Green platform project

HydroSun

Scatec · Ocean Sun

TGS · prediktor · Innovasjon Norge

Multiconsult · Hydro · UiO : Universitetet i Oslo

Statkraft · IFE · SINTEF · NIVA

Annual Report

2022


SN ABOITIZ
Scatec
Ocean Sun

Site visit at the pilot floating solar plant at Magat Dam, the Phillipines. From left: Sebastian Aboitiz (Scatec), Daniel Dalmacio (SNAP), David van Berkel (Scatec), Espen Krogh (Prediktor), Ine Oma (Scatec), Hanne Nøvik (Scatec), Øyvind Engelstad (Scatec), Daryl Homer Ramos (SNAP).

Content

Letter from the project owner

In this report we share the results from the Green Platform project HYDROSUN. In this project we collaborate with a strong consortium of industry and research partners to develop new technology and solutions for hybrid renewable power plants.

At Scatec, we are on a mission to bring clean and affordable energy to parts of the world where it's needed most. That implies doing things differently than what has been done before. Our main contribution to our world is to develop, build, own and operate renewable power plants within solar, wind and hydro power. We know that we must solve the problem of variability in renewable power, i.e. how to provide electricity also when the sun doesn't shine and the wind doesn't blow. We also know that this is urgent.

The Green Platform Initiative under Innovation Norway enables Norwegian consortium to accelerate the Green Energy Transition with the potential to expand to the entire world.

We in Scatec are very excited to have joint world class experience from some of Norway's most advanced industries in this HYDROSUN research program. Together we have access to world class competence from the Norwegian industries within renewable energy, digitalization, control systems and aquaculture! We want to develop one of the first fully integrated hybrid power plants, based on multi-technology including hydropower, solar and batteries.

Innovation lays in the core of what we are doing in Scatec! Every day our employees strive to redefine what is possible and to be a front runner in renewable energy. And now we are doing it together with our highly competent partners!

I hope you will enjoy reading about our HYDROSUN project and I am looking forward to keeping you updated on our progress in the months and years to come!

Terje Melaa
SVP Engineering and Technology - Scatec

The HYDROSUN project

HYDROSUN – a project funded through the Green Platform Initiative

The HYDROSUN project received funding in the first round of projects awarded through the Green Platform Initiative. The goal of this initiative is to strengthen exports from and value creation by Norwegian companies in green solutions and products, thereby creating green growth. The underlying assumption is that leveraging the realization of major projects will trigger opportunities for green value creation through entire green value chains.

The Green Platform Initiative was set up by Innovation Norway, the Research Council of Norway and SIVA to provide funding for companies and research institutes engaged in research- and innovation-driven green growth. The initiative was launched as a response to a targeted effort by the Norwegian government to stimulate accelerated investments from companies in green sustainable solutions and products. HYDROSUN was funded in the first Green Platform Initiative, which was a part of the Norwegian Government's third package of financial measures launched in May 2020 in response to the coronavirus pandemic. The Government granted NOK 1 billion over a period of three years to this initiative. The Green Platform Initiative projects comprise value chains spanning from research and knowledge production to testing, commercialization and industrialization of sustainable, green products and services. The HYDROSUN project is a good example of this.

A brief introduction to the HYDROSUN project

The HYDROSUN project is set up to support the realization of full-scale, integrated hybrid power plants. This type of power plants will be presented in more detail in the next chapter. Briefly explained, they are power plants that by combining two or more renewable electricity production technologies, energy storage and digital control systems aim to deliver predicable and controllable power to the grid on multiple timescales. Moreover, hybrid power plants can enable other important benefits, such as lower investment and operation costs and more sustainable construction and operation of the power plants. Finally, hybrid power plants might be one of few feasible approaches to enable integration of the vast amounts of new intermittent electricity production capacity that is anticipated to become connected to the grid within the next decade. We believe hybrid power plants can and will play a key role in the accelerated green transition. Multiple hybrid power plants based on various combinations of power production and storage are being developed by the project partners, all of which are supported by the HYDROSUN project. The HYDROSUN project has a particular emphasis on hybrid power plants made up by combining hydropower, floating solar (PV) power plants and battery energy storage systems (BESS).

Although the potential is large, there are few operational full-scale hybrid power plants in operation today. This is due to several challenges. Both the design and subsequent optimized control is challenging. Moreover, the profitability of a hybrid power plant relies on both optimal co-operation of all its parts, in addition to emerging market and regulatory frameworks valuing the predictable and controllable power generation enabled by such power plants.

The overall goal of HYDROSUN is to support the work by the partners in an Industry Project towards realizing a first, full-scale hybrid power plant based on the innovations developed in this project. This project will be described in more detail herein. We believe the funding was awarded at an ideal time. The field of hybrid power plants is maturing, and we believe it is possible for the partner companies to take pole position in a field anticipated to play an important role in the coming years.

In the HYDROSUN project, we will develop:

- New processes and tools for simultaneous planning, dimensioning and design of hybrid power plants.
- The World's first integrated control system for a hybrid PV-hydropower plant.
- New technology for floating PV power plants increasing power production and reducing costs.

The HYDROSUN project organization

The Green Platform project HYDROSUN consists of two distinct parts. One part, the Industry Project, is headed by Scatec and funded by Innovation Norway, Scatec, TGS-Prediktor and Ocean Sun. The heart of this project are three industry-led sub-projects wherein the innovations leading to the realization of hybrid power plants are performed. The Industry Project partners are Scatec, TGS-Prediktor, Ocean Sun, IFE and SINTEF Energi.

The other part of HYDROSUN is a Competence Project (KSP HYDROSUN) fully funded by the Research Council of Norway and headed by IFE. The competence project joins with the aim of developing a strong industry and competence cluster on hybrid power plants. In addition to the partners in the Industry Project, the consortium in the Competence Project also includes Hydro, Multiconsult, Statkraft, NTNU, the University of Oslo and NIVA as partners.

The contents of the Industry Project and the Competence Projects are presented in more detail in subsequent chapters in this report.

The project organization of the HYDROSUN project is shown below.

Main Goal:

First full scale hybrid power plant based on hydropower and floating solar

DP0 **Project management and communication**	DP1 **Scatec – Full scale hybrid asset**	DP2 **Prediktor - Digitale tools for hybride assets**	DP3 **OceanSun – floating solar**	**Competence prosject**
Scatec, IFE	Scatec	TGS, prediktor	Ocean Sun	Hydro, Statkraft, Multiconsult, IFE, SINTEF, NIVA, UiO : Universitetet i Oslo

Organization of the HydroSun project with the three industry partners; Scatec, Prediktor and OceanSun and the partners in the Compentence Project

The HYDROSUN project

Industry Project

Project owner: Scatec

Project manager: Øyvind Engelstad/ Scatec

Project partners: TGS-Prediktor, Ocean Sun, IFE, SINTEF Energi, Solenergiklyngen

Project financing: Innovation Norway, Industry Partners

Competence Project

Project owner: IFE

Project manager: Dr. Josefine Selj/ IFE

Project partners: NIVA, NTNU, SINTEF Energi, UiO, Scatec, TGS-Prediktor, Ocean Sun, Statkraft, Hydro REIN, Multiconsult

Project financing: Research Council of Norway

Hybrid power plants

What, how and why?

The grand challenge

One of the most important challenges today is to solve the so-called energy trilemma. We need to scale up renewable energy production as soon as possible while taking care to provide security of supply, sustainability and simultaneously enable affordable power production. This is no easy task! With increasing deployment of renewable electricity, challenges related to intermittency and balance of energy, land access, grid capacity and sustainability become increasingly important. Hybrid power plants can become a very important part of the solution to all these challenges.

The partners in HYDROSUN joins companies and research groups with long-standing experience and world-class competence in key areas for this development. The consortium accesses strong competence on hydro, PV and wind power, including floating solar power, battery storage, energy systems design, digitalization and cybernetics. The Norwegian hydropower industry has 120 years of history and remains one of the most advanced industries of its kind in the world. The HYDROSUN project is developed on the assumption that hydropower plants, which combine the ability of producing dispatchable and renewable power, will facilitate the development of hybrid power plants with significantly larger total power production.

What is a hybrid power plant?

A hybrid power plant is a power plant combining two or more energy production or conversion technologies, often also incorporating energy storage. Relevant examples of hybrid power plants for the HYDROSUN include PV + hydropower plants and PV + wind power. HYDROSUN has a particular emphasis on supporting the development of hybrid PV + hydropower plants based on floating PV technologies. Hybrid power plants can enable increased production of renewable electricity. They can simultaneously ensure robust, predictable and controllable electricity production on multiple time scales. Hybrid power plants can exhibit substantially higher capacity factors than stand-alone renewable power plants and facilitate integration of increased electricity production to, as well as increase the utilization of, the grid. Such power plants can also reduce the total area use, and hence the cost and environmental footprint, of electricity production. Hybrid power plants also present an opportunity to develop and use joint electrical and physical infrastructure and exploit synergies related to joint operations and maintenance (O&M).

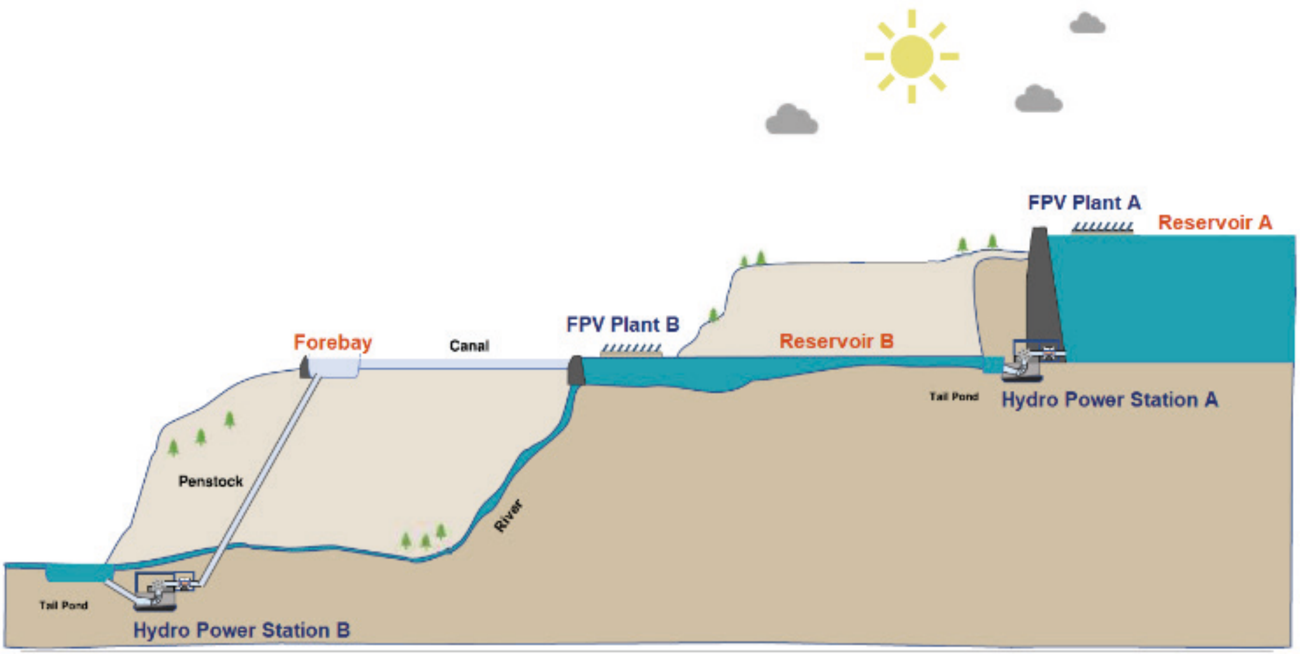
The added benefits of hybrid FPV-hydropower plants
The HYDROSUN project has a main emphasis on hybrid PV hydropower plants. These can unlock additional economic, social and environmental benefits. The main advantage is the potential use of the hydropower reservoir as energy storage to facilitate stable production on all timescales. In addition, the potential benefits of this particular type of hybrid power plants include increased profitability, reduced land utilization also for the reservoir, reduced evaporation from reservoirs if FPV is used, a decreased dependence on inflow for power generation, increased resilience to climate change and improved water management. Hybrid power plants can reduce the risk an energy asset developer takes towards the energy market by enabling predicable and controllable production. Most of the operational perspectives of this type of hybrid power plants are similar also for land-based hybrid PV hydropower plants, and many are generally applicable to any hybrid power plant. This expands the potential impact of the project.

Estimates of the FPV production potential show that this combination has huge potential. The technical potential for hydropower plants hybridized with FPV has been estimated to reach 10 000 TWh. By covering only 1% of the existing hydropower reservoirs in Africa such power plants could generate more than 50 TWh of sorely needed new, renewable electricity. Hybridization of FPV and PV power plants with hydropower also represents a great opportunity for Norway. Industry can be built on existing Norwegian excellence in industry and research within PV, hydropower and digitalization, in addition to a rapidly growing energy storage sector.

What are the challenges associated with hybrid power plants?

In spite of the many positive features of hybrid power plants, the number of such plants in operation is very limited. One major challenge is the lack of methods and models enabling optimal planning, design, dimensioning and control of such power plants. Up until now, the dominating design objective of PV and wind power plants has been to maximize kWh production. When larger shares of intermittent renewable energy sources are integrated in the grid, this must be reconsidered. Any change from the current model must be built on new business models for electricity production. A major obstacle for the development is therefore that the business cases critical for ensuring profitable long-term operation of hybrid power plants are still under development in most markets. The HYDROSUN project benefits greatly for being driven by Scatec, a company very much active in this development. This is required for keeping pole position in this highly competitive field. Yet another challenge is the lack of operational experience from such power plants, which adds uncertainty to investment decisions.

The HYDROSUN project is set up to resolve several of the major challenges and to contribute to the development of some of the first integrated hybrid power plants in the world. In the following chapters the two main components of the HYDROSUN project: the Industry Project and the Competence Project are described in more detail.



A hybrid power plant we have designed and optimized in HydroSun. This hybrid power plant includes two reservoirs, two hydropower plants in cascade and two floating PV plants (FPV)

Introduction to the Industry Project

The Industry Project is the core of HYDROSUN. In this project, the three companies Scatec, TGS-Prediktor and Ocean Sun collaborate with IFE and SINTEF Energi to develop new technology and processes for hybrid power plants and FPV technologies. The Industry Project is divided into three Sub-projects (DPs). These are:

DP1: Full-scale integrated Hybrid PV and hydropower plants

(Lead: Scatec)

In this DP, new processes and tools enabling simultaneous planning, dimensioning and design of hybrid power plants will be developed. This will enable designs that give lower costs through joint use of physical and electrical infrastructure, as well as joint systems for O&M. To support this, methods for precise and robust forecasts of joint power production on multiple timescales, as well as battery systems supporting stable and robust power production on multiple timescales are integrated in DP1.

DP2: Digital tools for planning, design, operations and maintenance

(Lead: TGS-Prediktor)

In this DP, an integrated control system for hybrid power plants will be developed. This will enable cost-efficient, robust and sustainable power production on both short and long timescales, as well as efficient real time operation of the hybrid power plant in markets for electricity, capacity and grid services.

DP3: Technology for FPV power plants

(Lead: Ocean Sun)

In this DP, new technology for floating PV power plants enabling increased production and lower costs will be developed. The targeted improvements in DP3 include increased yield and reliability, as well as reduced costs of transport and installation. Amphibious solutions are also investigated: this innovative approach can enable installation of the floating PV power plant before the hydropower plant is operational, enabling early revenue streams and power production.

In addition, the Industry Project contains a Sub-project dedicated to project management and communication which is led by IFE.

Workshop with the consortium. Back from left: Martin Hennum (Innovasjon Norge), Erik Stensrud Marstein (IFE), Øyvind Engelstad (Scatec), Terje Melaa (Scatec), Magnus Glomnes (Scatec), Arild Petersen (SIVA), Steinar Sælid (Prediktor), Alexander Telje (OceanSun), Rick Salmon (Quickminds) Mid from left: Ellen Krohn Aasgård (Sintef), Nenad Kerseric (OceanSun), Josefine Selj (IFE), Ine Oma (Scatec), Jiehong Kong (Sintef), Hanne Nøvik (Scatec), Gry Langbakk (Innovasjon Norge) Front from left: Siw Bang Larsen (Innovasjon Norge), Espen Krogh (Prediktor)

The Industry Project

Project owner: SCATEC
Project manager: Øyvind Engelstad/Scatec
Project partners: TGS-PREDIKTOR, Ocean Sun, IFE, SINTEF Energi, Solenergiklyngen

DP0: Project Management and Communication
Partners: Scatec, TGS-Prediktor, Ocean Sun, IFE, SINTEF Energi, Solenergiklyngen
Lead: Prof. Erik S. Marstein (IFE)

DP1: Hydro-PV Hybrid Power Plants
Partners: Scatec, IFE, SINTEF Energi
Lead: Hanne Nøvik (Scatec)

DP2: Digital tools for planning, design, operations and management
Partners: TGS-Prediktor, IFE, SINTEF Energi
Lead: Espen Krogh (TGS-Prediktor)

DP3: Technology for floating PV (FPV)
Partners: Ocean Sun, IFE
Lead: Børge Bjørneklett (Ocean Sun)

DP 1

Full-scale integrated Hybrid PV and hydropower plants

DP1 is the largest sub-project of the Industry Project. The overall goal of DP1 is to enable the development of the first full-scale, integrated hybrid power plant. Enabling as large a share of intermittent, renewable energy production as possible in the future is an enormous challenge. Hybrid power plants are believed to be a key technology for ensuring security of supply in an energy system increasingly dependent on sunlight, wind and rainfall. In HYDROSUN, we will develop the first full scale, integrated, hybrid power plant, based on hydropower, PV and batteries. In 2022, the work in DP1 focused on the following activities:

Market analysis

Developing the right market conditions and contracts for hybrid power plants is an important challenge which is addressed in HYDROSUN. An important element of DP1 is market analysis determining the value of flexibility in Scatec's focus markets. Communicating this value to governments, grid operators and funding institutions is crucial: long-term investments rely on long-term predictable frameworks and regulations. In 2022, market analysis for The Philippines, India, Brazil, Poland and South Africa have been performed. In addition, market analysis of the regions impacted by the Southern Africa Power pool (SAPP) and Western African Power Pool (WAPP) have been done. We have defined four typical services that governments/grid operators ask for in these markets.

1. Base load in specific times of the day
2. Generation during peak hours
3. Seasonal storage
4. Ancillary services in all these market types

The value of flexibility has been assessed in specific projects in Scatec's pipeline.

Scatec provides renewable energy solution in high growth markets. The company develops, builds, owns and operates renewable power plants based on solar, wind and hydropower. Scatec's vision is to improve our common future. Hybridization, combination of renewable energy production with energy storage and hydrogen and green ammonia production are at the core of Scatec's business. In 2022, Scatec's portfolio of power plants produced more than 10 TWh of renewable electricity worldwide, whereof 3.4 TWh were based on PV, 6.4 TWh on hydro and 0.4 TWh on wind power plants.

Tools for design and optimization of hybrid power plants

Development of tools for design and optimization of hybrid power plants is an important task in DP1. We will develop a pilot of control systems for hybrid power plants and subsequently use this as a basis for the development of a first, full-scale, integrated, hybrid power plant. In 2022, we have worked on tools for design and optimization of hybrid power plants. We organized a comparative test of different software where SINTEF Energi used SHOP and ProdRisk, Multiconsult PLEXOS and IFE, Norconsult and Scatec own code to address the same optimization problems.

Discussions on challenges and sharing of solutions gave very fruitful results. An approach for optimizing hydropower, PV and BESS down to hourly resolution has been identified. The next step will be to solve the challenges for sub minute/sub second optimization. A process has been started with TGS-Prediktor which will continue in 2023.

Pilot optimization

In 2022, two possible hybrid power plant projects have been optimized using the available tools in DP1:

- The Kogebedou-Frankonedou hydropower and PV power plant in Guinea
- The Mulungushi hydropower and PV power plant in Zambia
- Magat hydropower, floating PV and batteries hybrid power plant in the Phillipines

In addition, new hybrid possibilities have been identified. Scatec has identified 10 relevant projects with hybridization possibilities in the pipeline, including PV, hydropower, wind power and storage.

This is a clear demonstration of the relevance and excellent timing of the HYDROSUN project.

The work towards an actual project for a full-scale hybrid power plant has met some unforeseen challenges. Excessively high greenhouse gas emissions from a hydropower reservoir emerged as a potential challenge in one project. Slow, regulatory processes of water and water surfaces also remain challenges that are currently being addressed. We are now working on Magat Hydropower plant in the Phillipines as our full-scale hybrid power plant.

HydroSun team on Statkraft's floating solar panels at Banjë Dam, Albania. The FPV system is delivered by OceanSun. From left: Morten Bogetvedt (Prediktor), Casper Johansen (Prediktor), Alexander Telje (OceanSun), Hanne Nøvik (Scatec), Alexandra Shepard (Sintef/NTNU), Øyvind Klyve (IFE), Dag Lindholm (IFE).

DP 2

Digital tools for planning, design, operations and maintenance (Lead: TGS-Prediktor)

TGS-Prediktor's key focus market, technical asset management solutions for the renewable energy industry, is now facing significant changes. The challenge of intermittency with PV and wind power plants needs to be addressed, and storage of energy from non-dispatchable sources is an evident general solution. While this solves the intermittence challenge, and new opportunities to optimize the revenue generation from the assets, it also introduces more complex operations. TGS-Prediktor has decades of experience in optimizing operations of industrial assets. In DP2, this experience is applied to the hybrid renewable operations and optimization tasks. TGS-Prediktor will develop new products working on top of their own and 3rd party technical asset management solutions. In 2022, the work in DP2 focused on the following activities:

Analysis of hybridization scenarios

In 2022, most effort in DP2 has been devoted to analyzing and understanding different hybridization scenarios from a technical, commercial and operations perspective. Particular emphasis has been devoted to understanding the ongoing development of various hybrid scenarios. Concretely, the work has led to:

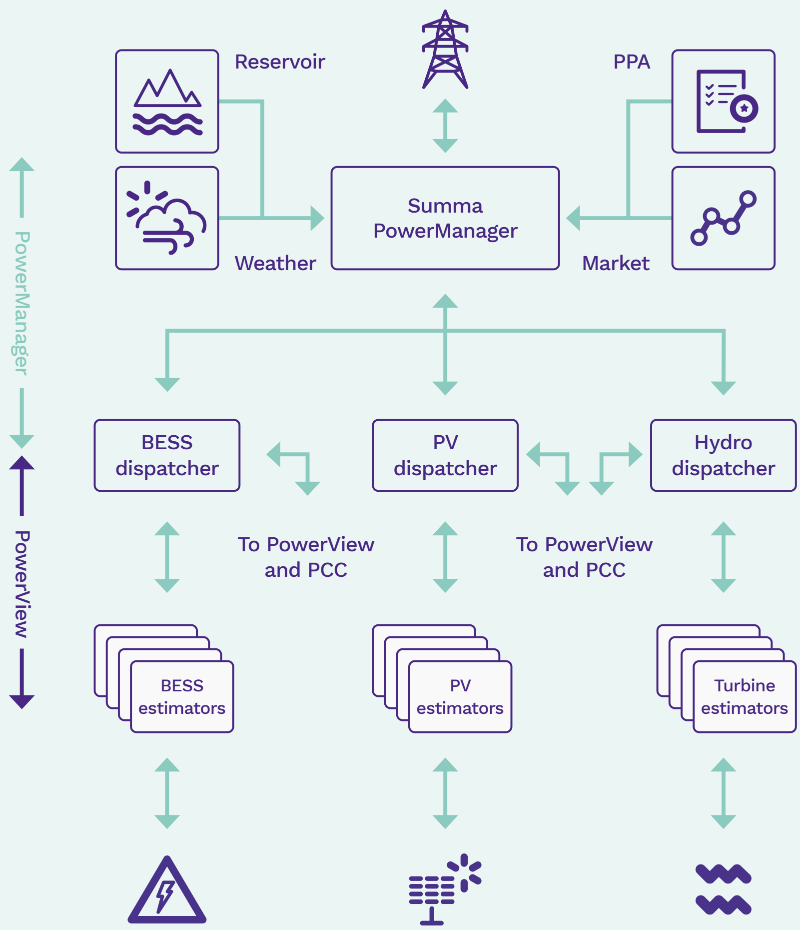
- An overview of all relevant hybrid power plant topologies, design-specific limitations, and the operational dynamics that must be understood in order to provide operators with decision support for optimal operation of hybrid power plants.
- Insight into the commercial services that potential customers are involved in, and the conditions surrounding these in relation to interaction with grid.
- A map of how system functions in a product architecture work together in an ecosystem of products, where TGS-Prediktor is only one supplier among many in the overall ecosystem of suppliers in the different segments.
- An overview of areas around design of facilities, operation of facilities and organization of the interaction between the facilities in a grid context.

Development of tools for operations optimization, hybrid operation and real-time prediction

The above activities have led to two important steps towards the planned developments in DP2. TGS-TGS-Prediktor has established a product strategy which takes the new knowledge into account. Moreover, the company has executed simulations to test possible algorithm approaches for the development phase of the tools. The main development of tools for operations optimization, hybrid operation and real-time prediction will take place in 2023 and 2024 as planned.

TGS-Prediktor is supplier of real-time data management solutions and technical asset management solutions for the renewable industry. TGS-Prediktor's mission is to assist the renewable operators to optimize the operations of their asset portfolios, through high quality digitalization and automated data driven asset management.

Functional architecture of software ecosystem for optimized operations of combined PV, hydropower and battery.



HydroSun consortium visit at the control room at Magat Power Plant in the Phillipnes. From left: Eliseo Ingles (SNAP), Arjay Francisco (SNAP), Juanito Pua (SNAP), Ariel Yao (SNAP), Ivar Blekstad (OceanSun), Sebastian Aboitiz (Scatec), Hanne Nøvik (Scatec), Ine Oma (Scatec), Øyvind Engelstad (Scatec), Daryl Homer Ramos (SNAP), Espen Krogh (Prediktor), Daniel Dalmacio (SNAP), David van Berkel (Scatec)

DP 3

Technology for FPV power plants (Lead: Ocean Sun)

The overall goal of DP3 is to demonstrate the performance of Ocean Sun's FPV technology and further develop the technology and related process for installation and O&M to reduce costs and improve durability. In 2022, the work in DP3 focused on the following activities:

Performance and reliability of Ocean Sun's technology

Ocean Sun has floating PV systems in operation in several locations. DP3 has used existing installations in Albania (Banjë) and the Philippines (Magat) to develop new data and knowledge related to performance and reliability of their technology. In 2022, a main emphasis has been put on the PV modules. 150 PV modules with 3.5 years of operation were investigated with respect to mechanically induced microcracks. No cases of microcracks were found in this study, showing that PV modules perform reliably after installation and subsequent operation in floating PV power plants based on Ocean Sun's technology. Ongoing research on several sites is evaluating the performance of the floating PV systems. This is done to support earlier findings showing that the performance ratio of Ocean Sun's floating PV systems can be substantially increased due to efficient cooling of the PV modules.

Transport and installation

DP3 has supported the development of new processes and designs for reducing transportation volumes and increasing installation rates to drive down cost. One very important result

Ocean Sun is a developer of an innovative floating PV technology offering a bold solution to global energy needs by combining Norwegian excellence in maritime technology and PV. The patented technology is based on PV modules mounted on hydro-elastic membranes and offers cost and performance benefits not seen in other floating PV systems. Ocean Sun has offices in Oslo, Singapore and Shanghai and aims to become the world's leading floating PV technology provider.

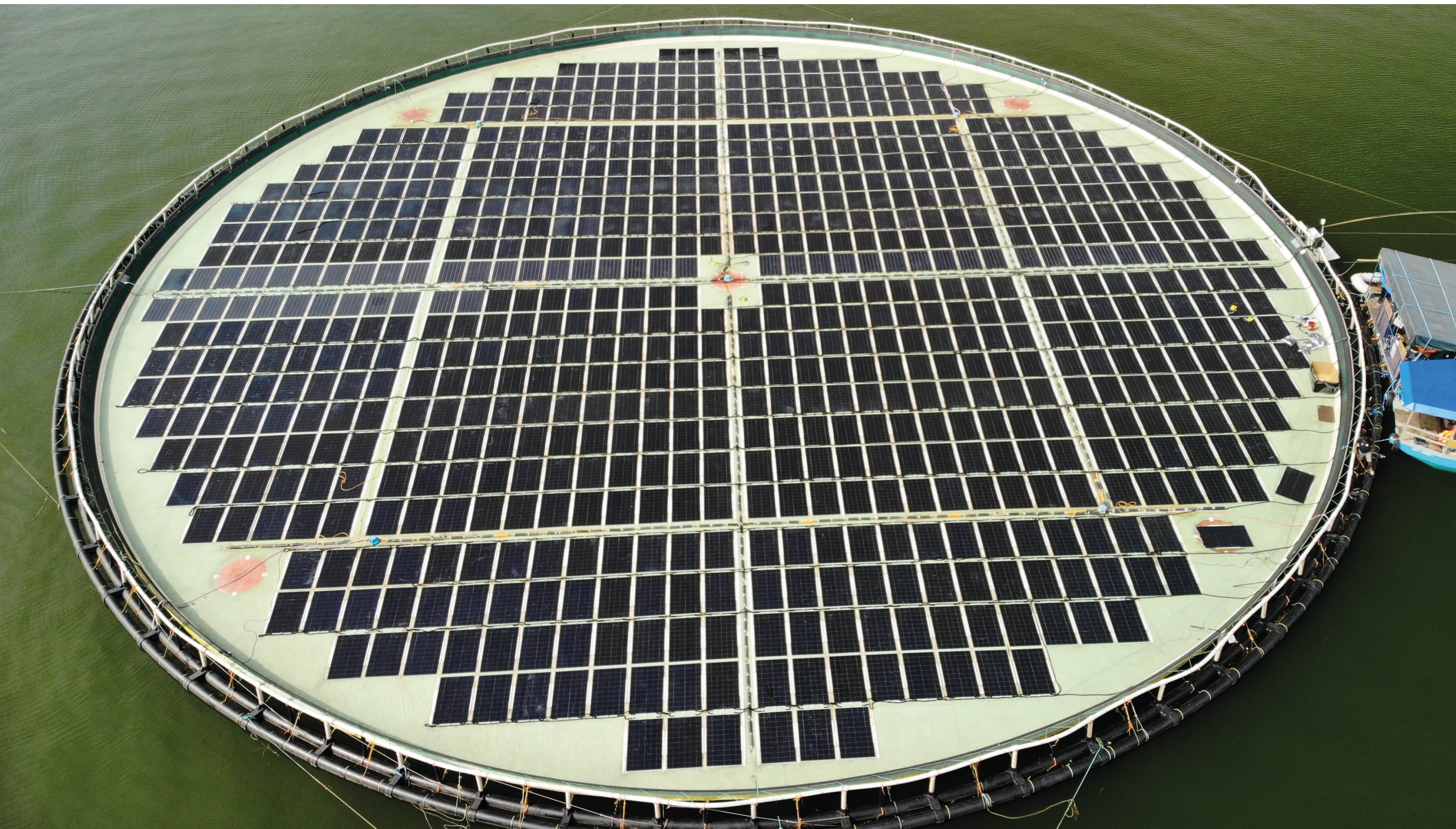
from 2022 was a new method for fitting two membranes into one container. Moreover, innovations in installation routines led to documented reductions in installation time of several days per ring at Banjë. Development of new designs for cost efficient mooring through coupled FEM and hydrodynamic analyses is in progress.

Operation and management of floating PV power plants

In DP3, Ocean Sun develops efficient methods for O&M including routines for cleaning and water management. To reduce cost, a system for condition based O&M is being developed. In 2022, a first version of this system was launched and is operative at Banjë and Magat. New routines for cleaning and bird prevention have been tested with good results. A new pump design for water management on the membrane has also been established.

Amphibious PV power plants

In DP3, new designs and materials enabling installation of Ocean Sun's technology on dry land before the reservoir is filled with water are investigated to enable early generation of power and revenue in hybrid power plant projects. In 2022, an initial evaluation of designs and materials for this application were evaluated and early tests carried out with promising results.



Introduction to the Competence Project (KSP HYDROSUN)

What is the Competence Project?

To support the Industry Project and broader Norwegian industrial activity related to hybrid power plants, HYDROSUN incorporates an interdisciplinary Competence Project (KSP HYDROSUN). This project, which is headed by IFE, joins 5 leading research groups (IFE, NIVA, NTNU, SINTEF Energi and the University of Oslo) and 6 leading companies (Hydro REIN, Multiconsult, Ocean Sun, Scatec, Statkraft and TGS-Prediktor) with the aim of developing the required competence base for development and operation of hybrid power plants. Although the emphasis is on hybrid power plants based on hydropower and floating PV, most operational perspectives are immediately relevant also for hybrid power plants integrating land-based PV power plants, and also relevant for the broader class of hybrid power plants integrating intermittent renewable power production.

The work in KSP HYDROSUN is structured into four work packages (WPs). These are described in some more detail across the following pages. Some of the results and work in 2022 is also presented here.

Research needs

The overall goal of KSP HYDROSUN is to develop knowledge enabling efficient design and operation PV-hydro and floating PV-hydro hybrid power plants. The basic principle of joint operation of such hybrid power plants is relatively straightforward: to utilize the hydropower reservoir as a flexible energy storage to support increased production of renewable power production by integrating large-scale PV production while simultaneously ensuring stable and controllable production. In spite of the many perceived advantages, the development of such power plants remains slow. Several important research questions must be answered to enable scalable, fast and robust development of hybrid power plants that are sustainable and profitable in the long term.

One set of questions that is addressed in KSP HYDROSUN is cost-optimal dimensioning and operation of the hybrid power plants. Additional storage is anticipated to add additional value by reducing the need for high frequency turbine setting changes. Therefore, modelling of the hybrid power plant operation with and without integrated battery storage is performed. A second set of questions is related to optimal control strategies for such power plants that ensure long-term predictable and controllable production within environmental and regulatory constraints while optimizing profitability. Yet another set of questions is related to the impact of both short- and long-term variations in weather, market, regulations and climate on the market conditions for hybrid power plants, and their ability to support energy security and profitable operation. A particular emphasis is put on the importance of forecast accuracy on the short- and mid-term operation. Finally, the use of floating PV imposes additional challenges compared to land-based PV. Although this is a technology that has been growing rapidly the last years, scientifically sound reports on performance, reliability and environmental aspects of various floating PV technologies have just recently begun to emerge. There is a critical need of high-quality data and a robust validation of the suggested environmental impacts of this new technology. KSP HYDROSUN will make important contributions also in this respect.

The impact of KSP HYDROSUN

KSP HYDROSUN addresses key research questions for hybrid hydropower PV and floating PV power plants. One set is related to the actual performance and reliability of key system components, which impacts detailed modeling of the power plant operation, development of control systems and adapted operations and maintenance (O&M) strategies. KSP HYDROSUN addresses strategies for efficient design, sizing, scheduling and real-time operation optimalization, all key knowledge for project development and operations. KSP HYDROSUN also investigates the resilience of hybrid power plants with respect to uncertainties in market, regulations and climate.

The targeted hybrid power plants can enable stable, predictable and controllable renewable energy production and simultaneously significantly reduce the local environmental and social impact of power production. Grid capacity can rapidly become a bottleneck in the green transition, and hybrid power plants can play a crucial role in maximizing the amount of renewable power generation the grid is able to utilize. Importantly, KSP HYDROSUN will evaluate and quantify benefits of concrete hybrid power plant case studies, benefits that are hitherto mostly only postulated for such power plants. This information is crucial for future project development.

Overall, the research in KSP HYDROSUN will provide a basis for developing new, sustainable business models and products. The knowledge gained in KSP HYDROSUN will reduce perceived risk and contribute to the bankability of hybrid power plants.

The Competence Project

Project owner: IFE
Project manager: Dr. Josefine Selj/IFE
Project partners: NIVA, NTNU, SINTEF Energi, University of Oslo, Scatec, TGS-Prediktor, Ocean Sun, Statkraft, Hydro REIN, Multiconsult

WP1: Hydro-FPV Hybrid Power Plants
Lead: Prof. Erik S. Marstein (IFE)

WP2: Operation scheduling and grid connection for Hydro-FPV Hybrid Power Plants
Lead: Dr. Jiehong Kong (SINTEF Energi)

WP3: FPV power plants
Lead: Dr. Josefine Selj (IFE)

WP4: Environmental and societal considerations of Hydro-FPV Hybrid Power Plants
Lead: Dr. Ingrid Nesheim (NIVA)

WP 1

Hybrid hydro-floating PV power plants

In this WP, IFE, NTNU, SINTEF Energi and UiO collaborate to answer important research questions related to how resource availability and intermittency, technology selection, market and regulations all impact design, dimensioning and optimization of hydro-PV and hydro-floating PV hybrid power plants. Two PhD candidates, Klyve and Sheppard, are affiliated with WP 1. The research questions addressed by WP1 are:

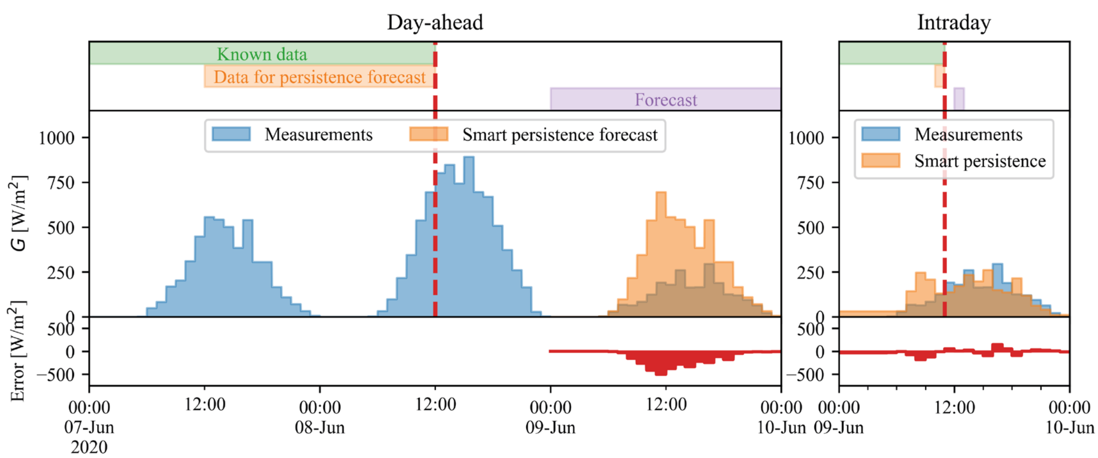
- How should hydro-PV hybrid power plants be modeled for optimizing revenue and resource utilization?
- What is the value of energy storage for short-term operation of hydro-PV hybrid power plants?
- Can energy storage technologies improve the profitability of hybrid power plants?
- Can reduced forecasting uncertainty give more efficient short-term operation of hybrid power plants?
- How can uncertainties related to future market and climate affect the dimension of robust hybrid power plants?

Main activities and results in 2022

One important activity was the development of a modelling framework for techno-economic analysis of hybrid power plants. This was successfully done and subsequently used to analyze a greenfield hydro-FPV hybrid power plant in West Africa. The hybrid power plant was analyzed under different pricing regimes. Parts of the work was shared with the international research community in an oral presentation at the important WPCEC8 conference, which took place in Milan. This work is followed up by a research paper in 2023. The work clearly showed that robust hybrid power plants can be designed based on the two technologies and also showed that such power plants can be more resilient to climate change than free-standing hydropower plants subjected to the investigated climatic conditions.

Another important activity was related to understanding the value of forecasting uncertainty for operation and profitability. Different forecasting methods are available and under development, and this activity was set up to quantify the economic benefit of increasingly precise forecasts. A journal paper has been submitted on this topic and has received positive review.

A final important activity in 2022 was related to understanding the role of battery systems for short-term operation of hydro-PV hybrid power plants.



Developing and integrating methods for precise PV production forecasts in market operations is an important activity in the HYDROSUN project. The figure shows measured and forecasted solar power production and how forecasting can be used to increase the profitability of PV power producers by enabling them to correct for deviations in day-ahead bids using more precise intraday forecasts. SOURCE: IFE

WP 2

Operation scheduling and grid connection of hybrid hydro-PV power plants

In WP2, SINTEF Energi, IFE and NTNU collaborate to develop operation scheduling tools for hydro-PV hybrid power plants. The PhD candidate Sheppard is jointly affiliated with this activity and WP1. The research questions addressed by WP2 are:

- How can algorithms and tools for hydropower and floating PV be combined for optimal hybrid power plant scheduling?
- What effect will hybrid operation have on the need and scheduling of maintenance for hydropower units?
- How can operation scheduling tools for hybrid operations be used to inform investment decisions?
- How can grid connection and integration be designed to facilitate efficient hybrid operations?

Main activities and results in 2022

In 2022, two versions of a hybrid scheduling tool, including PV production and reservoir evaporation, have been developed. The scheduling tool is open to all project partners. This scheduling tool can test the impact of power loss, turbine efficiency curves, market price settings, and evaporation on the operation pattern. The outputs are the reservoir trajectories, PV and hydro production schedules, and duration curves.

This hybrid scheduling tool is uploaded to SINTEF Energi Virtual Lab (vLab), a collaborative cloud-based toolbox for energy modelling. The vLab is a digital laboratory based on state-of-the-art robust, secure, and scalable infrastructure and serves as a user-based virtual environment where one can research, develop, run and interact with SINTEF Energi's hydropower models in an intuitive and easily collaborative way. All the tests are run by the latest version of SHOP and ProdRisk. Currently, two groups of master students from NTNU and the PhD candidate are using this scheduling tool.

A literature study for the state-of-the-art operational planning of hybrid power plants, including market pricing regimes and energy and capacity services delivery, is also in progress. A method for implementing a prototype of hybrid hydro and PV power scheduling was identified and will be the basis for further development. The impact of market pricing regimes on the operation pattern and the determination of maximum firm load under hybrid hydro and PV power scheduling was investigated in 2022. Four market pricing regimes were tested: a 1-, 2- and 3-tariff price system, and the South African Power Price market. The pricing regimes have substantial impact on the power plant operation.

WP 3

Floating PV power plants

In WP3, IFE and UiO collaborate to answer important research questions related to the performance and lifetime prediction of PV modules in floating PV systems. One PhD candidate, Harsha Walpita, is affiliated with this activity. The research questions addressed by WP3 are:

- How to adapt accelerated ageing tests to stressors experienced in the field for floating PV systems?
- How can precision of short-term floating PV power forecasting be significantly improved?
- To what extent can modern advances in automation and robotics enable reduced O&M costs for floating PV?
- How are commercial floating PV technologies performing?

Main activities and results in 2022

In 2022, data access was secured by IFE to an operational floating PV site in South Africa based on the Ciel & Terre technology, one of the market leading technologies today. The data from the site includes production data and sensor data from a monitoring system developed and installed by IFE at the site. The data from this site will be important for the planned research in WP3 in coming years.

Another main activity was related to developing and implementing a method for measuring mechanical stress on PV modules deployed in the field. Mechanical stress is anticipated to be very different for floating PV systems compared to conventional ground-mounted PV systems. A first prototype was successfully developed and tested in a field configuration in the IFE Outdoor PV Test Site.

International collaboration was also very important in 2022. IFE leads the IEA PVPS activity on Reliability of floating PV, and KSP HYDROSUN benefits strongly from discussions and shared experience from the other internationally leading research groups in the field. This collaboration will continue until 2025.

In addition to Harsha Walpita, who is fully financed through KSP HYDROSUN, two additional PhD students from IFE and UiO are affiliated with this WP: Nathan Roosloot and Vilde Stueland Nysted. Nathan is working with FPV reliability and Vilde with FPV performance.

An OceanSun Floating PV ring under installation at Statkraft's Banjë Dam, Albania. Back from left: Dag Lindholm (IFE), Alexander Telje (OceanSun), Alexandra Shepard (Sintef/NTNU), Morten Bogetvedt (Prediktor - TGS), Ivar Blekstad (OceanSun), Ivar Klyve (IFE). Selfie taker: Hanne Nøvik (Scatec)

WP 4

Environmental and social considerations of hydro-PV hybrid power plants

In WP4, NIVA and SINTEF Energi collaborate to answer important research questions related to the sustainable development of hydro-floating PV hybrid power plants. The research questions addressed by WP4 are:

- How does floating PV impact the local environment?
- What is the impact of floating PV hybrid power plants on socio-economic aspects?
- How can negative impact be mitigated and co-benefits enhanced?
- What are the greenhouse gas emissions associated with specific hybrid power plants?

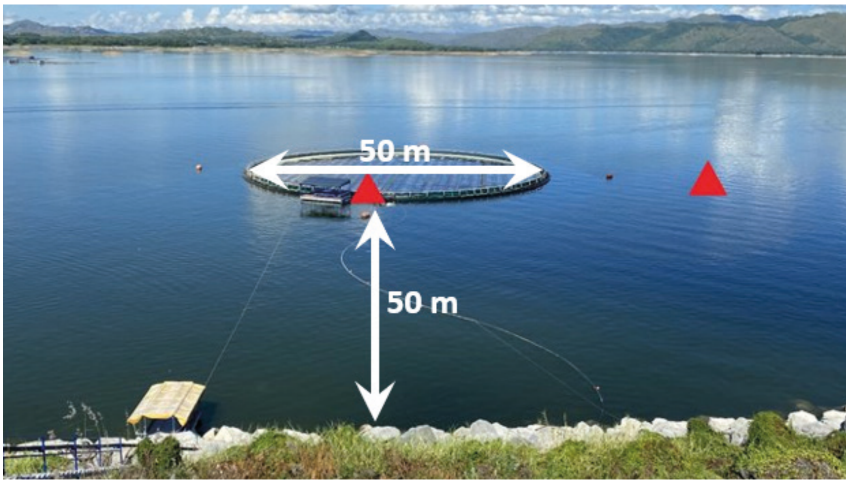
Main activities and results in 2022

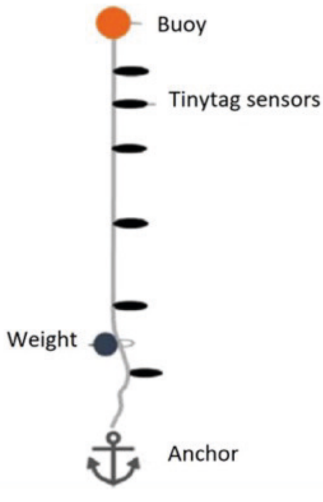
WP4 is set up to provide unique empirical field data for the environmental and societal effects of floating PV and hybrid hydro-floating PV power plants. One part of the work is related to any new environmental impacts (positive and negative) of floating PV power plants. It has been claimed that floating PV power plants can reduce evaporation, an impact that can have added value for ecosystems, energy production and other water uses. It is also anticipated that floating PV will reduce light penetration, heat and gas exchange at the water surface, including oxygen and greenhouse gases impacting algae production and emissions. Possible direct water and land use trade-offs, and indirect impact of environmental changes is also investigated in WP4 and the impact on socio-economic issues explored.

The literature to date is based on little data. To abate this, two field trips have been arranged in WP4 in June and November 2022 to start data collection and perform sensor placement. Sensors were placed for temperature logging, oxygen monitoring and water sampling for phytoplankton analysis.

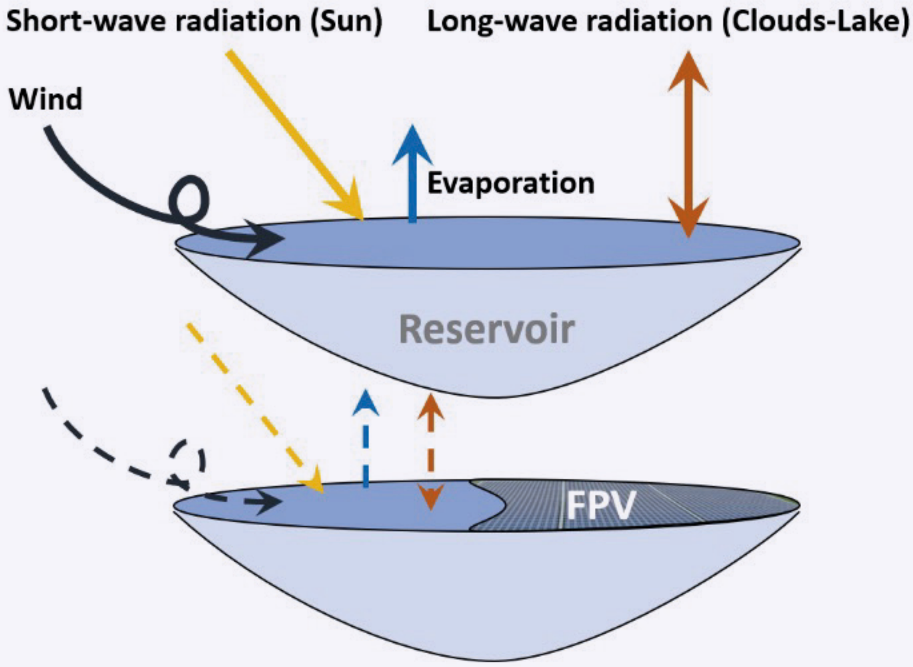
In parallel, a catchment and lake model were developed for the site.

During the field trips, stakeholder mapping was performed by NIVA to identify the main users and uses of the water body at Magat. The information related to environmental and societal impact will be an important basis for planned discussions with the industry partners regarding possible actions to reduce adverse impacts and increase co-benefits.

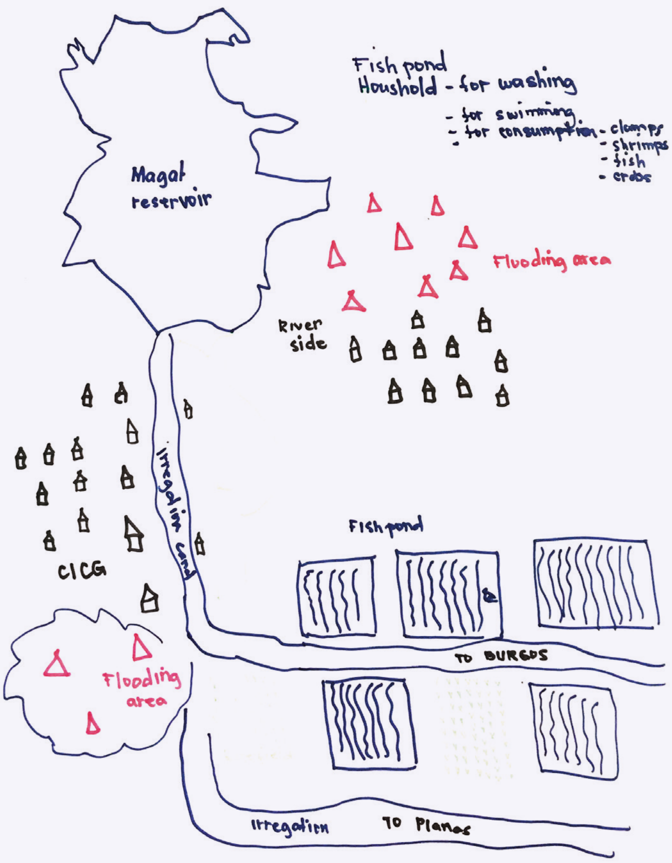




Field picture of a FPV unit. The red triangles highlight the location where water temperature logger chains were deployed, at the rim of the FPV unit and 50m away. The sketch on the right shows the design of the water temperature logger chain deployed. (Johnny Håll (NIVA), 2022).



Schematic representation of modelling approach displaying how FPV affect heat and water exchanges between the water and atmosphere (Francois Clayer (NIVA), 2022.



Water user interests presented on a map (prepared by people in the General Aguinaldo village downstream the Magat dam as part of attending a project group discussion event June 2022 organized by the project (WP4).

Education

One important goal of the HYDROSUN project is to educate experts with competence related to hybrid power plants and floating PV technology, two fields of rapidly growing importance both internationally and in Norway. The Competence Project grant includes funding of two PhD candidates, one at UiO and one at NTNU, in addition to a third PhD candidate financed by IFE and the University of Oslo is also integrated into the project.

Two additional PhD students: Nathan Roosloot and Vilde Stueland Nysted, both also from IFE and UiO are working towards WP3. Three Master students from NTNU have also been integrated into the project in 2022. In addition, a team of four summer students employed at Multiconsult worked towards the HYDROSUN project. Here is some information about most of the candidates.

Øyvind Sommer Klyve (PhD at IFE and UiO on Hybrid PV Power Plants)

Øyvind holds a M.Sc. degree in Energy and Environmental Engineering with specialization in Electric Energy Conversion from NTNU. At NTNU he also organized two bachelor courses as Scientific Assistant during his final year. He went directly from his studies there to a PhD position at IFE and UiO. His PhD is affiliated with the Department of Technology Systems. Currently he is in the middle of a 1 year stay at the Fraunhofer Institute for Solar Energy (ISE) in Freiburg, Germany.

What are you researching in your PhD?
The research focuses on how combining PV power with other renewable power and storage assets can result in power plants which are climate-change robust, as well as efficient and flexible in the energy markets. Specifically, the research has focused on how to reduce costs related to PV forecast errors, and under which conditions using dispatchable assets like hydropower to clear these forecast errors is beneficial. In addition, retrofitting hydropower plants with floating PV or batteries is investigated with use of techno-economic optimization.

What motivated you to join the HYDROSUN collaboration?
There is a desperate need for more renewable energy, at the same time as the market prices and the availability of the weather dependent resources are increasingly uncertain. Being part of the HYDROSUN project where both innovation and research are coming together to form the power plants of tomorrow, which are considering these uncertainties, is very cool.

What have been the best experiences from this collaboration so far?
Visiting the floating PV and hydropower plant in Banjë, gave a valuable confirmation on the fact that the technology to achieve hybrid power plants already exists, and that if the HYDROSUN research is fruitful, more of these systems can be built elsewhere.

Submitted articles:

- "The value of forecasts for PV power plants operating in the past, present and future Scandinavian energy markets."
- "Techno-economic feasibility of hybrid hydro-FPV systems in Sub-Saharan Africa under different market conditions."

Alexandra Sheppard (PhD at NTNU, IFE and SINTEF Energi on Optimisation of hybridized hydropower and floating PV power plants)

Alex completed her Bachelor of Science at the University of Sydney, 2016-2019, majoring in Mathematics and Nanoscience and technology. She thereafter did a M.Sc in Innovative Sustainable Energy Engineering at DTU and NTNU, focusing on solar cell systems and materials. After her graduation, she spent 1 year working as an Energy Modelling Analyst at the Sydney office of Aurora Energy Research.

What are you researching in your PhD?
My research focuses on optimal operation of hybridised hydropower and solar power in different market conditions. I am particularly interested in how different market structures and policies can affect the profitability and optimal operation of hybridised plants. So far, I've worked with research on the economic value of co-optimised hydro and FPV under different load obligations. My upcoming research will focus on the value of hybridisation under uncertainty, particularly investigating how solar forecasting uncertainty impacts hydropower scheduling in hybridised plants.

What motivated you to join the HYDROSUN collaboration?
There is a general consensus in our area of academia that the energy systems are not transitioning quickly enough. I was attracted to the HYDROSUN project because these plants are already feasible, and have large potential globally, but are somewhat restricted by the current level of operating knowledge and expertise. It's great that HYDROSUN includes both research and industry partners, to advance knowledge and follow through to implementable actions in several sites around the world. Naturally, the topic also aligns well with my background and academic interests so I'm excited to get to work with it for these years.

What have been the best experiences from this collaboration so far?
My highlight experience has to be the site visit to the Banjë dam in Albania. It was really exciting to see a plant operating so closely to the aims of this project, and definitely helped to make the HYDROSUN project tangible in my mind. In daily work life, the greatest part of the project is that it's very collaborative. So far everyone I've worked with is very passionate about the potential of HYDROSUN which makes the research really fun and motivating.

H.W. Harsha Lakmal Walpita

(PhD at IFE and UiO on Operation and Maintenance of Floating PV Systems)

Harsha completed his M.Sc. degree in Renewable Energy at the University of Agder in 2015. Since then, he worked at the University of Ruhuna in Sri Lanka as a lecturer in the fields of Renewable Energy, Power Systems and Electric Machines. He now holds a PhD position at IFE and UiO affiliated with the Department of Technology Systems at UiO.

What are you researching in your PhD?
The focus of my PhD is to support the development of cost-effective operation and maintenance practices for different floating PV systems. An important basis for this is time-series data analysis and IR thermographic image processing, which are used for e.g. fault detection and diagnostics, as well as quantifying soiling and degradation rates.

What motivated you to join the HYDROSUN collaboration?
As an academic I was intrigued about the concept of using water bodies for PV installations. HYDROSUN is an excellent platform for me to work with leading research institutes and industrial partners in Norway on floating PV technology.

What have been the best experiences from this collaboration so far?
Working closely with the Department of Solar Power Systems at IFE has been a pleasant and a productive experience for me. And this collaboration has enabled me to access the production data of real FPV sites, which is critical for the success of my research study.

Master students

Ivar Borge Nore and Kristoffer Winther are pursuing their M.Sc. degrees at the Department of Industrial Economics and Technology Management at NTNU. They are working on a joint thesis with the working title "Optimizing Hybrid Hydro-Solar Power Systems Using Two-Stage Stochastic Programming". Their master thesis concerns the short-term scheduling of a hydro-PV hybrid power plant located in Guinea, Africa. The problem they look at is how to maximize revenue with a day-ahead power purchasing agreement, which implies that the power producer nominates the amount of power they will produce during the next day and must stick to this promise. With uncertain PV power production and dispatchable hydropower, this becomes an interesting short-term optimization problem. Ivar and Kristoffer seek to develop a sophisticated hydropower model with both varying discharge and head-effects, coupled with a stochastic model for PV power production, and then solve this problem with an advanced optimization algorithm.

Vegard Kristiansen is pursuing his M.Sc. degree at the Department of Electric Energy at NTNU. The working title of his thesis is "Optimization of Hybrid Hydro and PV Power Plant". His thesis studies the benefits of hybridizing an existing hydropower plant with PV production. The power plant being investigated is situated in Zambia and has principally evacuated its power to firm-load customers under designated power purchase agreements.

With increased flexibility and power production it is profitable to enter the South African Power Pool. The work in this master thesis involves modeling the hybrid power plant in SHOP. Furthermore, different market scenarios are studied with the aim of improving the understanding of the value of hybridization and establish under what circumstances it is profitable to have hybridized operation.

Benjamin Trondsen is pursuing his bachelor's degree at the Department of Electric Energy at NTNU. He attended SINTEF "summer scientist" program in 2022 to work with experienced scientists on the HydroSun project. He quantified the benefits of accurate optimization when reservoir evaporation is considered in hydro and solar hybrid scheduling. He also tested the impact of noise and uncertainty for solar forecast on power production and load penalties.

Summer students

Four engineering students worked with the HYDROSUN project in the summer of 2022: Hanna Sletta, Ole Jakob Bedringås, Sigrid Sunde and Vegard Kristiansen. The students took part in Multiconsult's very popular summer internship program MUST. The transdisciplinary group of students were in Zambia for two weeks to collect data for design and optimization of a hybrid power plant. Their case study was the 30 MW Mulungushi hydropower plant in Zambia. The plan is to upgrade with a 5 MW PV plant. Mulungushi was the first hydropower plant in Africa south of equator, is almost 100 years old, and the water uses 1,5 hours from the reservoir to the powerplant.

An important part of HYDROSUN is to develop tools for design, optimization and operation of hybrid power plants. The MUST students have worked on improving and optimizing specific parts of the model, including:

- Power prices estimates and PPA's
- Hydraulic modelling of the waterway
- PV production
- Transmission lines

The students visited the dam and the reservoir and performed measurements along the waterway. They walked in the area proposed to be used for the PV power plant and visited a small, nearby PV-powered maize mill. They talked to the local energy traders and got to know the people at the site. They students claim this was the best experience of their entire study.

The MUST summer students visiting Mulungushi consisted of Hanne Nøvik from Scatec, Torje Evensen, a project manager from Multiconsult, and four summer students; Hanna Sletta, Ole Jakob Bedringås, Sigrid Sunde and Vegard Kristiansen.

Communication and dissemination of results

Although HYDROSUN started its operation in 2022, the project already started to produce and disseminate results in the first year. HYDROSUN contributed to the following presentations and visibility in press and media.

Presentations at scientific conferences

1. “Optimal scheduling of hybrid power plants”, B. Fjelldal and E. Krohn Aasgård, Oral presentation at the Hydropower Scheduling Conference 2022, Oslo Norway.
2. “Technoeconomics Optimization Model for Utility-Scale FPV/ Hydropower Plants”, Ø.S. Klyve, K. Haaskjold, V. Olkkonen, J. Fagerström and Erik Stensrud Marstein, Oral presentation at the WCPEC8 Conference 2022, Milano Italy.
3. “Hybrid operation of FPV and hydropower plants”, E.S. Marstein, Invited oral presentation at the Floating Solar PV Forum, Amsterdam Netherlands

Other presentations

1. “The HydroSun project“, E.S. Marstein, invitert presentation, NORWEP and Solenergiklyngen seminar
2. «Solar Energy – R&D and new technologies”, T. Melaa and E.S. Marstein, ONS
3. «Floating PV in Scatec», H. Nøvik, Clean Tuesday – Solenergiklyngen
4. “Fra flytende påstander til konkret kunnskap», T. Kjeldstad, Clean Tuesday – Solenergiklyngen
5. «Ocean Sun – world leading technology provider to floating PV”, B. Bjørneklett, Clean Tuesday – Solenergiklyngen
6. “HydroSun – Prepared for future energy markets”, H. Nøvik, Hydropower and Solar Energy Day, NORWEP

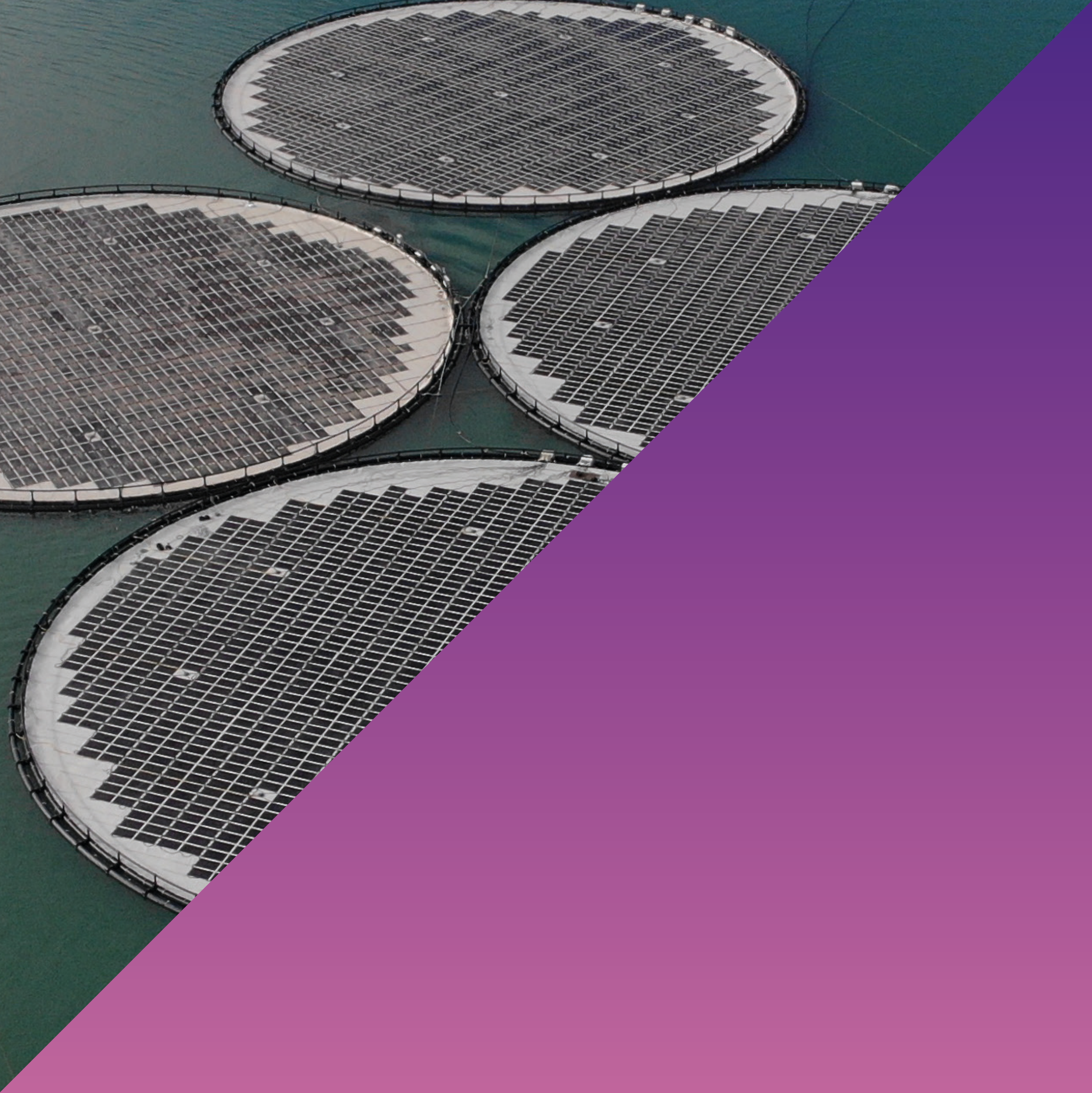
Communication:

HYDROSUN is a large project with multiple partners. In order to ensure good communication between all activities and partners, several meeting places have been developed. In 2022, a kick-off meeting was arranged in KSP HYDROSUN, and regular project meetings and work package meetings are arranged. In the Industry Project, the management team meets regularly to discuss the progress and plans of the project.

HYDROSUN has also initiated a webinar series on Hybrid power plants, which is arranged in collaboration with Solenergiklyngen. Two webinars were arranged with invited presentations from two of the leading research groups in the field: NREL (US) and DTU (DK). This webinar series will be continued in 2023.

Publications:

1. Project report: Implementation of evaporation data for the Frankonedou and Kogbedou HPP in pySHOP
2. Project report: Uncertainty of solar data in pySHOP
3. Oral presentation: Optimal scheduling of hybrid power plants, Bjørnar Fjelldal and Ellen Krohn Aasgård, Hydropower Scheduling Conference 2022, Oslo Norway, 12-14 September 2022.



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