TNO innovation for life

SENSE Hub MOOI622002 Public Report Feb 2024 until Jan 2025 (M12-M24)

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Energy & Materials Transition
www.tno.nl
+31 88 866 50 65
info@tno.nl

Introduction – 27 February 2025

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Author(s)	Oceans of Energy, NWO-NIOZ, Deltares, Primo Marine, New Ground Law, Advanced Electromagnetics BV, TNO
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Contents

1 Objectives of the project and cooperating parties

1.1 Problem statement and analyses

The addition of offshore solar to the offshore energy system has an enormous potential and can contribute to more than 50% of the Dutch energy consumption. The energy transition, accelerated by the energy crisis and the need to become independent from potentially hostile foreign sources of oil and gas, are resulting in enormous scaling plans for offshore wind and the required energy infrastructure. In particular, the Netherlands, Belgium, Denmark, and Germany have signed the Esbjerg Declaration (Figure 1). To ensure that optimal energy system developments are implemented, it is paramount to explore and fully unlock the huge potential of offshore solar.

Problem analyses
SENSE Hub consortium proposes to address critical aspects to enhance North Sea Energy hubs (offshore wind farms with hydrogen conversion/storage) with offshore solar.

Four domains are considered:

Offshore solar technology and effects on the environment:

- The current costs of offshore solar are still estimated to be 2 to 5 times higher than solar on land. The technology requires further optimization to become competitive.
- The energy generation performance of offshore solar over its lifetime is not yet as reliable as solar energy on land. The first grid connected projects will need to be used to shed new insights on lifetimes and possibilities to enhance the performance.
- Sustainable, 100% recycled materials should be used in next generation floaters together with an optimized strategy for end-of-life treatment of components to lower life cycle environmental impacts.
- The environmental impacts of large scale offshore solar are largely unknown. Despite positive hypotheses and first field observations, the impacts need to be monitored on the MW-pilot scale and then extrapolated through modelling studies to develop sufficient insight to responsibly implement offshore solar, co-located with wind.

Optimized integration of offshore energy system modules (wind, solar, hydrogen, storage, battery, cable, pipes):

- The energy system design concepts used in the past decades are not fully applicable anymore. New system integration services are needed to properly benefit from the vast amount of weather dependent electricity from wind and solar. Options such as cable pooling (same cable connections), energy storage and energy conversion need to be further explored from a technical and an economic perspective.
- Current assessments focus largely on the energy system on land, whereas the offshore renewable energy sector is now increasing. Secondly these assessments are not yet considering the addition of offshore solar and its potential benefits.
- The most feasible method of assessing integration of the modules and the development of sensitivity analysis and economic comparative studies is to work with

simulation models. Given the intermittency of the power generation, dynamic effects of the different energy components need to be included. To properly validate these models, data is required from actual testing through pilots.

Addressing non-technical barriers to scaling system integration concepts on GW-scale:

- Implementation of the concept needs to be tested through several legal assessments to point out current barriers and to suggest how these barriers can be removed in terms of legislation.
- Economic scenarios to understand how the technologies can interplay and create added economic value need to be based on dynamic models validated with real life data of offshore pilots and laboratory testing. Scaling up assessments, that can be used for policy referrals, will show how the future SENSE Hubs can contribute to cost reduction of electricity generation and transport onshore, and of (offshore wind generated) hydrogen production.

Public, social, political, legal, and environmental acceptance of SENSE Hub:

- The project aims to enhance the currently limited information and outreach to the public concerning the merits/disadvantages of adding offshore solar to North Sea Energy Hub plans. Of particular importance for the project is that the outcomes are useful to policymakers in order to modify/create new policies, regulations and legislation needed to realize and accelerate the clean tech solutions piloted in SENSE Hub.
- The high and rapidly increasing demand for maritime space for various functions, such as marine renewable energy infrastructure, continued gas exploration/exploitation, shipping and fishing activities, ecosystem and biodiversity conservation, recreation, aquaculture and underwater cultural heritage, as well as the multiple pressures on coastal resources, require an integrated planning and management approach. Understanding the complex landscape of stakeholders as well as the (cumulative) ecosystem effects of integrated energy parks is mandatory for a responsible and sustainable marine spatial planning of the North Sea.

1.2 Project definition and goals

The core of the SENSE Hub project is to develop an understanding of the merits/challenges for enhancing North Sea energy systems with a second, complementary intermittent energy generation source. Thereby the project addresses the integration of various energy system modules in the North Sea and the validation of the concept by focusing on the technical, economic and ecological implications of the SENSE Hub Concept.

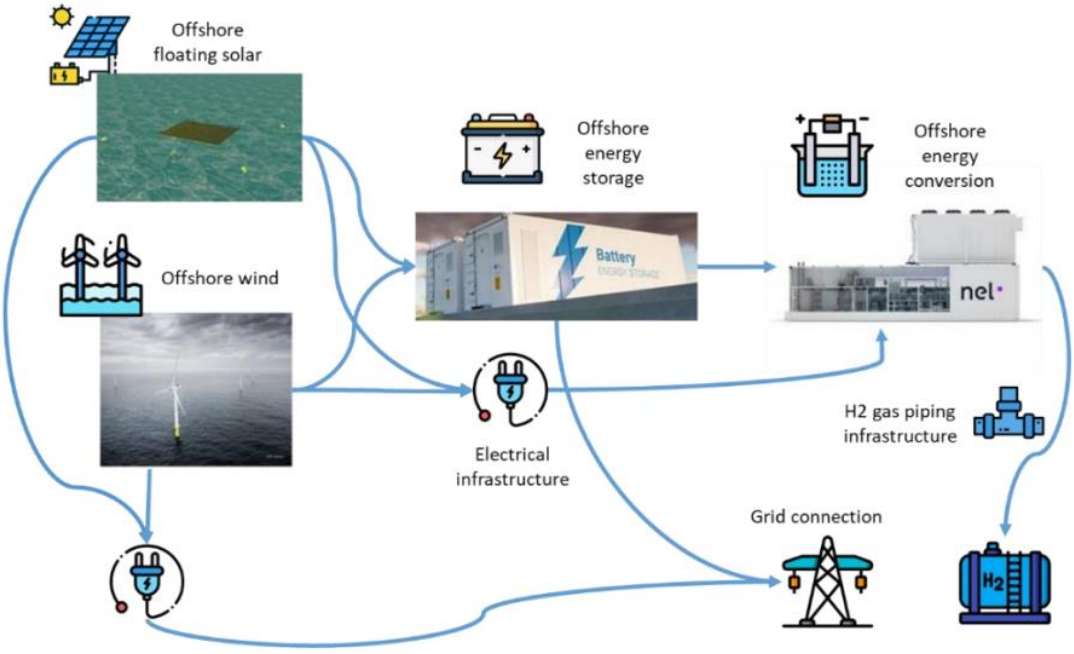


Figure 1 Illustration of the SENSE Hub Concept. A goal of the project is to identify the optimal system integration of the different energy components (connections, sizing, operational strategies)

SENSE Hub project has a duration of 4 years and is composed of 4 overarching objectives, further split in multiple SMART objectives which overlap with the project results (see Figure 2).

Overarching Objective A:

- Result 1, accelerate offshore solar acceptability, which is split further between the design, implementation and operation of an optimized offshore solar system
- Result 2, the understanding of the ecosystems effects of solar floating platforms
- Result 3, the understanding of the cumulative effects of offshore solar within wind farms

As shown in figure 2, the offshore solar farm with the improved and newly installed floating platforms, will be a unique R&D opportunity for gathering new field data to improve the ecological models, and for providing key information to the techno-economic objectives B and C. The extensive modelling effort will allow unprecedented quantification of (cumulative) effects at different length-scales, providing a solid base for the scaling-up assessment from an environmental point of view.

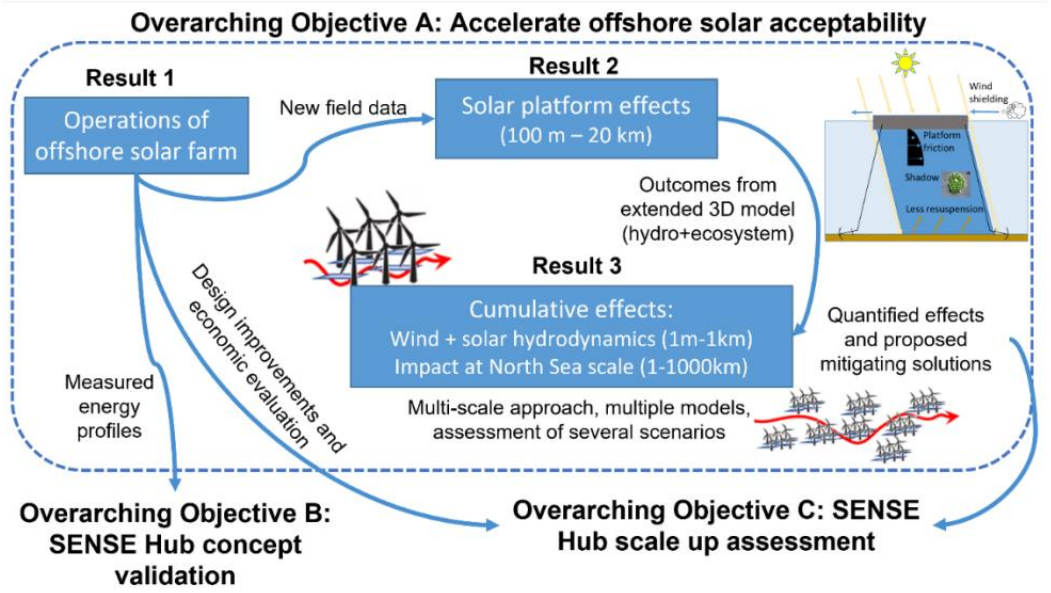
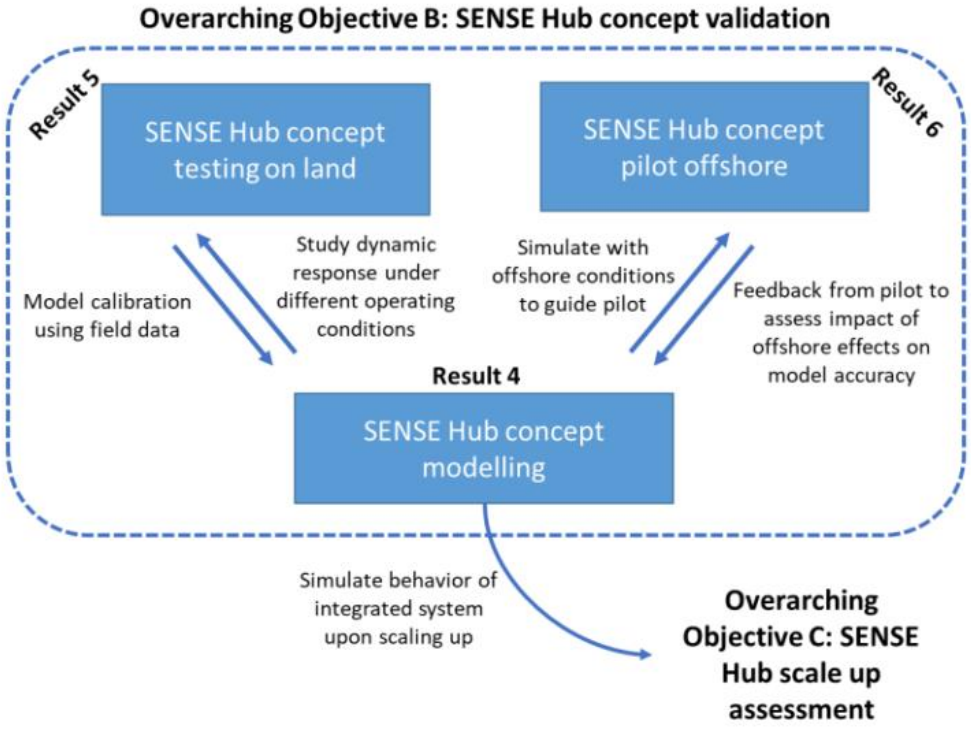


Figure 2 Schematic overview of the activities planned to reach Overarching Objective A

Overarching Objective B:

- Result 4, SENSE Hub Concept validation, which will address the dynamic model of the SENSE Hub concept
- Result 5, Extensive land tests on Switch fieldlab
- Result 6, Concept simulation at MW scale.

The interconnection between the 3 results achieved in Objective B is illustrated below:



Overarching Objective C:

- **Result 7,** SENSE Hub GW Level assessment, addressing the legal framework (Result 7) and
- Result 8, The techno-economic assessment of the SENSE Hub implementation at GW scale

Overarching Objective D:

- addresses the project governance, from technical project management, project coordination, advisory board development and engagement and implementation of the dissemination and communication activities.

1.3 Partners involved:

Oceans of Energy, start-up company developing and producing offshore solar energy systems. In SENSE Hub OOE intends to showcase, through the extended solar farm, design improvements resulting in higher power performance, lower costs and less system degradation. OOE also facilitates and contributes to the environmental field research and monitoring around the pilot farm and is responsible for achieving Result 1 of the project.

NWO-NIOZ, Royal Netherlands Institute for Sea Research is the national oceanographic institute and principally performs and promotes academically excellent multidisciplinary fundamental and frontier applied marine research addressing important scientific and societal questions pertinent to the functioning of oceans and seas. NIOZ serves as national marine research facilitator (NMF) for The Netherlands scientific community.
In SENSE Hub NIOZ will collect and analyze observations of offshore oceanographic and environmental processes, as well as numerical modelling. NIOZ is responsible to achieve Result 2 of the project.

Deltares is an independent institute for applied research in the field of water and subsurface. In SENSE Hub, Deltares will assess the cumulative effects of offshore solar within wind farms. This is crucial for responsibly scaling up offshore solar energy.

Primo Marine is an independent specialist with an extensive track record in subsea cable installation, protection and maintenance from landfalls to subsea marine infrastructures. The experience includes involvement in the planning, design, procurement, installation & commissioning of large cable installation projects as well Offshore Wind Farms (OWF's) and Export Grid Systems.
In SENSE Hub Primo Marine will provide input on Result 4, 5, 7 and 8 based on their involvement and experience in the 2GW research project for the Netherlands (TenneT) and Germany (a.o. research options to execute bundled installation and investigate the state-of the art technical possibilities)

New Ground Law is a top law firm with a strong focus on renewable energy and project development. Our experts have extensive knowledge of the regulated energy market, contracting within the energy market and the legal management of renewable energy projects, both onshore and offshore.
In SENSE Hub New Ground Law will provide insight into the relevant legal issues and help find solutions to them. New Ground Law is covering the complete work described in result 7 of SENSE Hub.

Advanced Electromagnetics BV (hereafter AE) is one of the world market leaders in the field of permanent drives and has a lot of know-how in the field of smart drives. It employs people with a development background as well as those involved in manufacturing and modelling and quality (such as one of the most challenging medical ISO 13485). The company has a lot of know-how in the field of smart drives and energy infrastructure.
In SENSE Hub AE will contribute to result 8, focusing on the conceptual design of the electrical infrastructure for the SENSE Hub Concept. AE will address the offshore considerations in the design, will evaluate the costs and will estimate the system footprint at a GW scale.

TNO is the largest fully independent Research, Development and Consultancy organization in the Netherlands. TNO provides contract research and specialist consultancy, as well as grant licenses for patents and specialist software. TNO also tests and certifies products and services, and issues an independent evaluation of quality.
In SENSE Hub, TNO will coordinate the project and will lead the work of Results 4, 5, 6 and 8. TNO will use the extensive knowledge and modelling tools to understand and optimize the SENSE hub concept. Next to this, TNO will use their Switch field lab facilities for extended land testing and validation of its SENSE Hub adapted models.

2 Activities and results over reporting period

In the SENSE Hub project the Results contain different activities with specific deliverables and milestones. Below you find an overview of the progress made in the second year of the SENSE Hub project. Some of the tasks have not been started as they are not due or are dependent of the results from an earlier tasks .

Result 1. The offshore solar system of Oceans of Energy has been extended with 160 kW optimized platforms by 2025

Activity	*Activity 1.1. Design of improved offshore solar system (Duration: M9 – M15)*	
Start-/end date	*October 2023 to May 2024*	Status: *Ongoing*
Activity 1.1 has been finalized in May 2024. The design optimalizations are a result from the North Sea Two (NS2) pilot at the Offshore Test Site. Design improvements are realized on different levels, e.g. material, component, system levels. Based on offshore performance data and validation of our numerical models, standard floater material has been optimized, which has resulted in significant cost reduction. Furthermore, an optimized PV mounting design resulted in approximately half the costs of the previous design. In addition, also manufacturing processes are being optimized, which results in significantly reducing manufacturing cycling time reduction – the time required to transform raw materials into a finished product. . Some design improvements were made based on feedback from offshore operational activities, such as an optimized boat landing floater design for people transfer from CTVs. In terms of power performance, the NS2 and NS3 farms had off-grid set ups, which enables comparisons between offshore and on land performance. Preliminary results validate that offshore solar has an increased power performance compared to solar on land, due to cooling effect of the water and more irradiance out at sea.		

Activity	*Activity 1.2. Engineering, Procurement, Construction, and Installation of NS2 extension (Duration: M15 - M27)*	
Start-/end date	*May 2024 to April 2025 (moved to November 2025)*	Status: *Not started*
Activity 1.2 started in May 2024. The results from task 1.1 for the optimized floater design, have been used internally to detail the design of the entire farm including the extension and subsequently fed into procurement preparations. The procurement planning and execution are followed by the construction of the offshore solar farm at the OOE Manufacturing Facility.		

Activity	Activity 1.3. Operations and evaluation of the system (Duration:M27 – M48)	
Start-/end date	*April 2025 to January 2026*	Status: *Not started*
This activity has not yet started.		

Result 2. The local 3D hydrodynamics-ecosystem model has been developed and validated with field data, and projections of ecosystem effects of km-scale floating platforms have been made

Activity	*Activity 2.1. Field observations (Duration: M1-M24)*	
Start-/end date	*February 2023 to January 2025*	Status: *Ongoing*
Time series observations using sensors of turbidity (suspended sediments) and fluorescence (phytoplankton) have been taken between February and December 2023. Four sets of water samples for sensor calibration have been taken and analysed. Also, shorter time series of Acoustic Doppler Current Profiler (ADCP, flow velocities) data were acquired.		

Activity	*Activity 2.2. Model validation and simulations (Duration: M1-M39)*	
Start-/end date	February 2023 to April 2026	Status: *Ongoing*
Work on the 1D version of the coupled hydrodynamics-ecosystem model has been performed; implementing the 1D model for the Scheveningen location, and incorporating the implementation of floating platforms developed by Karpouzoglou et al. (2020) into the most recent model version. This includes shadow effects, platform friction, and shielding from wind forcing. The tests highlighted issues with the 2024 ecosystem model version that are not fixed easily. Instead, the 2016 version of the ecosystem model used by Karpouzoglou et al. was implemented with the modern hydrodynamics model showing good results. After further testing the model will be implemented for the HKN wind park site.		

Result 3. Cumulative effects of offshore solar within wind farms using a multi-scale modelling approach has been estimated

Activity	*Activity 3.1. Small-scale modelling of wind turbines and floating solar to correctly parameterize combined effect on hydrodynamics (Duration: M1-M12)*	
Start-/end date	*February 2023 to January 2024*	Status: Ongoing
In year 2, Deltares finalized a CFD (Computational Fluid Dynamics) study on the interaction between offshore solar arrays and the local hydrodynamics. The final report for this activity has been completed. Furthermore, the results have been published in the peer-reviewed journal 'Frontiers in Renewable Energy'.		

Activity	*Activity 3.2. Implement parameterization in Delft3D-Flexible Mesh and test (Duration:M12-M18)*	
Start-/end date	*January 2024 to July 2024*	Status: *Ongoing*
The parameterization for offshore solar has been implemented in Delft3D-Flexible Mesh and has been tested. The final report is under development.		

Activity	*Activity 3.3. Large-scale hydrodynamic model using DCSM-FM including offshore solar (Duration:M18-M24)*	
Start-/end date	*July 2024 to January 2025*	Status: *Not started*
Preliminary simulations have been carried out using our Dutch Continental Shelf Model (DCSM-FM).		

Activity	*Activity 3.4. Large-scale water quality modelling on North Sea scale (Duration:M24-M36;*	
Start-/end date	*January 2025 to January 2026*	Status: Not started

Similar to the hydrodynamic modelling, we have carried out preliminary simulations. The water quality modelling will take place in parallel with the hydrodynamic modelling. Results are expected in the second half of 2025.

Activity	*Activity 3.5. Validation of models developed in Activities 3 and 4 (Duration:M18-36)*	
Start-/end date	*July 2024 to January 2026*	Status: Not started
Validation of the models will take place after Activity 3.3 and 3.4 have started.		

Result 4. The dynamic model of the SENSE Hub concept has been developed, validated and runs simulations for accelerated testing

Activity	*Activity 4.1. SENSE Hub concept design and scenario definition (Duration: M1-M12)*	
Start-/end date	*February 2023 to January 2024*	Status: *Finished*
A list of increasingly more complex scenarios to be investigated in the project was defined at the end of year 1. These scenarios are used to quantify the added value offshore solar (i.e., the SENSEHub concept) for various system configurations under different assumptions and boundary conditions.		

Activity	*Activity 4.2. Dynamic modelling of SENSE Hub concept (Duration: M9-M24)*	
Start-/end date	*October 2023 to January 2025*	Status: *Ongoing*
The main elements of the proposed scenarios have been implemented in the TNO computational framework PyDOLPHYN. This included both tailoring or extending existing energy component models and the implementation of the different asset configurations based on the scenarios defined in 4.1. The simulation framework was extensively tested. Preliminary simulations of the integrated assets have been performed. Results were discussed with partners, and insights from this activity are fed into 4.4 and 4.5.		

Activity	*Activity 4.3. Model validation based on field testing (Duration: M9-M24)*	
Start-/end date	*October 2024 to January 2025*	Status: *Not started*
The models of the various energy components have been compared/validated with data/information from literature/industry. Due to the delay of Result 5 (e.g. commissioning of electrolyser, see 5.3) no comparison with field data was possible. A delay of about 12 months is expected to fully complete this activity, this has little impact since Activity 4.4 that partly depend on this validation is expected to run until July 2026		

Activity	*Activity 4.4. Optimization of the SENSE Hub concept at kW scale (Duration: M24-M42)*	
Start-/end date	*January 2025 to January 2027*	Status: *Not started*
Not started, as it is dependent on activity 4.3		

Activity	*Activity 4.5. Translation to offshore conditions and scale-up to MW pilot (Duration: M24-M42)*	
Start-/end date	*January 2025 to July 2026*	Status: *Ongoing*
This activity has been anticipated as the component models and available information have been considered adequate for initial quantification of the offshore scenarios. Simulation results have been generated for 3 scenarios (offshore electricity generation, offshore hydrogen production, offshore electricity and onshore hydrogen) for the two selected offshore locations (20km and 60km from shore). Results were discussed with		

partners. Sensitivity analysis of some of the key simulation parameters is planned before finalizing the conclusions of the study associated to these scenarios.

Result 5. SENSE Hub Concept has been validated in the extensive land tests at TNO SWITCH Lab

Activity	*Activity 5.1. Experiment plan development and scenario definition (Duration: M1-M12)*	
Start-/end date	February 2023 to January 2024	Status: *Ongoing*
In parallel with the scenario development in Activity 4.1, a set of scenarios dedicated to the extensive onshore tests at TNO's SWITCH field lab has been defined. These scenarios have been aligned with the modelling efforts of Result 4 to ensure the developed SENSE Hub Concept can be validated in the land tests as best as possible. A draft version of the land tests (SWITCH) specific scenario set was presented to the partners in one of periodical consortium meetings, and has now been finalized based on their review. The experiment plan has been developed based on the outcome of the scenario development. In parallel with the delay in the electrolyzer commissioning of Activity 5.3, this activity was delayed, but has been finalized and reviewed internally by the end of M23. Due to the delay of the electrolyzer commissioning in Activity 5.3, this delay will not have an impact on the timely completion of Result 5.		

Activity	*Activity 5.2. Characterization of combined wind and solar generation profiles (Duration: M1-M18)*	
Start-/end date	*February 2023 to July 2024*	Status: *Ongoing*
Both the wind turbines and solar PV systems at the SWITCH field lab are operational, and measurements of the combined generation profile was started around M4. All gathered data has been stored both locally and in a TNO managed database. The measurement activity was finished as planned in M18, and the resulting dataset has been logged to the database. This dataset will be used to inform the modelling effort of Result 4, as well as the further experiments in Activity 5.3.		

Activity	*Activity 5.3. SENSE Hub extensive land testing and scenario validation (Duration: M9-M42)*	
Start-/end date	*October 2023 to July 2026*	Status: *not started*
Preparations for testing started up. Commisioning of the electrolyzer has been delayed due to issues with the supplier. First testing will be done of the combined profile (wind and solar) without the electrolyzer. Once the electrolyzer is fully commissioned at the Switch field lab, these scenarios will also be tested. This delay is not expected to postpone the completion of Result 5, and this activity is still expected to be finished by M42.		

Result 6 SENSE Hub Concept has been simulated offshore at MW scale

Activity	*Activity 6.1. Prepare the test plan (Duration: M12-M18)*	
Start-/end date	*January 2024 to July 2024*	Status: *Not started*
This activity is strongly connected to the PosHYdon Pilot. The initial testing considerations are included. Discussions between PosHYdon Consortium partners and Sense-Hub Consortium partners will start in May 2025 to align the planning and the agreements on data sharing, however these discussions are strongly dependent on the PosHYdon Pilot.		

Activity	*Activity 6.2. Dynamic power profile test scenarios (Duration M19-M26)*	
Start-/end date	*August 2024 to March 2025*	Status: *Not started*
Not started. Planning will need to be updated based on PosHYdon Pilot Operation Phase.		

Activity	*Activity 6.3. Data gathering and analysing during pilot operation (Duration M19-M26)*	
Start-/end date	*August 2024 to March 2025*	Status: *Not started*
Not started. Planning will need to be updated based on PosHydon Pilot Operation Phase.		

Result 7. A legal framework has been developed with a suggested approach for implementing SENSE Hubs on a GW-scale

Activity	*Activity 7.1. Overview legal regulatory framework (Duration: M1-M12)*	
Start-/end date	*February 2023 to January 2024*	Status: *Ongoing*
Research was conducted on the applicable legal frameworks from environmental and energy law perspectives. Specific attention was paid to the offshore application of these regulations. Since new laws and regulations for environmental law came into force on January 1, 2024, the study was updated accordingly. For the purpose of the study, consultations were held with Oceans of Energy and Ventolines last year. The study research report was shared for review and comments by the consortium partners. Input from the partners has been received and processed. A final version of the report has been shared with the consortium partners. The report will also be circulated to (external) legal contacts of NGL for their input.		

Activity	*Activity 7.2. Legal alignment and agreements with other offshore infrastructure (Duration: M1-M24)*	
Start-/end date	*February 2023 to January 2025*	Status: *Ongoing*
Research has been done and reporting on the legal findings is in a far advanced stage. The reporting will result in deliverable D15, a legal position paper regarding possible models for SENSE-Hub cable pooling. This legal position paper provides answers to the questions within result 7 on opportunities and challenges (i) for offshore cable pooling of offshore solar farms with existing infrastructure offshore wind farms and battery storage, and, (ii) for pooling different electricity sources on offshore hydrogen production. A draft of the legal position paper will be shared for review by the consortium partners around the end of February.		

Activity	*Activity 7.3. Obtaining government approvals and legal impact ecology (Duration:M12-M48)*	
Start-/end date	*January 2024 to January 2027*	Status: *Not started*
This activity has not yet started.		

Result 8. A techno-economic system design has been made for optimal system integration of offshore energy components at the GW-scale and has been tested via dynamic modelling

Activity	*Activity 8.1. Definition of challenges at GW scale and scenarios to simulate (Duration: M24-36)*	
Start-/end date	*January 2024 to January 2026*	Status: *Ongoing*
Literature and technical discussions have been already started. In this respect, floating transformers (or even substations) seems to be prepared more regularly for deep-water applications. Yet these floating systems come with their own challenges, e.g. floating structures are constantly in motion, exposed to vibrations and shocks from waves up to 15 meters in height, 365 days a year, for their whole lifetime. Further, there is an on-going internal discussion at TNO to get informed on scenarios that will be considered in other projects (e.g. North Sea Energy programme) and understand the envisioned business model for a future energy hub.		

Activity	*Activity 8.2. Evaluation via dynamic modelling (Duration: M36-48)*	
Start-/end date	*January 2026 to January 2027*	Status: *Not started*
This activity has not yet started.		

Activity	*Activity 8.3. Techno-economic considerations for subsea infrastructure (cables/pipelines) (Duration M24-M48)*	
Start-/end date	*January 2025 to January 2027*	Status: *Started*
CAPEX and OPEX studies were conducted and will serve as base for the Techno-Economical considerations.		

Activity	*Activity 8.4. Design of the electrical infrastructure for SENSE Hub Concept at GW scale (Duration M24-M48)*	
Start-/end date	*January 2024 to January 2027*	Status: *Started*
Initial discussion took place among the partners involved in the task and the preliminary considerations are aligned among the participants. Building offshore presents many challenges beyond the harsh saltwater environment. So far, only a small fraction of offshore potential has been exploited. Both fixed and floating transformers seem to be able to offer a solution. Yet floating systems come with their own challenges: over their entire lifetime, they are constantly in motion and can be exposed to vibrations and shocks from waves up to 15 meters in height. It seems very difficult to overcome harsh offshore conditions. Floating electrical systems are, however, an important development in the offshore renewable industry. If succeeded, this will open up tremendous additional opportunities for clean power. AE has looked at various collector step-up transformers, earthing transformers and shunt reactors for floating applications. Transformers and shunt reactors are key pieces of equipment in the grid infrastructure, enabling transmission of electricity generated from offshore energy sources. Further to the harsh environment also lightweight and modular design make up, specially the active part, tank, tap changer, accessories and external components. Further, how to reach the highest reliability and maximum availability to withstand dynamic motions, accelerations, and inclinations coming from normal floating operations and from extreme-weather conditions? In addition, also a deep understanding of grid requirements is essential with the aim to optimized Total Cost of Ownership (TCO) with best balance between initial investment and operational costs for increased sustainability. AE is investigating this trade-off, where no new transformers will be designed, but mere investigated for the point as mentioned.		

Result 9 All stakeholders are identified, informed and regularly engaged with through a variety of communication and dissemination tools and channels

Activity	*Activity 9.1. Dissemination, communication (Duration: M1-M48)*	
Start-/end date	*February 2023 to January 2027*	Status: *Ongoing*
Successful first stakeholder meeting was organized in summer of 2023. This was followed by another SENSE-Hub Stakeholder Forum in December 2024. This Forum explored the integration of solar, wind, and hydrogen technologies in the North Sea to advance renewable energy solutions. It brought together 85 participants from diverse sectors and organizations, promoting collaboration and knowledge exchange. Following both stakeholder meetings, a newsletter summarizing the discussions and outcomes was shared with attendees. Additionally, the SENSE-Hub project will be highlighted in the newsletter of the Community of Practice North Sea. The SENSE-Hub stakeholder forum also received attention on Deltares' LinkedIn page, which has a following of 50,000.		

The next stakeholder meeting is scheduled for 2026, in alignment with the Stakeholder Engagement Plan. This final meeting will focus on sharing the project results and discussing their implications with the stakeholders.

3 Results achieved per milestone

Milestone 1 Design of the 160 kW optimized offshore solar extension is completed Procurement and Construction activities can start.	**M15**
Connected/Achieved results: Milestone 1 is strongly connected to Result 1. The optimized design is based on NS2 pilot data. Motivation: The completed design is a Milestone as it represents an important step for Result 1.	Completed (April 2024, M16)
Milestone 2 The extension of the offshore solar (optimized 160 kW) was installed offshore and was put in operation. Data is collected for validation of improvements.	**M42, not due in this reporting period**
Connected/Achieved results: Milestone 2 is one of the most important milestones in the project and it shows that Result 1 of the project was achieved. Achieving Milestone 2 implies succeeding in completing the activities under Result 1, and achieving the stated performance targets of the system. Motivation: Operational extended optimized offshore solar floating is a big Milestone for the project addressing the main MOOI goals 1 and 2 for Innovation theme 2.	
Milestone 3 3D hydrodynamics-ecosystem model has been validated with field data.	**M39, not due in this reporting period**
Connected/Achieved results: In order to achieve the Milestone 3, multiple activities need to be successfully completed: e.g. development of the model and collection of field data. By using the validated model, predictions of effects at larger scale can be made. Motivation: Milestone 3 represents the successful completion of Result 2 leading to further understanding of the environmental limits of floating solar parks.	
Milestone 4 The understanding of the cumulative effects of offshore solar wind through validated models.	**M42, not due in this reporting period**
Connected/Achieved results: Milestone 4 represents the end of Result 3 an important achievement of the complete project. Motivation: International guidelines and national legal frameworks determine that offshore energy generation has to be within accepted limits of ecological space. This milestone is a crucial element in the roll-out of large-scale offshore solar within wind farms.	
Milestone 5 The dynamic model of the SENSE Hub concept has been developed, validated and runs simulations for accelerated testing.	**M42, not due in this reporting period**
Connected/Achieved results: Milestone 5 represents the end of Result 4 an important achievement of the complete project. Motivation: Milestone 5 represents an important pillar in development of the project. By reaching this milestone, multiple research questions are answered, and an optimal SENSE Hub concept is identified.	

Milestone 6 Onshore testing experiment plan and scenario definition completed.	**M12, January 2024**
Connected/Achieved results: SENSE Hub concepts scenarios are defined and modelled for onshore testing. This represents the starting point in extensive land testing and in understanding the limitations and opportunities in running the SENSE Concept. Motivation: Issuing and approving the land test plan and scenario definition it is an important step in extensive land testing campaign.	Completed
Milestone 7 Onshore testing and scenario validation completed.	**M36, not due in this reporting period**
Connected/Achieved results: Milestone 6 marks the end of Result 5 of the project. This is an important milestone as the consortium will understand the opportunities and challenges in running SENSE Hub concept on land. The results of the extensive tests will be further fed into Result 8. Motivation: The learnings of achieving Milestone 6 will allow the continuation of the project and will feed data for the scale up assessment of SENSE Hub Concept.	
Milestone 8 The legal framework for SENSE hub has been developed with clear recommendations for GW scale implementation.	**M48, not due in this reporting period**
Connected/Achieved results: Milestone 8 marks the end of Result 7 of the project. This is an important milestone as the consortium will understand legal framework in developing SENSE hubs at GW scale, including the regulatory framework for the complete concept, the opportunities and challenges in cable pooling and understanding of the governmental permissions. Motivation: The learnings of Milestone 8 are not only relevant for SENSE hub consortium partners but also for the project identified stakeholders.	
Milestone 9 A techno-economic system design has been made for optimal system integration of offshore energy components at the GW-scale.	**M48, not due in this reporting period**
Connected/Achieved results: Milestone 9 marks the end of Result 8 of the project. This is an important milestone as the consortium will understand the technical and economic challenges and opportunities in developing SENSE hubs at GW scale. Motivation: The learnings of Milestone 8 are not only relevant for SENSE hub consortium partners but also for the project identified stakeholders.	

4 Sense Hub contribution to the MOOI scheme objectives

SENSE Hub Project contributes to **MOOI mission A** – Electricity, and more specifically to Innovation **Theme 1** "Innovations as an integral part of offshore wind energy on North Sea" and **Theme 2** "Innovations for floating solar parks in the North Sea".

Innovation Theme 1 - SENSE Hub will contribute to a more affordable, a more spatial inclusive, and a more stable energy system within the offshore wind energy plans by optimizing various energy systems integration at North Sea energy hubs. The intermittence of solar is used as a hedge against the disadvantages of the offshore (wind) energy developments that are solely based on the intermittence of the wind. Solar contributes both seasonally as well as daily to a more complementary and stable energy pattern. This can result in 1) increased affordability of the offshore energy infrastructure (by means of higher utilization, output per investment increases) and 2) higher reliability (less weather-dependent energy generation). Moreover, the limited offshore space for offshore wind can be utilized (multi-use of the sea space as well as export cable, pipeline, and landfall space) and possible cumulative effects of the combination of wind + offshore solar may result in positive environmental merits. The SENSE Hub will validate the concepts / hypotheses by focusing on the understanding of the technical, economic and ecological implications.

Innovation Theme 2 – To enable the contributions at Innovation Theme 1 to act impactful, developments are required at offshore solar technology. These are mostly related to necessary cost reductions and increased lifetime reliability. Furthermore, environmental impacts (negative and positive) are largely unknown at sea and require further assessment (incl. as cumulative to offshore wind environmental effects). In SENSE Hub, the consortium will build on the learnings from NS2 DEI+ project and extend the solar park of Oceans of Energy focusing on a new design loop for an improved / cheaper offshore solar array with improved technical reliability. Pilot is furthermore monitored for environmental effects, which are used to feed into model developments for the assessment of environmental impacts of large-scale applications.

5 Spin off inside and outside the sector

During the reporting period no spin off or spin out results have been obtained.

6 Overview of public publications on the project and where they can be found or obtained

Date	Publicity title	Publisher
28/02/2023	*SENSE Hub Press release*	*Consortium*
28/03/2023	*Presentation on the project on the Energy Reinvented Community regarding wind and floating solar innovations*	*TNO*
15/03/2023	*Energeia.nl article – TNO onderzoekt inpassing offshore wind in energiesysteem-* link	*TNO*
12/11/2024	*LinkedIn post to invite stakeholders to join the second stakeholder forum*	*Deltares*
19/12/2024	*Newsletter summarizing the discussions and outcomes of the second Stakeholder Forum*	*Deltares, OOE and TNO*
19/12/2024	*LinkedIn post on Deltares socials – World first: quantifying the hydrodynamic wake induced by offshore solar arrays*	*Deltares*
21/01/2023	*LinkedIn post announcing sustainable energy from waves (AE Wave Hexapod) by AE Group Electric Drives*	*AE*
24/02/2024	*LinkedIn post of AE Wave Hexapod presenting at Recharge Earth Innovation expo*	*AE*
12/01/2024	*LinkedIn post of onshore demonstration of AE Wave Hexapod at Dordrecht by AE Group Electric Drives*	*AE*
20/05/2024	*LinkedIn post of AE Group Electric Drives presenting on Path towards sustainable tomorrow-magnetic solution via AE Wave Hexapod at IEEE(INTERMAG) conference*	*AE*
02/07/2024	*LinkedIn post of AE Wave Hexapod by AE Group Electric Drives obtaining the JTF IJmond subsidy*	*AE*
25/09/2024	*LinkedIn post of AE wave Hexapod presented at IEEE (ICRA) conference*	*AE*
06/12/2024	*LinkedIn post on presence of AE Group Electric Drives for the stake holders meeting at Utrecht university*	*AE*

Date	Publication title	Publisher
28/08/2024	*Modeling the hydrodynamic wake of an offshore solar array in OpenFOAM*	*Deltares – published in Frontiers in Renewable Energy*
20/11/2023	*Pitch SENSE-Hub - Johnny Meit, Oceans of Energy - onderdeel van podcast #ditisonzetijd: Groen*	*TNO*

	waterstof op zee voor verduurzaming industrie vanaf min 29:30 - Link	
Publications not directly related to SENSE-Hub but related to Offshore solar environmental research		
April 2023	Peer reviewed article in Sustainability – Vlaswinkel et al. Environmental Observations at the First Offshore Solar Farm - Link	*OOE*
Dec 2023	Peer reviewed article in Frontiers in Marine Science – Mavraki et al. Fouling community composition on a pilot floating solar-energy installation in the coastal Dutch North Sea - Link	*OOE*
12/06/2024	*Peer reviewed article in IEEE Transactions on Magnetics - Potential of Wave Energy Harvesting in the North Sea; the AE-Wave Hexapod WEC - Link*	*AE*

7 Contact

For questions or information about the SENSE Hub project you can contact the penvoerder:

Mrs. Georgiana Stan (georgiana.stan@tno.nl)

Energy & Materials Transition

Westerduinweg 3
1755 LE Petten
www.tno.nl

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