2.4.a A diagram inspired by the Leopold matrix.

WUFs Impact of scenarios on WUFs magnitude, significance	Water availability	Water quality	Biotic resources	GHG emissions	Physical production	Employment	Transportation	Electricity	Flood control	Food security	Good health	Recreation	Cultural heritage	Social cohesion	Landscape aesthetics
Baseline scenario															
FPV scenario 1															
FPV scenario 2															

Figure 2.4. *Visualizations of impact assessment results, here inspired by the Leopold mat*

3 An ex-ante impact assessment study of FPV panels on the Magat reservoir

3.1 Introduction

The Magat reservoir in the Cagayan Valley Region in the northern part of the island Luzon in the Philippines is used as reference case for the study addressing impacts of FPV on environmental, socio-economic, cultural issues. The Magat reservoir (Box 1) includes a hydropower plant being in operation since 1983 and a 220 kWp FPV pilot constructed in 2019. The FPV pilot produces electricity for a portion of the Magat HPP's house load requirements.

The Magat dam was identified as a suitable reference case study for the impact assessment considering the following selection criteria, (i) ongoing hydropower production, (ii) a FPV in operation, and (iii) project partners being owners of the FPV, (iv) low conflict levels in the case area. The existing hydropower plant was important to avoid confusion between impacts of FPV with effects of dam construction. The hydropower plant in combination with the FPV pilot allowed exploring hybrid technology solutions. The existing FPV panel on the reservoir allowed collection of data below and outside of the panel important for the environmental assessment. Project industry partners enabled and facilitated for access to both historic hydrology data from the Magat reservoirs and contact with local authorities and actors in Province Isabela.

In section 3.1, the data collection for the study is presented. The current situation, the system description, the indicators and the FPV scenarios are described in section 3.2 (the pre-modelling phase). Section 3.3 presents the assessment of the effects of the FPV scenarios on indicators (the modelling phase). Sections 3.4, and 3.5 presents the analysed impact on beneficiaries and on SDGs, while 3.6 discusses possible measures to address adverse effects and to enhance co-benefits (the post-modelling phase). Reflecting comments on the ex-ante impact assessment study is provided in 3.7.

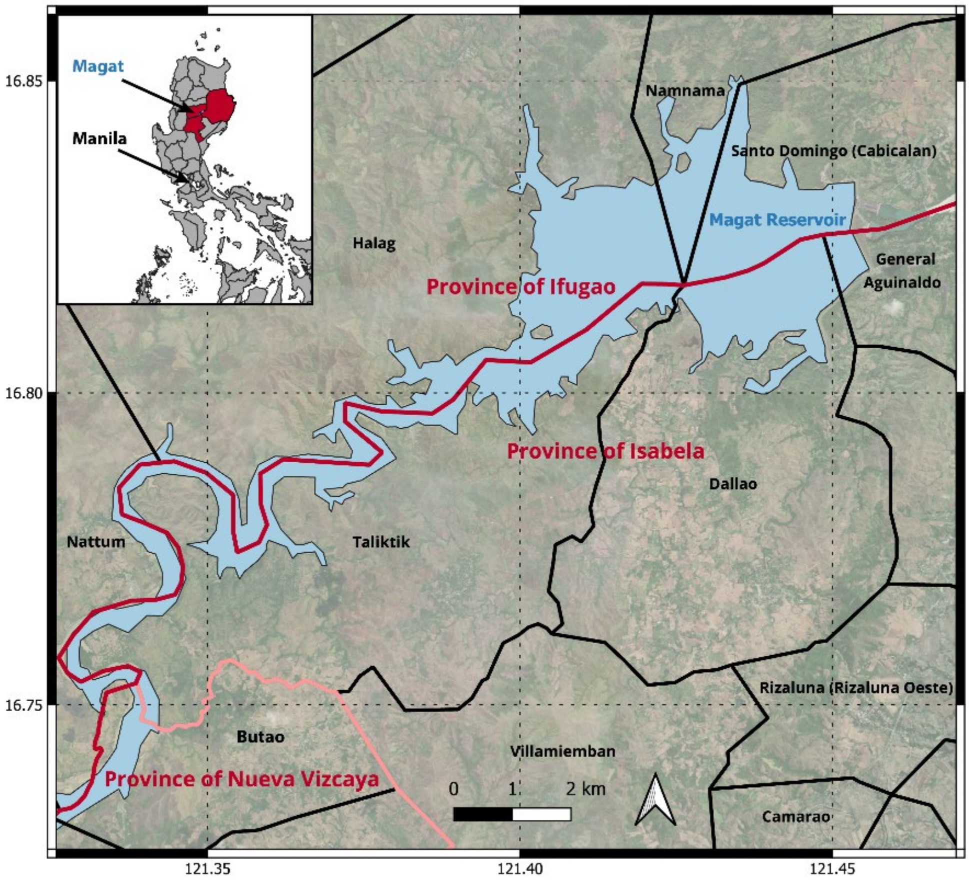


__Figure 3.1__. Location of the Magat reservoir in the Cagayan Valley, Luzon Island in the Philippines. Names of the provinces are in red; names of the barangays are in black. (Source: Satellite images from ESRI, Province and Barangay limits from Philippine Standard Geographic Code - https://psa.gov.ph/classification/psgc)).

Box 1. The Magat River Multipurpose Project (MRMP)

The Magat dam and hydroelectric power plant (HEPP) was built during 1975-1982 for irrigation and power generation purposes as part of the aim to promote economic and social development of the Cagayan Valley (Maranan et al. 2014). The dam located in Ramon municipality in Isabela Province, has a maximum height of 114 meters above the riverbed and comprises of 4,160 m. long earth and rockfill embankment located at the North bank of the Magat river (Figure 3.1). The spillway structure located at the headworks will in times of flood release floodwaters down to the outlet channel. Gates at lower elevation assist in passing large flood flows through the spillway and release irrigation water when the reservoir elevation is below elevation 174 m (Department of Agriculture 2007). The 360-megawatt Magat hydroelectric plant supplies power to the Luzon Island, and irrigation service for over 100,000 ha of agricultural area. The reservoir has a storage capacity of 1.08 billion m^3 being the second largest reservoir in the Philippines. When constructed, the reservoir impounded areas along the boundary of Ifugao and Isabela provinces displacing 431 households in Isabela and Ifugao provinces (ADB 2002).

The Magat HEPP was until its privatization in 2006 a state-owned facility operated by the National Power Corporation. The Magat HEPP was privatized in 2007 by SNAP. SNAP (SN Aboitiz Power) is a joint venture between Scatec (Norway) and Aboitiz Power Group of the Philippines (Scatec 2022b; SNAP 2024).

3.2 Data collection and analysis for the FPV impact assessment

The study to address impact of FPV takes a case study approach referring to a detailed study of a particular case, (or cases) to gain in-depth knowledge of an area in real-world situation (Yin 2009). The degree that results have generic relevance (see chapter 4 this report) needs to be assessed by addressing similarities/ dissimilarities between the respective case study and other cases (Gomm et al. 2009).

The ex-ante impact assessment has followed the different steps of the conceptual framework (Chapter 2), but data collection has been limited. A weakness of the study is that data has been collected from only two villages on the south-eastern side of the reservoir, respectively one upstream and one downstream of the dam. No data were collected from villages of the northern side of the reservoir where the population is Ifugao ethnic people. It also needs to be noted that the study did not consult with the local people on their perception of FPV deployment on the reservoir. It has not been an aim of the study to represent a full-scale EIA or and SIA. An EIA is usually conducted after a proposal has been developed, while upscaling of FPN on Magat is in a planning stage. Furthermore, in the Philippines, official guidelines for an EIA for FPV development has not yet been adopted.

Two case villages located in the Province Isabela were identified by the local industry partner SNAP for data collection and the study on economic, and social-cultural issues. In Figure 3.3, the approximate location of the case village is indicated. As the study lack of primary data collection on economic and social cultural users and usage in Ifugao indigenous villages, this is not addressed in the report.

Table 3.1 lists the primary data collected for the impact assessment.

3.2.1. Environmental data collection and modelling

The assessment of environmental variables uses models (see sub-sections 2.2.2 and 2.2.3) to predict quantitative effects. To analyse the effect on environmental indicators, semi-quantitative and qualitative knowledge rules established by literature are used (See on knowledge rules sub-section 2.2.1).

Field data collection included point measurements of nutrient concentrations (Total Nitrogen and Total Phosphorus) in the surface and bottom waters as well as complete depth profiles of oxygen concentration, conductivity, pH and water temperature using a CTD (Conductivity, Temperature Depth) probe for each field visit near the FPV pilot and near the turbine intake. During the first visit June 2022, two chains of thermistors (water temperature loggers) were installed to record hourly water temperature at various depths over the next year, one located below the FPV unit and one approximately 50 m away. On one occasion, in June 2023, water samples were also taken for the determination of dissolved gases (CO_2, CH_4 and N_2O) in surface waters near the FPV pilot, near the turbine intake and right downstream of the turbine. The sampling procedure is described in detailed in Valiente et al. (2022). The collected data was used for model validation in the modelling phase.

In addition, the hydropower company provided 11 years (2012-2022) of inflow, outflow discharge and water level data. Weather data over the same period was downscaled from the ERA5 dataset (Hersbach et al. 2020) and included daily air temperature, precipitation, wind speed, humidity, radiation and atmospheric pressure.

We developed a fully integrated physical-biogeochemical reservoir model (based on Norling et al. 2021) to simulate impacts of FPV on evaporation, heat exchanges (based on Lindholm et al. 2022), light penetration (e.g., Couture et al., 2015) and gas (O_2, CO_2 and CH_4) exchanges at the water surface. The model is driven by daily weather, inflow and outflow observations provided by the hydropower company and provides daily water level, evaporation, water temperature, nutrients, and dissolved gas concentrations in the epi- (surface mixed lake layer) and hypolimnions (bottom mixed lake layer). The Magat reservoir volume was estimated from bathymetric survey and represented by two adjacent, fully connected layered basins, one of which can be partly or entirely covered with FPV mounted on soft membrane in direct contact with water. The horizontal mixing between basins was controlled by a user-defined parameter.

In addition to water quantity, quality and GHG emissions, the model also predicted daily hydropower production and solar power production according to state-of-the-art equations. Hydropower was estimated from the head height (or vertical drop), considering a total installed capacity of 360 MW and an average efficiency of 90%, relevant for the Francis vertical shaft turbines (Umar et al. 2024), while solar production was estimated according to the PVGIS 5.2 tool methodology (Amillo et al. 2021). Total annual hydropower production reached 734 GWh on average while solar production was consistent with estimates from the PVGIS 5.2 tool (Amillo et al. 2021). However, the increased efficiency due to enhanced cooling was ignored resulting in likely a conservative estimate of the solar production. Considering hydropower production, the head height has a strong influence on the power efficiency, i.e., the amount of hydropower produced by volume of water discharged. In fact, assuming an optimal head height at 193 masl, the coefficient efficiency at 171 masl is 20% less than at 193 masl. Therefore, hereafter, the 171 masl is considered as a threshold above which water is considered to contribution to efficient hydropower production.

As a default setup, it was assumed that the solar energy generation did not affect the water intake operational regime, i.e., the same amount of water was withdrawn from the reservoir as if FPV was not there. In another model setup, we assumed that the solar energy production enabled the operational regime to save an equivalent amount of hydropower production resulting in water savings considering that the mismatch between solar energy availability and energy demand was compensated by the battery park. This model setup is referred to as “solar for hydro” setup. This adaptive process can yield much higher water level during the dry season when the reservoir water level is typically low. This adaptive measure is only considered as a potential process to mitigate adverse impacts and not in the default modelling setup since it involves modifying the reservoir operational regime, e.g., following a higher water level rate curve.

To account for expected changes in Magat inflow due to climate change, we performed additional simulations where inflows were reduced as expected from the recent modelling study (Singson et al. 2023). We considered only the case during dry years when inflows are expected to be reduced because this is the only situation when climate change will worsen the negative impacts. When inflows are expected to increase, the negative impacts are expected to remain unchanged or to be decreased.

3.2.2. Socio-economic and socio-cultural data collection and analysis

Both secondary and primary data were collected for the study. To analyse effects on environmental, economic and social cultural indicators, semi-quantitative and qualitative knowledge rules established by literature are used (See on knowledge rules sub-section 2.2.1).

Secondary data collection: A literature review involving search for scientific papers, reports, and online news, press release etc. for information about actors, the current situation and the history of the Magat River and reservoir were undertaken. The review also targeted scientific papers and reports on the impact of FPV on socio-economic and socio-cultural issues (Ranjbaran et al. 2019; World Bank Group 2019; Makhija et al. 2024).

Primary data collection: The primary data collection was initiated by a participatory mapping of important actors and stakeholders in the area. This overview provided a list of actors for later interviews. During the data collection, there was an emphasis on recording the perspectives and understandings of different stakeholder groups included industrial actors, local authorities (includes dam and irrigation operator and regulatory authorities), and residents. Representatives from ethnic groups were not interviewed. During the final stages of writing the report in 2024, correspondence by means of virtual meetings on teams and by emails were undertaken with a local fish cage farmer, and with the energy company SNAP for follow up questions on the local situation, and to enable comments and text corrections.

Local authorities: Data were collected as part of interviews with local authorities in Isabela Province, in June 2022 and in June 2023 (Table 3.1). During initial round of meetings, the project was introduced, and data were collected on, policies, pressures and trends. In 2023 interviews local authorities and workshop with focus group discussions (FGDs) involving NIA, BFAR, Ramon LGU and SNAP were undertaken in Isabela Province. FGDs is a qualitative data collection technique involving interactive discussions among people in groups of six to eight people; the purpose of fdgs is to gain a broad range of views and perspectives on predefined topics. (Hennink 2013). Data on the current situation of variables needed to estimate indicator values, such as the number of aquaculture farmers, licenses, fish yield were collected. These interviews provided insight on the type of economic data collected by and available from local authorities. The focus group discussion included a ranking of WUFs and indicators; also measures to enhance co-benefits and reduce adverse impacts were presented for feedback.

Local residents: Two case villages, one downstream and one upstream of the Magat dam in Isabela Province were selected for data collection (Figure 3.3). The project was first presented to representatives from the village council for introduction purposes. Workshops were organised in June and in November 2022, and each workshop lasted about three hours including lunch. About 30 people participated in each village. Leading and facilitating for the workshop were two from NIVA and three representatives from SNAP. The presence of the local energy firm represented anchoring of the project and a link to the FPV pilot on the reservoir.

In June 2022, data were collected to gain an overview of water users and usages. The participants discussed and identified, (i) the main water use activities and where they are located, (i) the location of villages, and settlements, and (iii) potential problem areas. Each group discussed for about 45 minutes, drawing the results on a map (Figure 3.2). Then each group presented the discussion points in plenary, allowing for follow up questions. The data collection session in November 2022, revisiting the same villages, discussed and selected relevant indicators to characterise the economic and social cultural issues, and indicated some indicator values. The participants discussed the appropriateness of approaches and indicators, including the relevance of the suggested indicators with reference to local-, regional- and national-level assessments. The data collection allowed recording beneficiaries in the watersheds, stories associated with the benefits experienced, and interlinkages between the upstream and downstream areas, and documenting usages on a map allowed identifying direct impact, that is the competition for space between different water uses, fishing grounds, aquaculture cages, navigation routes, area for FPV (Figure 3.2).

Industry partners: The industry partners, and other research institution partners were asked to suggest relevant indicators to assess the water use function, provision of electricity. This represented an iterative process ongoing during most of the project period. The indicator framework was presented at each of the project’s annual meeting, and indicators were discussed bilaterally with partners to ensure representativity and relevance.

Indicative measures to enhance co-benefits and reduce adverse impacts were first identified as part of informal conversations with staff of industry partners during 2022 and 2023. The possible indicative measures were then presented and discussed at project workshop August 2023 including all the project's research institutions and industry partners. The cost of measures and the feasibility of implementing measures were discussed. In October 2024, an outline of the setup of measures were presented to selected industry partners in Norway and in the Philippines for feedback.

3.2.3 The assessment of magnitude and significance

The impact is described with reference to scales of magnitude and significance and for national, regional, and provincial and local level referring to the predicted change of indicator values (Table 2.3). The assessment was undertaken as part of an internal discussion among the co-authors of the report. The scale of impacts hence represents the perspective and the understanding of the situation by the co-authors. In this semi-quantitative / qualitative assessment we considered the assessed effects on the indicators, and the anticipated impact on the influenced communities. Regarding impact of the scenarios on SDGs[7], it is only indicated if a positive or negative impact are expected (the impact expected is not scaled).

3.2.4 Uncertainties in estimated results

The assessments of indicators are based on primary and secondary data collection. Uncertainty in the assessment of impacts on environmental WUFs stems from natural variability (climate, hydrology), limitations in monitoring methodology (low temporal and spatial resolution for some variables), and the assumptions required for hydrodynamic modeling and environmental impact analysis. The aims to maintain transparency by explicitly detailing the assumptions and methodologies used, allowing for a clear understanding of the basis for the findings. The results should be viewed as representative rather than definitive, with further studies or long-term monitoring recommended to enhance confidence in the conclusions. Regarding the estimated effect of FPV on economic and socio-cultural indicators, as number of data sources are very limited, results can be characterised as uncertain. In particular the results related to aquaculture production, and the number of aquaculture farmers can be characterised as uncertain as available secondary information presented a wide range different values (i.e. production in tons, and number of aquaculture farmers).

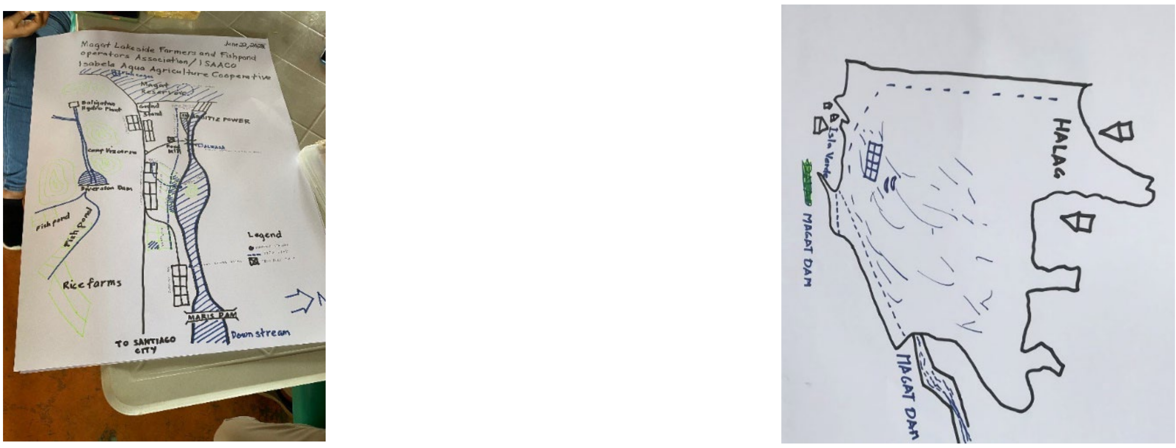


Figure 3.2. Example of maps produced by drawing by participants in the FGDs, 2022.

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[7] *The SDGs that are being considered includes 1. No poverty, 2. Zero hunger, 3. Good health and well-being, 6, Clean water and sanitation, 7. Affordable and clean energy, 8. Decent work and econ. Growth, 9. Industry innovation infrastructure,11. Sust. cities and communities, 13. Climate action, 15. Life on Land.*

Table 3.1. Overview of data collection and methods used in the Magat case study

Type and date		Data collection	Data analysis
Environmental data	June 2022	Water sample for chemistry Water temperature loggers installed near the FPV pilot and 50-m away from the pilot recording hourly temperature from 5 different depths Profiles of dissolved oxygen and CTD	Mechanistic models
	November 2022	Water sample for chemistry Profiles of dissolved oxygen and CTD	Mechanistic models
	June 2023	Water sample for chemistry and greenhouse gases Water temperature loggers retrieved Profiles of dissolved oxygen and CTD *Other ancillary data gathered (weather, hydrology, catchment characteristics, bathymetry)*	Mechanistic models
Economic and socio-cultural data	June 2022	*Mayor local municipality, NIA, BFAR, FGDs in* villages upstream and downstream the Magat dam to identify water users and usages. Around 25 people present at each FDGs.	*Map based approach.*
	November 2022	*FGDs in* villages upstream and downstream the Magat dam to identify and discuss indicators to represent water users and usages. Around 25 people present at each FDGs.	Knowledge rules and Quantitative empirical models to quantity indicators
	June 2023	*Interviews with Ramon LGU. FGDs with LGU, NIA and BFAR to*	
	August – November 2024	Follow up questions to enable comments and corrections to the text with a local fish cage farmer, and with the energy company SNAP.	

3.3 The Magat reservoir, the system, indicators and scenarios

The Magat dam and hydroelectric power plant located was constructed between 1975-82 for irrigation, flood control and hydropower generation, with policy priority for irrigation purposes (Department of Agriculture, 2007). The Magat dam has been in operation since 1983 (IFC, Retrieved november 2024). In March 2019, a 220-kWp floating PV test facility was installed on the Magat dam, with successful operations in 2020. (Pilskog 2021). The energy company SNAP plans to scale up the FPV installation following a stepped approach starting with 10 to 12 MW in the next two years and potentially scaling it up to 100 MW or more depending on the impacts (Personal communication the project's industry partners, October 2024). The first phase of 10 MW FPV installation is expected to generate 3.6 GWh per year (Personal communication with SNAP, November 2024). The FPV installation will be connected to the Magat HPP switchyard which in turn is connected to the NGCP through the existing 14.5 Magat – Santiago double circuit 23 kV transmission line. Securing of environmental and social consents from Philippine authorities have not been received due to the pending EIA guidelines for FPV projects from the Environmental Management Bureau of the DENR.

The sub-section addresses the environmental situation, population characteristics, the socio-economic, and socio-cultural situation, and institutions and the governance. Trends and main policy drivers focusing on Isabela Province, which is the province of the selected case villages. Moreover, the identified scenarios and the selected indicators are presented.

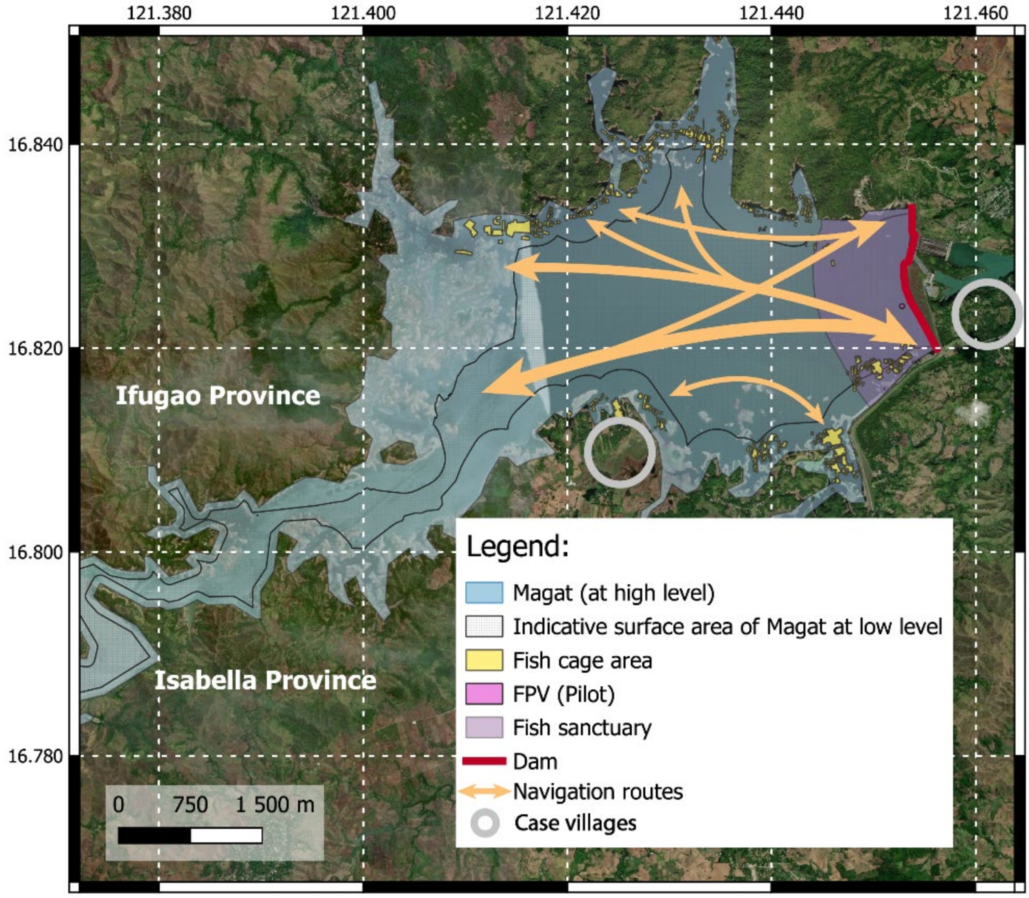

Figure 3.3. *The Magat reservoir area. The FPV pilot is shown as a pink circle in the fish sanctuary area. The empty area with black contour shows an indicative surface area at low water level. In these situations, the fish cages are displaced in the centre of the reservoir and will compete with FPV for surface area. (Source, Satellite images are from ENSRI).*

3.3.1. The system description of the Magat reservoir case study area

The boundaries of the case study include the Magat reservoir and barangays located along the reservoir and on the immediate downstream area (16°49′30″N 121°27′14″E, 8–28 km2, (Figure 3.1, Figure 3.3). The watershed of the Magat reservoir (Figure 3.1) lays within the administrative jurisdiction of the provinces of Nueva Vizcaya (60%), Ifugao (33%) and Isabela (7%) (Department of Agriculture 2007). The Magat reservoir is in Province Isabela, in Province Ifugao and a small part is in Nueva Vizcaya. The barangays that have border to the reservoir includes Cabulay, and Planas (Isabela province), and Santo Domingo and Halag (Ifugao province). Downstream the dam the barangays are, General Aguinaldo (Isabela) and Santo Domingo (Ifugao). Table 3.2 provides an overview of the variables, the situation that characterises the Magat reservoir case study area.

3.3.1.1. Population characteristics -

Residents around the Magat reservoir live in Isabela and Ifugao provinces (Figure 3.1). Agbayani and Tiongson (2003) refers to 28 ethnic groups in the area, and that the majority are Ilocano and Ifugao. Residents in the three provinces all use Magat reservoir for livelihood and socio-cultural activities. The system description addresses the situation for Isabela Province as primary data collection were only undertaken in this province.

There are in Isabela province 422,670 households and average household size is 4.3 (Isabela Province 2023). The population density is 130 inhabitants per square kilometer (Philatlas 2024), and the average annual population growth rate between 2015-202 is 1,33 percent. The province includes three cities and 34 municipalities, and 1055 barangays. The official Isabela Province website (2023) states that literacy rates are 97%, and that the lifestyle is suburban.

Villages upstream of the dam – Residents around the reservoir mostly live of rainfed agriculture, and fishing. Some also gain income from aquaculture production on the reservoir, some own fish cages, others work on other's fish cages. In this area roads, market outlets and information to upstream communities are limited (Author's observation, personal communication with local actors, 2023). The one road is a dirty road and not all residents have access all months. It is not recommended to drive on this road after around five PM in the evening. Mostly transportation occurs by boats between villages and from the villages to the central boat landing area in Ramon municipality (Figure 3.3). There are primary schools in the area. The youth need to travel on boat for secondary and higher education. Elazegui and Combalicer state in their report (2004) that some communities receive intensive support, resources, information or influence from NGOs and donors.

Elazegui and Combalicer (2004) and JICA (2004) describe conflicts in communities around the reservoir (including also the area of provinces) regarding land and water resources use.

Villages downstream of the dam – Residents in this area gain income from irrigation agriculture, from fishponds and from working in the service and industry sectors (personal observation 2021- 2023 and information from FGD 2022). There is accessibility to roads, markets and schools. The area can be characterised as suburban. The general economic development is higher in the downstream villages than in the villages upstream of the dam. The population growth rate is higher in this area (4,92 % in the barangay General Aguinaldo) compared to the mean growth rate of 1,33 percent in the province (Philatlas 2020).

3.3.1.2. The Environmental situation

Climate is characterized by two tropical monsoons: the southwest monsoon from June to October with the larger proportion of the rainfall and the northeast monsoon from November to February. Storms including typhoons may strike from July to December. The annual rainfall in the watershed ranges from 1400 mm in low elevation areas to about 2,600 mm or more in high elevation areas (LUCC, 2001 as referred to in Tattao 2010). The dry season is from December to May. Average rainfall for the Cagayan region lies between 1500 and 2000 mm per year. During dry years, the annual rainfall is below the 25th percentile of the historical rainfall distribution, about 1500 mm. In contrast, wet years are defined as years when the annual rainfall is above the 75th percentile corresponding to approximately 2000 mm. Both dry and wet years occur regularly, at least once every decade, and their frequency is influenced by various climatic factors, including El Niño and La Niña events (Bharambe et al. 2023).

The Magat dam when constructed in 1982 created a reservoir on the Magat River which runs 226 km from south to the north (Maranan et al. 2014). The area of the reservoir ranges between 8 to 30 km^2 depending on the water level. The elevation of the reservoir is 160 to 193 m. The maximum depth is 60 m. Regarding the inflow discharge, a recent study used the Soil and Water Assessment Tool (SWAT) model to predict the dam's inflow under different climate change scenarios (Singson et al. 2023). The study found that during dry years, there will be an average decrease of inflow (17% under RCP 4.5 and 23% under RCP 8.5 by the end of the 21st century), and that during wet years, there will be an increase of 19.25%. Peak flow during wet years is expected in September, with a maximum discharge of up to 342.46 m^3/s by the late 21st century (Singson et al. 2023).

The watershed of the Magat reservoir includes woodlands, grass and agricultural areas of which about 20% is managed by different institutions including the Lower Magat Forest Reserve covering about 5% of the watershed through Proclamation No. 573 on June 26, 1969. The forest reserve was established for, “human survival and environmental balance in the region” (Elazegui and Combalicer 2004). Despite these established protection areas there has been a decline in forest areas, uncontrolled forest fires, illegal logging, grazing, shifting cultivation. Largely related to high soil erosion rates[8] from deforestation and the subsequent land degradation are increased sediment inflows to the Magat reservoir (Latap 2014; Bato et al. 2021). Flooding is considered to be of major concern, and inundation of low-lying areas along the river is a common occurrence. Acceptable ecological status is met only 5,4 months / yr (this study). Baleta and Bolanos (2016) reports that water quality referring to the Physico-chemical factors; temperature, transparency, dissolved oxygen, pH, ammonia and phosphate within the acceptable range for fish culture. Fish mortality is more pronounced during dry months (March – June) and is believed to be caused by fluctuating temperature, water quality issues, pollution, and bird predation based on farmers’ opinions (Baleta et al. 2019).

3.3.1.3. The economic and social cultural context

Water users are households (domestic usage), fishermen, aquaculture farmers, agricultural farmers upstream and downstream the dam, the energy company and tourist suppliers, recreational users. The main sources of revenues are agriculture, aquaculture, livestock, and service sectors (Isabela Province 2023).

Cage culture of Nile tilapia (*Oreochromis niloticus*) is an important source of income for several households around the reservoir (Baleta and Bolaños 2016). Most of the fish cage operators has a licence for aquaculture, but some operates without a licence (Personal communication with NIA 2023). It can be estimated that there currently are around 500 fisherfolk, with around total of 10 tons of fish catch per day. In the 2023 BFAR annual report (2023) it is stated that 83,927 m^2 are covered by cages. Using Google satellite images, the total water surface area used for fish farming is estimated at least 48 ha (2024). Cage farming has increased in recent years (Baleta et al. 2019). The law stipulates that 450 ha (10% of the reservoir area) can be used for aquaculture (Department of Agriculture 2023)[9]. During the peak production of aquaculture production, daily harvest was referred to in a newsletter to include 35 tons (Prudencio 2018).

Irrigation agriculture mainly occurs downstream of the Magat dam on the flat areas adjacent to the Magat river and its tributaries. Income from fishpond production, and fishing in the canals downstream of the dam are other sources of revenues. The focus group discussions in the two case villages also revealed that some also receive income from taking tourists and others for boating on the reservoir (see also about Magat as tourist spot, Maranan et al. 2014).

Social and cultural issues and practices: Informants to the study attending the focus group discussions told that the shoreline of the reservoir is used for picknick and camping when the water level is lower, mostly during the dry season. Boating on the reservoir is important for recreation by residents around the reservoir, and by residents in villages downstream the dam. Most of the households have access to a boat. Informants also told that the reservoir is used for swimming, for boat parades and for ceremonial rituals. Rituals and traditional practices referred to include different types cleansing rites, “gulgol”[10], and baptism, however it was indicated that such practices are not very common. It was noted that for

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[8] *A soil erosion index using GIS to determine soil erosion potential generated a score of 1.68 for Magat Watershed.*

[9] *It may be reflected on that 450 ha for aquaculture production is not realistic during low water levels of the reservoir.*

[10] *Gulgol is a tradition of the Illocano to drive away the spirit of a dead relative (Acabado, 2016).*

the reservoir, swimming, and the boat parades are no longer permitted (see also, Maranan et al. 2014). Downstream the dam, the channels are used for swimming (Figure 3.4.g).

With reference to social cohesions, about conflicts in the area - Interviews and personal communication with NIA in 2022, in 2023 and in 2024, indicate that in general conflicts are rarely observed and very low. It was informed that conflicts among fish cage farmers may arise regarding space for the fish cages, in particular related to the dry season, when the fish cages need to be moved because of shallow water. Conflicts arise because space for the fish cages is more limited.

3.3.1.4. Governance and institutional context

In the Philippines the public domain belongs to the State (Philippine Constitution 1987). The governance units include regions, provinces, municipalities and barangays (the lowest political administrative unit of the Philippine government).

The Magat watershed includes four areas managed by different institutions (Table 3.2). The jurisdiction over the Magat watershed is shared between the National Power Corporation (Magat Watershed Unit) and NIA. The Ifugao portion (north) is under the jurisdiction of NPC while the Isabela (south) is with NIA. The Lower Magat Forest Reserve (Proclamation No. 573 in 1969) is co-managed by the Department of Natural Resources (DENR) and local government units (LGUs) in the Nueva Vizcaya Province (Elazegui and Combalicer 2004). There is no overall watershed management plan for the Magat watershed[11].

For the operation of the Magat dam, a manual the “Operation, maintenance and safety manual for the Magat Dam” was jointly developed by NIA, NAPOCOR and NWRB in 1985, and updated in 2007 (Department of Agriculture 2007). The manual includes a curve presenting optimal utilization of the water stored in the Magat reservoir for release of water from the dam determines the minimum month-end reservoir elevations that shall be maintained by controlling reservoir releases through the Magat HEPP and at the Baligatan Outlet Works (BOW) to ensure water availability for irrigation on a year-round basis (Department of Agriculture 2007). The strong prioritization of water for irrigation implies limited flexibility to plan and use water for hydropower production. It also means that ecological status has less priority during the dry season. That the water level in the reservoir is below the threshold during the dry season is not uncommon (Authors, observation, and personal communication 2022).

The following five government agencies have authority and responsibility for implementing watershed-related programs, and for enforcing legislation (Table 3.2).

The National Irrigation Administration (NIA) has the authority to manage, develop and rehabilitate the watershed areas. NIA planned the Magat dam project for irrigation of agriculture (192,000 ha of rice farms). NIA own, operate and manage non-power components such as the dam, reservoir, and intake gates (Diliman 2019). NIA is levying irrigation fees, it rents out area on the reservoir for fish cage production to aquaculture operators, and it rents area for the FPV system to SNAP (Personal communication NIA, 2023). NIA and National Power Corporation (NACOPOR) have only marginal responsibilities for erosion control around the reservoir (Elazegui and Combalicer 2004). In the new Aquaculture Farm Agreement promulgated by NIA[12], it is stated that fish cages must be at 2km away from the main dam embankment (Personal communication, SNAP 2024).

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[11] Department of Environment and Natural Resources (DENR) and the Japan International Cooperation Agency (JICA) prepared in 2003 a Master Plan Study for Watershed (JICA, 204).

[12] *https://omcrs.nia.gov.ph/?q=tags/aquaculture-farm-agreements*

The Department of Energy (DOE), the Energy Regulatory Commission (ERC), and the Philippine Competition Commission are responsible for policy and regulation of the Philippine power industry, including the Wholesale Electricity Spot market (WESM). Such policies set by the DOE includes the promotion of renewable energy supply sources (more in trends and policies).

National Power Corporation (province and municipal offices (NACOPOR**)** is responsible for providing electricity. The Philippine power system is sub-divided into three island-grid systems: Luzon, Visayas and Mindanao. All generation capacity and power demand within each of the island systems are pooled into a centralized and advanced electricity trading venue known as the Philippine Wholesale Electricity Spot market (WESM). Through the WESM, non-contracted buyers and sellers trade electricity as a commodity where prices are determined based on actual use and availability through the entire system.

Department of Environment and Natural Resources (DENR) is the primary government agency responsible for conservation, management, development and proper use of environment and natural resources. The DENR pursues its functions through the Regional Environment and Natural Resources Offices (ENRO). Tenurial instruments is the responsibility by DENR and include Community-based Forest Management Agreements, Industrial Forest Management Agreements, Socialized Industrial Forest Management Agreements, and Forest Land Grazing Management Agreements (Elazegui and Combalicer 2004). The DENR promulgated water quality guidelines applicable for all water bodies in the Philippines with target values for several water quality parameters depending on the intended beneficial use, e.g., water supply, recreational, fishery or protected wates (DENR 2016).

National Commission on Indigenous Peoples (NCIP) – is responsible for matters concerning Indigenous Peoples (IPs). In the Magat watershed, the province NCIP, Office for Northern Cultural Communities (ONCC) needs to be consulted in hearing processes concerning development projects that may have an impact on IP.

Peoples organization (PO) – independent associations of citizens that promote the public interest and represent grassroots sectors (Jose 2011). According to a report by Elazegui and Combalicer (2004) the Ifugao has an indigenous resource management system that ensures community involvement, technology applicability, supportive role of culture in forest conservation and sustainable development.

Weak strong governance: Considering the Worldwide Governance Indicators (WGI), the Philippines ranks above regional peers in Voice and Accountability and Regulatory Quality but below regional peers in Government Effectiveness, Control of Corruption, and Rule of Law (World Bank Group 2019) Limited government effectiveness is known to result in poor implementation of the government policies and programs. Limited capacity of institutions to enforce the fish sanctuary on the Magat dam was referred to in informal conversions by local people (June 2023).

***Table 3.2** Population characteristics and on environmental, economic and socio-cultural variables, and authorities, institutions, mandates, selected legislation and rules.*

Relevant variables	Data and source
Population characteristics	
Population numbers around the reservoir	The following barangays borders the Magat reservoir and the immediate downstream area (population estimates from census 2020 (Phil Atlas, retrieved Nov. 7th 2024) Cabulay Barangay, Santiago City, Isabela Province population 3,565. Planas Barangay, Ramon municipality, Isabela Province population 3,029. General Aguinaldo Barangay, in Ramon, Isabela Province, population 5,965. Santo Domingo Barangay in Alfonso Lista municipality, Ifugao Province, population 2,206. Halag Barangay, Aguinaldo Municipality, Ifugao Province, population 1 999.
Population growth, density.	Santiago City, a growth rate of 2,07% (2015-2020). Population density 582 per km2. Ramon municipality, a growth rate of 1,48% (2015-2020). Population density 418 per km2. Alfonso Lista Municipality, a growth rate of 1.24% (2015-2020). Population density 98 per km2.

	Aguinaldo Municipality a growth rate of 1,89% (2015-2020). Population density 39 per km2
Ethnic people	28 ethnic groups in the area, mostly the Ilocano and Ifugao
Urban / rural situation	The Magat reservoir with surrounding villages is rural. The area downstream of the dam is semi-urban. Santiago City in Ramon municipality drives urbanization in the downstream area.
Environmental variables	
Climate	Two tropical monsoons; Annual rainfall Cagayan River Watershed is estimated at 2,600 mm. Dry season (December - March). PAGASA, NOAA
Solar irradiance	Global datasets (ERA5)
Temperature variations	Global datasets (ERA5)
Wind patterns	Global datasets (ERA5)
Geological aspect rim stability	Data not collected in the case study for analysis.
Magat reservoir area	8 to 28 km2 (depending on the water level of the reservoir being related to dry or wet climate conditions). Official authorities state that the reservoir is up to 45km2. Our estimates of the reservoir area considering the bathymetry, wet conditions, dry conditions and the maximum water level allowed at the dam area (194 masl).
Bathymetry of reservoir	Bathymetric survey (SCATEC)
Depth of reservoir	Ranging between 25 to 60 m. (SCATEC)
Hydrological dynamics: flow patterns, water levels	Historical streamflow records of 35 stream gauging stations in the Cagayan River basin were used. Flood control facilities constructed under the direction of the Bureau of Public Works is only partly effective, under extreme flooding experience show that this this not sufficient (KMP 2020).
Water quality variables	Dissolved Oxygen, Total Nitrogen, Total Phosphorus (NIA) were collected. Other variables as biological oxygen demand (BOD), heavy metals or any relevant pollutants.
Land cover, terrestrial biodiversity, vulnerable species	Land cover in Isabela is dominated by forests (41%) and annual cropland areas (31%). The Philippine Eagle (Pithecophaga jefferyi) is an endangered species in the Philippines that has been observed in the Magat watershed area (JICA 2004). There are sightings of Luzon bleeding heart and Philippine duck both vulnerable (Avifauna survey, 2022). JICA (2004) refers to that IUCN lists 19 species and CITES 29 lists29 for Cagayan Valley on the list for conservation. No observation has been around Magat reservoir. *Terrestrial land cover, biodiversity are not affected variables in the scenarios*.
Land degradation and deforestation	Extractive activities as logging and mining, road incursions, and encroachment from agricultural activities are pressures (ESSC 2020).Isabela Province: From 2001 to 2023 lost 36.1 kha of tree cover, equivalent to a 7.0% decrease in tree cover since 2000 (GlobalForestWatch 2023).
Erosion, sedimentation	*High erosion and sedimentation levels (Latap 2014, Bato, Paningbatan et al. 2021). Deforestation and land degradation are main causes.*
Aquatic ecology, biodiversity, vulnerable species	Fishs, bunog, dalag, tilapia, mud fish (JICA, 2004). Magat catfish (Plicofollis magatensis) characterized as vulnerable (pers com SNAP, 2024). The construction of the Magat dam in 1982 reduced fish diversity by preventing fish migration from lower areas.
Water ecological status.	Acceptable ecological status is met 5.4 months/yr (based on Baseline Scenario). The oxygen concentration remains below 6 mg/L about 6 months per year, according to the reservoir biogeochemical modelling and some field data.
Economic variables	
Socio-economic classes including poverty situation	Poverty As of the 2015 Poverty Census, poverty incidence in the Philippines stands at 21.6 percent (https://pcij.org/2018/07/12/stats-on-the-state-of-the-regions-hubs-of-wealth-ponds-of-poverty/) Province Isabela has a food security program (https://sites.google.com/site/tesdaisabela/programs-and-projects/masaganang-isabela)
Economic growth	Province Isabela is considered "as a first-class province and considered among the richest and most progressive provinces in the Philippines (Official webpage Province Isabela. Department of Tourism (2024) states that Santiago City is a commercial and trading center of Cagayan Valley, that several business enterprises, banking institutions, educational entities, as well as manufacturing companies are located here.
Employment & sectors	Agriculture is the biggest industry in Isabela Province. Other economic activities are commercial and service, fishery and industry.450 hectares of fish cage culture at Magat Dam Reservoir (Official webpage Isabela Province, Economic profile). Unemployment rate in Isabela is 4,4% (2022). Unemployment data is not available for lower administrative levels.
Use of water for economic purposes	Fishing, aquaculture, fishpond cultivation, irrigation, transportation, hydropower production, solar energy production, tourism. (Data, FGD in upstream and downstream villages in 2022.).

Infrastructure and accessibility,	Navigation routes on the reservoir: Satellite images from NIA. Location of fish landing and port: observation, Photos, satellite images, GIS coordinates. Access to roads for the villages: Observation, and from FGDs.	
Food insecurity		
Health		
Social and cultural variables		
Recreation activities	Activities by different groups of people, families, youth, elderly people, vulnerable people, indigenous people and benefit assessment. (Data, FGD in upstream and downstream villages in 2022.). Data not collected from Ifugao Province.	
Cultural heritage situation; Presence of cultural /sacred sites	According to Water plays a part in death, rebirth, and cleansing in Ifugao cosmology (Acabado and Martin 2016). Ancestral domains, and certificate of ancestral domains: Data not collected.	
Identity and social cohesion	Elazegui and Combalicer (2004) stated in 2004 that there are conflict and disputes among stakeholders over land and water use. Personal communication with a fish cage farmer revealed occasional conflicts on space for the fish cages (2023). e Elazegui and Combalicer (2004).	
Authorities, institutions	**Mandate**	**Important regulatory documents**
Bureau of Fisheries and Aquatic Resources (BFAR)	Responsible for the development, improvement, management, and conservation of the country's fishery and aquatic resources. https://www.bfar.da.gov.ph/	Strategic Agriculture and Fishery Development Zones (SAFDZs) - Pursuant to the Agriculture and Fishery Modernization Act (R.A. 8435, s-1997)
National Commission on Indigenous Peoples (NCIP)	Protect and promote the interest and well-being of the ICCs/IPs with due regard to their beliefs, customs, traditions and institutions. Provincial office focus on the identification of ancestral land domain, and organization of indigenous cultural communities and indigenous peoples.	Indigenous Peoples' Rights Act (IPRA) (R.A. 8371). NCIP Administrative order No. 3, (2012)
Department of Energy (DOE) https://doe.gov.ph/what-we-do	Prepare, integrate, coordinate, supervise and control all plans, programs, projects and activities of the Government relative to energy exploration, development, utilization, distribution and conservation.	Circular No. 2022-11-0034. DOE amended the 2008's Renewable Energy Act to allow foreign ownership of renewable energy resources Renewable Energy Act in 2008 Republic Act 9136 or the Electric Power Industry Reform Act (EPIRA) Energy Efficiency and Conservation Act (RA 11285)
National Irrigation Administration	A government-owned and controlled corporation responsible for irrigation development and management.	National Integrated Protected Areas System (NIPAS) Act (R.A. 7586).
Department of Natural Resources (DENR) national, regional, province.	Responsible for the conservation, management, development, and proper use of the country's environment and natural resources, specifically forest and grazing lands, mineral resources, including those in reservation and watershed areas, and lands of the public domain, as well as the licensing and regulation of all natural resources as may be provided for by law.	DENR Administrative Order 03-30. or the Implementing Rules and Regulation of Presidential Decree No. 1586. Forest reserve in the watershed area (road construction is not allowed (Proclamation No. 573 on June 26, 1969. Water quality Guidelines (DENR Administrative order 2016-08 National Integrated Protected Areas System (NIPAS Act: R.A. 7586). Philippine Mining Act (R.A. 7942): Mines and Geosciences Bureau of DENR
Local government unit (LGU) (barangay	Implement government policies and activities in the community, create projects in its territory and to deliver basic services of the government to the people. LGU ordinances to control and manage natural resources, lumber and water.	Local Policies. The legislative power of LGUs over the natural resources is ensured by the Local Government Code. LGUs implement and enforce the national forestry laws and regulations. LGU rules related to watershed management are as follows:
National Power Corporation	Shall perform missionary electrification function through the Small Power Utilities Group, provide power generation and associated power delivery systems. Responsible for operation and transmission systems. https://www.napocor.gov.ph/missionary- electrification-mandate/	
PO, Peoples committee	Independent associations of citizens that promote the public interest and represent grassroots sectors (.	
Other NGOs	Integrated Fishery Aquatic Resources Management Council	

3.3.1.1. Trends and policy drivers

The following presents the main identified trends and policy drivers in the Magat case study area, and how these are expected to influence the future.

Economic development and urbanization trends – Philippine official websites, social media stories, newsletters, and reports describe a situation of economic development, population growth and urbanization in Isabela Province (Philatlas 2020; Isabela Province 2023; Philatlas 2024). The census in Santiago city 2020 denotes a growth rate of 2.07%, since 2015 (Philatlas 2023). The Santiago City in particular represents a driver for commercial activities, economic grown the urbanization (Guerrero 2012; Bumanglag et al. 2021; Camella 2022). Economic development, population growth are known to cause increased demand for fresh water, increased diffuse and point source pollution influencing *water quality* status (Anh et al. 2023), and increased demand for electricity (Kumar and Saroj 2014; Bijl et al. 2018). Economic development is also known to generate income-generating activities, more goods and services available to the population, and modernization in terms of conversion of agricultural land use to industrial and commercial (Orum and Chen 2003).

Technological development trends – The construction of the Magat hydropower plant being in operation since 1983 represented a major technological development by providing electricity to the Luzon Island. It is stated by the Asian Development Bank (2002) that rural electrification on Luzon Island grew from 30 % in 1980 to 61% in 1990 due to the construction of Magat hydropower plant. Technological development is according to Volti and Croissant (2024) the single main source of economic growth. Technical change in society have also been seen to modify social roles, relationships, values and practices (Orum and Chen 2003; Volti and Croissant 2024). Bumanglag et al. (2021) writes in a paper from their study in Santiago City that people (in the city) “perceived changes to be inevitable”, and that they find that “here is a need to adapt to the changes in order to belong and survive the consequences of modernity and progress”.

Renewable energy and power production policies - Several policies have been adopted recent years to promote power generation: Cordillera Regional Development Plan (2024- 2028) by National Economic and Development Authority (NEDA) focuses on river systems and geothermal resources as a contribution to increasing the country’s power reserves (Power Philippines News 2024); the national programmes, Build! Build! Build! (2016- 2022), and, Build Better More (BBM) (2022-2028) aim to improve infrastructure situation, including access to electricity in the Philippines (Roxas and Santiago 2016). Furthermore, *EPIRA law of 2001 Full foreign* ownership of renewable energy projects. This includes the exploration, development, and utilization of solar, wind, hydro, and ocean or tidal energy resources (Department of Agriculture 2007). The “Integrated key energy statistics and energy-related indicator database (Department of Energy 2020), presents the current energy mix, that 34,3% is renewable, 5,8% is natural gas, 29,0% is oil and 30,9% is coal. The national DOE targets are to bring the renewable energy share in the power generation mix to 35% by 2030 and 50% by 2040 from the current 34,3% resulting in significant GHG reductions (Department of Energy 2020)

Strategies planned: An upgrade of the transmission line from Magat. It is planned to use the Magat HPp switchyard to connect 140 MW Alimit HPP and 20 MW BESS to the Luzon grid. This upgrade will allow additional sale of power to the spot market. Output is sold through a mix of spot market (WESM) trading via bilateral contracts, and as ancillary services in the reserve market. The plant also operates as a grid service provider with each generating unit having the ability to deliver electricity in less than 2 min. The Electric Power Industry Reform Act (EPIRA) (Republic Act 9136) (DOE, 2001) stipulates that host communities will get a share of one centavo for every kilowatt-hour (Php0.01/kWh) of the total electricity sales of power generation companies operating in its area.

Agriculture irrigation policies – On national level the National Irrigation Master Plan 2020-2030 (NEDA et al. 2020) describes aims to promote, "acceleration and improvement in irrigation implementation and operation performance of NIA and other involved agencies". It is referred to the previous "slow irrigation development", and it is stated that "the ratio of total actual to total potential irrigable area in the country, is estimated at 61.4%". For the operation of the Magat Dam reservoir, water for irrigation of agriculture downstream the dam is a prioritized water usage by law (Department of Agriculture 2007). The operation rule curve is set to "to ensure water availability for irrigation on a year-round basis" (Department of Agriculture 2007). Farmers that currently do not have access to irrigate their fields demand access (FGD, 2022). On the Ifugao Province, the Alfonso Lista Pump Irrigation Project by NIA-Cordillera Administrative Region, targets to irrigate 2,300 hectares of farmlands downstream the dam in Alfonso Lista municipality using water from the reservoir (NIA Cordillera Administrative Region 2024). Construction works for this project were ongoing in 2023 (Author's observation). Irrigation of additional agricultural areas downstream the dam was discussed at NIA (Personal communication NIA, 2022).

Currently low water levels regularly occur in the dry season, resulting in water level below the threshold set at 160 meters (Authors observation, 2022, 2023, and personal communication with local actors). At Elevation 193.00 meters the area of the reservoir is 3,000 hectares, while at 160 meters the area of the reservoir is 1000 hectares. Under optimal conditions, the water level should be maintained as close as possible to the rule curve which has a minimum level of 175 m. It is thus considered that water level below 174 m is not optimal for irrigation purposes. The plans for further irrigation of new areas may cause further pressure on the water availability for hydropower production, and aquaculture production and for biodiversity and the reservoir ecosystem. When there is less water in the reservoir this has negative effects on parameters as oxygen concentration, and nutrient levels since the anthropogenic inputs are not diluted (this study).

Aquaculture trends and policies- The purpose of the Magat River Multipurpose project was to "utilize the flows of the Magat River to provide dependable water supply for irrigation and for power generation (Department of Agriculture, 2007). It is referred to in the dam operation manual that aquaculture is one of the benefits created by the dam. The initiation of aquaculture in the 1980 – 1990ties has provided income to fishermen in Isabela and Ifugao provinces. It is regulated so that about 10% of the area can be used for aquaculture (BFAR 2021), this implies that 450 ha can have fish cage production, currently it is estimated that there are around 48 ha with fish cages. The Philippine News Agency writes in "that early to mid-2000's, fish cage operators were able to harvest an average of 35 metric tons of tilapia daily, and that fish cage operators numbered about 12,638 at its peak (Prudencio 2018). NIA informed that some operate fish cages without licence. During high peak production levels, the activity contributed to deteriorating water quality locally, in particular when low water levels (Baleta et al. 2019). Despite that it is not allowed to have aquaculture in the fish sanctuary, several fish cages are in this area (Authors observation). The BFAR in collaboration with NIA and SNAP established the Magat Aquapark Project in 2012 for improved sustainable management of aquaculture (Prudencio 2018).

Policies for fishponds downstream: The release of water from the Magat dam spill way has benefitted for establishment of fishponds downstream the dam (Figure 3.4j). In 2019, the total area of fishponds in Ramon, Isabela was 362 hectares (BFAR 2021). Using the average size of fishponds of 600 m^2 this corresponds to approximately 22 fishponds in Ramon municipality. Fishpond operators in this area are mainly operated and owned by local people. The Department of Agriculture support further development of fishponds and the LGU of Ramon plans to assist farmers who desire to venture into tilapia fish culture by preparing their fishponds for free; there is a plan to purchase two excavators (Deparatment of Agriculture 2019).

Nature, environmental protection policies, and climate mitigation policies: The watershed of the Magat reservoir encompass the Magat River Forest Reserve through *Proclamation 573 of 1969,* and it is classified as a critical watershed by virtue of PD 705 in 1975. DENR and NIA have renewed their commitment to the rehabilitation of the Magat Watershed Forest Reserve (MWFR) covering the provinces of Isabela and Nueva Vizcaya (Domingo 2023). The land area around the reservoir is therefore not open for development activities apart from agriculture and grazing that are carried on in the watershed.

Water quality guidelines applicable for all water bodies in the Philippines specifies targets for several water quality parameters depending on the intended beneficial use, e.g., water supply, recreational, fishery or protected wates (DENR 2016). The Magat reservoir falls under water body classification SA, protected waters for the fish sanctuary, with dissolved oxygen target concentrations of 6.0 mg/L or above, and water temperature between 26 and 30°C (DENR). For recreational and water supply, these target values are 5.0 mg/L for dissolved oxygen and water temperature between 26 and 30°C. These rules and guidelines represent thresholds for water quality parameters relevant also for FPV development (sub-sections 3.4 and 3.5).

The *fish sanctuary* area on reservoir, shown in Figure 3.3, starts by the dam area and extends 2 km. No activities including aquaculture and fishing should occur in this area, however enforcement is weak.

Climate mitigation - The national DOE targets are to bring the renewable energy share in the power generation mix to 35% by 2030 and 50% by 2040 from the current 34,3% resulting in significant GHG reductions (Department of Energy 2020). The current share of renewable energy in electricity production in the Cagayan Valley and adjacent regions is currently at 26% with an average GHG footprint of 680 g CO2 eq. per kWh for electricity production (Regions I, II, III and CAR; Power statistics Department of Energy 2023a). It is considered that this represents important policy aims promoting FPV development on Magat reservoir.

Policies for the protection of Indigenous people: The Philippines is a culturally diverse country with an estimated 14- 17 million Indigenous Peoples (IPs) (UNDP 2013). The “Indigenous Peoples Rights Act” (1997, IPRA, Republic Act 8371), recognizes the right of IPs to manage their ancestral domains (UNDP, 2010). The law states, “Protect the rights of ICCs/IPs in the introduction and implementation of plans, programs, projects, activities and other undertakings that will affect them and their ancestral domains to ensure their economic, social and cultural well-being”.
In cases where a development project will influence the rights of indigenous people, the NCIP needs to be consulted / is a hearing part. If NCIP considered that the project will affect the IP in the area, investigations in line with the NCIP Administrative order No. 3, (2012) are required.


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Figure 3.4. *Water user activities,a) The boat landing area at the reservoir, b) The 220 kWp FPV pilot (June, 2022), c) The boat landing area at reservoir at low water levels (June 2023), d) Fish cages on reservoir (June 2023), e) The local fish market at the boat landing area, f) Transport of children to the school by boat, g) Youth swimming downstream the dam (, h) A downstream recreation area for swimming and picnicking, high water flow, i) A man fishing in a channel, j) Feeding of fish in a fishpond. All pictures were taken November 2022. (Source Ingrid Nesheim).*

Table 3.3. Trends and policies as drivers, influence on WUFs.

Drivers / Effects WUFs	Trends and policies as drivers					
	Economic development, urbanization trends	***Technological development trends***	***Renewable energy production policies***	***Agriculture irrigation policies***	***Aquaculture policies***	***Nature, environment protection policies***
Environment (Available freshwater, Good water quality, Biotic resources Reduced GHG emissions)	Contributes to population growth by migration, increased abstraction of water and then more frequent low water levels. Without proper sewage and waste management systems increased point source and diffuse pollution reduce water quality status. Increased population may lead to increased deforestation and land degradation causing erosion and sedimentation. Little direct effect on GHG.	With appropriate regulations and enforcement - may enable more efficient water use, less runoff of point source and diffuse pollution. If insufficient regulations - contribute to increased water consumption, and increased pollutants i.e. degradation of aquatic and terrestrial ecosystems.	Construction of more renewable energy projects including, hydropower, solar energy etc. will reduce GHG emissions – beneficial for climate change mitigation. Renewable power plants depending on proper impact assessments and mitigation measures may have adverse effects on some ecosystems, on the economy of certain groups, and on socio-cultural factors.	Construction of irrigation projects may depending on proper impact assessments and regulations, negatively affect ecological status of water and reduced availability of water for other purposes e.g. energy generation.	Favourable policies will further increase aquaculture on the reservoir. Without proper regulations this is expected to reduce water quality and ecological status in the reservoir (Baleta et al. 2019)	Various regulations are adopted (Table 3.2) to protect nature and the environment, but there is limited enforcement. Regulations do not allow construction of roads in the forest reserve area to reduce land degradation. Insufficient control on deforestation cause erosion and sedimentation to the reservoir.
Economy (Physical production, Provision of employment, Access to transportation, Provision of electricity, Flood control, Food security Good health)	Increased consumption of electricity and water, more service production, less primary production. Employment more in secondary and tertiary sectors. *The effect on poverty and food security depends on distribution effects.*	For agriculture - higher yield, higher income, often more favourable for well off farmers. For energy production – more efficient and flexible power production, economic development.	Construction of power plants is known to contribute to economic development, establishment of enterprises, generating employment and income.	More area under irrigation will increase yield and thereby income for the population of benefit. Will lead to economic development.	Favourable policies will drive investment and more people working in the industry, in particular residents around the reservoir. Increased income for workers.	The Watershed Forest Reserve restricts economic development and construction of road infrastructure in the area. This will reduce population growth in this area.
Social-cultural WUFs (Recreation opportunities, Protection of cultural heritage, Provision of landscape aesthetics Social cohesion)	*Economic and technological development may not have direct effect on recreation opportunities. Cultural heritage and practices often decline with economic development and urbanization, the degree will depend on protection* policies. *For Magat reservoir – the rules prohibiting* swimming in the reservoir reduce recreation practices. Some people in upstream villages practice rituals but this is only to a limited degree recognized known by local authorities.		The effect depends on the degree that energy projects, irrigation, aquaculture compromises the possibility for recreation and cultural practices. For the Magat reservoir, swimming and boat parades are practices that are no longer permitted. The impact of continued policies depends on whether development project allow or facilitated for continuation of practices. It can be expected that co-benefits for economic development will not be equally favourable for different groups in society (Axon and Morrissey 2020), a situation that is known to cause conflicts and reduce social cohesion (Dainius 2016).			Protection of the natural environment is known to also preserve cultural practices and heritage.

3.3.1. Scenarios and indicators

The scenarios being assessed were discussed and agreed within the project consortium during 2020-2021 and includes a (i) baseline scenario, (ii) a low cover FPV scenario, and (iii) a high cover FPV scenario. The scenarios were selected to enable comparing the environment, economic and socio-cultural factors and variables in a situation where, a minor part of the reservoir would be covered with FPV panels, and to the situation where a relatively higher part would be covered with FPV with a baseline situation without commercial FPV production. An overview of trends and policy drivers and the expected future influence on the system is presented in Table 3.3.

The FPV panel design: The FPV system installed on Magat reservoir are from a technology developed by Ocean Sun AS, consisting of horizontal PV modules mounted on a thin hydro-elastic membrane floating on the water surface allowing thermal contact between the PV modules and the water (Kjeldstad et al. 2021).

Baseline scenario with climate change: The scenario addresses the influence of identified trends and policy drivers as population growth, economic and technological development, urbanization, climate change, irrigation and aquaculture policies, and environmental rules and conditions in a future situation for the selected variables (sub-section 3.31.5). Climate change will lead to increased reservoir inflow during wet years, largely due to a substantial increase in rainfall input to the watershed and a significant reduction in reservoir inflow during dry years due to decreased rainfall (Singson et al. 2023). The model considered the expected impacts of climate change related to RCP scenarios 4.5 and 8.5 on reservoir inflow (Singson et al. 2023) and, on air temperature (PAGASA 2018).

Low cover FPV scenario – refers to the installation of FPV with a capacity of 60 to 70 MW. *It can be noted that this scenario represents 5 to 7 times larger intervention than the 10-12 MW planned as part of the first step of commercial FPV* production (plans described in the introduction). For this scenario, the FPV installation being composed of 96 circular structures mounted on a floating membrane, hereafter referred to as "rings", with a diameter of 75m will cover 3 to 6% of the reservoir. Whether the coverage is 3 or 6 % depends on the water level fluctuations which impacts the surface area of the reservoir. About 0.9km^2 would be occupied by the FPV with some free water in between the FPV rings (based on GIS files). The scenario involves anchoring the FPV panels in the area of the current boat and fish landing area, and removal of aquaculture cages to allow space for the panels. The panels will occupy parts of the navigation routes of residents north of the reservoir in Ifugao Province (Figure 3.1).

A high cover FPV scenario – refers to the installation of FPV with a capacity of approximately 300 MW. This intervention represents 25 to 30 times larger intervention than the 10-12 MW planned as the first step for commercial FPV production. The scenario does not reflect long-term commercial plans of the industry partners, the scenario was developed to investigate the impact of an extreme case. For this scenario, the FPV installation being composed of 430 rings with a diameter of 75m will cover 9 to 24% of the reservoir, and an area of 4.1km^2 would be occupied by the FPV with some free water in between the FPV rings (based on GIS files). During extreme dry years, at the lowest water level, the FPV structure might occupy most of the navigable water surface area (Figure 3.4). The scenario involves anchoring the FPV panels in the current boat and fish landing area.

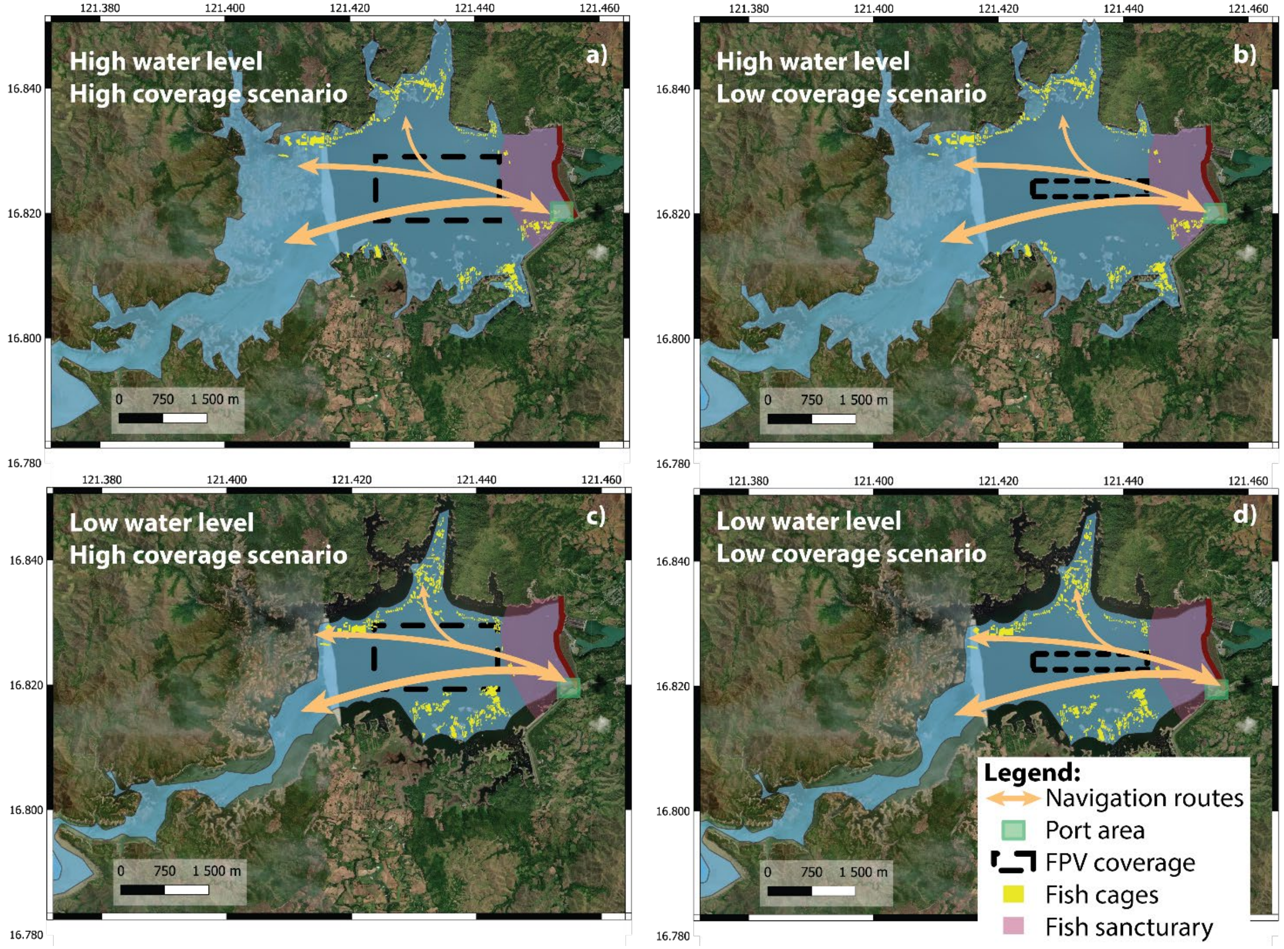

Figure 3.5. *Maps illustrating the competition for space on water in high (a and b) and low (c and d) water level and for both low (b and d) and high (a and c) cover scenarios. The yellow filled area is the water surface area occupied by fish cages, estimated from satellite images at high water level. For the low water level maps, the yellow area was displaced trying to not overlap with FPV or other constraints. However, fish cages need a minimum of 8 to 10 m depth which was not verified here. The location of the fish cages for the low water level is indicative. The low water level is approximated and only for illustration purposes. (Source, Satellite images are from ENSRI).*

WUFs and indicators selected - In total 15 water use functions associated with the environmental, the economic and the socio-cultural sustainable development dimensions were identified by stakeholders to assess effects of the FPV rings on the Magat reservoir (Table 3.4). In total 40 indicators presented in Table 3.4 were selected to characterize the WUFs. The number of indicators were kept as small as possible in line with the aim to avoid redundancy (Rice and Rochet 2005), while still fulfilling the needs of all users. More water uses were identified by stakeholders attending the focus group discussion in the upstream village than in the downstream village. More water use activities were described by local residents than what was referred to by local authorities (Interviews June 2022, and June 2023).

In line with the identified WUFs and indicators, we identified beneficiaries of different levels (local, provincial and national) which are summarized in Table 3.5.

Table 3.4 *Magat case study selected indicators for the current situation*

Water use functions	Indicator results current situation	Verification
Available freshwater	Number of months pr year (downstream) access to irrigation water for agriculture area: 12 months/yr – current area = 85’000 ha. The service area of Magat is 104, 405 hectares.	Reservoir model calculation, 3.4.1. Magat River Integrated Irrigation System, 2023
	Number of months water level reservoir above optimal level (174 m): over 1984-2022 – 9.6 month/yr	Reservoir model calculation, 3.4.1
	Number of months water for efficient hydropower production (> 171 m): over 1984-2022 – 10.3 months/yr	Reservoir model calculation, 3.4.1
Provision of good water quality	Number of months with acceptable ecological status (i.e., O2 > 6 mg/L): 5.42 months/yr	Reservoir model calculation, 3.4.1
	Number of months acceptable status for domestic usage (i.e., O2 > 5 mg/L): 11.7 months/year	Reservoir model calculation, 3.4.1
	Number of months acceptable status for swimming (i.e., O2 > 5 mg/L): 11.7 months/year	Reservoir model calculation, 3.4.1
	Abundance of algae and cyanobacteria: chlorophyl-a 38 µg/L	Reservoir model calculation, 3.4.1
Provision of biotic resources	Fish diversity Indices: no data Degree fish mortality - fingerlings / young / adults: Some fish die during the dry season, isolated cases. Change of fish body mass and size: no data	Reservoir model calculation, 3.4.1
Reduced GHG emissions	GHG emissions; Relatively low GHG emissions dominated by downstream CH4 degassing: 25 ktons CO2 eq /yr | 35 g CO2 eq/kWh	G-Res tool and Reservoir model calculation, 3.4.1
Physical production	Sale of fish from reservoir: High fishing yields. Ton aquaculture production: 2022 fish cage production in the Magat reservoir - 875, 270 kgs valued at PhP79M. Sale of agricultural production downstream: (No data) Fishpond production downstream: 362 hectares (BFAR 2021); corresponding to approximately 22 fishponds.	Focus group discussion (2022), Interview fish cage farmer (2023). Provincial Fisheries Office, 2022
Provision of employment	% of. households (upstream) income aquaculture: About 856 fish cage operators (2023). % of households (upstream) income from free fishing: % of the households downstream income from irrigated agriculture: (no data) % households downstream receive income from fishponds: (no data)	Focus group disc. (2022), interviews NIA (2023)
Access to transportation	% households that use boats for transportation: All upstream residents use boats for transport for most daily activities. Navigation time: Depend on length, estimated 20 -30 min. from s-w end to port Navigation expense: Depends on the fuel price and the length. From the s-w side of the reservoir to the port area – 3-5 litres gasoline. Port for boats: For all village around the reservoir, only one boat and fish landing area on Isabela Province side.	Conversation boat drivers, and observation (2023).
Provision electricity	*Degree sufficiency of energy supply / stabilizing power*. Tot. generation Magat HEPP: 734 GWh (2009–2015). Tot. annual electricity produced by the FPV: Not yet constructed. Tot. annual electricity produced by the hybrid hydro-FPV plant: No yet constructed.	https://www.snaboitiz.com/about-us/

Provision of flood control	Frequency of flooding events destroying property: No data collected. Flooding occurs annually, high flooding occurs every 5-10 years. Not relevant for scenarios.	SNAP (Pers com 2024)
Provision of food security	Level of support needed by the Local Gov. Unit (LGU): provides support, ca. 50% of household in reference. % households that use fishing for as contribution to consumption: People participating in the FDG indicated that all households fish for own consumption.	FGD village upstream, 2022)
Good health	Situation waterborne diseases: There is no occurrence in diseases as malaria in the area. There is dengue in the area. Some occurrence – WASH related diseases. No primary data collected.	
Recreation opportunities	Proportion that uses boating for recreation: The majority of households. Both upstream and downstream residents go to the reservoir. Proportion that uses the area around the reservoir for picknicks: It is common. Swimming: Though prohibited people swim in the reservoir. Youth and adults swim in channels downstream area. Education: the Magat	Observation, FGD 2022. Personal communication, 2023.
Protection of cultural heritage	Rates of occurrence traditional practices as, cleansing rites, baptism, "gulgul": Such activities are not common practices, but they do occur – mostly by residents in villages upstream the dam.	FGD 2022.
Existing social cohesion	Occurrence of conflicts among people associated with water use: Conflicts among aquaculture farmers have been reported, previous years more intense, current situation conflict level is low.	Personal communication, 2023
Provision of landscape aesthetics	Nearby residents who experience reduced the landscape aesthetics due to the FPV. The pilot 220-lWp FPV occupies less than 0.01 % of the waterbody and is not seen to influence the waterscape.	Authors understanding 2024.

Table 3.5. *Magat case study selected beneficiaries and stakeholders by WUFs*

Water use functions	Beneficiaries / Stakeholders	Level
Available freshwater	NIA SNAP Aquaculture farmers, Fishpond farmers, Agriculture farmers Residents upstream, particularly in Isabela and Ifuago provinces	Provincial Local
Provision of good water quality	DENR, BFAR Aquaculture farmers, Fishpond farmers, Local population Residents upstream, particularly in Isabela and Ifuago provinces	Provincial Local
Provision of biotic resources	DENR, BFAR LGUs Aquaculture farmers, Fishpond farmers Residents upstream, particularly in Isabela and Ifuago provinces	Province Local
Reduced GHG emissions	DOE SNAP	National Provincial
Physical production	Aquaculture farmers, Fishpond farmers Residents upstream, particularly in Isabela and Ifuago provinces	Local
Provision of employment	LGU Residents upstream, particularly in Isabela and Ifuago provinces	Local
Access to transportation	Local population in	Local
Provision electricity	DOE SNAP Population and industries in Northern Luzon Island	National Provincial
Provision of flood control	NIA, LGU Residents mostly downstream villages	Provincial Local
Provision of food security	LGU Residents upstream, particularly in Isabela and Ifuago provinces	Local
Good health	LGU	Local

	Residents upstream, particularly in Isabela and Ifuago provinces	
Recreation opportunities	LGU Residents upstream, particularly in Isabela and Ifuago provinces, also residents in downstream villages	Local
Protection of cultural heritage	NCIP, LGU Residents upstream, particularly in Isabela and Ifuago provinces, also residents in downstream villages	National Local
Existing social cohesion	National authorities? LGU Residents upstream, particularly in Isabela and Ifuago provinces, also residents in downstream villages	National Local
Provision of landscape aesthetics	Residents upstream, particularly in Isabela and Ifuago provinces, also residents in downstream villages	Local

3.4 The modelling results- Magat case indicator assessments

There are different types of tools and approaches which allow analysis of and visual presentation of complex interrelationships, as for example Bayesian framework analysis (Alastair et al. 2022). While system dynamics refers to mathematical modeling technique to frame, understand, and discuss complex dynamic relationships including some feedback mechanisms. In accordance with the scope of the study and this report, relations between variables and indicators are in the assessment of the FPV on the Magat dam only described qualitatively.

This section presents the model results of PFV on the environmental variables, and the analysed predicted effect on environmental, economic and social cultural indicators.

3.4.1. The model results of FPV deployment on environmental variables

Magat bathymetry and the seasonal water level situation - The Magat Reservoir bottom has a distinct shape which has been surveyed multiple times through bathymetric surveys (Scatec personal communication, 2024). The figure 3.5a below shows that the reservoir surface area can fluctuate between approximately 10 km^2 to 28 km^2 in relation with the water level constrained by the operational range of 160 to 190 meter above sea level (masl). Water level typically decreases during the dry season, from November to May, often down to 170 masl, and regularly to the minimum allowed level of 160 masl, and then increases again during the wet season from June to October (Figure 3.6d). This typical yearly cycle has strong implications for the water volume present in the reservoir and for the potential impacts of FPV. The FPV system will have a constant surface area coverage throughout the year, and we can thus expect that the highest impacts will be during the lowest water level, typically at the end of the dry season.

Hence, the percentage of the reservoir covered with FPV is largely dependent on water level fluctuations. For the low cover scenario, FPV coverage varies between 3 and 6 % while for the high cover scenario, it spans 9 to 24%.

The hydrological model calibration results- The water level simulated over a 10-year period without FPV coverage is in excellent agreement with observations (r^2 of 0.98 and Nash-Sutcliffe efficiency of 0.98; Figure 3.6d) while the epi- and hypolimnion temperatures are consistent with observed sensor data (Figure 3.6c) providing strong support for accurate simulations of the water and heat balances.

The modelling approach allows us to predict changes in the environmental variables, such as evaporation, water level, water temperature, and oxygen concentrations, chlorophyl-a and greenhouse gas emissions. It also provides the potential to predict changes in nutrients and other chemical variables which were not assessed in the present study because of the lack of calibration and validation data.

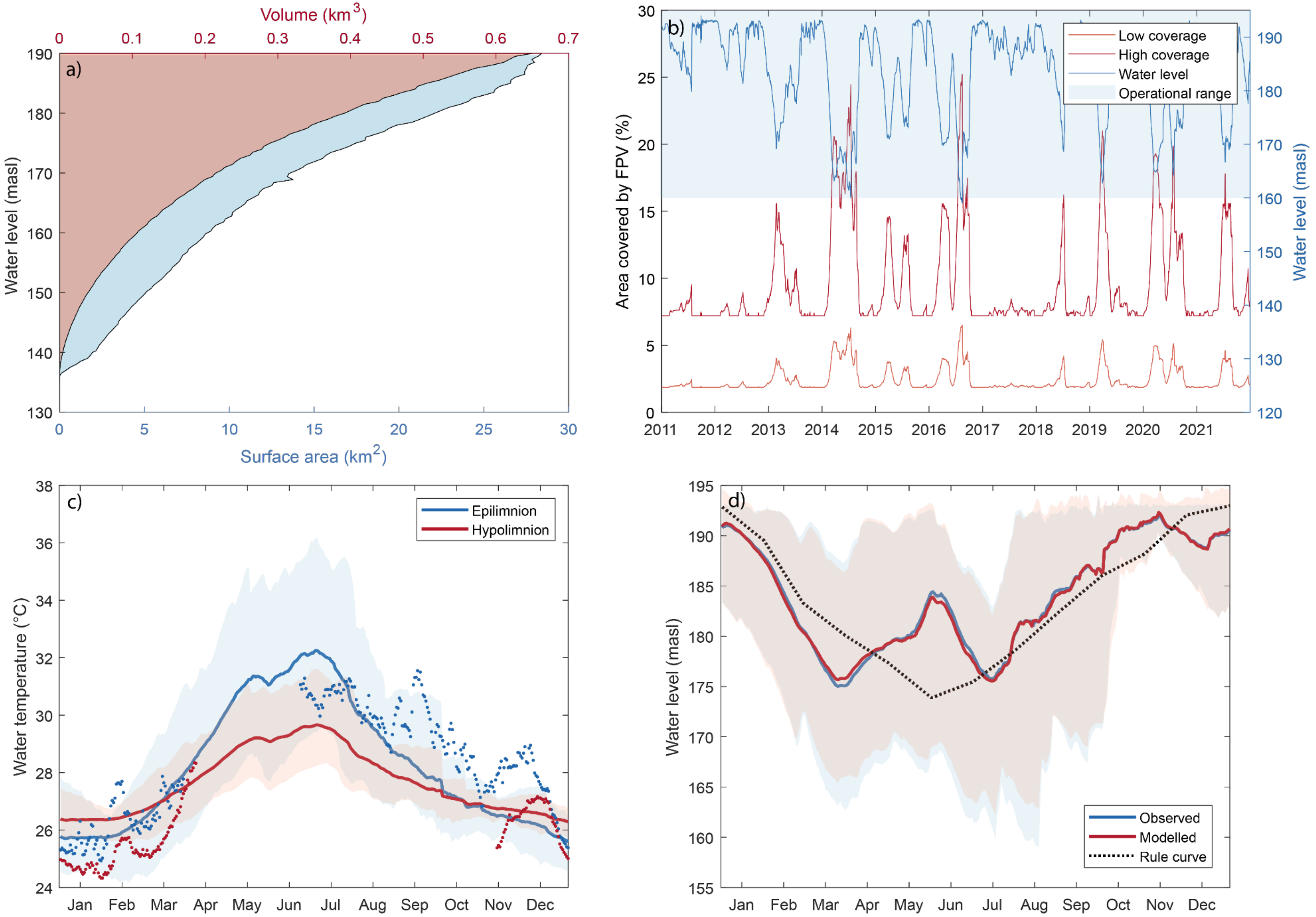

***Figure 3.6.**: a) Magat reservoir cumulated volume and surface area as a function of water level; b) Observed water level of Magat reservoir as well as percentage of the reservoir surface area covered by FPV according to the two scenarios; c) Simulated water temperature in the epi- and hypolimnion of Magat reservoir over 2012-2022 (lines) and observed water temperature over June 2022 and April 2023 recorded with temperature loggers (dots). d) Comparison of observed and simulated water level at Magat Dam during historical period (2012-2022).*

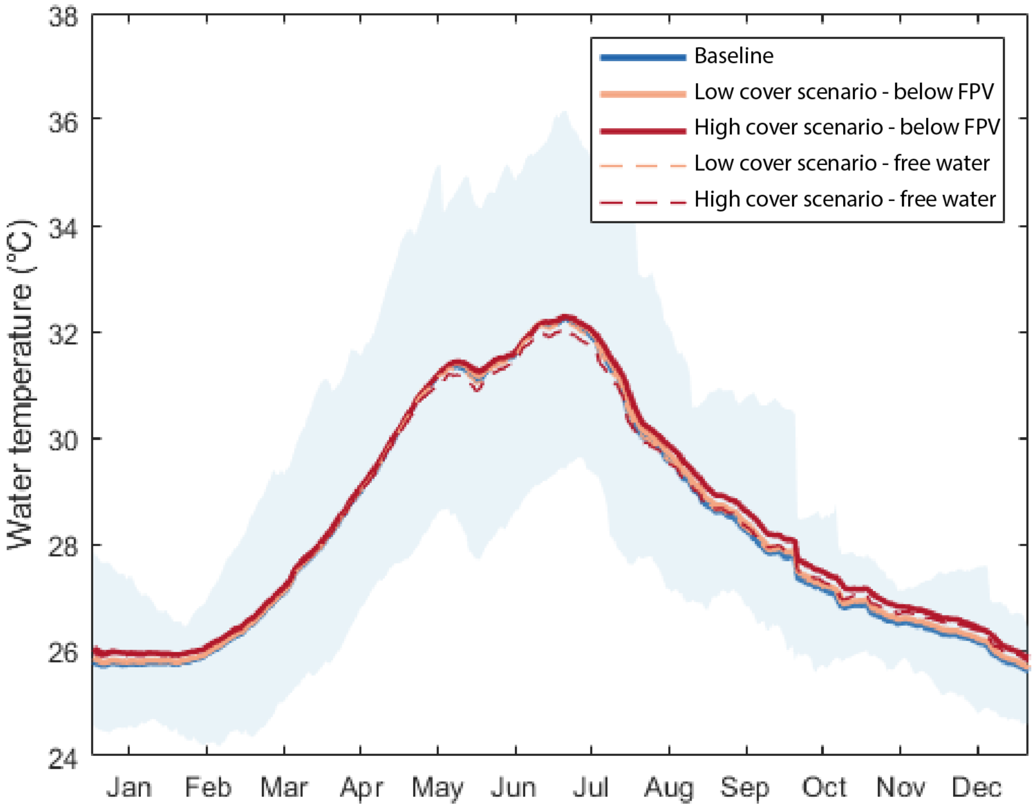

Figure 3.7: Simulated surface water temperature in Magat over 2012-2022 in two distinct areas of the reservoir: below the FPV and in areas with no FPV, i.e., free water, following the three scenarios: baseline, low and high cover.

The FPV installation showed small impacts on environmental variables under normal conditions, even for the high cover scenario. On average, evaporation was 3% (64 mm yr-1) and 12% (220 mm yr-1) lower for the low cover and high cover scenarios, respectively, compared to no FPV coverage. However, the amount of water saved represents only about 0.01% and 0.05% of the total yearly inflow, respectively. Similarly, water temperature in the epilimnion was 0.02°C and 0.12°C higher, and oxygen concentrations were slightly lower than without FPV. Nevertheless, under selected extreme events, such as prolonged low water level, the presence of FPV can significantly increase the numbers of days where O_2 concentration falls below 6 or 5 mg L^{-1} or temperature rises above 35°C, considered as thresholds with some impacts on fish growth (Abd El-Hack et al. 2022). These extreme events are expected to be more frequent with climate change especially during extreme dry years where the inflow runoff could be decreased by up to 23% (Singson et al., 2023). In absence of adaptation of the operational regime, the extension of low water level periods would dramatically increase the impacts of FPV.

On the other hand, if the operational regime is adapted to keep a water at a higher level to avoid very low water level and maximize water volume in the reservoir, extended periods of very low water and associated dramatic impacts of FPV can be completely avoided (Figure 3.8). Figure 3.8 shows that under the “solar to hydro” setup, the water level is constantly higher than the default setup and never goes below 170 masl. On average the water level is 4.3 m and 6.5 m higher for the “solar to hydro” setup compared to default conditions for both the low cover and high cover scenarios, respectively.

The primary water use for Magat is irrigation for rice cultures. Cultures of rice require 300 mm or 400 mm per month for irrigation (Bouman et al. 2007), of which 30 to 45% is directly provided by effective rainfall on the cultures (yearly basis); 2 to 79% depending on the months. The rest is provided by irrigation water from Magat Dam. Considering that 85’000 ha are irrigated with water from Magat, the monthly irrigation requirements should reach 255 to 340 million m^3 without effective rainfall. For the baseline, the 400 mm irrigation requirement is not met over 1.63 months per year, on average (1.09 months if we consider 300 mm requirement). Some years, the irrigation requirement is not met up to 3 months in a row. In contrast, for the high cover scenario with the Solar to Hydro setup, the 400 mm irrigation requirement is not met over 1.45 months pear year (0.7 months if we consider 300 mm requirement). Some years, the irrigation requirement is not met up to 3 months in a row.

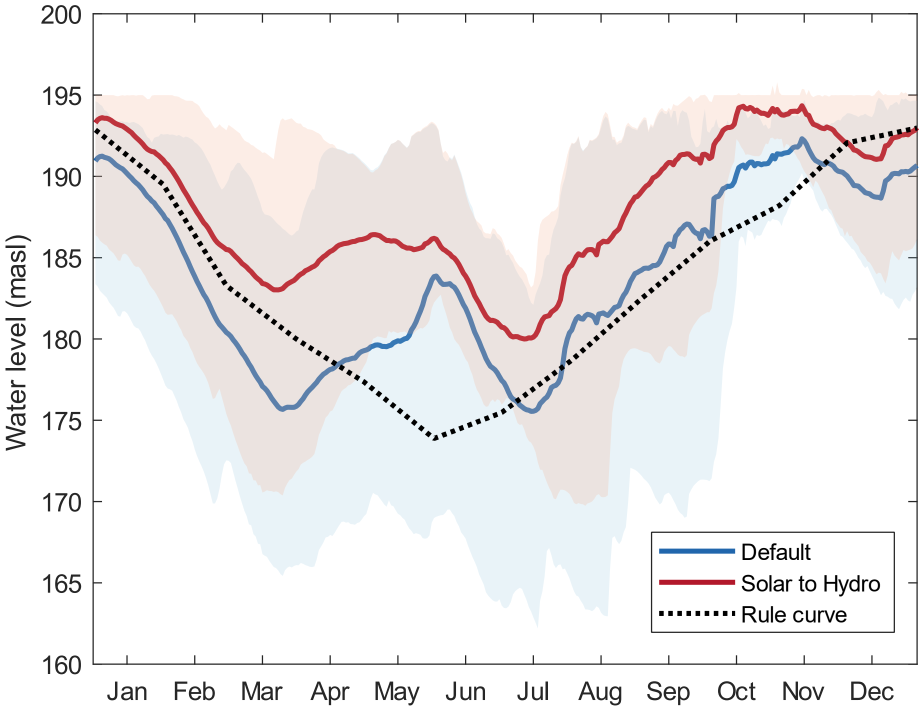

***Figure 3.8:** Comparison of simulated water level at Magat Dam during historical period (2012-2022) with the default and "solar to hydro" model setups both for the low cover scenario.*

3.4.2. The effects of the scenarios on indicators

This sub-section presents the analysed effects of the FPV scenarios on environmental, economic, and socio-cultural indicator values. Knowledge rules (sub-section 2.2.1) are used to analyse and predict the influence of the baseline and the FPV scenarios on selected indicators using the current situation documented by primary and secondary data collection as reference (sub-sections 3.1, 3.2). Figure 3.5 visualises the competition for area on the reservoir for the different water uses: solar energy generation, aquaculture production, fishing, navigation / transportation, and port versus mooring of the FPV system in the different FPV scenarios.

The WUF may be a composite of several usages or have several different effects. In such cases, more than one indicator was selected to characterize the WUF. An example is access to transportation, where the effect is a composite of, removal of port, increased costs for fuel, and increased transportation time. The choice of indicators was made based on how well they present the impact on the beneficiaries, while also avoiding redundancy. We take the precaution that the list of indicators provided in this chapter may not be exhaustive. The following sub-sections presents an analysis of the effects of the FPV scenarios relative to the baseline scenario, for each of the identified indicator. Table 3.5 presents the data used in the assessment of the predicted effects of the scenarios for each indicator. Not all the indicators listed in Table 2.3 are analyzed in the case study.

3.4.2.1. Environmental *indicators*

Provision of water availability (quantity) FPV can affect water availability for irrigation by reducing direct sunlight exposure to the water surface. This shading effect may decrease evaporation rates, potentially preserving water levels during critical months for irrigation of cultures and hydropower production. In line with these water uses; three indicators were selected: (i) the number of months per year with access to irrigation water (irrigation requirement; see section 3.3.1.4), (ii) Number of months with water level reservoir above optimal level for irrigation (>174 m; see section 3.3.1.4) and (iii) Number of months water with water level above threshold for efficient hydropower production (> 171 m; see section 3.2.1). The thresholds are described in section 3.4.1 above.

At Magat, both FPV coverage scenarios resulted in small savings of water related to reduced evaporation. The low and high cover FPV scenarios corresponded to 3–6% and 9–24% FPV coverage, respectively, and yielded a modelled reduction of evaporation of 3 and 12%, respectively. The volume of water saved is very small compared to the annual discharge (< 0.1%). Considering only reduced evaporation, the indicator values for the baseline and the two scenarios are similar. For the FPV coverage to result in water savings, there need to be a much larger fraction of the reservoir covered with FPV (Essak and Ghosh 2022). Water savings can however be achieved by making use of the solar energy production to replace some of the hydropower production by adapting the operation regime (see section 3.6.1). This adaptation would have several benefits related to higher water level in the reservoir.

Provision of good water quality[13]: FPV can influence the ecological status of water bodies. By shading the water surface, the panels reduce light penetration and thereby potentially reducing aquatic plant growth and nutrient cycling. Algae growth may be reduced with less light penetration. Changes in water temperature and nutrient dynamics related to FPV (see sub-section 3.4.1) may affect taste, odour, and overall suitability for drinking or for swimming. In addition, the FPV cover blocks air-water exchanges of dissolved gases such as oxygen. In line with these potential effects, we selected four indicators: (i) number of months with acceptable ecological status (O_2 > 6 mg/L; see section 3.3.1.4), (ii) number of months with acceptable water status for domestic usage (O_2 > 5 mg/L; see section 3.3.1.4), (iii) number of months with acceptable water status for swimming (O_2 > 5 mg/L; see section 3.3.1.4), and (iv) abundance of algae and cyanobacteria (chlorophyl-a). The acceptable ecological status is not met year-round already for the current situation where only 5.4 months/yr show acceptable ecological status. For the low cover scenario, the number of months with acceptable status for domestic usage or for swimming is reduced by about 1 month, under the high cover scenarios this can reach 5 months. Note that these indicators are an integration of normal, wet and dry years, implying that during wet years the acceptable ecological status can be met year-round, while during dry years, the acceptable ecological status cannot be met at all in the most severe cases. Similarly, the acceptable water status for domestic and recreational usage shows a reduction of 0.8 and 3.4 months/yr for the low and high cover scenarios respectively (Table 3.5). Regarding abundance of algae and cyanobacteria, compared to baseline the abundance is reduced by 1 µg/L and 4 µg/L for the low and high cover, respectively. This indicator shows a positive effect on water quality, consistent with the expected decrease in algal growth.

Provision of biotic resources: FPV can influence biotic resources from the reservoir through habitat alteration, shading, changes in algal production, oxygen levels. Reduced evaporation due to shading may maintain water levels, benefiting fish habitats, however, here this effect is expected to be insignificant. In contrast, FPV cover might exacerbate the occasional events of reduced oxygen levels (already happening in the baseline) and high-water temperature under and around the FPV which may stress fish populations and reduce Fish diversity and abundance. These conditions were however never met for the

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[13] Other water quality issues - Cleaning of FPV with detergents. The effect of the panels such as from detergents cleaning the panels have not been discussed. Microplastic emissions from the natural degradation of plastic component of FPV. There is too little knowledge on these topics. Best recommendations are to monitor the water quality for these risks.

baseline and for the low cover scenario. The modelling results show that on extreme episodic events, the dissolved oxygen concentrations can drop below 4 mg/L and water temperatures can rise above 35°C for only a few days for the high-cover scenario only.

Reduced GHG emissions: Through the FPV system's effect on water temperature, thermal stratification and nutrient cycling of the reservoir, FPV influences greenhouse gas emissions from the reservoir. FPV systems themselves do not directly emit greenhouse gases. Also being considered is that provision of renewable energy through solar production can avoid GHG emissions from electricity production in coal power plants. Therefore, we selected two indicators: (i) GHG emissions and (ii) Avoided GHG emissions due to renewable power generation, both expressed in CO_2 equivalents. Regarding GHG in Magat Dam, CH_4 degassing downstream of the outlet release represent the main emission pathways (about 65%) while the remaining emissions are through CO_2 and CH_4 emissions at the reservoir surface. The average GHG emissions during baseline was estimated to reach 35 g CO_2 equivalents per kWh which is in line with estimates from the G-res tool (see chap. 5). The soft membrane FPV technology used in the Magat case (Kjeldstad et al. 2021) blocks the surface CO_2 and CH_4 emissions, which for CO_2 only increases slightly its residence time in the water while for CH_4, it also increases its probability to be oxidized to CO_2. Under the low cover scenario, the GHG emissions would be slightly reduced by up to 2.5%. For the high cover scenario, GHG emissions would be reduced by up to 11%.

For the indicator, avoided GHG emissions, production of additional renewable energy from the FPV would avoid some GHG emissions if the equivalent energy would be produced through current energy mix of the Cagayan Valley region and adjacent regions (Regions I, II, III and CAR; Power statistics Department of Energy 2023a). For the baseline scenario including increased electricity demand (sub-section 3.3.1.5), in absence of added solar power from FPV, there may be a production gap leading to additional usage of fossil fuels, considering that the current power plants are dominated by fossil fuels in the Luzon electricity grid (84% with an average of 680 gCO_2 eq/kWh GHG footprint). Hence, producing electricity with the FPV would avoid the emission of 44 ktons CO_2 eq. per year and 196 ktons CO_2 eq. per year for the low and high cover scenarios, respectively.

3.4.2.2. *Economic* indicators

Provision of physical production*:* The assessment focussed primarily on the production of aquaculture. Only qualitative estimations are provided for production from fishing by nets in the reservoir, from fishponds, and from irrigated agriculture.

Considering production of aquaculture, for t*he baseline scenario,* increased aquaculture production can be expected in line with increased production in recent decades and the trend of increased number of aquaculture farmers (Araullo 2001; Baleta, Bolanos and Medrano 2019) (Personal communication, 2023). In case the fish sanctuary policy (NIA, adopted in 2004) will be enforced, then around 4-6 ha of fish cages, or 8-12 % of the fish cages present, will have to be removed reducing yields (depends on options for relocation). Interviews in 2023 with the local authorities did not indicate that this would happen soon. For the FPV *low cover scenario,* reduced aquaculture production is expected as FPV panels will be replace around 5-20% of fish cages (actual reduction depends on options for relocation). Also, the mooring of the panels will be located in the current fish landing area expected to come with a negative influence on sale of fish (Figure 5.4; Unknown, 2021). For the *high cover scenario,* as more area on the reservoir will be covered by panels (Figure 3.5) about 40 -70% of the current 48 ha of fish cages will be removed. As the fish cages are six meter deep, there is a need for a water depth of minimum eight to ten meters. In the dry season the water depth closer to the shores of the reservoir is below eight meters and the fish cages are moved towards the middle of the reservoir where the reservoir is deeper. The large range of values for this indicator represents the uncertainty regarding the area with deep enough water that will be available for fish cages in the context of the FPV scenarios as well as the possibility for relocation.

Each fish cage module is 6 X 12 X 5 meters (standard dimension from BFAR). Considering the current situation referring to the year 2023, when yearly fish production reached 875 270 kg, for the low cover scenario, a reduction of 5-20% of the fish cages will result in a reduction of 44 – 175 tons per year. For the high cover scenario, a reduction of 40 -70% of fish cages may result in reduction of 350 – 612 tons per year (current production reference is much lower than the peak production around year 2000; (Prudencio 2018). It can, however, be expected that the physical production of fish will be lower for the high cover scenario due to episodic harmful levels of low O_2 concentration for Tilapia, and increased water temperatures, having negative effects on fish growth and survival (considering the number of fish that dies). Production of fishing by nets, is not expected to be affected in the low FPV scenario. For the high FPV scenario, the reduced water quality, and reduced access to fishing grounds will reduce fishing yields.

For “production from the fishponds”, the baseline may represent an increase, while insignificant changes are expected for the FPV low, and high cover scenarios.

Regarding, “production from irrigation agriculture” some increased production may be expected for the baseline scenario following the national policies aiming for more irrigated area. Considering the low and high FPV cover scenarios, roughly the same situation is predicted as available water quantity stays the same. Reduced evaporation due to the FPV cover remain negligible unless a very large fraction of the reservoir is covered (this study; Chang, Shih and Kao 2023).

Provision of employment: The indicators to evaluate change in employment address (i) households upstream with main income from aquaculture, and (ii) the number of people that will be employed due to ripple effects of FPV. For the *baseline scenario*, no change is expected. Considering 183 fish operators (annual report BFAR, 2021), and the estimated reduction of 5-20% area of fish cages, for the low FPV scenario, a range of 10-37 number of households will experience reduced income. For the high cover scenario, considering the estimated reduction of 40- 70% area of fish cages, a range of 75 – 129 households are estimated to have reduced income. Most fish cage operators employ other people to work, hence the number of households influenced can be multiplied by two or more. It should however be considered that the number of people working on the fish cages are much higher than the number of reported fish cage operators. In an interview with NIA in 2023, it was informed that in 2022, 773 people were leasing area, and in 2023, 856 people were leasing area for fish cage production.

Regarding the number of people that may be employed directly on the FPV power plant and indirectly due to the FPV intervention, few publications document the situation. On Magat, a third-party contractor will be responsible for maintenance of turbines, and other facilities related to the FPV system including cleaning. Regarding the number of people to be employed to work on the FPV power plant, around 20-30 people may be employed as part of the FPV intervention (Pers com. 2023; 2024). It is uncertain if the new employment opportunities will benefit the people that experience reduced income. It may be predicted that for the *high cover FPV scenario,* only few households around the reservoir will have income from the same activities, as fish yield is expected to be low (see physical production above).

On long term however, drawing on publications and experiences from other energy development projects, the FPV intervention with increased power generation can be expected to stimulate investments in industries and the service sectors and thereby employment (Esteves and Barclay 2011; Kjærland et al. 2012). The degree that local people will be employed depend largely on available competence, but also on company policies.

Access to transportation: The study focuses on the access to navigation on the reservoir as this is the main mode of transportation for households around the reservoir. Four selected indicators, (i) navigation time, (ii) navigation expenses, and (iii) access to boat landing area represent different elements of accessibility, (iv) % households that use boats for transportation. Each of these can imply different effects on access for households, e.g. insufficient time, insufficient financial means. No effect is expected on villages downstream of the dam. The *baseline scenario* is not expected to imply change on indicators. The Lower Magat Forest Reserve rules do not allow construction of roads (DENR, 1969). For the *low cover scenario,* the FPV panels will occupy some of the area representing navigation routes, potentially implying around 10 to 20 minutes increased time on transport, and thereby increased expenses for fuel (Personal communication, SNAP November 2024). Reduced access to boat landing area due to the anchoring of the panels will have a negative effect. Yet it is expected that the same proportion of households will use boats for transportation. For the *high cover scenario,* access to transport will be reduced for most of households in upstream villages as the panels will make navigation on the reservoir complicated. Navigation time, and fuel costs will be much higher, but more important only limited area will be available for boats (Figure 3.5).

Provision of electricity[14] - is addressed by assessing the indicator, "total annual electricity produced by the FPV". For the indicators, (i) tot. annual HEPP generation, and (ii) total electricity produced by the hybrid-FPV plan only expected qualitative results are presented (Table 3.5). Other indicators (Table 2.3) to represent earning opportunities such representing as the spot price per kWh are also relevant. This is not analysed here.

The baseline scenario does not imply any change in power production for Magat (734 GWh by hydro production; the FPV pilot of 220 kW is not connected to the grid). For the low cover scenario referring to hydro plus solar about 804–818 GWh annual electricity production is estimated (considering a 60–70 MW FPV plant), an increase of 9-11% compared to the baseline. For the high cover scenario, (considering 300 MW FPV) annual production hydro plus solar is estimated at 1028-1056 GWh and 40-44% increase compared to the baseline (hydropower of 734 GWh). According to an unpublished prefeasibility report, the current plans to construct a commercial efficient hybrid hydro FPV, and the planned upgrade of the transmission line from the FPV project to the Luzon grid, will provide increased, and more stable power generation (Unknown 2021).

Provision of flood control - is addressed by the indicators, (i) expected reduced frequency of damage on property, and (ii) expected reduced costs of damage on property. The indicators inform on the degree that the FPV intervention will enable flood control, while also considering the frequency of flooding and extreme weather events. It is not expected that the FPV system will fluence control of flooding because the emergency protocol during flood operations is implemented at a higher priority than electricity generation (Department of Agriculture, 2007). The protocol rigorously considers flood security through several decision flow diagrams taking inter alia rainfall forecasts and water level into account.

Provision of food security*:* The study measures potential effect on food security by the indicator, "poverty assistance by the LGU", assuming a relationship between food insecurity and support to vulnerable households in upstream villages with income from fishing and aquaculture. People attending the FGDs informed that around 50% percent of the households in the villages around the reservoir receive support. For the *baseline scenario*, there may be some improvement in the food security situation due to the due to the general economic growth in the area the recent decades (IsabelaProvince 2023), this is however uncertain. Regarding the effect of the *low cover scenario*, among the 20 -30 households with family members that receive income from aquaculture, for the vulnerable portion of these, food insecurity is expected to increase. For the *high cover FPV*, it is expected that also a certain proportion of households that are currently not vulnerable, will for a period experience food

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[14] Other indicators not calculated representing other values are also relevant, as, (i) value in the capacity market, (ii) value based on reduced O&M costs (using PV+battery may save wear on turbines), Spot market, ancillary services, energy capacity market (Table 2.3). In Luzon Island there is stable provision of electricity, hence the indicator is not relevant.

insecurity, as aquaculture will diminish, and fishing for own consumption and income will be reduced. Quantitative estimates of effects are not provided as this will be highly uncertain.

Provision of good health: To measure the degree that FPV panels influence physical, mental and social well-being of people (WHO, 1948), the study focuses on the indicators, "Occurrence of waterborne diseases", and "Occurrence of WASH (water sanitation and hygiene) related diseases". This situation is monitored by local authorities and made available online (Department of Health 2024). Regarding the occurrence of waterborne diseases, malaria is distinct in the area. Dengue is present. There are some occurrences of WASH related health issues. No change on these indicators is expected with the baseline scenario, or the low cover FPV scenario. For the high cover FPV scenario, an increase in WASH related diseases may be expected due to reduced water quality for the proportion of households that use water from the reservoir for domestic purposes. Regarding a possible effect on mental and social well-being embedded in the WHO's definition of good health (1948), there may be a negative effect on well-being associated with the high cover FPV scenario influence on such as employment, food insecurity, reduced recreation opportunities on the reservoir, and change of traditional practices.

3.4.2.3. Social and cultural indicators

The assessment focuses on recreation opportunities, protection of cultural heritage, provision of landscape aesthetics, and existence of social cohesion. In this assessment we have focused indicators where available data and literature can support scenario predictions (representing accepted knowledge rules). See also 2.1.2 on socio-cultural situation and indicators.

Recreation opportunities: The study addresses the potential impact on recreation opportunities by addressing three indicators, (i) the number of boats on the reservoir, as boating for recreation was identified as a highly important activity for most of the households located both upstream and downstream of the dam, (ii) the "number of days with safe (or unsafe) swimming" downstream of the dam; it was stressed that in cases of release of stream flow this causes unsafe swimming conditions, (iii) number of people visiting the panels for education interests. The focus group discussion undertaken in 2022 in upstream and downstream villages revealed also other recreation activities, such as camping and picknicks along the shores of the reservoir, and swimming in the reservoir, and boat parades on the reservoir. Regarding swimming and boat parades on the reservoir, it was made a remark that this is no longer permitted. The possible benefit of FPV for recreation and education interests is measured by the "number of people visiting the panels for education interests". The energy company has indicated that there will be plans to facilitate for schools and tourists local and others to visit the panels Since 2007, when SNAP gained responsibility for Magat HEP, it has been open to visits from schools, local government officials, private sectors (Personal communication SNAP October 2024).

The *baseline scenario* is not expected to influence the indicators for recreation activities.

For the low FPV scenario, households may reduce boating for recreation due to inconvenient boat landing (the current port is removed), however, the effect on boating is uncertain. In contrast for the high FPV cover, it can be expected that the conditions mentioned represent high inconvenience leading to a halt of boating as only limited area on the reservoir will be suitable for boating (Figure 3.5). Also reduced recreation quality can be expected caused by glare from the panels and low landscape aesthetics (see, World Bank Group, 2019).

Regarding effect on FPV scenarios on the indicator "safe swimming conditions", this will depend on the specified water release operation regime and the degree safety is prioritized when releasing water from the dam to avoid sudden flash floods downstream. Operation regime to avoid flash floods and information about operation regime to villages and households are critical. Practices and information will determine if people trust that swimming in the channels is safe. Some people in the FGDs indicated that provision of information about high floods in the channels is not satisfactory. For the FPV scenarios, without an operation regime specifying water release regime being considerate of downstream recreational users, the risk will increase. For the indicator, "number of people visiting the panels for education interests", the value will depend on whether this will be facilitated for by the energy company and the actors in charge. Based on interviews, both with actors of the energy company and local authorities, utilizing the FPV intervention for education (and tourism) purposes is an intention, while not yet specified in planning. It was referred in interviews that the current pilot FPV panel receives interest from the public and that there currently are more than ten visits per year (Personal communication SNAP, November 2024).

Protection of cultural heritage – refers to the situation that the ability to perform traditional practices and rituals is not disturbed in any way by development interventions or associated policies, a situation measured by *t*he indicator, "rates of occurrence traditional practices" as, cleansing rites, baptism, "gulgul". Rituals as "gulgol" / cleansing rites and traditional practices are according to the FGD in 2022 practiced by some people around the reservoir, and but primarily by the Ifugao indigenous people.

For the *baseline scenario*, it is expected that a reduction of traditional practices and rituals will continue in parallel with the current trends and situation informed of by people in the FGD in the downstream village, that, recent decades there has been a reduction of the number of people that practice rituals. It is acknowledged that traditional behavior and practices are often disappearing with urbanization, modernization and technological advancement (Bumanglag et al. 2021). It can be expected that the FPV low and high cover scenario will further promote urbanisation and modernization by technologic development and thereby loss of cultural heritage (Kuddus et al. 2020).

Provision of landscape aesthetics – Landscapes and waterscapes are known to influence people's wellbeing (Abraham et al. 2010). The study focuses on the degree that nearby residents experience reduced the landscape aesthetics (are disturbed by this and from potential glare from panels) due to the FPV. Few studies have been undertaken to assess people's perception of FPV (see World Bank group, page, 75), but there are several publications on people's perception of windmills (Klæboe and Sundfør 2016; Grieken and Dower 2023). Also, the topic was not addressed with local people during the study. The baseline scenario reflecting the current situation with a 220 kph FPV panel representing one circular ring of 25-meter radius (Figure 3.3) were observed by the authors of the report, not seen to people's perception of landscape. For the low cover FPV scenario representing 96 number of rings of 70 m diameter occupying 3 to 6 % of the waterscape, it may be expected that some residents will experience a reduction in landscape aesthetics. For the high cover scenario representing 430 rings occupying 9 to 20 % of the waterscape, the immediate landscape aesthetics will change for the majority of users (depicted in Figure 3.5).

Existence of social cohesion – If the FPV development favours certain groups in society while others are being disadvantaged regarding such as reduction in income, reduced recreation opportunities etc., increased local conflicts can be expected reducing social cohesion. For the *baseline scenario*, the current level of conflicts is not expected to change (if aquaculture farmers will have to close down due to enforcement of the fish sanctuary rule then conflicts are expected). For the low cover scenario, it is uncertain if conflicts will occur due to FPV. Rather than the FPV cover, the information process to villages and households, may be important for avoiding conflict. For the high cover FPV scenario that will imply change of practices and behaviour and economy, and employment for the majority of the households in the upstream villages, a high conflict situation can be expected to result from the high cover FPV – and reduced social cohesion are predicted.

***Table 3.5** Indicator results for the baseline and the low and high FPV cover scenarios (most relevant indicators are considered)*

Environmental indicator results for the baseline, and the low and high cover scenarios.									
Water Use Functions	**Indicators**	**Data considered**	**Scenarios - Response function & indicator results**						**Comments**
			Baseline compared to current status		**Low cover FPV compared to baseline**		**High cover FPV compared to baseline**		
Provision of water availability (quantity)	*No. of months pr year (downstream) access to irrigation water for agriculture area*	Focus group disc. (2022), interviews NIA (2023). Model result of reduced evaporation due to FPV cover.	Insignificant change expected. For extreme dry years, reduced availability (Singson et al., 2023): 12 months/yr		No additional impact. Much higher coverage is needed to see positive impacts (Essak and Ghosh 2022)		No additional impact unless the operation regime is adapted		According to results in the "solar-to-hydro" setup, for both the low and high cover scenarios, significant water savings can be achieved by changing the operational regime with positive impacts on high water level for hydropower production and avoiding extreme low water level.
	No. of months water level reservoir above optimal level (174 m)		Status regularly below 170m (optimal level) (Pers. com. NIA 2022, personal observation 2023), frequency is expected to increase to due to C.C. 9.6 months/yr		No additional impact unless the operation regime is adapted		No additional impact unless the operation regime is adapted		
	No. of months water for efficient hydropower production (> 171 m)		Frequency is expected to decrease during dry years due to climate change. 10.3 months/yr		No additional impact unless the operation regime is adapted		No additional impact unless the operation regime is adapted		
Provision of good water quality	*No. of months with acceptable ecological status (i.e., $O_2 > 6$ mg/L)*	Focus group disc. (2022), interviews NIA (2023). Model result of water quality. Possible toxic effect of FPV panels	Low risk of more frequent low O_2 concentrations during extreme dry years during the dry season (Mar-Jun)	5.4 months / yr	No additional impact under normal conditions but low to moderate risk of more frequent low O_2 concentrations and high temperature during the dry season (Mar-Jun)	4.3 months / yr	Negative impacts on oxygen availability. High risk of more frequent low O_2, high temperature events during low water levels during the dry season	0.5 months / yr	According to results in the "solar-to-hydro" setup, for both the low and high cover scenarios, significant water savings, counteracting some impacts of FPV as well as climate change can be achieved by changing the operational regime.
	No. of months acceptable status for domestic usage (i.e., $O_2 > 5$ mg/L)			11.7 months / yr		10.9 months / yr		8.3 months / yr	
	No. of months acceptable status for swimming (i.e., $O_2 > 5$ mg/L)			11.7 months / yr		10.9 months / yr		8.3 months / yr	
	Abundance of algae and cyanobacteria		No change expected. Average chl-a: 38 µg/L		Reduced algal growth due to reduce light penetration. Average chl-a: 37 µg/L		Reduced algal growth due to reduce light penetration. Average chl-a: 34 µg/L		
Biodiversity / biotic resources	*Fish mortality* *(Not considered, Fish diversity, fish body size).*	Local observation for current status. Model results regarding O2 concentration below thresholds & frequency.	Low risk of more frequent low O2 concentrations with impacts on fish growth during extreme dry years		No additional impact.		Reduced oxygen with high risk of more frequent low O_2 concentrations with strong impacts on fish growth and possibly reproduction, only for episodic events.		Detergent for cleaning the panels can impact water quality and biotic resources, depending on the type of detergent. Not addressed here.
Climate change mitigation GHG emissions	*GHG emissions in CO_2 eq. per KWh.*	Model results of GHG emissions.	Baseline: 35 g CO_2 eq / KWh for hydropower		Uncertain additional impact. Possible higher downstream degassing (higher CH_4 concentrations) but lower surface emissions resulting in 2.5% reduction		Uncertain additional impact. Possible higher downstream degassing (higher CH_4 concentrations) but lower surface emissions resulting in 11% reduction		The baseline estimates was performed with mechanistic model calibrated against observations (single-day campaign)
	Avoided GHG emissions due to renewable electricity production	Model results of solar power production	Baseline: no solar power production, no GHG emissions avoided.		GHG emissions avoided from coal powerplants by solar power: 44 ktons CO_2 eq / yr		GHG emissions avoided from coal powerplants by solar power: 196 ktons CO_2 eq / yr		

Economic indicator results for the baseline, and the low and high cover scenarios.

Water Use functions	Indicators	Data reference	Baseline	Low cover FPV	High cover FPV	Comments
Physical production	*Sale of fish (weight) local fish market (increased / reduced)*	Data from modelling effect of FPV cover Data on water usage & users from FGD MAP based approach.	No data specified on sale of fish from fishing with a net, the activity is common.	Some reduction in sale is expected due to removal of port.	Reduced sale due to: - increased mortality, poor growth caused by low O2 concentration, - reduced access to fishing area (as covered by FPV).	Reallocation of fish cages to other alternative areas is a mitigation measure. Fish cages need to be moved towards the middle of the reservoir during the dry season as there is requirement for around 10 m. depth. Data on sale of fish for Isabela also includes sale by people in Ifugao Province.
	Ton aquaculture production	Data on current sale (ton) BFAR (BFAR, 2021).	Fish cage production in the Magat reservoir - 875 270 kgs is expected due to trend of increasing registered & unregistered cages.	Upstream, some reduction in yield, as the fish cages in the fish sanctuary zone will have to be removed.	Upstream, substantial less yield due regular low O2 concentration and due to the large area covered by panels.	
	Sale of agric. production upstream / downstream	Secondary data reports on in area trends.	A slight increase may be expected associated with general increased economic activities / growth in the area.	Same as baseline	Some increase due to expected increased irrigation water.	
	Fishpond production downstream	362 hectares (BFAR 2021); corresponding to approximately 22 fishponds.		Same as baseline – FPV panels are not expected to influence fishpond prod. downstream		
Provision of employment	*No. fish cage operators.*	856 people leasing for fish cage (NIA, pers. com, 2023).	In line with the trend, a minor increase of operators can be expected.	Upstream, an assumption of about 5- 20 % reduction of aquaculture farmers.	Upstream, an assumption of about 40 – 70 % reduction of aquaculture farmers.	
	% households w. main income from fishing	Data on water usage & users from FGD MAP based approach.	Most residents around the reservoir fish for consumption, some, in particular vulnerable groups also fish for income.	Some reduction households w main income from fishing.	Significant reduction households w main income from fishing.	
	No. people employed due to ripple effect FPV	Expectation based on reference to other studies	No ripple effect of FPV in baseline.	Change in distribution of employment. Positive effects on industries as economic ripple effects can be expected (Pouran et al. 2022).		
	No. people employed - the FPV intervention.	Power company plans	New local employment opportunities such as for cleaning and maintenance of the panels are planned			
Access to transportation	*The proportion of households that find navigation on reservoir to be inaccessible*	Information from LGU, village councils.	All households in upstream villages use boats for transportation.	A minor proportion of households perceive navigation on reservoir for transport to be inaccessible.	The major proportion of households find navigation on the reservoir to be inaccessible.	
	Navigation time	Information from LGU, village councils.	Time depends on starting point and wind. From northern end, 20 min – 30 min.	Some increase (10- 25 min increased time.	Substantial increase, - longer transportation time to school & transportation difficult.	Navigation on the reservoirs is the main mode of transportation. For all village around the reservoir, only
	Navigation costs	Information from boaters. (pers. com. / observation 2023)	From the s-w side of the reservoir to the port area 3-5	Some increased fuel expenses.	Substantial increased costs.	

			l. fuel. Costs depend on price.			one boat and fish landing area on Isabela Province side.
	Port for landing	Observation 2023, and personal comm. (2023)	An area is used as port, but no port constructed. No plans.	The current port area will be used for anchoring of the FPV intervention.		
Provision of electricity	*Tot. annual HEPP generation*	SNAP	Current situation, tot. HEPP: 734 GWh (2009–2015). No change expected.	Not analysed here. Increase in electricity generated due to the hybrid technology expected. (See, Fagerström et al. 2024).		Other indicators on economic gains as, spot price per kWh could be relevant. Which markets/ services for return on depends on the PPA and/or location. This is not analysed here.
	Total annual electricity produced by the FPV	SNAP	No change expected	About 804–818 GWh annual electricity production compared to the baseline is estimated.	About 1028–1056 GWh and 40-44% increase compared to the baseline (hydropower of 734 GWh).	
	Tot. annual electricity produced by the hybrid hydro-FPV plant.	Modelling	No change expected	Not analysed here. Increase in electricity generated due to the hybrid technology expected. 8See, Fagerström et al. 2024).		
Enabling flood control	*Frequency of damage on property*	https://www.geoportal.gov.ph/ : (layer	No change expected	It is not expected that the FPV scenarios will influence flood control (Pers. com Snap, Nov. 2024)		
	Costs of damage on property	https://www.geoportal.gov.ph/ : (layer	No change expected			
Provision of food security	*Level of support needed by the Local Gov. Unit (LGU*	Local people informed in FGD (2022) 2 about poverty support. Economic growth the recent decade in the Isabela province.	The current needed support of ca. 50% of the households can be expected to be reduced as a consequence of the general economic growth in the area.	The current needed support of ca. 50% of the households upstream villages may increase for a period due to an expected reduction in income from fishing and aquaculture due to removal of port.	The current needed support of ca. 50% of the households is expected to increase for a longer period; reduced income from fishing and aquaculture, the general economic growth may not benefit sufficiently the same actors.	
Provision of good health	Waterborne diseases occurrence	Data on malaria, dengue fever.	The Department of Health (DOH) has declared the province of Isabela in Cagayan Valley malaria-free.			
	Occurrence of wash related diseases	Data on cholera, diarrhoea, dysentery, shigellosis, and typhoid	No change expected	No change expected	Due to reduced oxygen concentration WASH may increase.	

Economic indicator results for the baseline, and the low and high cover scenarios

Water Use Functions	**Indicators**	**Data considered**	**Baseline**	**Low cover FPV**	**High cover FPV**	**Comments**
Recreation opportunities	*Proportion that uses boating for recreation*	FGD & map-based approach local villages 2022 –	The majority of the of households use boating for recreation, both upstream and downstream residents no particular change is expected.	Similar to the baseline, the majority of the households is expected to use boating for recreation. The panels will 3- 9 % of reservoir, area will be available for boating.	The panels will cover 9-24% of the reservoir; available large open areas for boating are limited. It is assumed that the proportion that will use boating for recreation is low.	Assumptions are uncertain.

	Proportion that uses the area around the reservoir for picnicking	FGD and pers com local actors (2022-2023).	It is common for people to picnic along the shores of the reservoir. This is assumed that this situation continues.	Similar to the baseline, the main proportion of the households is expected to picknick along the shores for recreation.	It is expected that a reduced portion of people will picknick along the shores of the reservoir. The degree is uncertain (no reference other studies.	Depends on effects on the shoreline and on how people experience the landscape changes.
	Number of days w. unsafe swimming conditions	Though prohibited people swim in the reservoir, and in channels downstream area.	Upstream - few changes are expected. Downstream, swimming in channels is expected to continue, but depends on occurrences of hazards, accidents due to sudden release of water.	In line with baseline: upstream - few changes are expected, downstream, swimming in channels is expected to continue, but depends on occurrences of hazards, accidents due to unexpected high water flow.	Upstream, swimming in reservoir is expected to stop. Downstream swimming in reservoir depends on dam operation regime, sudden release of water is makes it dangerous to swim.	Depends on enforcement of rules and norms regarding swimming in reservoir.
	Number of visits to the FPV and the HEEP system for education purposes	Since 2007, when SNAP gained responsibility for Magat HEP, it has been open to visits from schools, local government officials, private sectors (Pers. com. SNAP October, 2024).	N. of visits are currently relatively low, around 10 /yr. Some increase may be assumed as there are plans to facilitate for more visits by SNAP.	An increase in visits for education purposes, and for tourists is expected in line with statements from the energy company (SNAP).	Similar situation as for the low cover scenario. An increased number of visits for education purposes, and for tourists are expected.	Coordination with relevant officials at schools and local officials with responsibility for education are needed.
Protection of cultural heritage and	*Proportion of households undertaking traditional practices as, cleansing rites, baptism, "gulgul":*	FGD & map-based approach local villages 2022.	Traditional practices are not common practice, but more common in some villages than in others – in some 10%, in others around 30 -60% can be assumed. For the baseline, in line with increase economic development and urbanization (table X) a reduction of practices can be expected.	The impact of increased economic development, urbanization and population growth is expected to reduce, more than the situation for the baseline, the proportion of households undertaking traditional practices.	The impact of increased economic development, urbanization and population growth, and the changed character of the landscape, is expected to reduce extensively the proportion of households undertaking traditional practices for most villages.	The proportion of households depends on the particular practice. No studies are undertaken on this, apart from studies to identify practices by indigenous groups (Acabado and Martin 2016). More in rural less is sub-urban, urban areas.
Contribution to social cohesion	*Occurrence of conflicts among people associated with water use*	The history of conflicts among aquaculture farmers. NIA regulation fish sanctuary FPV Pre-feasibility plan.	Conflicts among, and with aquaculture farmers can be expected to increase if the fish sanctuary regulation prohibiting fish cages will be enforced.	The general conflict level in the upstream villages – can be expected to further increase compared to the baseline due to removal of port, and some reduced navigation.	Conflict levels in the upstream villages – can be expected to further increase compared to the baseline due to removal of port, and navigation challenges, and the following change of practices.	The low cover FPV scenario situation may be addressed by mitigating measures.
Provision of landscape aesthetics	*Nearby residents who experience reduced landscape value due to FPV.*	*Secondary literature, authors observation.*	The pilot 220-lWp FPV occupies less than 0.01 % of the waterbody and is not seen to influence the waterscape.	Uncertain.	Negative impact on landscape aesthetics expected (Ioannidis and Koutsoyiannis 2020; Enserink et al. 2022).	

3.5 The post modelling - The Magat case impact assessments of selected scenarios

This section presents the impact of the baseline and the FPV scenarios on WUFs considering groups of beneficiaries, and the SDGs (Tables 3.6a, and b). The impacts are described by comparing the low and the high FPV cover scenarios with the baseline scenario. The effects of deploying FPV on the reservoir for wet and normal climate conditions compared to dry climate conditions are different. Below we describe the scale of impact for wet and normal climate conditions, and for dry conditions with low water level. As dry years occur regularly in Isabela Province (sub-section 3.3.1.1), we consider that the dry climate conditions determine the impact on the WUFs. The predicted impacts (dry climate conditions) are visualized by means of a spider diagram in Figure 3.9.

The impact is described with reference to scales of magnitude and significance and for national, regional, and provincial and local level referring to the predicted change of indicator values. Table 2.3 defines the different scales of magnitude and significance (authors of the report). An optimal assessment of the impact of would require involvement of main stakeholder groups, the beneficiaries in the area to provide their perspectives of impacts (considering the assessed indicator values). These different perspectives can be visualized and may represent a basis for an understanding of attitudes and as input for how to proceed regarding information strategies, and mitigation measures needed.

The impact assessment presented in this report did not include any involvement of stakeholders. The assessment was undertaken as part of an internal discussion among the co-authors of the report (see sub-section, 3.2.3). The scale of impacts hence represents the perspective and the understanding of the situation by the co-authors. In this semi-quantitative / qualitative assessment we considered the assessed effects on the indicators, and the anticipated impact on the influenced communities.

Regarding impact of the scenarios on SDGs[15], we only indicate if a positive or negative impact are expected (the impact expected is not scaled). The indicators were selected primarily to address impacts on the local situation, this is in contrast to the SDGs that primarily address national or regional scales.

The *baseline scenario* focuses on the impact of trends and policy drivers such as population growth, economic and technological development, and policies for irrigation agriculture, aquaculture, nature protection, and the impact of climate change (sub-section 3.3.2).

For the baseline scenario, potential changes are expected to have insignificant_impact for national, regional, provincial and local level for most WUFs (Table 3.6). For the WUF available freshwater, considering trends of increased population growth, urbanization, irrigation development, climate change (sub-section 3.3.1.5) minor reduction in freshwater can be expected due to increased abstraction by different user groups. For the WUF good water quality, the current situation are characterized by insufficient water quality (Table 3.2), while reduced freshwater quantity and increased population growth may further reduce provision of good water quality. In the assessment we thus consider that any impacts of climate change would be fully mitigated by an adaptive behavior and would result in a situation like current situation. Regarding climate change, it would not be realistic to consider that the expected changes in provision of WUFs, e.g., a decrease of up to 23% in the inflows to Magat Dam during dry years by the end of the 21st century, would not be mitigated by an adaptation of the dam operation regime.

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[15] *The SDGs that are being considered includes 1. No poverty, 2. Zero hunger, 3. Good health and well-being, 6, Clean water and sanitation, 7. Affordable and clean energy, 8. Decent work and econ. Growth, 9. Industry innovation infrastructure,11. Sustainable cities and communities, 13. Climate action, 15. Life on Land.*

3.5.1. Predicting impacts of the low FPV cover scenario

For national and regional level intermediate positive impact for reduction in GHG is predicted, for the other environmental, economic socio-cultural WUFs insignificant change is predicted. For provincial and local level beneficiaries, predicted impacts on WUFs are described below. Regarding i*mpact on SDGs*: Positive effect for the environmental SDG-13 Climate action because the non-negligible increase in renewable energy production through solar will contribute to offset some of the provincial fossil-based electricity production. For other SDGS impacts are predicted to be insignificant[16].

The environmental dimension: Overall no adverse effects on environmental variables are predicted for normal and wet climatic conditions. During the dry season in dry years, reduced oxygen levels and increased temperature are predicted.

For **available freshwater quantity** – insignificant change is predicted relative to the baseline scenario (section 3.5 and Table 3.6 for possibilities for co-benefits resulting from the hybrid hydro solar technology at Magat and in increased provision of freshwater). For **good water quality,** and **biotic resources**, during normal and wet years insignificant change are predicted. For dry conditions (low water levels), minor reduction in provision of water quality and biotic resources are predicted with impact on fish cages farmers, DENR, and BFAR, and LGU Municipal Agriculture Office (MAO). The impact is expected to be of intermediate significance.

For **GHG emissions**, reduced emissions are predicted as a non-negligible quantity of GHG emissions would be avoided through the additional production of renewable electricity with FPV (offset of GHG emission from otherwise fossil-based electricity, for more see 3.4.2.1). The impact of FPV on GHG is expected to be of intermediate positive impact (reduced emissions), important for the Philippines national GHG inventory.

The economic dimension: Adverse impacts of the FPV is caused by removing the current “port” and fish landing area and by replacing fish cages with FPV panels. Impacts will be disproportional for families taking their children to school, and for vulnerable households around the reservoir.

Minor reduced provision of **physical production**, and minor reduced **provision of employment** for households around the lake are predicted. It is estimated that 10-37 fish farmers that receive income from working on fish cages will have experience reduced income and or be unemployed[17]. A co-benefit situation of the FPV for employment is expected (see 3.5), referring to the estimated 25 people to clean the panels, however, it is uncertain if this will benefit the same fisherfolk, and with the same income opportunities. It can be expected that the FPV development will promote economic development and thereby diversity of income opportunities on long term, the immediate ripple effects benefiting local people however is uncertain (see 3.3.2 for literature on economic and technological development).

Minor or intermediate level of reduced ***provision of transportation*** is predicted on short timescale. Removing the one established boat landing area will represent an inconvenience to a larger or lower extent for different people. Some increased time for transportation will be needed and some increased expenses. On longer terms, however, it may be foreseen that people will find other places to anchor their boats.

Intermediate increased **provision of electricity** is predicted as the hybrid hydro FPV plant will increase the the annual production to 804–818GWh (considering 60–70 MW FPV) representing an increased annual provision of 9-11%. This is expected to represent an intermediate increase in the provision of

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[16] *The authors consider that SDG indicators are not well suited to present the local situation as they are developed to target country and larger regions.*

[17] *Secondary data were not available for barangay level, accurate primary data were not collected. Estimation was undertaken based on expert discussion with a fish farmer.*

electricity with intermediate significance for regional and provincial authorities, and the energy company.

For provision of, ***flood control*****, food security and good health** insignificant magnitude of change is predicted. Vulnerable households affected may experience minor reduction in food security temporarily.

The socio- cultural dimension: Adverse impacts can be expected due to the removal of the port area. It may be assumed that the main impact for the sociocultural activities is associated with the general trend of population growth, economic development and urbanisation – described by the baseline scenario.

Minor reduction in **recreation opportunities** for people who enjoys boating as a recreation activity due to removal of the port, it is expected that this refers to short term. Otherwise for existing **cultural practices and heritage**, **social cohesion** and **landscape aesthetics** insignificant change caused by the FPV is predicted.

3.5.2. Predicting impacts of the high cover FPV scenario

Regarding the *high cover FPV scenario*, both positive and negative change in the provision of WUFs are predicted, mostly on local level but also for national and provincial level. While impacts for some beneficiaries imply added provision of WUFs, for others, the provision is predicted to be significantly reduced. The significance is expected to be intermediate or high for local level, for regional and national level the change is expected to be intermediate or high for certain WUFs. The scale of impacts for provincial and local level are described below.

Regarding impact on SDGs: Negative impacts are expected for SDG 1 No poverty, and 15. Life on Land (which includes life in freshwater bodies) because of reduced provision of acceptable ecological status for water quality and biotic resources Both positive and negative impacts are expected for 8. Decent work and econ. Positive effect for the 9. Industry innovation infrastructure environmental SDG-13 Climate action by contributing to reduce the GHG footprint of the hydropower energy production and by increasing renewable energy production through solar and offsetting some of the provincial fossil-based electricity production.

The environmental situation: Adverse impacts are caused by reduced oxygen concentration and increased temperatures in the reservoir.

For provision of **water quantity** similar to the low cover scenario, insignificant impact is predicted (in absence of measures to enhance co-benefit, sub-section 3.5; Table 3.7). For provisions of good **water quality**, for wet and normal years, the severity in reduced provision is predicted to be minor, during dry years water quality impacts are expected to be severe. For provision of **biotic resources** during the dry season and for dry years, sub-optimal growth conditions for fish and including episodes of fish kills is predicted to have severe negative impact in particular for aquaculture farmers, and with negative impact for DENR, BFAR, LGU. The impact is expected to be highly important for stakeholders.

The reduction in **GHG emissions** due to GHG emissions avoided by the additional production of renewable electricity through FPV represent a significant positive impact as it will increase the renewable energy share within the energy mix to 35% by 2030. It is expected to have high significance for DOE, the Philippines national GHG inventory considering the Philippine ambitious GHG reduction targets (Department of Energy 2023a; b).

The economic dimension: Adverse impacts of the FPV are caused by, (i) removing the current “port” and fish landing area; (ii) 40-70 % of current fish cages will be replaced with FPV panels, and (iii) by reduced provisions of good water quality and biotic resources (caused by reduced oxygen levels, and increased temperatures) for physical production, employment, food security. In contrast, positive impacts are predicted for provision of energy, for employment opportunities due to ripple effects and co-benefits.

Regarding **physical production**, for households upstream the dam, severe reduced provision of physical production from fishing and aquaculture are predicted as it can be expected that 40 – 70 % of the aquaculture cages will have to be removed from their current position because of FPV rings. The FPV rings can also be expected to reduced access to fishing grounds. Fish growth (fish body size), will be reduced (oxygen levels and increased temperatures).

Severe reduction of **employment** (short – to intermediate time scale) is expected as the majority of the households upstream receive income from fishing and aquaculture. Physical production from the downstream areas is not predicted to increase compared to the baseline as irrigation opportunities is limited by freshwater availability (NIA, 2020). Figure 3.9 visualise in a spider diagram the impact referring low water level. On long time scales, a higher diversity of employment opportunities is expected, but representing other activities.

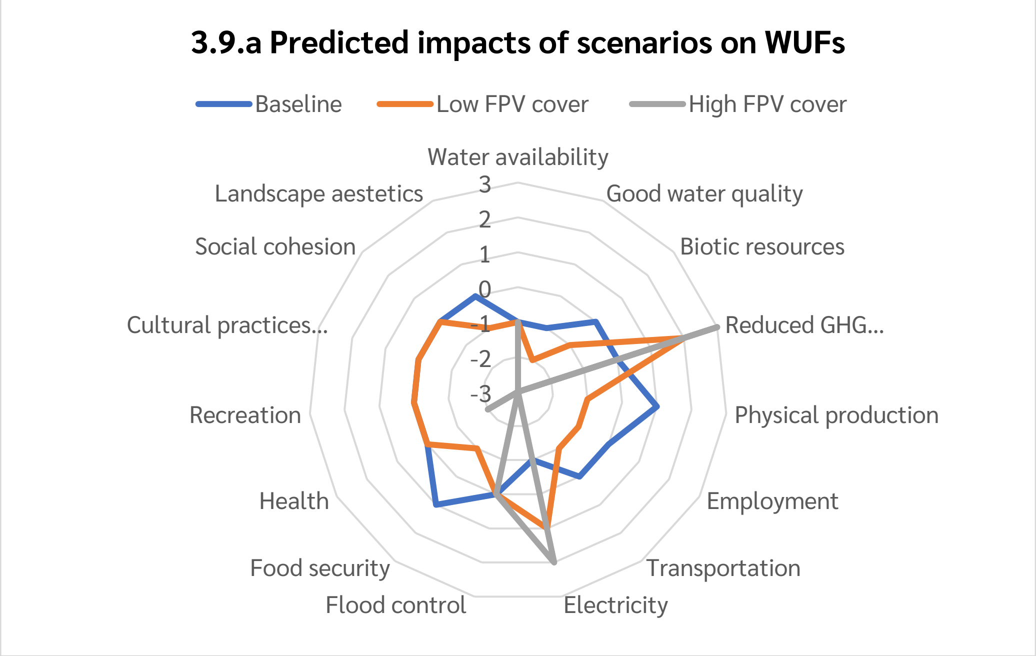
Substantial reduced ***provision of transportation*** is predicted for households around the lake as the FPV rings covering relatively large areas will be placed in areas of the navigation routes. Costs and time, will increase, and the area for boating will be limited large parts of the year. This will make it difficult to bring their children to school, to access markets, for access to medical help etc.

Substantial increased **provision of electricity** – as there will be an annual production of 1028–1056 GWh representing an increase of 40% to 44% (considering 300 MW). The change is expected to have intermediate significance for beneficiaries, i.e. for the energy company, and for regional and national energy authorities.

Enabling **Flood control:** The FPV scenarios are not expected to have any impact on flood control (SNAP, November 2024).

Regarding **food security**, (a risk of food insecurity measured as the need for support from LGU) intermediate reduced provision may be expected for households in the upstream villages, as current means of income and consumption for people are mostly based on or related to fish from the reservoir. It can be assumed that direct and indirect effect of the FPV cover will require as a minimum on short term substation support to people to avoid lack of food security. Intermediate impact on **health** can be assumed for households upstream, due to reduced access to health services due to reduced access to transportation).

The social - cultural dimension – adverse impacts are expected for socio-cultural features and practices. Severe impact is expected for **recreation** and **cultural practices and heritage** as it can be assumed that the reservoir does will have only limited opportunities for recreation activities. The impact will mostly be experienced by residents around the reservoir, but the situation will also reduce recreation opportunities for residents downstream the dam. As water rituals an important feature in cultural heritage regarding death, rebirth, cleansing and agricultural practices (Acabado and Martin 2016), reduced access to the reservoir, and a disturbed water / landscape can be expected to have severe impact on cultural heritage, of high importance for beneficiaries The reduction in access to recreation activities, cultural practices, and reduced **landscape aesthetics**, will have be more severe for rural people around the reservoir, compared to residents in more urban areas. Furthermore, it can be expected that co-benefits for economic development will not be equally favourable for different groups in society (Axon and Morrissey 2020), a situation that is known to cause conflicts and reduce **social cohesion** (Dainius 2016).



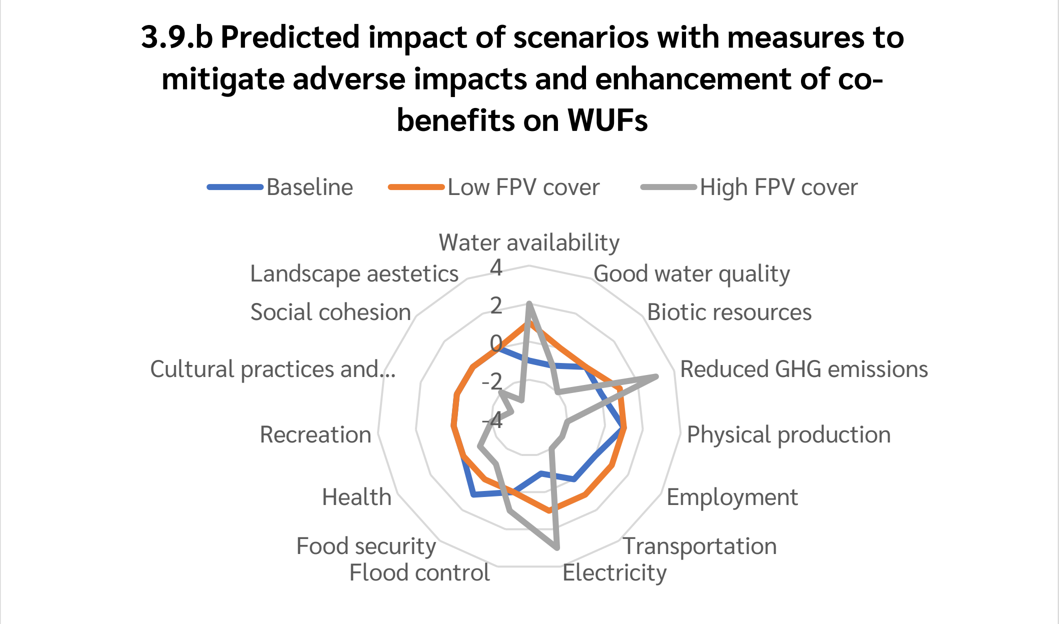


Figure 3.9: *Spider diagrams showing the positive (magnitude scale from 1 to 3) and negative (magnitude scale from -1 to -3) impacts on each WUFs for each of the three scenarios assuming no measures (a) and with some measures (b) implemented to mitigate adverse impacts and enhance co-benefits.*

Table 3.6a. *Magat case study, impacts on beneficiaries with no measures implemented (color coding for magnitude[18]).*

WUFs	Indicators	Scenarios and predicted impact on beneficiaries					
		Baseline no FPV compared to current situation		Low cover FPV compared to baseline		High cover FPV compared to baseline	
		Magnitude	Significance	Magnitude	Significance	Magnitude	Significance
Availability of fresh water	No. months access to water for irrigation						
	No. months water level above optimal level (174 m)	-1	*				
	No. months for efficient hydropower production	-1	*				
Provision of good water quality	No. months acceptable ecological status	-1	*	-1	**	-3	***
	No. months acceptable status for domestic use			-1	*	-2	*
	No. months acceptable status for swimming			-1	*	-2	*
Provision of biotic res.	Fingerlings / youth / grown fish mortality	-1	*	-1	**	-2	**
GHG emissions	GHG emissions (g CO2 eq / kWh)			+1		+1	
	GHG emissions avoided due to renewable energy prod..			+2	**	+2	**
Provision of physical production	Sale of fish (net fishing) (weight) (increased / reduced)			-1	*		
	Ton aquaculture production (cages)	+1		-1	*	-3	***
	Sale of agric. production upstream and downstream the dam	+1					
	Fishpond production downstream	+1					
Provision of employment	No. Households w. income aquaculture.	+1		-1		-3	***
	No. Households w. main income from fishing by nets					-3	
	No. people employed - the FPV intervention.			+1		+2	
Provision of transportation	% percentage households that use boats for transportation			-1	*	-2	***
	Navigation time change			-1	*	-3	***
	Navigation costs change			-1	*	-3	***
	Port for landing change			-3	***	-3	***
Provision of electricity	Tot. annual HEPP generation						
	Total annual electricity produced by the FPV			+1	*	+2	**
	Tot. annual electricity produced by the hybrid hydro-FPV plant			+1	*	+2	**
Provision of flood control	Frequency of damage on property						
Health	Occurrence of waterborne diseases, WASH related diseases					-1	*
Food security	Level of support needed by the Local Gov. Unit (LGU					-2	**
Recreation opportunities	Proportion that uses boating for recreation			-1	*	-3	**
Cultural heritage practices	Proportion of households undertaking traditional practices,	-1		-1	*	-2	**
Social coherence	Occurrence of conflicts among people			-1	*	-3	***
Landscape aesthetics	Nearby residents who experience reduced landscape value			-		-3	**

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[18] *Color coding index, magnitude: red highly severe reduction, dark orange severe impact, orange minor reduction, yellow some reduction, no color - no change, light green some positive increase, green substantial positive increase, dark green high substantial increase; Significance, blank insignificant, number of * represents increased levels of significance (see table 2.3 for index description).*

Table 3.6b*. Magat case study, impacts on the SDGs*

SDG	Relevant indicators	Impact SDGs		
		Baseline scenario	**Low cover FPV scenario**	**High cover FPV scenario**
1.: No poverty:	*Level of support needed by the Local Gov. Unit (LGU*): provides support, ca. 50% of household in reference.	Insignificant impact	Insignificant impact	Negative impact (short, intermediate term)
2: Zero hunger	*Level of support needed by the Local Gov. Unit (LGU*): provides support, ca. 50% of household in reference.			Negative impact (short, intermediate term)
3. Good health and well-being	Occurrence of wash related diseases; *Number of boats on the reservoir*			Negative impact (short, intermediate term)
6, Clean water and sanitation	Number of months access to water for irrigation Nu. months acceptable status for domestic use			Negative impact (short, intermediate term)
7: Affordable and clean energy	Situation security of energy supply			Positive impact
8 Decent work and econ. growth	Nu. Households with income from (i) fishing; (ii) from aquaculture, (iii) from irrigation agriculture.			Both negative and positive impact.
9. Industry innovation infrastructure	Access to port for fish and boat landing.			Positive impact
11. Sust. cities and communities	Social cohesion,			Both negative and positive impacts
	Frequency of damage on property			
13. Climate action	GHG emissions (g CO2 eq / kWh) GHG emissions avoided due to renewable energy prod..		Positive impact	Positive impact
15. Life on land	Nu. months acceptable ecological status Fish diversity / Fish abundance			Negative impact

***Table 3.7** Magat case study, impacts on beneficiaries - with some measures implemented[19]). "Measure" is considered in a broad sense, including also changes in regulatory terms, i.e. the dam operation regime.*

WUFs	Indicators	Scenarios and predicted impact on beneficiaries					
		Baseline no FPV compared to current situation		Low cover FPV compared to baseline		High cover FPV compared to baseline	
		Magnitude	Significance	Magnitude	Significance	Magnitude	Significance
Provision of water	No. months access to water for irrigation			+1	*	+1	*
	No. months water level above optimal level (174 m)	-1	*	+2	**	+2	**
	No. months for efficient hydropower production	-1	*	+2	**	+2	**
Provision of good water quality	No. months acceptable ecological status	-1	*	+1	*	-1	**
	No. months acceptable status for domestic use					-1	*
	No. months acceptable status for swimming					-1	*
Provision of biotic res.	Fingerlings / youth / grown fish mortality	-1	*			-1	*
GHG emissions	GHG emissions (g CO2 eq / kWh)			+1		+1	
	GHG emissions avoided due to renewable energy prod..			+2	**	+2	**
Provision of physical production	Sale of fish (weight) local fish market					-2	**
	Ton aquaculture production (cages)					-2	**
	Sale of agricultural production downstream			+1		+1	*
	Fishpond production downstream			+1		+1	*
Provision of employment	No. Households w. income aquaculture.					-2	**
	No. Households w. main income from fishing					-2	**
	No. people employed - the FPV intervention.			+1		+1	*
Access to transportation,	% percentage households that use boats for transportation						
	Navigation time change					-1	*
	Navigation costs change					-1	*
	Port for landing change			+2		+2	**
Provision of electricity	Tot. annual HEPP generation			+1 (Uncertain)	*	+2	**
	Total annual electricity produced by the FPV			+1	*	+2	**
	Tot. annual electricity produced by hybrid hydro-FPV plant.			+2 (Uncertain)	**	+3	***
Provision of flood control	Frequency of damage on property					+1	*
Food security	Level of support needed by the Local Gov. Unit (LGU					-1	**
Health	Occurrence wash related diseases; waterborne diseases					-1	*
Recreation opportunities	Proportion that uses boating for recreation					-1	*
Cultural heritage, practices	Proportion of households undertaking traditional practices,	-1				-2	**
Social coherence	Occurrence of conflicts among people					-2	**
Landscape aesthetics	Nearby residents who experience reduced landscape value			-1		-3	***

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[19] *Color coding index magnitude see Table 3.6; Coding for Significance, see, Table 3.6. (see Table 2.3 for index description).*

3.6 Measures for enhancing co-benefits and reducing adverse impacts

This section presents the measures identified as potentially relevant to enhance co-benefits, and to reduced adverse impacts (Table 3.7). The identification of possible measures has been part of a process during the course of the project, from bilateral discussions with different industry partners (2022-2023), feedback on a project meeting (August 2023), and then discussion of costs and convenience aspects of the measures August – October 2024). The anticipated contribution to the WUFs is indicated with reference to the five levels, very negative, negative, insignificant, positive, and very positive.

3.6.1. Measures for environmental, economic and socio-cultural WUFs

Addressing adverse effects on dissolved oxygen levels and increased water temperatures

- *Allowing space between the panels for airing of the water surface:* Covering the reservoir with FPV rings will reduce dissolved oxygen levels in water, and cause higher temperatures in the dry warm season, with negative effect for environmental WUFs. Leaving some space between individual floats or groups of floats will reduce this impact by allowing natural airing of the water and reduce local build-ups of low oxygen and high temperature waters. In addition, artificial water circulation can be implemented if the impact is severe. The cost will include some adaptation of the installation plans/procedures as well as some potential maintenance costs. Allowing space between the individual floats will lead to a larger total cover area of the FPV and higher cost per installed kW. The industry partners in the project considered that these additional costs will not be high, and that there will be only little inconvenience. Positive effects are expected to be important for biotic production, and for the economic WUFs physical production, therefore for aquaculture farmers, for residents around the reservoir, and for DENR, LGU, BFAR. Regarding other relevant water quality variables, such as biological oxygen demand or any relevant pollutant, that was not possible to assess here, the best recommendations are to monitor the water quality for these risks.

Enhancing co-benefits regarding water quantity with positive effects on provision of good water quality and biotic resources – and for economic and socio-cultural WUFs

- *Adapting power production and operational regime of the hybrid hydro-FPV to save water*: Current operational regime is constrained by the rule curve established by NIA to ensure sufficient water for irrigation, as well as by the flood emergency protocol to ensure flood control. As solar power production may represent an alternative to hydropower production, maintaining water levels at a higher level than the rule curve during dry periods is possible. This measure on adapting the operational regime would thus require developing a new rule curve. *It needs to be noted that this requires regulatory changes from the authorities, it is outside the scope of the mandate of the power producer or developer can do.*

  Under the “solar to hydro” setup, i.e., when water savings related to solar power production as an alternative to hydropower production were considered, a significant volume of water could be kept in the reservoir resulting in a water level that is on average 4.3 m and 6.5 m higher for the low and high FPV cover scenarios, respectively. Under these circumstances, significant amounts of water could be saved and increase the number of months when water level is above the threshold for efficient hydropower production, also above the threshold for the optimal water level for irrigation but also help address some of the adverse impacts mentioned above. Higher water level is beneficial for addressing environmental impacts related to increased water temperature and reduced oxygen levels with beneficial impacts on biotic resources. This measure would furthermore increase the overall efficiency of hydropower production since the head height will be 4.3 to 6.5 m higher than the baseline situation. The hydropower production would be 4% and 7.5% more efficient, on average, for the low and high cover scenario, respectively, compared to baseline situation.
- *Planning to optimize solar energy generation time of the hybrid hydro-FPV to save water for multiple purposes:* To ensure that the combined use of water resources optimizes solar energy

generation, hydropower production and irrigation, careful planning is needed. This measure implies the need to modify the water release rule curve, and that responsibilities of setting water level targets are made more flexible with inputs from the hybrid powerplant operator together with NIA. This requires adaptation of the rules of the operation regime and a tight communication, also on short notice, between regulatory authorities and the powerplant operator. *It needs to be noted that the current assessment showed that optimizing the operations to retain more water in the reservoir, i.e., a higher water level than for the baseline, yield more hydropower production. However, if the operations are optimized for a different purpose, the impact on hydropower production is uncertain.* This measure is about making the rule curve more flexible also on short notice to find synergies between multiple water uses, e.g., irrigation, hydropower or any other relevant use.

The results from the "Solar to Hydro" setup, which represent a situation where the water level is optimized for combined solar and hydro power production, not for irrigation, still showed positive impacts on irrigation requirements with a decrease in months when irrigation water is not sufficient (see Section 3.4.1). In fact, the simulation yielded some delay in water releases during the first months of the dry season, leaving a large and less variable amount of water for irrigation during the last months of the dry season. Given that we did not optimize the water level for irrigation requirements during this simulation, the potential for co-benefit is expected to be even higher.

The current assessment does not consider the intra-day power market constraints, hence solar power generation is believed to be in-line with energy demand. It is known that solar production peaks (noon) do not align with consumption peak demand (morning and evening). This can be partly solved with the combination of the battery park to allow for short-term fluctuations in the production-delivery patterns which is currently assumed. The measure can be characterized by a low cost. The degree that this represents inconvenience depends on the perspective of the responsible authorities. The potential impact of adapting the regime can be very positive for a range of different beneficiaries.

3.6.2. Measures for economic and socio-cultural WUFs

Enhancing co-benefits and addressing adverse effects of removing the boat and fish landing area for mooring of the FPV panels

- *Construct a new port for fish and boat landing* - the FPV scenarios imply that residents upstream of the dam will not any long be able to use the current port for anchoring of boats, and for sale of fish. Constructing a new port is expected to mitigate the negative effect of this aspects for the physical production, and employment. The measure will rings also benefit residents using the reservoir for recreation, in particular boating. Costs may be considered substantial but limited in time. The measure is perceived to represent some inconvenience related to identifying an area that can be appropriate for construction of a port. There is a risk that the rules of the Magat Forest Reserve (DENR) represent hindrances. There is an issue of identifying an appropriate area for the port and being in accordance with the fish sanctuary and forest reserve rules.

- *Construct a port for boats with electricity and freezer*: As part of constructing a new port to replace current area boat and fish landing area, providing a freezer for storage of fish would represent a co-benefit for fisherfolk and aquaculture farmers. The additional costs of a freezer would not be high. The measure would also involve the need for electricity to this area, and willingness and involvement of different local authorities. Administration and management of the use of the freezer would also involve some additional costs. The measure is expected, if administrated in a fair and transparent way to have positive effect on physical production and employment particularly on residents in upstream villages.

Enhancing co-benefits and addressing the adverse effects of replacing the fish cages with panels represents adverse effect on physical production and employment

- *Allocating space for the aquaculture cages on other areas of the reservoir:* The FPV scenarios imply replacing aquaculture cages in the northeastern and southeast part of the reservoir with FPV panels. An effective mitigation measure would be to allow aquaculture farmers to rent space for fish cages in another area on the reservoir. The measure would imply for the local authorities, NIA - some cost, and some inconvenience. It is possible that also for the fish farmers this might cause some inconvenience. It is important to lower conflict levels that there is fair and transparent allocation of space for fish cages.

- *Mitigating reduced employment / income and providing co-benefits as part of employment opportunities:* Some households will lose or have reduced income from aquaculture production and from fishing by nets. There will be a need for cleaning of the FPV rings two days a week. For the low cover scenario, this would imply cleaning of 96 rings as a minimum two days a week. For the high cover FPV scenario, this would need the cleaning of 430 rings two days a week. Additional need work for maintenance on the FPV system are also expected. Providing capacity building and education opportunities to local residents would imply in addition important co-benefits. Employing residents to work on the FPV system also represents a measure to reduced adverse impacts. Costs and convenience are expected to be relatively low.

Addressing adverse effects of occupying area on the reservoir with FPV for transportation

- *Allowing corridors between the FPV floating structures for navigation*: The FPV power plant will cover area used for navigation on the reservoir, resulting in longer transportation time and fuel costs. Corridors between the FPV rings for boats is expected to largely mitigate the negative impact on access to transportation. From the perspective of the industry partners, cost and inconvenient related to the measures is expected to relatively low, with important positive effect for beneficiaries. For the high cover scenario, this does not represent a relevant measure to mitigate adverse impacts as for this scenario, during low water levels there will be little space for navigation.
- *Construct roads upstream to provide an alternative to navigation on the reservoir*: As an alternative to navigation on the reservoir, roads for improved access to schools, markets and health services etc. could be constructed. This measure however is not feasible, as the Forest Reserve rules does not allow road construction in this area.

Addressing adverse effects of the FPV on recreation opportunities, heritage and cultural practices and tradition, social cohesion, and landscape aesthetics

- *Consideration of people's recreation activities in the planning of the FPV intervention*: While the reservoir and river are important sites for recreation activities for both upstream and downstream residents; in the recent decades, rules restricting recreation opportunities such as swimming and water sports previously part of peoples' behaviours, have been introduced. Considerations for mitigating reduced opportunities for recreation could comprise different types of measures, including allowing space for boating (see also above), but also for example facilitating for designated picknick areas, and identifying safe zones for swimming. The costs and the convenience situation are expected to be moderate. Efforts will be needed to engage different local authorities, and if relevant NGOs in the area for a coordinated approach. The potential added value for local people can be expected to be high and contribute to social acceptance (Ellis and Ferraro 2016).

- *Information to people about the water management release regime: The operation regime and the technical hybrid hydro solar plant will enable sudden* release of water through the gates that can provide risk for people downstream. It will be important to provide clear and early information to people about the water release situation and always prioritize risk reduction.

- *Monitor the situation regarding social cohesion and conflicts between different water users to address the situation:* Studies have documented that energy development projects have disproportionate effect on different groups of stakeholders where some are more advantaged than others (Levenda, Behrsin and Disano 2021). To avoid conflicts and reduced cohesion in the area, plans for monitoring of the situation in the different villages, during the different phases of the project will be important for the possibilities to take necessary actions.

- *The hybrid – hydro solar plant can be an important source of education and awareness raising*: The local energy company SNAP has opened the site for visits by schools for education purposes. Further developing the power plant as a site for education and awareness raising by constructing or allocating some space such as a visitor centre where information including videos and posters about climate change, GHG emissions, the need for deployment of renewable energy and the opportunities and benefits of hybrid hydro FPV for flexible and robust electricity provision are presented. Such a site may be a collaboration between different local and provincial authorities and the energy company for better coordination and for sharing of costs. Such a centre could be important for increased understanding of the need for renewable energy projects, and represent a local meeting place, as well as employment opportunities.

Table 3.10. *Overview of measures, indicative evaluation of measures, and mitigation and co-benefit effects.*

Measures identified to mitigate adverse effects and enhance co-benefits	**Evaluation of measures**		**Mitigation and co-benefit effects on WUFs (negative, neutral, positive)**													
	Costs (high, intermediate, low)	**Feasibility** (high, intermediate, low)	**Water quantity**	**Water quality**	**Biotic resources**	**GHG emission**	**Physical producti.**	**Employm.**	**Transportation**	**Electricity**	**Food security**	**Health**	**Recreation**	**Cultural practices, heritage**	**Social cohesion**	**Watersc., landscape aesthetics**
Allowing space between the floats for airing of the water surface	Low	High	Pos. effect expected													
Adapting power production and operational regime of the hybrid hydro-FPV	Intermediate	Low - Intermediate	Pos. effect										Potential pos. effect			
Construction of a new port for fish and boat landing	High / uncertain	Uncertain					The measure is expected to offset negative effect				Offsets neg. effect		Offsets neg. effects			
Provide electricity and freezer at the port	Low - Intermediate	High					Pos. effect				Positive effect				Potential pos.	
Allocating space for aquaculture cages on other areas	Low-intermediate	Intermediate					Positive effect				Positive effect					
Mitigating reduced employment / income, add co-benefits by contrib. to employment opportunities	Low	Uncertain						Pos. effect			Pos. effect	Pos. effect				
Allowing corridors, space between the panels for navigation	Low	High	Pos. effect				Pos. effect						Pos. effect			
Construct roads upstream to provide an alternative to navigation on the reservoir	High	Low	Potential neg. effect*				Pos. effect				Pos. effect	Pos. effect	Pos. effect			
Consideration of people's recreation activities in the planning of the FPV intervention	Low	Intermediate ?										Pos	Pos. effect			
Information to people about the water management release regime	Low	High										Pos.	Pos. effect			
Monitor the situation regarding social cohesion and conflicts between different water users to address the situation	Low	Intermediate										Pos.	Pos. effect			
The hybrid – hydro solar plant represent can be an important source of education and awareness raising	Low	High	Pos. effect					Pos. effect					Pos. effect		Pos. effect	

3.7 Reflecting comments on the ex-ante impact assessment of FPV on Magat

The ex-ante impact assessment of FPV power plant on the Magat reservoir has involved primary and secondary data collection with subsequent analysis of environmental, economic and socio-cultural variables. The assessment which has followed the conceptual framework described in Chapter 2 of this report has considered direct and indirect consequences on selected indicators. It has been an aim to take a holistic approach by addressing both adverse and positive effects, and measures to enhance co-benefits for different beneficiaries including sectors in the area, and for the environmental, economic and socio-cultural sustainable development dimensions.

A hydro-biogeochemical model was developed to assesses effects of FPV on water quantity and quality parameters, on GHG emissions, and for solar and hydropower production. Studies on thresholds values for tilapia fish and DENR water quality guidelines were used in combination with modelled oxygen and temperature data to predict harmful effects for fish and requirements for various water uses. The development of the hydro-biogeochemical model for the impact assessment represents a strength of the study as it allows direct quantification of expected impacts through state-of-the-art process understanding with some ground-truthing with field data. The approach goes therefore beyond empirical models and knowledge rules. According to our knowledge, the modelling approach is the first to also include dynamic representation and quantification of GHG emission pathways, as well as solar and hydro power production. Modelled GHG emission estimates, consistent with field data, were also corroborated with the G-res tool estimations (Chapter 5). Water users and usages on and around the reservoir as well as downstream of the dam have been mapped, and data has been collected on aquaculture production, forming a scientific basis for assessing the potential effects of the FPV scenarios.

Important results from the study include that, considering relatively low FPV cover, adverse impacts on environmental and the economic indicators are mostly minor. We furthermore consider that these adverse impacts are relatively easy to mitigate. For the high cover FPV scenario, despite mitigation measures, adverse impacts for several environmental and economic indicators are predicted. Positive impacts of the FPV hybrid power plant are primarily predicted for provision of electricity, and for reduction of GHG emissions. Regarding the socio-cultural situation, however, adverse effects on traditional practices and on recreation opportunities are already expected due to economic and technological developments under the baseline scenario. In addition, further adverse impacts from FPV are expected linked to the adoption of new rules, indirectly related to FPV development, and to disturbance and limitation of space on the reservoir for traditional practises and recreation activities as well as reduced landscape aesthetics. The combination of underlying drivers from the baseline and additional pressures from the FPV intervention on the socio-cultural situation makes the adverse impacts less easy to mitigate compared to environmental or economic impacts. It can be considered that the effects on social cohesion and on social acceptance of FPV power production will depend on the degree that relevant alternative recreation activities are available, that cultural heritage is strengthened by other initiatives, and that the FPV development steps are seen as transparent by stakeholders. Emphasis should be put on sharing information and allowing stakeholder dialogue for feedback on mitigation measures. It will be important to include, into the FPV power development plan, a strategy for how to address socio-cultural effects and implications.

To be highlighted is the suggested measures for co-benefits which represents important opportunities for diverse water user interests. An adjusted dam operation regime and the hybrid- hydro solar technology provide new opportunities to keep more water in the reservoir in dry periods by replacing some of the hydropower production by solar energy production taking advantage of the flexibility of the battery park. This is important for maintaining high water level in the reservoir, sustaining good water quality in the reservoir and for avoiding critically low water levels during dry climate conditions.

Adverse impacts will have disproportional effect on residents in villages upstream of the dam. This is in particular due to the limited alternative modes of transportation, and local infrastructure in the area. In this area the main means of livelihoods are from primary production. Important measures identified to address adverse impacts include construction of a port for boat and fish landing, good navigation routes on the reservoir, and relocation of fish cages for continued aquaculture production. For more urbanized areas downstream of the dam, adverse impacts are predicted to be much lower as residents in these areas have more livelihood opportunities, and better access to transportation, to markets, schools and health services.

The ex-ante impact assessment undertaken in this study represents a systematic and structured approach based on indicator values to assess effects. Making use of indicators facilitates communication with policy and decision makers. Involving local stakeholders in identifying beneficiaries in the system, and in selecting relevant and representative indicators, anchors the assessment to local realities and perspectives. Over the project period (2021-2024), we have presented our study plans, approaches, methods and assumptions to the research and industry partners in project meetings and bilateral meetings with emphasis on building trust and allowing for scrutiny and validation of the findings. In this report, we prioritized transparency of the approach and in the data used for the indicators' assessment, allowing for verification of indicator values and insightful discussions among project partners, to promote trust in the process.

4 The generic relevance of the results from the Magat case study impact assessment

The interactions and drivers identified for the Magat case study can be helpful for assessing the sustainability and environmental compatibility of FPV technology in other contexts. Cumulative impacts from FPV should be considered in combination with other industries in the local context. Cross-sectoral collaboration between researchers, stakeholders and decision-makers is essential to address data gaps and implement appropriate solutions including monitoring.

This chapter discusses in section 4.1 the generic relevance of the results from the ex-ante impact assessment of FPV on the Magat reservoir.

4.1 Generic relevance of the findings on environmental impacts

The environmental impacts and their magnitude will largely depend on the typologies of the reservoirs, such as the climate they are subjected to (air temperature, precipitation, wind and irradiation; long periods of high radiation without rain), the hydrology (e.g., long periods of reduced inflow, e.g., dry versus wet seasons), reservoir morphology and characteristics (depth, volume, shape, water level fluctuations), the degree of FPV coverage, as well as the FPV technology (floating system) utilized.

The results from the present study comparing the low and high cover scenario show, in agreement with Essak and Ghosh (2022), that shows that the percentage of FPV cover on a water body largely determines the magnitude system's impact on water quality and biodiversity. Based on the results from the Magat study, it is anticipated that impacts will be stronger in shallower waterbodies, with higher coverage, and that the impact will depend on FPV design. Below we summarize the generic relevance of our findings for effects on the environmental variables, temperature regulation and evaporation, dissolved oxygen, hydrodynamics, greenhouse gas dynamics.

Temperature Regulation and Evaporation Reduction

The presence of FPV systems can alter the thermal dynamics of a reservoir by producing a shading effect, reducing surface water temperature and potentially affecting thermal stratification and water evaporation. For the Magat case, the FPV technology with solar panels lying on a soft membrane would involve a small reduction in evaporation (negligible compared to yearly inflow of water to the reservoir) and a net warming effect for the underlying water. Counterintuitively, the shading effect is counteracted by a larger reduction in water cooling at night. Overall FPV provide more heat to the water that can eventually evaporate near the FPV. Such impacts would be likely to happen with the same design in other locations, especially in locations with long periods of continuous stable irradiation.

The magnitude of this shading effect highly depends on the design of the power plant. Where the degree of coverage is large, the warming effect of soft membrane FPV would be exacerbated but the water savings through reduced evaporation would be increased. Deploying FPV technologies with air between the PV panels and the water body would lead to more convective cooling by air and less heat transfer to the water body. This could potentially further increase water savings through reduced evaporation.

Dissolved Oxygen Levels

Shading from FPV panels can impact photosynthetic activity and influence oxygen production in the water. Reduced light penetration decreases photosynthesis by aquatic plants and algae, potentially leading to lower dissolved oxygen levels, which can negatively affect aquatic life.

At the Magat case, the soft membrane technology will reduce gas exchange at the water surface over the surface area it covers and decrease algal growth due to the shading effect. The modelling exercise showed that the impact was on average lower algal biomass but also lower oxygen concentrations, down to level where the ecological status is no longer acceptable for an additional few months per year (See Table 3.5). This mixed impact, reduce algal biomass and reduce oxygen concentrations, is likely to happen where the same soft-membrane design is applied.

Installation of the different FPV design technology where there is air in between the solar panels and the water surface, would have lower impact on oxygen concentrations, since the air-water exchange would still be effective, although slightly reduced because of lower air turbulence.

Hydrodynamics

FPV systems can modify the hydrodynamics of a reservoir by altering natural water flow patterns and mixing processes. Reduced mixing can lead to the accumulation of nutrients in certain areas as well as to a decrease in oxygen and increase in temperature, potentially exacerbating water quality issues.

For the Magat case, the FPV intervention was only considered in the central part of the Magat Reservoir where there is significant water circulation. However, the dynamic reservoir modelling showed that reducing the water circulation between the water covered with FPV and the rest of the reservoir would result in lower oxygen concentrations, higher nutrient levels and higher water temperature (data not shown). It is thus strongly recommended that FPV are installed over well circulating waters to avoid amplifying the compartmentation of a given water body. In highly dendritic reservoirs, installing FPV systems in isolated arms which do not receive large inflow of water is not recommended.

Greenhouse gas dynamics

By covering the water surface, FPV represents a physical barrier reducing diffusive GHG emissions from the surface and the amount of sunlight penetrating the water, which in turn can decrease algal and biomass growth. A reduction in biomass can translate into a reduction in organic matter degradation and GHG production.

The soft-membrane design deployed at the Magat reservoir is particularly effective in blocking CO_2 and CH_4 diffusive emissions from the surface, as evidenced by accumulation of CH_4 below the FPV pilot. The accumulation of CH_4 in the water column moreover provides conditions for CH_4 oxidation to CO_2 and likely reduces the overall CH_4 surface emissions (Chapter 5 below focusses on GHG emissions in more detail). At Magat, it was estimated that FPV would reduce the GHG emissions at the water surface but would increase CH_4 degassing downstream of the turbine. The overall net effect was estimated to be a reduction in GHG emissions from the Magat reservoir. However, FPV will also influence the oxygen concentrations and thermal stratification regime (see Table 3.5 and Figure 3.7) which can have diverse and contrasted impacts on GHG emissions.

The installation of soft membrane FPV at Magat, as well as other FPV designs, will likely reduce GHG emissions at the water surface by representing a physical barrier for dissolved gas exchanges. However, different FPV design are likely to have different impact on the oxygen concentrations and the thermal stratification regime, which, together with other local reservoir characteristics such as bathymetry, operation regime, residence time, would have intricate influence on GHG dynamics and emissions.

4.2 Generic relevance of the findings on economic and socio-cultural impacts

The effects of FPV on socio-economic and socio-cultural factors in a specific case will depend on water and land uses in the area and should be investigated in its respective context. Similarly to environmental impacts, impacts on society will depend on the scale of the FPV intervention on the reservoir, however, impacts of the FPV system will be largely influenced by other factors such as population and economic development. If the FPV system is in a remote area distant from human communities, the scale of impacts on society will obviously be lower than in populated areas. Also, the scale of impacts can be corelated with the degree that the population in the area depends on the reservoir for resources, e.g., for consumption, transport, recreation, etc. It may also be considered that rural communities are more dependent or tend to use water bodies more as a source for livelihood, income, and for recreation. Studies show however that the wellbeing of urban people is also influenced by access to nature and recreational activities in nature (Juntti and Ozsezer-Kurnuc 2023; Taylor, 2018).

Below we comment on the generic relevance of the findings from the Magat study for economic, and socio-cultural water use functions.

The impacts on physical production and employment

The Magat reservoir represents a source for employment and income for the larger proportion of the population living around the reservoir. For these residents, when FPV coverage compromises access to the water surface, and when FPV reduce oxygen concentration in the water negatively affecting fish growth, the significance of the impact is high. This impact is worse because of the limited road infrastructure and thereby the relatively low access for households to urban areas that represents alternative options of income and employment. For areas where access to other means of income is diverse, then the impact on levels of employment is less significant. This can also be exemplified by reference to lower impacts on the population of villages in the more sub-urban areas downstream of the Magat dam.

The impact on transportation

The finding from the Magat study that the there is a relatively strong adverse impact on access to transportation for people and residents in the area is associated with the situation that there are few roads around the Magat reservoir (upstream the dam), and that travel by boat on the reservoir is the traditional way for transport. The effect of FPV on access to transportation, depend on whether there are alternative modes of transportation. It is common to use the water surface for transportation, but the degree will differ among cases.

The findings on increased generation of electricity:

The findings on generation of electricity at the Magat dam is that the dam operation regime is optimized for and prioritises the use of water for irrigation. The dam operation regime also prioritises the emergency protocol during flood operations which has a higher priority than electricity generation (Department of Agriculture, 2007).

It is possible to increase the net electricity produced significantly by installing FPV on a hydropower dam. The value of the additional power produced will depend on the capacity of the grid, the complementarity of the solar and hydro resources at the site, and the markets and/or power purchase agreement(s) that the power plant(s) operate(s) under.

The effects on flooding:

It is not expected that the FPV system at the Magat dam will influence control of flooding. The dam operation regime considers an emergency protection and flood operations.

The findings on impacts on food security and health

Negative impact on food security may occur as a direct effect of the FPV system when the FPV infrastructure limits access to fishing area, access to the port for fish landing, and area for aquaculture production, and, indirectly when the cover of the FVP reduce oxygen concentration with negative effects for fish production. People attending the FGD informed that for the residents around the reservoir, around half of the households receive poverty support, and that it is common to fish for own consumption. This context and the lack of road infrastructure implies that the population is vulnerable to food insecurity. Regarding the impact of the FPV on health, residents around the reservoir don't have access to tap water. There are wells and springs in the area, but some also use the reservoir for domestic purposes. With high cover FPV the model exercises inform that the water quality will be reduced.

The impact on food security and on health can be expected to be different and lower when the FPV system are placed close to more urban areas, and in areas where poverty is not a risk.

The findings on access to recreation and cultural heritage, landscape and social cohesion

The findings from the study of the impact of FPV on the Magat reservoir for sociocultural aspects, can be characterised as largely uncertain for the low cover FPV. For high cover FPV, access to recreation on the reservoir, cultural heritage can be assumed to be directly related to scale, that is the degree that the water surface is still accessible. This study, however, did not investigate peoples' perspective and attitude to FPV on the reservoir, that is, how different FPV may influence how people experience recreational activities. For residents both upstream and downstream the dam, the reservoir was important for recreational activities.

There is knowledge that landscapes and waterscapes influence people's wellbeing (Abraham, Sommerhalder and Abel 2010), and that water and waterscapes are sources of recreation and important for cultural heritage and identity. It is also a general finding from other studies that, when energy or industrial projects favours certain groups in society while others are being disadvantaged, an increase in local conflicts can be expected reducing social cohesion (Dainius 2016). Few studies have been undertaken to assess people's perception of FPV (see World Bank group, 2019).

5 Assessment of the impact of floating solar panels on greenhouse gas emissions

Since the early 1990’s, hydropower reservoirs have been identified as a potentially significant source of carbon dioxide and methane for the atmosphere. The real perturbation of the carbon cycle and related emissions due to reservoir creation should take into account the carbon cycle and emissions from the whole catchment before the creation of the reservoir and compare this to the situation after the reservoir has been built (Prairie et al. 2021, see Figure 5.1). Key parameters that effect the GHG emissions are concentrations of dissolved oxygen, water temperature, organic matter concentrations, supply of nutrients and biomass of plants, algae, bacteria and animals in the reservoir. Floating solar PV in hydropower reservoirs may directly or indirectly alter these parameters, leading to changes in carbon cycle and GHG emissions.

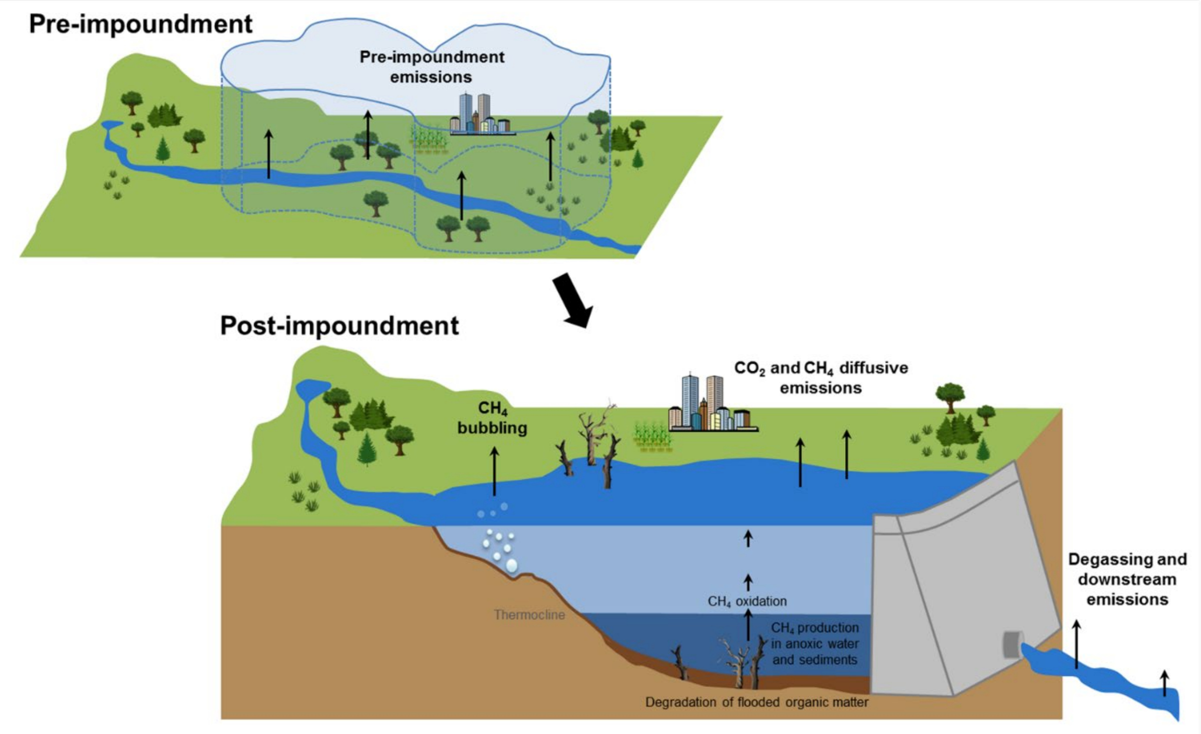

***Figure 5.1**. Schematic view of a catchment and river with emissions pathways before installation of a dam (pre-impoundment) (top), and the situation after impoundment (below), from Prairie et al 2021.*

The main pathways of GHG emissions from reservoirs are:

- Diffusive emissions from the reservoir surface to the atmosphere. The flux of CO_2 and methane between the water-air layer will go from the side with the highest concentration of gas towards the other. In most cases, the flux is from the reservoir to the atmosphere, but there are also cases where the reservoir is absorbing GHG from the atmosphere.
- Bubbling emissions (mainly methane) from the sediments in shallow (normally < 10m depth) areas in the reservoir. Gas bubbles may be released from decomposing organic matter in the sediments. Bubbling seldom occurs at water depths above 10 m.
- Emissions (mainly methane) from turbined water downstream the outlet of the power plant. Emission flux depends on the GHG concentration in the water that is used for turbining.

5.1 Modelling GHG emissions from hydropower reservoirs

To better understand the processes leading to GHG emissions from reservoirs, or to assess GHG emissions from reservoirs, modelling can be a useful tool. Several attempts to develop a physical-based model to represent GHG emissions have been made, without yet to reach verified and internationally accepted status. Instead, the empirical model G-res tool (Prairie et al. 2018) originally designed as a screening tool, have gained much attention. It has been used by IPCC for guidance to national inventories (IPCC 2019), and for assessments following the EU Taxonomy for sustainable finance.

The G-res tool is an empirical model developed to describe the four main pathways of greenhouse gas emissions from reservoirs: diffusive CH4 and CO2 emissions from the reservoir surface, CH4 emissions from shallow areas of the reservoir and downstream degassing of CH4. The model is based on extensive meta-data analysis of published data, developed into statistically robust models to predict reservoir emissions over time (Prairie et al 2021). The G-res tool is freely available, used in the IPCC guidelines for national inventories (IPCC 2019) and recommended used for the EU taxonomy (EC 2020).

G-res tool use data from the catchment and the reservoir. The main input data to G-res tool are given in Table 5.1.

***Table 5.1** Data to the G-res tool.*

Reservoir data	Catchment data
Location	Catchment area
Climate zone	Population in catchment
Monthly air temperature data	Catchment annual runoff
Impoundment year	Land cover in catchment
Reservoir area	Wastewater treatment (four classes)
Reservoir volume	Pre-impoundment land cover in reservoir
Maximum and mean depth of reservoir	
Water intake depth	
Installed capacity in hydropower plant	
Mean annual hydroelectricity generation	

Our main case for analysis of GHG emissions from reservoirs with floating solar PV is the Magat reservoir. To give a broader perspective, we have also analysed GHG emissions from three other reservoirs, the newly constructed Banja reservoir in Albania and the planned Kogbedou and Frankonedou reservoir in Guinea. The reservoirs in Guinea are planned in a cascade, where the upper reservoir Frankonédou has a large storage and large reservoir. The lower reservoir has just a small reservoir, but larger installed power capacity. These two reservoirs are assessed combined, even though floating solar PV potential is highest in the upper reservoir.

The reservoirs differ in age, as the Magat reservoir has been in operation since 1982, the Banja reservoir since 2016 and the two reservoirs in Guinea are only planned and not constructed. The reservoirs also have different characteristics with some key factors described in Table 5.2.

Table 5.2. Key characteristics of selected reservoirs

Name	Surface area	Climate zone	Installed capacity	Catchment land cover
Magat	30 km^2	Tropical	360 MW	55% croplands, 30% forest, 9% grassland, 5% settlements
Banja	14 km^2	Temperate	72 MW	29% forest, 27% grassland, 19% croplands, 12% settlements
Kogbédou	8 km^2	Tropical	88 MW	89% forest, 9% grassland
Frankonédou	162 km^2	Tropical	33 MW	89% forest, 9% grassland

5.2 GHG emissions from reservoirs without FPV

To find the effect of floating solar PV on GHG emissions in reservoirs, it is necessary to analyse the GHG emissions without floating solar PV, and then compare it to analysis of GHG emissions with floating solar PV. Emissions were estimated using G-res tool for all four reservoirs. In Banja, SINTEF Energy Research have also conducted measurements of GHG emissions that are available.

Magat reservoir

G-res tool for Magat reservoir was originally used by Mercier-Blais et al. (2021), estimating net GHG emissions to 743 g CO_2-eq/m^2/year and 19 gCO_2-eq/kWh. The main source of GHG emissions is degassing of methane downstream the powerplant. It seems like the analysis from Mercier-Blais et al. (2021) was not using updated values of land use and population in the catchment, which can have a significant impact on results. We have therefore used the G-res tool with alternative input data, resulting in estimated net GHG emissions of 1 407 g CO_2-eq/m^2/year and 36 gCO_2-eq/kWh.

Banja reservoir

The G-res tool for Banja gives unrealistic values of pre-impoundment emissions that are higher that post-impoundment emissions. Therefore, we show the estimated gross emissions from Banja, estimated to 1 442 t CO_2e/year resulting in 5,7 g CO_2e/kWh. Onsite measurements (unpublished data from Harby and Sundt) suggest higher emissions, but measurements are only done the first years after impoundment. In the first years after impoundment, methane emissions from bubbling and downstream emissions seem to be important. It is expected that emissions will decrease rapidly after the first years, which has also been seen in the measurement data so far.

Guinea reservoirs

Six separate calculations of potential greenhouse gas (GHG) emissions from the planned reservoirs Kogbédou and Frankonédou were done with the G-res tool. Calculated emissions are high for Frankonédou (984.3 gCO_2e/kWh) and very low for Kogbédou (10.3 gCO_2e/kWh) when running separate calculations for each reservoir. However, as both reservoirs will be connected and operated for both hydropower plants, GHG emissions should be calculated together for both reservoirs and power plants. When combining both reservoirs and both hydropower plants, calculated GHG emissions are 271.0 gCO_2e/kWh when allocating 80 per cent of the emissions to hydropower, or 163.3 gCO_2e/kWh when including solar power generation. 47 per cent of methane emissions from Frankonédou are due to degassing downstream the power plant. Such emissions may be eliminated depending on detailed technical design and operation. If we assume that degassing emissions are eliminated, calculated net emissions are 70.3 gCO_2e/kWh for both hydropower plants, and 42.3 gCO_2e/kWh when including solar power generation. The results show it's a risk for high emissions above 100 gCO_2e/kWh, but they also show a potential for mitigation measures to bring the emissions below 50 gCO_2e/kwh.

5.3 Floating solar panels impact on GHG emissions from reservoirs

Several factors may influence GHG emissions from reservoirs when solar PV are installed on the reservoir. First, it depends on how much of the reservoir surface that is used for solar PV and the type of device to keep the solar PV floating. A membrane type of floating device will give other impacts than different types of floaters that leaves some kind of gap between the water surface and the solar PV.

Floating solar PV may lead to changes in important factors for determining GHG emissions, such as water temperature, light penetration, waves, currents and reservoir water depth (due to changes in hydropower operations). This will again lead to changes in water retention time, algal growth and other biologic processes, dissolved oxygen concentration, ecosystem composition, etc.

Inflow, outflow and water level changes due to operation of the hydropower and dam facility, can also have a strong effect on GHG emissions. For instance, low water level in a reservoir may lead to larger areas of shallow water that are favorable conditions for bubbling emissions.

Magat reservoir

Methane is formed in anoxic conditions, which may be affected by FPV. However, the small effect on temperature and oxygen levels from our studies (see sub-sections 3.3.1) have most likely a small effect on GHG emissions.

Under the low cover scenario, the GHG emissions would be slightly reduced by up to 2.5%. In fact, the soft membrane is blocking the surface CO_2 and CH_4 emissions, which for CO_2 only increases slightly its residence time in the water while for CH_4, it also increases its probability to be oxidized to CO_2. Similarly, for the high cover scenario, GHG emissions would be reduced by up to 11%.

Banja reservoir

Banja reservoir has quite low GHG emissions from the reservoir surface, but there is significant methane bubbling from shallow areas. However, installation of floating solar PV will not impact this emission pathway.

The surface and downstream GHG emissions are impacted by the water quality, temperature and oxygen levels, as well as the operation of the hydropower plant. It is possible that FPV may change the water temperature and oxygen levels, but it is not possible to say in which direction as it depends on the amount, type and distribution of FPV within the reservoir. The current FPV in Banja (Figure 5.2), is installed close to the dam and may impact the water quality and dissolved levels of GHG in front of the turbine intake, which make it possible to tailormade FPV to keep GHG emissions low or reduce them.

__Figure 5.2__. Installation of floating solar PV from Ocean Sun by the shore in Banja reservoir (photo Atle Harby).

Guinea reservoirs

Both reservoirs in Guinea have around 40 % of the emissions from bubbling, which will not be significantly impacted by floating PV. Kogbédou power plant can be planned to avoid degassing (downstream emission) by smart technical design. Frankonédou reservoir are expected to produce degassing that actually will be released into Kogbédou reservoir as it receives water from Frankonédou. There is a risk that the potential methane derived from Frankonédou will be emitted as surface emissions from Kogbédou reservoir. It seems like the potential for reducing GHG emissions by installing FPV in Kogbédou and Frankonédou reservoirs are limited. However, solutions that eventually can capture methane from a membrane type of FPV, may have a potential to reduce overall GHG emissions.

5.4 Conclusions on GHG emissions from reservoirs with FPV

Floating solar PV can impact processes and physical, chemical and biological conditions in the reservoir. Results from environmental modelling of the Magat reservoir have shown it is most likely possible that floating solar PV can both decrease and increase concentrations of dissolved GHG in the reservoir, potentially leading to both increase and decrease in diffusive and downstream emissions.

The risk of high GHG emissions is associated with the faith of methane produced in the sediments. If methane is oxidised to CO2 on its way towards the reservoir surface, the net effect of such emissions is low. Most of the methane produced in the sediments normally originates from organic materiel transported to the reservoir from the upstream catchment or from biogenic production within the reservoir (autochthonous). CO2 emissions from such sources are just a part of the short-term natural carbon cycling, and does not add emissions to the atmosphere. However, if such emissions are converted to methane, the impact is much stronger.

In contrast to diffusive and downstream emission pathways, it is unlikely that floating solar PV can impact bubbling emissions as it mainly occurs in shallow areas near the shore where it is not always suitable to install floating solar PV. Even if FPV is installed, it is likely that that methane bubbling will find its way to the surface regardless of the FPV or other obstacles. However, if FPV combined with hydropower can help keeping the reservoir level higher, reducing the risk of bubbling emissions as there will be less areas in the reservoir with shallow depths.

If there are significant levels of methane generation below FPV, there is a potential of capturing methane caught under the membrane although the technology is not yet fully developed. This also requires quite large amounts of methane generation to be economically viable (see https://www.bluemethane.com/).

From the studies at Magat, it is also clear that reservoir operations may be an important factor controlling some of the processes in the reservoir and hence impacting the potential for GHG emissions.

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7 Annex: Licence framework

A license is a document which grants special permission to a specified company to do, use, or own something. In this report it refers to the permission to develop and run Hybrid Hydro FPV power stations as specified in the license, including conditions and rules of operation. In particular, a license may be issued by authorities, to allow an activity that would otherwise be forbidden. It may require paying a fee or proving a capability (or both). The requirement may also serve to keep the authorities informed on a type of activity, and to give them the opportunity to set conditions and limitations.

A license can also be defined as a permission granted by the authorities to cause disturbance or damage to the environment. Before a company, an entity is allowed to construct a power plant, a license or a permit must be obtained. The licence may require permits from several different sector authorities.

The framework for obtaining a licence is developed by national state authorities and makes reference to national legislation and responsible licensing authorities (See, Thaulow, Nesheim and Barkved 2016).

7.1 Philippine Licence framework

(Information provided by Enrico Laluan, SNAP (August 2024)

As of December 2024 in the Philippines, requirements for obtaining a licence for environmental compliance/consent for construction of commercial FPV systems has not been specified. The Environmental Management Bureau (EMB) is in the process of finalizing the final guidelines for the Environmental Impact Assessment procedure for FPVs.

A number of different permits with specified license requirements from different authorities are needed to obtain the licence. The licences relevant for SD considerations includes:

- *Environmental Compliance Certificate (ECC) - Department of Environment and Natural Resources (DENR)*
- *Certificate of Pre-Condition - National Commission on Indigenous Peoples (NCIP)*
- *Local Government Unit (LG) Endorsement – Affected LGUs*
- *Permit to use water resource - Reservoir operator*
- *Permit to use Land Area - Reservoir operator*
- *Land lease agreement*
- *Registration as Hazardous waste generator - DENR*

Below the process needed for obtaining a license according to Philippines Department of Environment and Natural Resources (DENR). Administrative Order 03-30 or the Implementing Rules and Regulation of Presidential Decree No. 1586).

Project categorization: Projects are initially screened and categorized based on their potential environmental and social impacts and project scale. In DAO03-30, projects are classified into categories to identify the level of assessment needed:

- Category A – Environmentally Critical Projects (ECPs) in or out of Environmentally Critical Areas (ECAs) that typically require a full Environmental Impact Assessment (EIA), applications are processed in the DENR central office. Solar projects under this category are those with capacity greater or equal to 100 MW

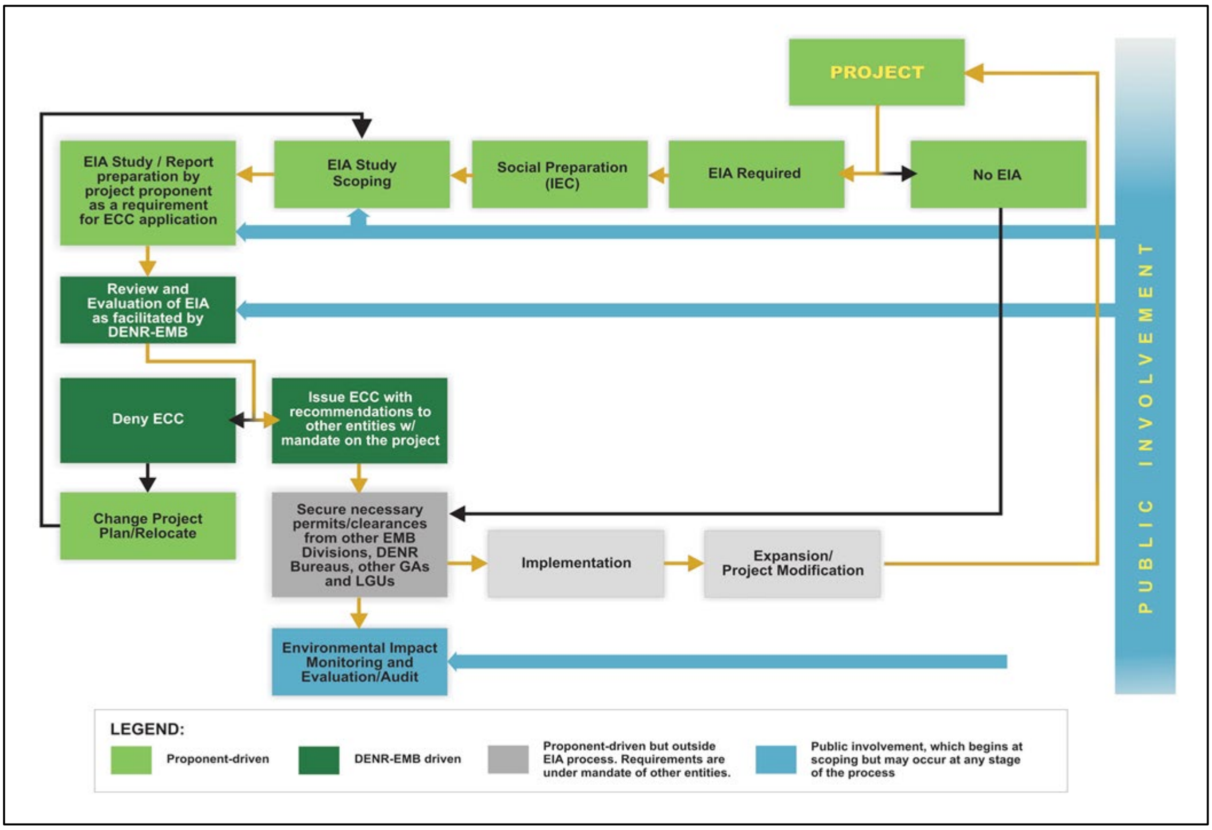
- Category B – projects that are not classified as ECPs but are located within ECAs. This project requires a full EIA but application will be processed at the regional DENR office. Solar projects covered under this category are those with capacity between 5 to 99 MW
- Category C – projects with minimal environmental impacts, typically requiring no environmental study or only minor documentation. Solar projects with less than 5 MW capacity fall within this category

Scoping: Identification of significant environmental aspects that need to be studied. Key stakeholders, including the project proponent, DENR representatives, community members, and other concerned entities, outline the focus of the EIA study. During this phase, the Terms of Reference (ToR) for the EIA study are established, setting specific parameters for what will be studies, analysed in the EIA.

Conducting the Baseline and Impact Assessment Study: This includes gathering of baseline data on environmental, social, and economic conditions, modeling potential impacts, and evaluating mitigation measures. Key areas of assessment typically include air and water quality, biodiversity, socio-economic factors, cultural heritage, and land use.

Submission and review of the EIA Report: The review process include consultations with experts (Review Committee) and if necessary, public hearings to address community concerns.

Decision and Issuance of the ECC: The EMB decides whether to issue an ECC based on the result or merits of the EIA study. An ECC is issued if the project has been shown to have adequate mitigation measures in place for significant environmental impacts.



Source: From, Administrative Order 03-30 or the Implementing Rules and Regulation of Presidential Decree No. 1586).

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