

Final report

1. Project details

Project title	250 MW wave power in the Danish North Sea by 2030 – phase 1
File no.	64022-1062
Name of the funding scheme	EUDP
Project managing company / institution	Exowave ApS
CVR number (central business register)	36477865
Project partners	AAU, Semco, DanWEC, MDT and ECD
Submission date	14 October 2025

2. Summary

The purpose of the project

The project addressed the need for renewable offshore energy production with minimal environmental and visual impact using Exowave technology. The scope was to develop and demonstrate the innovative and fully submerged wave energy converter - that converts wave motion into hydraulic power for electricity production. The technology was validated through advanced modelling, numerical analysis, model and laboratory tests, and large-scale DNV-witnessed tests.

Results, conclusions and perspective

- The project successfully designed and demonstrated the Exowave Wave Energy Converter (WEC 1:2 of full scale), including the wave receiver, power take-off, foundation structure, flowlines, hydro turbine generator and SCADA system.
- Structural and fatigue integrity, targeting 20 years of lifespan, were confirmed through extensive finite element analyses following DNV standards.
- Factory Acceptance Tests (FAT) witnessed by DNV demonstrated stable PTO performance with 76–78% efficiency at 40–60 bar operating pressure, controlled by the hydro turbine.
- The numerical model was further developed and revised in several iterations and now stands as a powerful tool capable of simulating the Exowave WEC in any configuration, location and wave climate, which is highly useful for the design of future global wave energy plants.
- The design and engineering of all Exowave subsystems were completed to an industrial standard, reaching a level suitable for efficient manufacturing, assembly, and future mass production

The results of this EUDP project will be used to develop global projects and deployment of Exowave WEC and wave farms. The results also support continued collaboration with clients and industry partners for further developments to drive down the LCOE.

Exowave has already started close commercial dialogue with global energy players and developers. In January 2025 we established a JV in USA for the Americas region. Ongoing is commercial dialogue about a Taiwan based JV to cover the APAC region. JV is expected for the regions: Indian Ocean, North Sea, Europe and Africa. The project results were actively disseminated during the project to raise public awareness and engage key stakeholders, as described later.

Projektrésomé

Formålet med projektet

Projektet adresserede behovet for bæredygtig offshore energiproduktion med minimal miljømæssig og visuel påvirkning ved hjælp af Exowave-teknologien. Formålet var at udvikle og demonstrere den innovative og fuldt neddykkede bølgeenergikonverter, der omdanner bølgebevægelserne til hydraulisk energi til elproduktion. Teknologien blev valideret gennem avanceret modellering, numeriske analyser, model- og laboratorietests samt ved storskala test bevidnet af DNV.

Resultater, konklusioner og perspektiv

- Projektet har med succes designet og verificeret den komplette Exowave teknologi i stor skala (WEC 1:2), herunder bølgemodtager, power take-off (PTO), fundamentkonstruktion, rørsystemer, vandturbiner, generator og SCADA-system.
- Den strukturelle og udmattelsesmæssige integritet, med en forventet levetid på 20 år, blev verificeret gennem omfattende analyser udført i overensstemmelse med DNV-standarder.
- Test (FAT) af PTO systemet, som blev overvåget og bevidnet af DNV, viste stabil ydelse med en virkningsgrad på 76–78 % ved et driftstryk på 40–60 bar.
- Den numeriske model blev videreudviklet og revideret ad flere omgange og fremstår nu som et kraftfuldt værktøj, der kan simulere Exowave WEC i enhver konfiguration og ethvert bølgeklime, hvilket er særdeles nyttigt og afgørende i forbindelse med projektering af fremtidige globale bølgeenergianlæg.

Resultaterne fra dette EUDP-projekt vil blive anvendt til at udvikle globale projekter og implementering af Exowave WEC og bølgeenergiparker. Resultaterne understøtter desuden fortsat samarbejde med kunder og industripartnere med henblik på yderligere udvikling og reduktion af LCOE.

Exowave har allerede indledt kommercielle drøftelser med globale energiselskaber og udviklere. I januar 2025 blev der etableret et joint venture i USA for regionen Amerika. Der pågår desuden kommercielle drøftelser om et joint venture i Taiwan for at dække APAC-regionen. Yderligere joint ventures forventes etableret for regionerne Det Indiske Ocean, Nordsøen, Europa og Afrika.

3. Project objectives

The objective of the project was to develop, design, and demonstrate a reliable, cost-efficient, and fully submerged wave energy converter (Exowave WEC) suitable for integration with offshore wind farms and as a

standalone installation. The goal was to validate the technology through numerical modelling, laboratory testing, and full-scale design to reach TRL 6–7, proving technical functionality, structural integrity, and scalability toward commercial offshore deployment.

The project developed and demonstrated the Exowave Wave Energy Converter, a hydraulic-based, submerged wave energy system that converts wave motion into pressurized water for electricity generation. The system consists of a wave receiver, hydraulic power take-off (PTO), and hydro turbine generator, with a low-maintenance energy conversion chain. The technology was validated through advanced modelling, testing, and DNV-witnessed Factory Acceptance Tests, demonstrating efficiencies of 76–78% and readiness for open-sea installation at Hanstholm. The TRL reached +6.

4. Project implementation

The project progressed from detailed design and modelling to prototype construction, verification, tank tests and general component testing. The first phase focused on refining the numerical model and completing the structural and hydraulic design in collaboration with Semco Maritime and Aalborg University. Subsequent phases included finite element verification, manufacturing of the Power Take-Off (PTO) system, and Factory Acceptance Tests (FAT) witnessed by DNV, confirming stable performance and efficiency. The project evolved as planned however, extra engineering was required for revising the foundation from gravity based to piled based. Additional extra engineering time was also needed to redesign the PTO to lower the CAPEX.

Key risks identified and managed throughout the project included:

- Technical risk: potential failure in scaling from laboratory and previous design. Mitigated by thorough FE analysis and design reviews, tank testing and iterative testing.
- Structural risk: uncertainties related to offshore loads and fatigue life. Addressed through thorough analysis and DNV-compliant design verification.
- Operational risk: delays in component delivery or testing due to supplier dependency. Managed through close coordination and schedule flexibility.
- Financial risk: cost increases due to inflation and material prices. Controlled via staged procurement and fixed supplier contracts. However, more project hours spend than according to budget.
- Regulatory/environmental risk: permitting and site approval at Hanstholm. Managed through early engagement with ENS and environmental screening; however, additional time was required to secure the offshore operation permit due to the withdrawal of the “open-door” scheme, the change from a gravity-based to a piled foundation, among other factors.

The project developed largely according to plan and milestones outlined in the EUDP plan. Design, verification, and factory testing were completed on schedule, and the technology achieved the targeted TRL 6–7. Minor adjustments were made to optimize testing and documentation procedures, but the overall progress remained consistent as planned.

However, the delay in achieving the permit and project finance results in closing the project earlier than expected on the 15th of October 2025. Demonstration offshore to be executed at a later stage outside this project.

5. Project results

The overall objectives of the project were achieved; however, it was accepted by EUDP not to carry out the offshore demonstration during the project period due to the lack of an operation permit and insufficient project funding to cover this activity.

Since the project application was submitted in March 2022, market prices have risen significantly, which led the project to focus strongly on design optimization to reduce costs, a focus that has had a positive effect on the project—particularly by lowering CAPEX and thereby the LCOE going forward, setting the stage for a very competitive technology.

Technical Milestones and Results:

- **Design Basis:** The numerical model was revised several times and verified through multiple 2D and 3D tank tests. As a result, we now have a highly efficient software tool that can be used for future Exowave WEC design projects. This has been crucial in ensuring survivability and in determining production, loads, and engineering design. In addition, an algorithm for optimizing production using MPPT (Maximum Power Point Tracking) was evaluated, which in combination with AI will further increase efficiency in future projects.
- **Foundation:** At project start, a gravity-based foundation type was planned. However, the LCA study showed that the environmental footprint was relatively high due to the large amount of cement and reinforcing steel. Verification also revealed a potential sliding risk between the foundation and seabed. Therefore, an alternative solution was investigated, and a FEED study was carried out for a monopile foundation, which is widely used in the offshore wind industry. The results showed that the footprint from using cement/concrete was eliminated and the total amount of steel significantly reduced. Furthermore, design standards, fabrication, and installation methods for monopiles are well-established and familiar in the market, making the monopile solution ideal for future large scale deployments.
- **Wave Receiver:** Initially, lightweight materials such as fibre-reinforced plastics were considered. However, these materials showed a large negative environmental and climate footprint, similar to what is known from wind turbine blades. A steel-based solution was therefore chosen and optimized during the project, proving to be the most advantageous option in terms of both environmental impact and cost.
- **Power Take-Off (PTO):** The PTO has been a major focus as the most complex component. Initially, conventional construction methods were considered, but this resulted in excessive material use, cost, and carbon footprint. Instead, we partnered with the same supply chain that has driven cost reductions in the wind sector over the past two decades, using ductile cast iron components. This allowed optimal shaping of structural parts, ensuring adequate strength and lifespan. Moreover, this supply chain is highly mature, competent, and efficient.
- **Hydro Turbine:** From the beginning, the project selected hydro turbine technology to convert hydraulic power from the PTO into electricity. A Pelton-type turbine, known for its high efficiency, was chosen. A complete system was developed including turbine, generator, and control for grid connection. A full modular system was designed, built, and tested, controlled by the WEC SCADA system including MPPT.
- **Temporary Phases:** These included transport and installation (T&I). The shift from gravity to monopile foundation simplified and reduced the cost of these operations significantly. Installation using monopiles can now be done with well-known methods, and since Exowave monopiles are much smaller than those used for offshore wind, the need for large vessels and heavy equipment is minimized, resulting in a much smaller environmental (noise) impact. Nevertheless, noise dispersion remains an important focus area in cooperation with ENS/MST.
- **Balance of Plant:** The hydraulic power produced is transmitted to the hydro turbine through high-pressure piping. The global market was carefully screened, and the most optimal solution identified—flexible plastic-reinforced high-pressure pipes. Optimization of the hydraulic energy transfer system for MW-

scale WEC clusters remains ongoing. In addition, a SCADA system was developed to regulate system pressure according to the prevailing wave climate, thereby achieving maximum energy production.

- **FAT:** The core and most critical component, the PTO, was tested together with the hydro turbine connected to the electrical grid. The system was tested at various pressures (40, 45, 50, 55, and 60 bar), achieving an efficiency between 76% and 78%, which was concluded to be stable and satisfactory.

The technical results achieved, including several unexpected positive findings, have been highly valuable for the overall development of the Exowave technology and have improved its technical maturity, now well on its way to TRL 7.

Commercial Milestones and Results

- **Project dissemination:** Results were continuously shared via social media (e.g., LinkedIn), at the Wave Energy Day hosted by Horten, the DROP2025 Conference and at Folkemødet 2024 and 2025, where Exowave, Crestwing, and Wavepiston jointly presented and debated. This outreach created a much larger (and positive) impact than anticipated.
- **Universities:** In addition to close collaboration with Aalborg University (Aalborg and Esbjerg), Exowave maintained contact with several national and international universities, including Aarhus University, University of the Faroe Islands, NTUA, TU Delft, UPC, Leibniz Universität Hannover, University of Siena, ETH Zürich, Nanyang Technological University, and National Taiwan Ocean University. This has led to new collaborations and potential projects in the EU, Faroe Islands, Singapore, and Taiwan, which were not expected at project start.
- **Industry conferences:** Project results were presented at the European Wave and Tidal Energy Conference (2023), Ocean Energy Europe (2023 and 2024), Danish Offshore Technology Conference (2024), and Innovation Center Denmark Climate Tech (2025).
- **Technical magazines:** Results were published in Energy Watch (2023), Energy Supply (2024), and Offshore Energy (2025).
- **Energy companies and developers:** Exowave presented its hybrid wind–wave technology to leading national and international operators and developers including Ørsted, CIP, TotalEnergies, NorthWind, Mitsui, Vena Energy, and Marubeni.
- **Potential investors:** During the project, Exowave initiated dialogue with numerous Danish and international investors, including Design Impact, Heartland, CIP, Maj Invest, TotalEnergies, NorthWind, Mitsui, Vena Energy, Marubeni, Burnt Island, KMM, Footprint Firm, and SWEN.
- **Television interview:** On 14 June 2024, TV2 conducted an 8-minute live interview about the Exowave technology and the EUDP project.

The achieved commercial results have fully met and exceeded expectations, opening doors to new partnerships and potential customers. The Exowave technology targets energy companies and developers, particularly within the wind sector, as well as customers in off-grid regions such as islands, industry, tourism, and agriculture. The communication and dissemination of project results have made it significantly easier to engage with new customers and stakeholders.

6. Utilisation of project results

The achieved technical results will generally be utilized in full detail, specifically as follows:

- **Design Basis:** To be applied directly (1:1), with particular emphasis on the revised numerical model.
- **Foundation:** Future foundations will be pile-based, as developed in this project. However, the use of screw anchors will be explored further and may be developed in a new project.

- Wave Receiver: To be applied directly (1:1); however, for micro-scale systems, conventional buoy-type designs will be used.
- Power Take-Off (PTO): Conceptually, to be applied (1:1).
- Hydro Turbine: To be applied directly (1:1).
- Transport & Installation: To be applied conceptually (1:1); buoyancy of the Wave Receiver during installation will be controlled using seawater and air.
- Balance of Plant: To be applied conceptually (1:1).

The achieved results will be used by Exowave in connection with commercialization together with partners.

The commercial results are being incorporated into Exowave's Go-to-Market (GTM) strategy. In short, Exowave will establish Joint Ventures (JV) globally for the following regions: Americas, Asia Pacific, Indian Ocean, North Sea, Europe, and Africa. The JV for the Americas has already been established with a U.S./Canadian partner, and the development of a JV for Asia Pacific is ongoing.

This EUDP project has strongly contributed to the progress of establishing global JVs and attracting capital investment in Exowave. In the short term, this will lead to increased exports, revenue, employment, and activity for Exowave, its partners, and suppliers, as well as additional investment in the company itself.

The competitive landscape in the energy market is generally tough, complex, and politically driven. In the short term, Exowave focuses on markets with limited competition—such as isolated regions, like islands and remote communities where electricity is produced by diesel generators, where market prices exceed 300 USD/MWh. In such markets, Exowave can easily compete. In the longer term, Exowave will compete directly with offshore wind, where it sees an opportunity to maximize the utilization of offshore areas through hybrid wind and wave energy solutions.

The main barriers are expected to be related to project financing and permitting. Therefore, our strategy is to ally with local partners through Joint Ventures in the defined global regions mentioned above.

Exowave and this project contribute to increasing the share of renewable energy supply and reducing the need and dependence on fossil fuels, fully aligned with Danish and EU energy policy.

7. Project conclusion and perspective

The conclusion is that the Exowave concept represents a real and promising opportunity for a renewable energy system that can be applied in coastal areas and at shallower to intermediate water depths in combination with offshore wind.

The next step is to demonstrate the Exowave technology together with our current and future joint venture partners globally for potential customers, and to further refine our technology with a strong focus on reducing DEVEX, CAPEX, and OPEX, and thereby continuously lowering the LCOE.

In the future, Exowave will be demonstrated and developed both in Denmark and internationally, particularly in regions where there is focus and support for wave energy. Once the Exowave technology reaches cost competitiveness with offshore wind, the growth potential will be substantial. In the near term, Exowave will also deliver micro-scale systems to regions with favourable wave climates that are not connected to the electrical grid, where there is a need for energy for electrification and seawater desalination. Exowave estimates the total addressable market (TAM) to be extremely large — with a potential value exceeding €1,000 billion.

There is still a long journey toward full commercialization, but this EUDP project has been instrumental in paving the way, for which Exowave is deeply grateful.

8. Appendices

The appendices below are confidential but available on request.

- 0. Exowave pitch deck
- A. Design Basis - Loads AAU
- B. Design basis - EIA AAU
- C. Design basis - LCA AAU
- D. Foundation - Design brief Exowave
- E. Foundation - Design loads Semco
- F. Foundation - MP analysis ISC
- G. Foundation - MP installation Aarsleff
- H. Hydro Turbine - GA Gugler
- I. Hydro Turbine - SCADA system Gugler
- J. Power Take-off - FAT DNV witness
- K. Power Take-off - FAT setup Semco
- L. Power Take-off - Drawings Exowave
- M. Power Take-off - Structural analysis Semco
- N. Wave Receiver - Drawings Exowave
- O. Wave Receiver - Structural analysis Semco
- P. WEC - General Arrangement Exowave
- Q. AAU report - Accuracy of Directional Spectrum
- R. AAU report - Directional spectrum estimation
- S. AAU report - EWTEC2023
- T. AAU report - Experimental testing of Exowave
- U. AAU report - Separation of nonlinear multidirectional waves