Increasing offshore safety through geological hazards identification with ultra-high resolution marine seismic

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As offshore wind energy scales up, safety and precision are non-negotiable. Fraunhofer IWES applies ultra-high resolution multichannel seismic (UHR MCS) technology to identify geological hazards with unmatched clarity, delivering sub-meter resolution imaging critical for risk mitigation, efficient design and safe construction. Tailored to the unique demands of offshore wind, this advanced geophysical approach minimizes environmental impact, enhances ground models and supports smarter decisions from planning to operation.

As the demand for renewable energies intensifies, offshore wind farms have emerged as a vital component of the global transition to sustainable energy. The complexity in engineering required for offshore wind farm development includes many variables, from innovative technological structural designs to the challenges posed by unpredictable weather conditions. Moreover, offshore operations for wind farm development not only involve working in challenging and hazardous environments but also require identifying geological hazards that may otherwise go undetected without the appropriate datasets.

Ensuring risk mitigation through accurate geological characterization is essential for preventing accidents, reducing the risk of costly project delays and securing the safety of personnel and equipment.

Regulatory framework and requirements

Seismic data plays a crucial role in geological characterization and hazard identification, providing detailed insights into the sub-seafloor geology. The ISO 19901-10:2021(E) standard states that seismic surveys, including High Resolution (HR), Ultra-High Resolution (UHR) and Ultra-Ultra-High Resolution (UUHR) seismic reflection methods, are essential for mapping sub-seafloor conditions.

Several guidelines highlight the critical role of geophysical surveys for site characterization in the development of offshore wind projects and emphasize that these surveys are essential for preliminary design activities and accurate project cost estimation.

According to the Standard Ground Investigations for Offshore Wind Energy from the Federal Maritime and Hydrographic Agency of Germany (BSH - Bundesamt für Seeschifffahrt und Hydrographie), the minimum requirements for the development of offshore wind farms include a desk study, hydrographic survey, geotechnical survey and a geophysical survey. The combination of these investigations should help the applicant demonstrate that the integrity of the structure is guaranteed, which is a crucial part of the approval procedure for installing offshore structures.

The desk study typically involves a review of existing literature, maps, and data related to the proposed site. This initial phase helps identify any known hazards and informs the planning of subsequent surveys.

Hydrographic surveys focus on measuring water depth, currents and other physical characteristics of the marine environment. Geotechnical surveys assess the properties of the seabed materials, while geophysical surveys, such as UHR and UUHR Multichannel Seismic (MCS), provide detailed images of the subsurface geological structures. These surveys are intended to provide sufficient data to support the conceptual design of offshore wind projects.

The role of geophysics

UHR MCS is a cutting-edge geophysical technique used to image the subsurface with exceptional detail. Originally developed over decades for the oil and gas industry, multichannel seismic methods have since been adapted for the specific conditions associated with offshore wind farm environments. However, the requirements of the wind energy sector differ considerably from those of oil and gas. While hydrocarbon exploration targets subsurface structures several kilometers deep on a larger scale, wind farm developers are primarily concerned with the top 100 to 200 meters of the seabed and need to identify geological features at meter and sub-meter resolution.

This method involves the use of seismic sources and receivers to record high-resolution data, allowing for precise mapping of geological structures.

By utilizing advanced equipment UHR MCS can achieve sub-meter horizontal and vertical resolution, making it ideal for identifying subtle geological features that are relevant for the engineers. The seismic method operates with high-frequency sources such as mini air guns, sparkers or boomers to generate acoustic waves that travel through the water and penetrate the seabed.

These waves are reflected to the surface by the different underground geological structures and sediment layers. An array of closely spaced receivers, so-called hydrophones, then detects these reflected waves, recording the data from multiple channels simultaneously, allowing us to have a 2D or 3D image of the subsurface.

To fulfil the needs from the wind farm developers, Fraunhofer IWES uses a customized acquisition system that allows the correct imaging of such small geological structures, the system's modular design can be tailored, e. g. by using a different source or spacing of the receivers, to suit the specific client's requirements including being able to solve different depths or spatial resolutions.

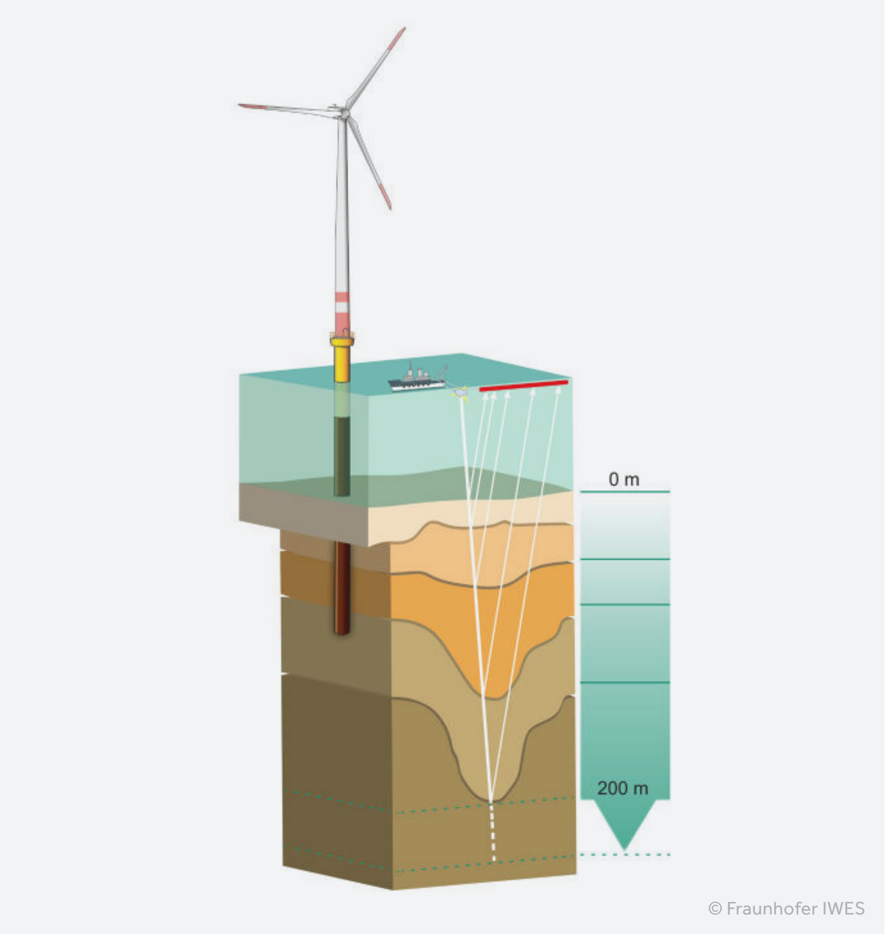
Site characterization for offshore wind farm development

Fraunhofer IWES initially acquires the UHR MCS during an offshore survey campaign, which is carefully designed based on the specific needs of the client and informed by existing geological knowledge of the area. Once the data is collected, it undergoes thorough processing onshore to enhance its quality and extract the most valuable information. Advanced processing techniques filter out noise, remove undesired artifacts and improve the clarity of the images.

This processed data is then meticulously interpreted by geologists to identify geological structures. The UHR MCS later is integrated with other datasets such as hydroacoustic or geotechnical data to build a ground model and be able to assess naturally occurring or man-made potential hazards that might adversely impact the project.

Ground models provide relevant information like water depth and seafloor topography, and are essential for interpreting key information such as sediment layering, lithological changes, obstructions, e. g. boulders or pUXO (potential unexploded ordnance), structural features like faults or channels, and shallow gas or organic-rich weak layers.

These features may originate from glacial, fluvial, or other geological processes and can vary widely in shape and scale. Moreover, ground models offer insights into sediment composition, including the distribution and characteristics of different sediment types, such as sand, silt, clay and organic materials. By analysing the spatial arrangement and properties of these sediments, ground models can reveal information about their grain size, permeability and consolidation



2D acquisition layout depicting depth of interest for offshore wind farms and waves that are being reflected on the different underground layers

state, which are critical for understanding how these materials will behave under load.

With yearly thousands of kilometers of acquired, processed, and interpreted marine multichannel seismic data, Fraunhofer IWES has extensive experience in the Offshore Site Characterization field, providing high-quality data and ensuring reliable and accurate geological characterization for industry and research projects.

By leveraging state-of-the-art technology, expertise and a deep understanding of geological processes, Fraunhofer IWES, with its innovative approach, supports the wind energy sector in achieving its sustainability and safety goals efficiently and effectively.

Impact on project development and operations

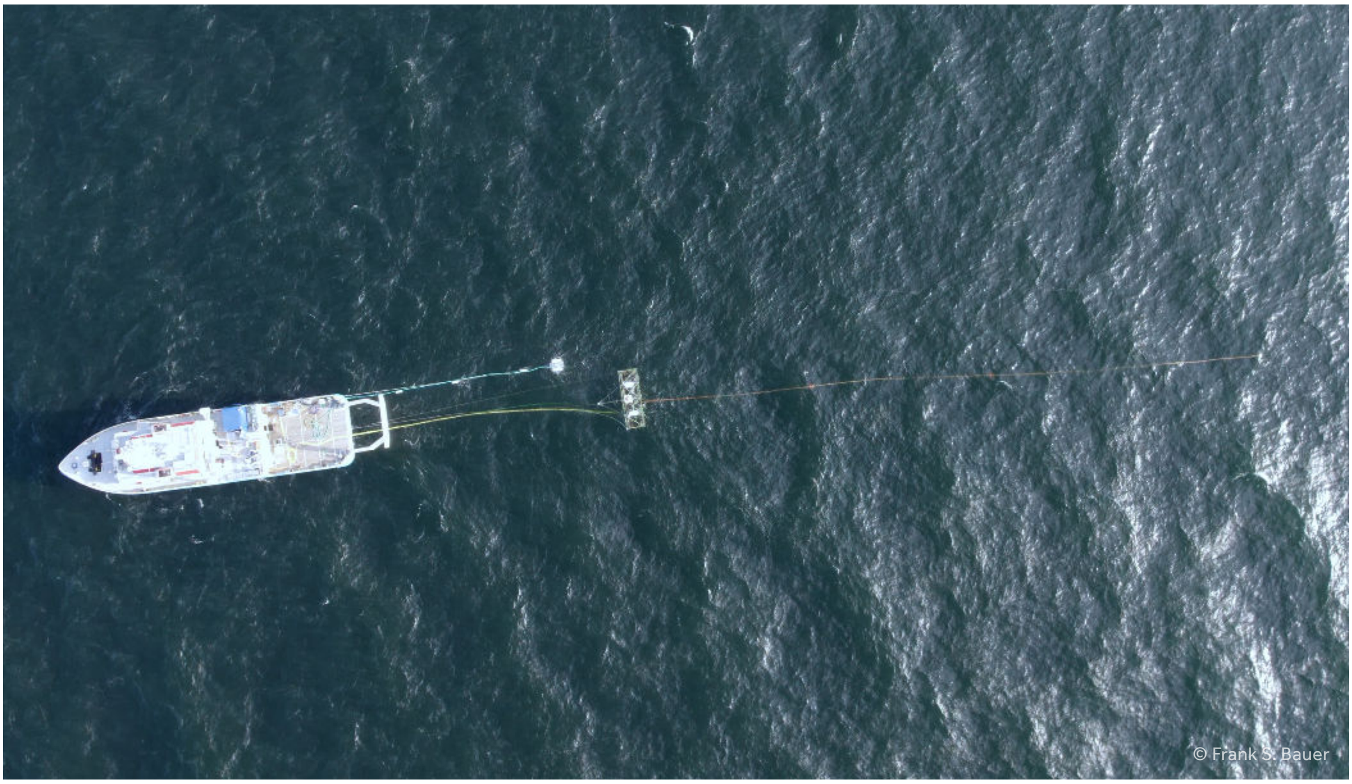
The identification of geological hazards through comprehensive site characterization is essential not only during the design phase but also has far reaching implications for the construction and operational phases of offshore wind farms. Accurate geological assessments support informed decision making that improves project safety, enhances efficiency and helps control costs throughout a wind farm's lifecycle.

For instance, if potential hazards such as buried channels or unstable soils are detected early, engineers can modify construction methods to mitigate risks effectively. This might involve adjusting the diameter and length of foundation piles or selecting alternative installation techniques tailored to specific geological conditions. Unanticipated obstacles or soft zones can lead to pile refusal, misalignment or even damage to equipment. By proactively addressing these issues, projects are less likely to encounter delays or budget overruns due to construction challenges.

A comprehensive understanding of the geological processes impacting the planned area is essential for designing foundations capable of withstanding environmental forces, ensuring the long-term stability of offshore wind turbines, and facilitating ongoing monitoring and maintenance. The structure of geological features and the composition of sediments beneath the surface, such as sand, clay and peat, are critical in determining the optimal location and design of foundations.

Different sediment types exhibit varying properties affecting stability and load-bearing capacity. For example, soft sediments may necessitate deeper foundations or specialized installation methods, while harder substrates may allow for more straightforward anchoring techniques.

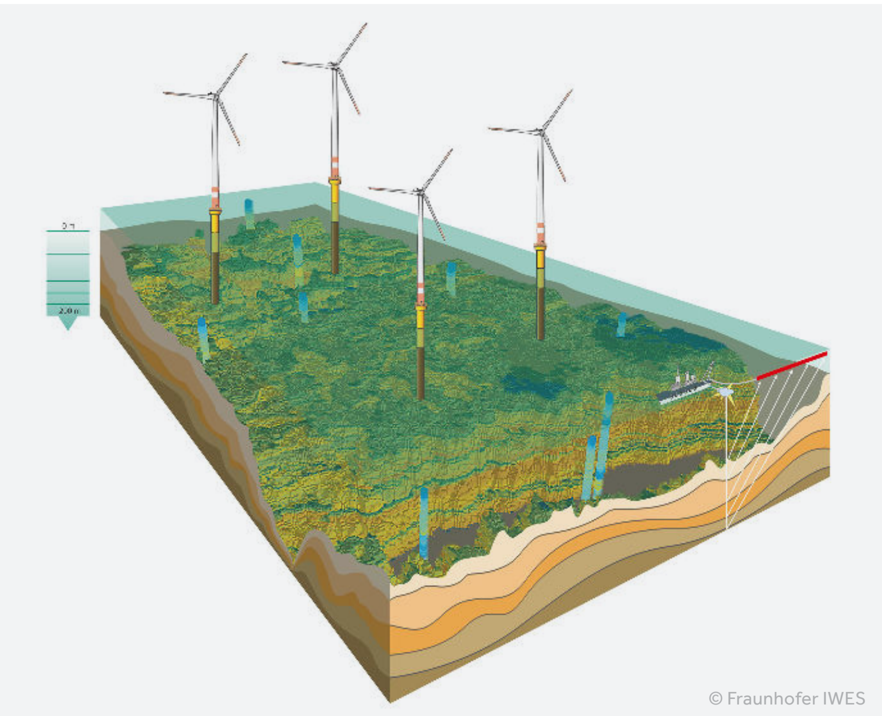
UHR multichannel marine seismic surveys play a pivotal role in enhancing site characterization while minimizing environmental impact.



Overview on an acquisition layout of an offshore survey

The high resolution of UHR seismic data enables more precise targeting for geotechnical sampling, significantly reducing the need for extensive and intrusive seabed drilling. This not only lessens the environmental footprint associated with site assessments but also conserves resources and time.

Moreover, UHR marine seismic data are invaluable for not only planning optimal turbine locations but also for determining the most efficient and secure routes for cable installation. By providing detailed insights into the sub-seafloor geology, UHR seismic surveys facilitate better decision making that contributes to the overall success and sustainability of offshore wind projects. This advanced approach ultimately leads to safer operations, reduced costs and a more efficient timeline for project completion.



Graphical representation of a geological ground model showing how the subsurface layers can vary within a planned wind farm area

Conclusion

The identification and assessment of geological hazards are critical components of offshore wind farm development. As the demand for renewable energy continues to grow, the importance of accurate geological characterization cannot be overstated. Through comprehensive site characterization and risk mitigation strategies, the offshore wind industry can continue to expand, contributing to a greener future while safeguarding personnel and assets.

By providing a comprehensive overview of the subsurface conditions, ground models allow developers to make informed, cost-effective decisions regarding turbine placement and foundation design.

As we move forward, the integration of geophysical data and innovative engineering solutions will be essential in addressing the challenges of offshore wind farm development and ensuring the integrity and safety of these vital renewable energy sources.

Research institutes like Fraunhofer IWES are instrumental in this process, providing expertise and cutting-edge technology to support the wind energy sector in achieving its goals of sustainability and safety.

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