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Presentation and Comparison of Site Investigation Methods for Offshore Wind Energy in the European North Seas Countries in the Context of the EU North Seas Energy Cooperation

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Presentation and Comparison of Site Investigation Methods for Offshore Wind Energy in the European North Seas Countries in the Context of the EU North Seas Energy Cooperation

Final report

by

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Abstract: Presentation and Comparison of Site Investigation Methods for Offshore Wind Energy in the European North Seas Countries in the Context of the EU North Seas Energy Cooperation

Following the Political Declaration on Energy Cooperation between the North Seas Countries of June 2016, ten European countries have founded a joint initiative to facilitate the further effective deployment of offshore renewable energy. Four European working groups SG 1 to SG 4 are established for this purpose covering the maritime spatial planning, the development and regulation of offshore grids and other offshore infrastructure, the support framework and finance for offshore wind projects, as wells as the standards, technical rules and regulations in the offshore wind sector. Within this context the potential harmonization of site investigation procedures is dealt with in the working group SG 4 on standards, technical rules and regulations in the offshore wind sector. Following the overall objective of the joint initiative to ensure a sustainable, secure and affordable energy supply in the North Seas countries, in this report a study on site investigation procedures that are applied in the countries is provided. The differences and similarities of the procedures are outlined with special consideration of regulatory and technical aspects as well as relevant site conditions. Recommendations are given on how to achieve the most uniform and economical approach possible for the site investigation, furthermore suggestions for the future steps are derived.

Kurzbeschreibung: Dar- und Gegenüberstellung der Baugrunderkundung für Offshore Windenergie in den europäischen Nordseeanrainerstaaten im Zuge der EU Nordsee Energiekooperation

Nach der Politischen Erklärung zur Energiezusammenarbeit zwischen den Nordseeländern vom Juni 2016 haben zehn europäische Länder eine gemeinsame Initiative gegründet, um den weiteren effektiven Einsatz erneuerbarer Energien auf See zu fördern. Zu diesem Zweck wurden vier europäische Arbeitsgruppen SG 1 bis SG 4 eingerichtet, die sich mit der maritimen Raumordnung, der Entwicklung und Regulierung von Offshore-Netzen und anderen Offshore-Infrastrukturen, dem Förderkonzept und der Finanzierung von Offshore-Windprojekten sowie den Normen, technischen Regeln und Vorschriften im Offshore-Windbereich befassen. In diesem Zusammenhang werden in der Arbeitsgruppe SG 4 Normen, technische Regeln und Vorschriften im Offshore-Windbereich sowie die mögliche Harmonisierung von Verfahren zur Baugrunderkundung behandelt. Entsprechend dem übergeordneten Ziel der gemeinsamen Initiative, eine nachhaltige, sichere und erschwingliche Energieversorgung in den Nordseeanrainerstaaten zu gewährleisten, wird in diesem Bericht eine Studie über die in den zehn Nordsee-Ländern angewendeten Verfahren zur Baugrunderkundung vorgestellt. Hierbei werden die Unterschiede und Gemeinsamkeiten der Verfahren insbesondere unter besonderer Berücksichtigung regulatorischer und technischer Aspekte sowie relevanter Standortbedingungen dargestellt. Darauf aufbauend werden Empfehlungen, wie eine möglichst einheitliche und wirtschaftliche Vorgehensweise bei der Baugrunderkundung erreicht werden kann, gegeben und Vorschläge für zukünftige Schritte abgeleitet.

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List of abbreviations

AFNOR	Association Française de Normalisation (French Standardization Association)
BAW	Bundesanstalt für Wasserbau (Federal Waterways Engineering and Research Institute)
BEIS	Department for Business, Energy & Industrial Strategy
BMWi	Bundesministerium für Wirtschaft und Energie (Federal Ministry for Economic Affairs and Energy)
BSH	Bundesamt für Seeschifffahrt und Hydrographie (Federal Maritime and Hydrographic Agency)
BSI	British Standards Institution
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CFMS	Comité Français de Mécanique des Sols et de Géotechnique (French Committee of Soil Mechanics)
CPT	Cone penetration test
CPTU	Cone penetration test with pore pressure measurement
CREG	Commissie voor de Regulering van de Elektriciteit en het Gas (Commission for Electricity and Gas Regulation)
DIN	Deutsches Institut für Normung (German Institute for Standardisation)
DNV GL	Quality assurance and risk management company, formed by merger of former Det Norske Veritas and Germanischer Lloyd
EEG	Erneuerbare-Energien-Gesetz (Renewable Energy Sources Act)
EEZ	Exclusive economic zone
EN	European standard, i.e. the national equivalent of the standard
ENS	Energistyrelsen (Danish Energy Agency)
FEED	Front end engineering design
GW	Gigawatt
HPDT	High pressure dilatometer test
IHO	International Hydrographic Organization
ISO	International Organization for Standardization
ISSMGE	International Society for Soil Mechanics and Geotechnical Engineering
LCCC	Low Carbon Contracts Company
MBES	Multi beam echo sounder
NF	Norm française (French standard)
PMT	Pressuremeter Ménard Test
RVO	Rijksdienst Voor Ondernemend Nederland (Netherlands Enterprise Agency)
SSS	Side scan sonar
SUT	Society for Underwater Technology
UBA	Umweltbundesamt (German Environment Agency)
WindSeeG	Windenergie-auf-See-Gesetz (Offshore Wind Energy Act)

Summary

In view of the regulatory requirements, the procedures of site investigation for offshore wind farms in the individual North Seas Countries can be divided into three main groups.

Group 1

Based on the evaluation carried out in this study, the site investigation for offshore wind farms in Belgium, Denmark, the Netherlands, and the United Kingdom can be classified in this group. In these countries, in which a significant amount of offshore wind farms has been installed yet, the planning of the site investigation is widely based on part 8 of the ISO 19901 standard and further recommendations taken from supplementary guidance for offshore wind energy such as for example the DNV GL standards. According to conversations with project developers, the involved parties are aware that the sole use of this ISO standard, which originates from the petroleum industry, does not provide a sufficient basis for site investigations for offshore wind farms. Therefore, the adequate scope of site investigations for offshore wind farms is usually derived from the developer’s experience (former projects) and the requirements of the foundation design methodology in question. In practice, the soil conditions of the wind farm and the requirements of the planned design methodology are the dominant criteria for the detailed scope of the site investigations. In addition, the scope of site investigations depends on experience and the innovative strength of the respective developer.

The project requirements rather than regulative requirements by the authorities drive the approach and the extent of site investigations. In these countries, detailed regulative requirements for site investigations are intentionally not issued by the authorities. Usually however, a certificate or a statement of compliance by an acknowledged independent certifier is required to ensure the adequacy of the site investigations.

Whilst for laboratory soil testing several ISO standards are stepwise transferred into the national codes, the use of the ISO standard for the determination of the scope of site investigation in addition with foreign national standards for laboratory testing have been carried out and accepted in the past.

Group 2

The second group solely consists of Germany. Here, a different approach is followed to ensure the adequacy of the site investigations. As no relevant standard was available during the development phase of the first offshore wind farms, the Standard Ground Investigations (BSH 2014) was published by the Federal Maritime and Hydrographic Agency (BSH). The minimum requirements for geophysical and geotechnical investigations were defined by a working group of experts and stakeholders under consideration of available guidelines and standards. In addition, the priority use of Eurocode 7, its national annex and DIN standards is a mandatory requirement of the Standard. The latest version of the Standard (BSH 2014) defines two main phases which describe the scope of the site investigation for a preliminary investigation and a detailed investigation - take into account the different phases of the wind farm planning and the belonging approval procedure.

Group 3

This group consists of the countries France, Norway, Sweden and Ireland that have already developed a strategic plan for the future use of renewable energy but where no significant number of offshore wind farms have been built yet and the development of a detailed regulatory approval procedure is still ongoing. Based on the evaluation of the available information, the site investigation for offshore wind farms in France, Norway and Ireland can be assigned to this group. The site investigation for offshore wind farms in Sweden is also assigned to this group, since the installation of new offshore wind farms is not planned in near future. In Sweden, a total of four offshore wind farms with 79 turbines were connected to the grid at the end of 2018 (WindEurope 2019a).

Luxembourg does not own suitable areas for offshore wind farms, therefore the corresponding site investigation is not relevant here.

Although the regulatory requirements about site investigations appear quite different in the individual countries, in practice a similar investigation technique is applied.

In the further course this study a more detailed comparison of the employed techniques and the extent of the investigations will be pointed out. Public available information for site investigations like for the Dutch wind farm Borssele and the Danish wind farms Kriegers Flak and Horns Rev 3 will be taken into account here. In addition, the authors' experience from wind farm projects and conversation with developers and relevant stakeholders like the Carbon Trust will be used.

As concluded from the conversation with developers, a comprehensive and meaningful site investigation is considered as one of the pre-requisites for a cost-effective development of a wind farm project. Furthermore, the mechanisms of the energy market will increase the need for cost-effective and more sophisticated foundation design, making comprehensive exploration and sophisticated investigation methods increasingly important. The importance of a meaningful site investigation from a developer's perspective is already outlined in a conference paper published in 2013 (Wood & Knight 2013).

The direct costs related to site investigation are usually in the range of a single-digit percentage of the total capital investment for an offshore windfarm. However, the quality and the extent of site investigations is of fundamental importance for all of the following project phases.

As a supplement to the investigation by boreholes, CPT and soil sampling that will continue to form an integral part of the future surveys, the supplementary use of innovative '3D seismic surveys' is currently in the focus of ongoing developments. This technique is not yet a standardized investigation method. Furthermore, '3D seismic' cannot completely replace the geotechnical investigation by boreholes or CPT as the interpretation of seismic surveys will always require geotechnical investigations for calibration purpose and for the determination of soil parameters. The use of these systems may in some cases be subject to more stringent requirements with regard to sea state conditions than the use of conventional seismic survey methods. However, '3D seismic' could for example be used for a cautious assessment of the soil conditions between existing locations from geotechnical investigations. Thus, the supplementary use of this innovative seismic survey technique could provide more insight into the ground conditions and could assist to optimize the park layout.

Significantly different regulatory requirements for soil investigations in the individual countries will cause additional efforts on the developer's side and will increase the risk for misunderstandings or misinterpretations of the prevailing rules during the project implementation. Most of the North Seas Countries have deliberately not issued detailed requirements about the site investigation to achieve cost-reductions by flexibility for the project developers.

Since most of the North Seas Countries did not issue binding regulations about details of the soil investigation procedure, a 'harmonization' in the meaning of aligned standards is hardly possible. Rather than seeking 'harmonization', an 'exchange of best practices' is therefore currently considered to be the most beneficial measure.

Zusammenfassung

Anhand der regulatorischen Anforderungen kann die Baugrunderkundung für Offshore-Windparks in den einzelnen Nordseeanrainerstaaten in drei Gruppen unterteilt werden.

Gruppe 1

Auf der Grundlage der bisherigen Recherche können die Regelungen zur Baugrunderkundung für Offshore-Windparks in Belgien, Dänemark, den Niederlanden und im Vereinigten Königreich einer Gruppe zugeordnet werden. In diesen Nordseeanrainerstaaten, in denen eine bedeutende Anzahl von Offshore-Windparks errichtet wurde, basiert die Planung der Baugrunderkundung weitgehend auf dem Teil 8 der Norm ISO 19901. Die Regelungen in der Norm werden durch weitere Empfehlungen und Regelwerke aus dem Bereich der Offshore-Windenergie, wie beispielsweise den Standards des DNV-GL, ergänzt. Nach Gesprächen mit Projektentwicklern ist der Industrie bewusst, dass die alleinige Anwendung dieser ISO Norm, die aus der Erdöl- und Erdgasindustrie stammt, keine ausreichende Grundlage für die Baugrunderkundung für Offshore-Windparks bietet. Der Umfang der Baugrunderkundung für einen Offshore-Windpark wird daher üblicherweise aus den bisherigen Erfahrungen eines Projektentwicklers abgeleitet und durch zusätzliche Anforderungen aus den jeweiligen Bemessungsverfahren für das Fundament ergänzt. In der Praxis bilden daher die Standortbedingungen des Windparks und die Anforderungen des geplanten Bemessungsverfahrens die dominierenden Kriterien für den Umfang der Baugrunderkundung. Darüber hinaus hängt der Umfang der Baugrunderkundung auch von der Erfahrung und der Innovationskraft des jeweiligen Projektentwicklers ab.

Die Projektanforderungen und weniger die regulatorischen Vorgaben der Behörden bestimmen das Vorgehen und den Umfang der Baugrunderkundung. In den Ländern der Gruppe 1 haben die Behörden bewusst auf die Vorgabe detaillierter regulativer Anforderungen an die Baugrunderkundung verzichtet. Üblicherweise wird jedoch ein Zertifikat oder eine Konformitätserklärung einer anerkannten Prüforganisation gefordert, um eine aussagekräftige Baugrunderkundung sicherzustellen.

Während für die Laboruntersuchungen zunehmend ISO Normen als nationale Normen übernommen werden, ermöglichen einzelne Länder die Anwendung der ISO Norm für die Planung der Baugrunderkundung in Kombination mit ausländischen nationalen Normen für die Laboruntersuchungen.

Gruppe 2

Diese Gruppe wird ausschließlich aus Deutschland gebildet. Im Vergleich zur Gruppe 1 wird in Deutschland ein anderes Vorgehen angewendet, um eine angemessene Baugrunderkundung zu gewährleisten. Da bei der Entwicklung der ersten Offshore-Windparks in Deutschland keine hinreichenden Regelungen zur Baugrunderkundung existierten, hat das Bundesamt für Seeschifffahrt und Hydrographie (BSH) den Standard Baugrund veröffentlicht (BSH 2014). Die darin enthaltenen Mindestanforderungen an die Baugrunderkundung wurden von einer Arbeitsgruppe aus Fachleuten und Interessenvertretern der Industrie und unter Berücksichtigung der verfügbaren Richtlinien und Standards festgelegt. Darüber hinaus ist die vorrangige Anwendung des Eurocodes, seines nationalen Anhangs und der DIN Normen eine verbindliche Anforderung des BSH Standards für die Baugrunderkundung. Weiterhin definiert der BSH Standard (BSH 2014) zwei Hauptphasen, die den Umfang einer Vorerkundung und einer Haupterkundung beschreiben und die unterschiedlichen Phasen der Projektentwicklung und des Genehmigungsverfahrens berücksichtigen.

Gruppe 3

Nach der bisherigen Recherche kann das Vorgehen zur Baugrunderkundung für Offshore-Windparks in Frankreich, Norwegen, Schweden und Irland am ehesten dieser Gruppe zugeordnet werden. In diesen Nordseeanrainerstaaten, die bereits einen Strategieplan für die verstärkte Nutzung erneuerbarer Energien entwickelt haben, aber in denen bislang noch keine signifikante Anzahl von Offshore-Windparks errichtet wurde, befindet sich das detaillierte Genehmigungsverfahren in der Regel noch in der Entwicklung. Die Baugrunderkundung für Offshore-Windparks in Schweden wird ebenfalls dieser Gruppe zugeordnet, da der Bau neuer Windparks in naher Zukunft nicht geplant ist. Zum Jahresende 2018 waren in Schweden vier Offshore-Windparks mit insgesamt 79 Turbinen an das Netz angeschlossen (WindEurope 2019a).

Luxemburg besitzt keine Flächen für Offshore-Windparks, die entsprechende Baugrunderkundung ist deshalb nicht relevant.

Obwohl die regulatorischen Anforderungen an die Baugrunderkundung in den einzelnen Ländern sehr unterschiedlich erscheinen, wird in der Praxis eine ähnliche Untersuchungstechnik angewendet.

Im weiteren Verlauf dieser Studie wird ein ausführlicher Vergleich der eingesetzten Technik und des Untersuchungsumfangs für eine Baugrunderkundung analysiert. Veröffentlichte Informationen über die Baugrunderkundung zum Beispiel für den niederländischen Windpark Borssele und die dänischen Windparks Kriegers Flak und Horns Rev 3 werden dabei ebenso berücksichtigt wie die Erfahrungen der Autoren und deren Erkenntnisse aus Gesprächen mit Projektentwicklern und Interessenvertretern wie dem Carbon Trust.

Aus Gesprächen mit den Projektentwicklern geht hervorgeht, dass eine umfassende und aussagekräftige Baugrunderkundung als eine der Voraussetzungen für die wirtschaftliche Entwicklung eines Windparkprojekts angesehen wird. Zudem werden die Mechanismen des Energiemarktes auch das Erfordernis nach kostengünstigen Fundamenten und fortschrittlichen Bemessungsverfahren verstärken, wodurch eine umfassende Baugrunderkundung und hochentwickelte Untersuchungsmethoden an Bedeutung gewinnen. Aus Entwicklersicht ist die Bedeutung einer aussagekräftigen Baugrunderkundung bereits vor einigen Jahren in einem Konferenzbeitrag dargestellt worden (Wood & Knight 2013).

Die direkten Kosten der Baugrunderkundung liegen in der Regel im geringen einstelligen Prozentbereich der gesamten Investitionskosten für einen Offshore-Windpark. Die Baugrunderkundung ist jedoch für alle folgenden Projektphasen von übergeordneter Bedeutung.

Neben den Untersuchungen durch Bohrungen, CPT sowie die Analyse von Bodenproben, die auch in Zukunft integraler Bestandteil der Untersuchungen sein werden, steht der ergänzende Einsatz innovativer "3D-Seismik" derzeit im Fokus der laufenden Entwicklungen. Diese Technik ist noch kein standardisiertes Untersuchungsverfahren. Die "3D-Seismik" kann zudem die geotechnische Untersuchung durch Bohrungen oder CPT nicht vollständig ersetzen. Der Einsatz dieser Systeme kann teils strengere Anforderungen an die Seegangsverhältnisse stellen als der Einsatz konventioneller seismischer Erkundungsverfahren. Die Interpretation seismischer Untersuchungen erfordert immer auch geotechnische Untersuchungen zur Kalibrierung und zur Bestimmung der Bodenparameter. In erster Linie könnte die "3D-Seismik" beispielsweise für eine vorsichtige Beurteilung der Bodenbeschaffenheit zwischen bestehenden geotechnischen Untersuchungspunkten eingesetzt werden. So könnte der ergänzende Einsatz dieser innovativen

Untersuchungsmethode mehr Einblick in die im Parkgebiet vorhandenen Bodenverhältnisse geben und zur Optimierung des Windparks beitragen.

Unterschiedliche regulatorische Anforderungen an die Baugrunderkundung in den einzelnen Ländern führen zu einem erhöhten Aufwand auf Entwicklerseite und erhöhen das Risiko von Missverständnissen oder Fehlinterpretationen der geltenden Regeln bei der Projektdurchführung. Die meisten Nordseeanrainerstaaten haben bewusst keine detaillierten Anforderungen an die Standortuntersuchung gestellt, um durch Flexibilität für die Projektentwickler Kostensenkungen zu ermöglichen.

Da die meisten Nordseeanrainerstaaten keine verbindlichen Vorschriften über die Einzelheiten des Bodenuntersuchungsverfahrens erlassen haben, ist eine ‚Harmonisierung' im Sinne von abgestimmten Normen kaum möglich. Statt eine ‚Harmonisierung' anzustreben, wird daher derzeit ein ‚Austausch bewährter Praktiken' als die vorteilhafteste Maßnahme angesehen.

1 Objective

This report provides the results of a comparative study about site investigation methods for offshore wind energy in the European North Seas Countries. The study contributes to the overall scope, which has been defined following to the political declaration on energy cooperation between the North Seas Countries initiated by the European Community.

In this context the term site investigation denotes the investigation of the ground by geophysical and geotechnical investigations. The study is prepared by Fichtner Water & Transportation GmbH on behalf of the German Environment Agency. This study was prepared from June 2018 to November 2019.

This study is intended as a basis for further exchange between the North Sea countries and a mutual understanding of the different procedures. Although the potential for aligned site investigation procedures is part of the scope, the study primarily aims to draw up an overview of the procedures applied in the individual countries rather than to issue a uniform regulation about the site investigation throughout Europe.

2 Terms for site investigation

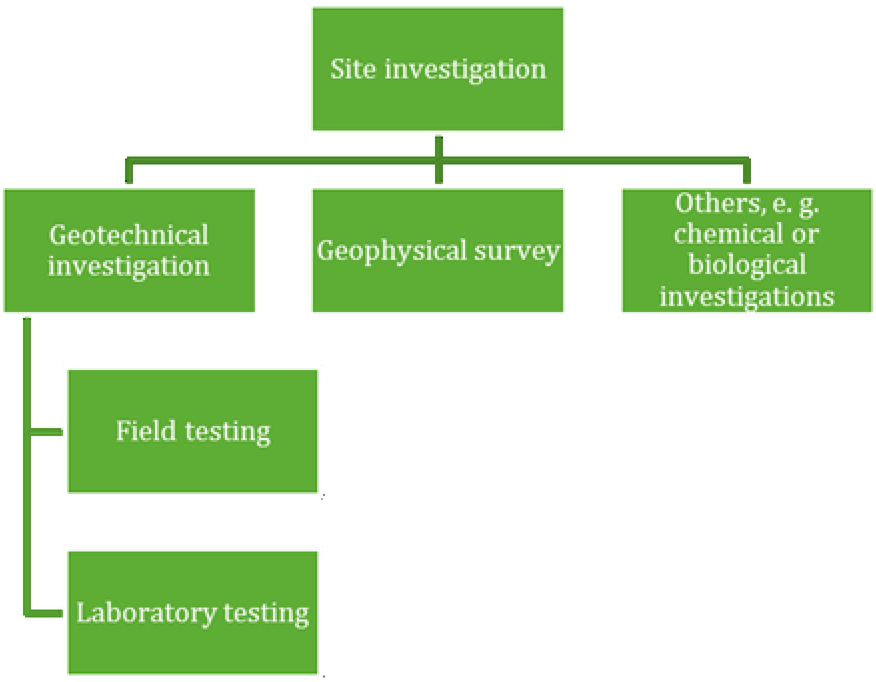
The technical planning and the installation of the offshore structures to generate and transmit electrical energy from offshore wind turbines requires certain information about the engineering properties of the soil. In this context 'soil' is employed as a generic term for the material below the seabed level independent of its nature or genesis.

Within this report the focus is put solely on the properties of the soil as input for engineering tasks. The ecological assessment of the soil is not considered. The investigation of the material properties and the seabed features is denoted as 'site investigation'. The authors are aware that the complete site investigation covers further aspects like e. g. the met ocean conditions or archaeological heritage to name some of them. However, in the context of the defined work package only the above described part of the site investigation is considered.

The site investigation denotes the total works at the site, in the laboratory, the interpretation of the measured values and the reporting. This term is used regardless of the applied technique. If individual parts of the site investigation are addressed, this is denoted by additional wording, such as for example geotechnical site investigation or geophysical survey. The geotechnical investigation usually provides point-shaped information at a specific location whereas the geophysical survey usually provides areal information.

Based on the type of technique used, the site investigation is furthermore divided into the geotechnical investigation, the geophysical investigation and others. The geotechnical investigation can be divided into field testing, that is carried out on-site and into laboratory testing that is carried out on specimens that are extracted from soil samples. Further investigations of the soil can comprise for example chemical or biological investigations to determine additional soil properties. The above terms that are used in this report are depicted in the scheme of Figure 1 below.

Figure 1: Terms for site investigation



Source: Own illustration, Fichtner Water & Transportation GmbH

In the main part of this study, chapter 7, the usually applied approach for site investigations for offshore wind farms in the individual North Seas Countries is described. The description provides information about the employed techniques for site investigation and about the formal requirements by the authorities, if applicable.

3 Scope of work

Following the political declaration on energy cooperation between ten European countries, namely the 'North Seas Countries' Belgium, Denmark, France, Germany, Ireland, Luxembourg, Norway, Sweden, the Netherlands, and the United Kingdom, a joint initiative has been established "to facilitate the further cost-effective deployment of offshore renewable energy, in particular wind", excerpt quote from (North Seas Countries 2016).

This overall aim is envisaged "through voluntary cooperation, with the aim of ensuring a sustainable, secure and affordable energy supply in the North Seas Countries, thereby also facilitating further interconnection between North Seas Countries and – whilst focusing on a step-by-step approach – with the perspective of further integration and increased efficiency of wholesale electricity markets in the longer term, contributing to a reduction of greenhouse gas emissions and in average wholesale price spreads and to enhanced security of supply in the region", excerpt quote from (North Seas Countries 2016).

The political declaration is supplemented by a work program from 2016 to 2019 that covers four main areas. Each of these areas is assigned to a specific support group (SG).

Maritime spatial planning (SG 1)

- Development and regulation of offshore grids and other offshore infrastructure (SG 2)
- Support framework and finance for offshore wind projects (SG 3)
- Standards, technical rules and regulations in the offshore wind sector (SG 4)

The work of SG 4 on standards, technical rules and regulations in the offshore wind sector comprises seven topics as summarized in Table 1.

Table 1: Topics of SG 4 (North Seas Countries 2016)

Topic	Description
1	The harmonization of rules concerning aviation markings and lights
2	The harmonization of health and safety requirements
3	The alignment of crew and vessel requirements
4	The mutual recognition and harmonization of certification standards for components in offshore wind projects
5	Exchanging best practices on park layout constraints including line of sight requirements
6	The establishment of a common approach, for example by establishing facilities for innovation, testing and demonstration of new technology
7	Investigating a common approach to rules applicable to offshore turbines in territorial waters and exclusive zones

This study about site investigation contributes to topic 5 as part of the scope of works addressed to SG 4.

Overall, the technical planning of an offshore wind farm requires comprehensive information about the site conditions, such as for example wind, sea state, water levels or soil conditions to name the most relevant ones, only. This information is usually obtained through site-specific measurements and investigations. Of course, the park layout, which is synonymous with the term ‘wind farm layout’, depends largely on aerodynamic aspects. For example, the adequate spacing of the turbines shall minimize the adverse wake effects from neighbored turbines. In addition, the appropriate choice of the individual turbine locations shall minimize the risk that results from geological features, such as for example glacial channels or areas with boulders. Thus, soil investigation is assigned to the planning of the wind park layout.

The focus of this study is on the soil investigation for the purpose of technical planning. Other regulative requirements, like for example the environmental impact assessment or gathering meteorological-oceanographic data, are not addressed here but without questioning their importance within the overall consent process. For this, in the following, the term ‘site investigation’ is synonymous with the term soil investigation.

As for most of the technical aspects in the wind farm design, also for the site investigation, a range of standards, technical rules and guidelines is available. However, this normative and regulatory framework can be different in the individual countries.

In accordance with the overall objective of the political declaration this study is also addresses the potential alignment of the relevant normative and regulatory framework to ensure a sustainable, secure and affordable energy supply.

At first, the procedures in the individual countries are presented. Subsequently, their advantages and disadvantages are worked out. Finally, components of the existing procedures are identified which are potentially suitable for alignments among the countries. In this context technical aspects, regulatory aspects as well as commercial aspects will have to be taken into account. The study shall answer the following main questions

- What practices are applied in which countries, and why?
- What are the relevant rules, and why?
- What are the advantages and disadvantages of the respective standards and methods?
- In what areas would an alignment be possible, and how to achieve?

In consideration of these main questions, the detailed scope for this study is arranged into four pre-defined work packages.

Work package 1

- Set-up of the detailed work plan
- Set-up of the project schedule including relevant milestones and interactions with SG 4
- Outline of the current site investigation procedure in Germany

Work package 2

- Research and outline of the current site investigation procedures in the North Seas Countries
- Comparison of the procedures in the North Seas Countries
- Identification of differences and similarities between the procedures

- Identification of pros and cons of the procedures

Work package 3

- Identification of components potentially suitable for a future alignment and the required subsequent steps
- Identification of components unsuitable for an alignment
- Estimate of cost reduction that results from an alignment in consideration of the relevant support regime for offshore wind energy

Work package 4

- Compilation of the final report and presentation of the results

4 Backgroundinformation

Beside publicly available information, background information provided in discussions with relevant stakeholders from the industry and member states is considered as an indispensable source of information. The support from the wind energy sector was therefore an essential prerequisite of the planned scope.

The site investigation procedure in Germany has been outlined as part of the deliverables of work package 1 in (Fichtner 2018) and is included in section 7.4 of this study. For most of the North Seas Countries at least a brief outline of the regulatory procedure for site investigation could be derived from public information. Particularly in the Netherlands, Denmark and Germany, the competent authorities provide comprehensive public information sources on the regulatory system and on technical details of site investigations carried out for wind farms in the course of the respective auction procedures. The regulatory requirements for site investigation are described in section 7 of this report.

A more detailed comparison of the performed site investigations for exemplary projects complements the results of work package 2. The scope of the geotechnical soil investigation has been compared for different North Sea countries based on publicly available data like for the Dutch wind farms Borssele, Hollandse Kust and the Danish wind farms Kriegers Flak and Horns Rev 3. Although Kriegers Flak is not located in the North Sea, due to the comprehensive published data, it has been considered as valuable for this comparison.

Detailed background information regarding costs for site investigation and in particular about potential future cost reductions turned out to be very sensitive. In view of the strong competition in the offshore wind energy sector, it is all too understandable that the industry and authorities are very cautious to provide such information. Nevertheless, at least some current cost information from the market environment is obtained in the course of the study and is provided in section 9 of this report.

Due to the different intended priorities in the development of offshore wind farms, the initially envisaged harmonization of technical rules for the planned site investigation is not considered to be a realistic scenario within a reasonable timeframe.

Rather, the mutual understanding of the different intentions and the ongoing exchange about best practices for site investigation appears to be the most promising way forward.

Summarizing, this study gives an important contribution to the overarching aim of the political declaration (North Seas Countries 2016), which has already found its way into a statement of the North Seas Energy Cooperation (North Seas Energy Cooperation 2019).

5 Excursus on technical systems for geophysical and geotechnical site investigation

Despite the different regulatory frameworks in the individual countries, comparable systems are generally used for the field works of the site investigations. In particular as the same vessels with its equipment for field testing are used in several North Seas countries. In addition, to a certain extent an adjustment will take place for laboratory testing due to the transfer from ISO standards into EN standards and subsequent national standards by the national standards committees. For example, triaxial testing, which is one of the most-frequently used laboratory tests, is standardized by EN ISO 17892 parts 7 to 9 which have already been issued as corresponding national standards by for example DIN and BSI.

A concise description of typical systems is contained in the relevant standards, such as (ISO 2014) or (BSH 2018). More detailed information including pros and cons of the individual systems is given in the relevant technical literature but also in public available studies as for example in Volume 2 and Volume 3 of (Fugro 2017). In general, the continuous improvement of design approaches is expected to lead to an increasing use of more sophisticated investigation techniques.

6 Excursus on ISO 19901 part 8

The international standard on marine soil investigation for offshore structures of the petroleum and natural gas industry (ISO 2014), which has been transferred by the CEN into a European standard and subsequently established as a national standard in the individual countries by its relevant national standardization committees, is widely used as an overall standard for the planning and execution of geotechnical site investigations for offshore wind farms in Europe.

The standard provides recommendations and guidelines for marine site investigations regarding:

- Objectives, planning and execution of marine site investigations including guidance on relevant requirements on Health Safety and Environment (HSE) as well as on quality assurance (QA) for marine operations
- Deployment of the investigation equipment, for example either non-drilling mode or drilling mode, requirements on accuracy of vertical depth measurement and positioning
- Drilling and logging to meet the objectives of the drilling, to choose the adequate technique for the present ground conditions, and to record relevant drilling parameters
- In situ testing including a description of the equipment, the test procedure, the checks and the presentation of results for most-frequently used tests like the cone penetration test, the pore pressure dissipation test, the ball and T-bar penetration test, the seismic cone penetration test or the field vane test
- Sampling, handling, transport and storage of samples including guidance on the use of different sampling tools in dependency of the encountered ground conditions and the objective of soil sampling
- Laboratory testing, preparation of samples for testing and presentation of results. The detailed procedures for laboratory soil testing are not part of the standard. For this the informative annex F of (ISO 2014) provides a brief description and a reference to the relevant standards for about thirty of the most-frequently used tests for classification and index testing, strength testing, consolidation and stiffness, cyclic testing, small-strain testing, heat conductivity, soil corrosiveness, to name only some thereof
- Reporting including the requirements on the description of the field operations, the presentation of the measured data, the derived geotechnical parameters, the data interpretation and the evaluation of representative geotechnical parameters

Geophysical investigations are not covered by this standard. Furthermore, the investigation of rock is only included “to the extent that ordinary marine soil investigation tools can be used, e.g. for chalk, calcareous soils, cemented soils or similar soft rock”, excerpt quote from (ISO 2014). Thus, the sole use of this standard does not cover the entire range of the site investigation that is required for the assessment of the relevant ground conditions. For this, supplementary guidance on geophysical investigations is given in section 5.2 of (ISO 2014) by a reference to the recommendations of the ISSMGE (ISSMGE 2005) and in section 6.3 of (ISO 2014) to the recommendations of the IHO (IHO 2008) and (OGP-IMCA 2010). For the investigation of rock a reference is made to annex F.13 of (ISO 2014) that provides supplementary references to relevant standards as ASTM, BSI, ISO or part 2 of Eurocode 7.

Without prescribing a mandatory scope for the specific project in question, section 5.2 of (ISO 2014) contains recommendations for possible phases of the site investigations. Generally, the investigation can comprise three main parts:

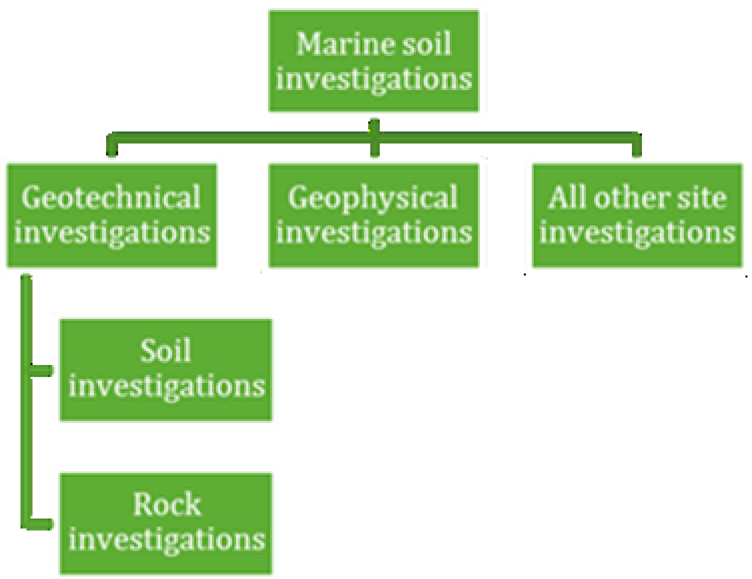
- A desk study to evaluate available public information and previous investigations
- Shallow geophysical investigations which typically comprise bathymetry and seafloor topography by use of echo sounder or swath bathymetry, seafloor features and obstacles by use of side-scan sonar and magnetometer, seabed stratigraphy by use of high-resolution reflection seismic
- Geotechnical investigations that can comprise several phases, adapted to the required level of detail of the project planning

According to (ISO 2014) the definition of the detailed scope and the sequence of the investigation is subject to project-specific requirements.

Due to its origin and beside the gap regarding geophysics and rock material, the standard does not cover all of the relevant aspects for the foundations of offshore wind energy turbines. Thus, supplementary guidance should be used to set-up an adequate site investigation for offshore wind farms. Nonetheless, the principles that are laid out in this standard and the comprehensive guidance on usual soil testing is a valuable basis for the planning of the site investigation for offshore wind farms, even more since in most of the cases the same vessels with its field testing apparatus and drilling technique are used for offshore wind farms as well as for other offshore structures throughout Europe.

The different types of the site investigation as described in the ISO standard are illustrated in the figure below (ISO 2014). As already described, for the planning and the assessment of geophysical investigations further guidance is required in addition to the ISO 19901-8.

Figure 2: Overview about the several types of marine soil investigation according to ISO standard



Source: Own illustration, Fichtner Water & Transportation GmbH

7 Regulatory requirements for site investigation in the North Seas Countries.

7.1 Belgium

Up to now in Belgium, no mandatory requirements about the site investigation procedure are defined by the competent authorities, which are at foremost the 'Federal Public Service for Economy, SMEs, Self-Employed and Energy' and the federal regulator CREG (CREG 2019). Generally, a concession and several follow-up permits are required for example in view of the environmental impact and the construction of the wind farm. Without stepping into details of the subsidy system, the grid connection is generally provided by the transmission system operator Elia (Elia 2019). In the absence of more definitive requirements by the authorities, the site investigation is usually carried out in accordance with international acknowledged standards, such as for example (ISO 2014) and in compliance with the general requirements of relevant standards for offshore wind energy such as for example (DNV GL 2018).

7.2 Denmark

7.2.1 General procedure for the development of offshore wind farms

This section outlines the procedure that is relevant for the project developer of a Danish wind farm. Up to now, the grid connection is executed by the transmission system operator which he will hand over to the wind farm developer afterwards. The conditions for offshore wind farms are defined in the Promotion of Renewable Energy Act. According to section 3 of this Act the right to exploit energy from water and wind within the territorial waters and the exclusive economic zone (up to 200 nautical miles) around Denmark belongs to the Danish state.

Energistyrelsen (ENS), the Danish Energy Agency, serves as a 'one-stop-shop' for the project developer. Three of the main important licenses that are granted by ENS are:

- License to carry out preliminary investigations
- License to establish the offshore wind turbines (license is only given if the preliminary investigations show that the project is compatible with the relevant interests at sea)
- License to exploit wind power for a certain number of years, and an approval for electricity production (only given if the conditions of the license to establish the project are kept).

Generally, there are two procedures for the development of offshore wind projects in Denmark (Agora and DTU 2015), (ENS 2015), (ENS 2017):

- Open door procedure
- Tendering procedure (which is the common procedure for recent projects)

The tendering procedure is carried out for a designated area, whereas the 'open door procedure' invites unsolicited applications for areas not yet reserved for tendering procedures. Recent projects however where solely established by the tendering procedure. For both procedures, the project developer must acquire all three licenses.

Within the governmental tendering procedure, ENS selects a site for which interested developers can participate into a tender process. The idea behind the tendering scheme is to implement new offshore wind farms at specific sites in the most cost-efficient way. For large scale offshore wind farms the transmission system operator Energinet constructs, owns and maintains both the transformer station and the export cable to land.

7.2.2 Site investigations for the tendering phase

Upon instruction by ENS the national independent transmission system operator carries out site investigations (geophysical and geotechnical) in advance of the call for tenders for an offshore wind farm (ENS 2017).

Based on the results from a desk study and the preliminary geophysical investigation, the applicants can submit recommendations for additional tests and investigations that shall be carried out during the preliminary geotechnical investigation campaign (Energinet 2013c). The transmission system operator decides together with ENS if the planned scope shall be changed or extended.

The resulting technical reports about the geophysical and geotechnical investigations are made available to the applicants on the transmission system operator's website (energinet.dk) and in due time before end of the tendering phase. ENS informs the applicants about the costs of the preliminary site investigations in the course of the tendering procedure. As the applicant has to bear these costs, they have to be included into the applicant's bid.

This early action is implemented in order to give applicants better possibilities to offer a price that is based on most realistic costs. The preliminary site investigation reports provide fundamental data for the determination of relevant soil conditions and for the design of the foundation types.

Besides others, the provided tender documents include a draft investigation permit. The successful applicant of the tendering procedure can expect a governmental investigation permit soon after completion of the tendering process.

The investigation permit allows the developer to conduct further geotechnical and geophysical investigations, if applicable, in the area of the wind farm and the cable route to supplement the investigations that were already carried out during the tender process.

7.2.2.1 Exemplary scope for geophysical investigations

For recent offshore wind farms in Denmark the ENS has appointed the Danish transmission system operator Energinet to tender and contract geophysical seabed surveys. In the following the scope for the geophysical surveys as input for the development phase of the wind farms Kriegers Flak, Horns Rev 3 and Thor is outlined based on published information. The wind farm Kriegers Flak is not located in the North Sea, but the scope is provided for additional information.

7.2.2.1.1 Offshore wind farms Kriegers Flak in the Baltic Sea and Horns Rev 3

The specifications by the ENS include:

- Detailed mapping of the surface of the seabed including objects of biological relevance, archaeological relevance, man-made objects, natural seabed features, geohazards (Energinet (2013a)
- Geophysical investigations in the wind farm area to set up a preliminary three-dimensional geological model to a minimum depth of 100 metres below seabed (Energinet (2013a)
- Map geological layers and structures well below the expected maximum foundation depth, which is assumed with approximately 30 to 60 m below seabed (Energinet (2013a)

The objective of the geophysical survey is to obtain adequate information to establish a geological understanding of the offshore areas to a minimum depth of 100 metres below seabed and to provide input to environmental, biological, archaeological and unexploded ordnance device 'UXO' evaluations. The geophysical survey shall provide input to the design of a subsequent and separate geotechnical testing and sampling program.

The objective of the marine cable route survey between the offshore wind farm and the corresponding landfall is to assist in planning of the sea cable routes and to provide input to environmental, biological, archaeological and unexploded ordnance device evaluations. Furthermore, the survey shall provide information for the design of the cables and the installation operations.

The following operational requirements were defined by the Danish transmission system operator Energinet for the geophysical survey for the wind farms Kriegers Flak and Horns Rev 3, taken from (Energinet 2013a). The specific devices that were finally used for individual parts of the survey to meet the functional requirements may differ from the exemplary devices.

- Survey along 100 m line spacing and crossing lines every 1000 m to achieve:
  - Full coverage by multi beam echo sounder with an accuracy of order 1a surveys according to (IHO 2008)
  - Full coverage by side scan sonar, 200 % coverage with two different high frequencies
- Three sub bottom profiler (SBP) systems run 2 by 2:
  - Relative high frequency SBP system, for example 'pinger', along every line
  - Relative medium frequency SBP system, for example 'sparker', along every second line
  - Relative low frequency multichannel SBP system, for example 'air gun', along every other second line
- Magnetometer, gradiometers consisting of two magnetometers along every line
- 1 x 1 km grid: To establish a general overview of the geology in the wind farm area and to evaluate acoustic possibilities and limitations

7.2.2.1.2 Offshore wind farm Thor (ENS 2019a), (ENS 2019b)

- High-resolution bathymetric mapping
  - 100 % coverage of the wind farm area
  - Target of mapping: water depth
  - Deliverables: overview digital terrain model, detailed digital terrain model, contour curves
- Acoustic surface mapping, ferromagnetic reconnaissance
  - 100 % coverage of the wind farm area
  - Target of mapping: seabed surface
  - Deliverables: maps of surface geology, maps of surface morphology, maps of man-made objects
  - Magnetometer survey along all survey lines with a line spacing of 100 m
  - The anomalies of the magnetometer do not replace an UXO investigation. As a guidance however, the detected anomalies are classified as either natural or anthropogenic (ENS 2019b)
  - Side scan sonar with dual frequency, 200 % coverage of the wind farm area, detect all objects larger than 0.5 m
  - Multi beam echo sounding with full coverage, at least IHO special order survey, digital terrain model with 0.25 m spatial resolution, re-survey after approximately 1 year

- (Ultra-)High-resolution seismic system and medium-resolution seismic system
  - 100 % coverage of the wind farm area
  - Target of mapping: seabed geology
  - Deliverables: maps of soil unit interfaces related to chart datum and related to seabed elevation, thickness of main geologic units, 3D geological model
  - The 3D geologic model of the wind farm site is derived based on the geophysical surveys. However, according to (ENS 2019b) this 3D geologic model is not based on a '3D seismic survey', which would not be possible within the scheduled time frame of the surveys.
  - Ultra high resolution survey with 250 m line spacing and penetration to 100 m below seabed (ENS 2019b)
  - High-resolution seismic profiling with penetration to 10 m below seabed, line spacing 100 m, single channel receiver system
  - Medium-resolution seismic profiling with penetration to 60 m below seabed, line spacing 500 m, multi-channel receiver system
- Requirements on positioning
  - Horizontal positioning tolerance less than 0.5 m for vessels
  - Horizontal positioning tolerance less than 2.5 m for towed equipment

According to (ENS 2019a) the geophysical survey does not deviate from the technical requirements laid out in the BSH standard (BSH 2014), except for organizational matters.

Note: According to (BSH 2014) the geological survey for turbine locations requires order 1b surveys for multi beam echo sounder and in accordance with IHO (IHO 2008). According to part D of (BSH 2014) IHO special order surveys (IHO 2008) are required for the inner-array cable routes and the export cable routes. Thus, the basic requirements of ENS for IHO special order surveys are even above the minimum standard as specified in (BSH 2014).

For the geophysical site survey three elements of quality control are foreseen by ENS: offshore client representatives during mobilization and investigation, verification of the deliverables by qualified geotechnical engineers and contract terms for deliverables.

7.2.2.2 Exemplary scope for geotechnical investigations

The following scope was contracted by the Danish transmission system operator Energinet for the preliminary geotechnical investigations for the wind farms Kriegers Flak (GEO 2013a) and Horns Rev 3 (GEO 2013b). The offshore wind farm Kriegers Flak is not located in the North Sea, nevertheless the scope is provided here for further information. In addition, the scope for the future Danish offshore wind farm Thor is outlined based on published information (ENS 2019a) and (ENS 2019b).

7.2.2.2.1 Offshore wind farm Horns Rev 3 (GEO 2013b)

- Piezo-cone penetration testing (CPT)
  - 28 deep pushed seabed CPT at 28 locations with an average depth of 30.6 m
  - Supplementary boreholes at 12 of the CPT locations
- Borehole drilling including down the hole CPTs (DTH-CPT)
  - 12 geotechnical boreholes drilled 50-80 m below seabed including soil sampling
  - DTH-CPT performed in every borehole

- Pressuremeter tests performed in 4 boreholes

► Laboratory tests on soil samples

Offshore laboratory works include:

- Extruding Shelby tubes and splitting PVC liners for hammer samples and core samples
- Core logging, geological description of all samples
- Photography of all Shelby tubes, core samples and hammer samples
- Pocket penetrometer test on appropriate cohesive soil samples
- Determination of moisture content
- Determination of bulk density
- Determination of total core recovery for all cores
- Selection and preservation of disturbed and undisturbed subsamples for onshore testing

Onshore laboratory works include:

- Moisture content
- Bulk and dry density
- Particle size distribution
- Liquid and plastic limit
- Particle density
- Maximum and minimum dry density of granular soils
- Organic content
- Chloride content
- Carbonate content
- Sulphat content
- Degree of roundness of sand
- Thermal conductivity
- Saturation moisture content
- One-dimensional consolidation properties of soil
- Unconsolidated undrained triaxial compression (UU triaxial test)
- Anisotropically consolidated undrained triaxial compression test (CAU triaxial test)
- Consolidated drained triaxial compression Test (CD triaxial test)
- Direct simple shear test
- Cyclic CAU triaxial test

The onshore laboratory works were conducted based on standards of CEN ISO/TS, ASTM, BSI and Deltares in-house work procedures.

7.2.2.2.2 Offshore wind farm Kriegers Flak in the Baltic Sea (GEO 2013a)

► Piezo-cone penetration testing (CPT)

- 67 deep pushed seabed CPTs at 42 locations with an average depth of 13.7 m
- Supplementary boreholes at 12 of the CPT-locations

► Borehole drilling including down the hole CPTs (DTH-CPT)

- 17 geotechnical boreholes drilled 50-70 m below seabed including soil sampling
- DTH-CPT performed in every borehole
- Pressuremeter tests performed in 4 boreholes

- Laboratory tests on soil samples

Offshore laboratory works include:

- Extruding Shelby tubes and splitting PVC liners for hammer samples and core samples
- Core logging, geological description of all samples
- Photography of all Shelby tubes, core samples and hammer samples
- Pocket penetrometer test on appropriate cohesive soil samples
- Determination of moisture content
- Determination of bulk density
- Determination of total core recovery for all cores
- Determination of rock quality designation for all limestone cores
- Determination of induration and fissuring on undisturbed limestone cores.
- Selection and preservation of disturbed and undisturbed subsamples for onshore testing

Onshore laboratory works include:

- Moisture content
- Bulk and dry density
- Particle size distribution
- Liquid and plastic limit
- Particle density
- Maximum and minimum dry density of granular soils
- Organic content
- Chloride content
- Carbonate content
- Sulphate content
- Degree of roundness of sand
- Thermal conductivity
- Unconfined compression test on fine grained soil
- Saturation moisture content
- One-dimensional consolidation properties of soil
- Unconsolidated undrained triaxial compression (UU triaxial test)
- Anisotropically consolidated undrained triaxial compression test (CAU triaxial test)
- Consolidated drained triaxial Compression Test (CD triaxial test)
- Direct simple shear test
- Cyclic CAU triaxial test

The onshore laboratory works were conducted based on standards of CEN ISO/TS, ASTM, BSI and Deltares in-house work procedures.

7.2.2.2.3 Offshore wind farm Thor (ENS 2019a), (ENS 2019b)

The following scope of the preliminary geotechnical survey for the Thor wind farm is taken from the published information about the dialogue on site investigations (ENS 2019a) and (ENS 2019b).

Generally, the BSH standard ground investigations (BSH 2014) is used as a guideline for planning and performance of the site investigations.

The scope for geotechnical investigations of the 440 km^2 area comprises:

- Boreholes
  - 15 to 20 borehole locations with soil sampling (ENS 2019b)
  - Target depth: 50 to 70 m below seabed

- ► Cone penetration testing (CPT)
  - 60 to 80 CPT locations (ENS 2019b)
  - Various modes: continuous from seabed, down-the-hole, blind-drilled boreholes
  - PS logging is included for a limited number of CPT locations
  - Target depth: 50 to 70 m below seabed
- ► Laboratory testing
  - Water content
  - Saturated moisture content
  - Bulk density
  - Grain size distribution
  - Atterberg limits
  - Particle density
  - Maximum and minimum dry density of granular soils
  - Organic content (loss in ignition)
  - Degree of roundness of sand
  - Advanced laboratory testing includes triaxial and shear tests, over-consolidation ratio (OCR), thermal resistivity and pore pressure dissipation (ENS 2019b)

According to (ENS 2019a) the scope of the geotechnical preliminary investigations deviates from the BSH standard (BSH 2014) in view of organizational matters and due to the fact that the turbine locations are not determined yet.

The authors of this study would like to add, that comparably with German wind farms at the time of the preliminary site investigation the final park layout is usually not determined.

Three elements of quality control are foreseen by ENS for the preliminary geotechnical investigations: offshore client representatives during mobilization and investigation, verification of the deliverables by qualified geotechnical engineers and contract terms for deliverables.

7.2.2.2.4 Amount of boreholes and CPT for recent projects

An overview about the number of borehole locations and CPT locations for the preliminary site investigation of recent Danish wind farms is taken from (ENS 2019a) and summarized in Table 2. More detailed information about the preliminary geotechnical site investigation for Horns Rev 3 is taken from (Geo 2013b) and for Kriegers Flak from (Geo 2013a).

Table 2: Number of borehole locations and CPT locations for the preliminary geotechnical site investigation (ENS 2019a)

Offshore wind farm	Borehole locations with soil sampling and/or CPT (including PPDT, SCPT etc. if applicable)	Depth of boreholes below seabed, TD = target depth	Locations with seafloor CPT (including PPDT and SCPT etc., if applicable)	Depth of seafloor CPT below seabed
Horns Rev 3	12	TD: 4 x 50 m TD: 8 x 70 m	28	15.7 – 48.4 m
Kriegers Flak (Baltic Sea)	17	TD: 11 x 50 m TD: 6 x 70 m	42	0.6 – 26.7 m
Vesterhav Nord	3	n.a.	12	n.a.
Vesterhav Syd	2	n.a.	12	n.a.
Thor (planned)	15 - 20	TD: 50 - 70 m	60 - 80	TD: 50 - 70 m

7.2.3 Detailed design phase

After contract award by the ENS, the developer elaborates the preliminary farm layout. In the following, the developer performs an additional geotechnical site investigation based on the preliminary farm layout and the provisional foundation design. The extent of the additional geotechnical investigation is determined by the developer or his engaged geotechnical engineer, respectively.

7.3 France

In France, up to now no mandatory requirements about the site investigation for offshore wind farms are defined by the authorities. Since, except of prototypes, no large-scale offshore wind farm were installed yet in France, the detailed approval procedure is still under development. The authorities have not yet classified these specific structures at sea and their corresponding planning principles.

Despite the pending regulatory requirements, special guidance on site investigation for offshore wind turbines is already developed from a technical point of view. A non-binding guidance about the site investigation for offshore wind energy has been published by the non-governmental 'French Committee of Soil Mechanics and Geotechnics'. The actual version of the recommendation (CFMS 2019a), (CFMS 2019b) provides guidance on the determination of the met-ocean site data, the geotechnical site data and the calculative models for foundation design. Separate chapters are dealing with the geotechnical design of the most frequently used foundations types, which are monopiles, pile foundations in general and gravity base foundations.

Generally, the recommendation (CFMS 2019b) intends to compensate for the absence of normative documents or national regulatory requirements about the design and construction of foundations for offshore wind turbines in French territorial waters and the French EEZ.

The French recommendation (CFMS 2019b) summarizes relevant guidance from existing overall standards and recommendations. In particular, reference is made to the relevant rules of

DNVGL, BSH and ISO. The actual versions of these standards are (DNV GL 2018), (BSH 2014) and (ISO 2014). Furthermore, the recommendations from ISSMGE (ISSMGE 2005) and SUT (SUT 2014) are considered. For specific soil conditions, such as for example chalk, the recommendation (CFMS 2019) refers to acknowledged international publications. In addition, the French recommendation refers to the French standard on pile foundations NF P94-262 (AFNOR 2012) which is a relevant national application standard for the European standard Eurocode 7.

The list of geotechnical standards, which are valid in France, is published by the BNTRA (BNTRA 2018). The present list as of September 2018 is available for example at the website of the CFMS. However, according to note 4 of this list (BNTRA 2018) the use of specific standards is not mandatory in France, except for those standards that refer to earthquake, fire and public safety. For the remaining fields of application, other standards than the listed ones may be used in France subject to the acceptance by the insurance company and in accordance with the hierarchy of standards and other documents introduced in the decree of 28 August 2006 on the technical specifications of contracts and framework agreements and its revised version of 3 October 2011, respectively. Within the limits of this framework, the developer can define the governing standards according to his discretion.

According to the recommendation of the CFMS (CFMS 2019b), the geological and geotechnical information shall be determined according to an acknowledged standard. No specific standard is requested, for this the developer can choose from several standards, like for example ISO, BS, ASTM or NF.

Although the ISO-standard on marine soil investigations (ISO 2014) was primarily developed for the oil and gas industry, it is considered in (CFMS 2019b) to provide relevant guidance on

- The planning and implementation of geotechnical reconnaissance campaigns
- The implementation of drilling, coring and in situ testing systems
- Soil sampling, transport, storage
- The performance of laboratory tests on standard or advanced type samples including
- Cyclic and dynamic tests
- The presentation of results and the contents of reports.

In addition to these basic recommendations about applicable standards the recommendation (CFMS 2019b) provides a detailed guidance on the degree of detail for the geophysical and geotechnical investigations as well as on the step-wise planning of the site investigation. Furthermore, the suitability of different investigation techniques, such as for example cone penetration testing or side scan sonar, is rated with school grades from 1 to 5 for the several objectives of the site investigation campaign.

7.3.1 Step-wise approach

The proposed site investigation scheme comprises three phases with increasing degree of detail. The step-wise approach is summarized in Table 3 that is taken from (CFMS 2019b).

Table 3: Project phases and the objectives of the corresponding site investigation

Project stage	Project sub stage	Activity	Objective of the project stage Assessment of geotechnical risks	Geological studies, geophysical and geotechnical recon-naissance to be carried out
Preliminary	Conceptual design	Pre-project	Pre-selection of the structures and foundations types Financial and technical assessment of the project	Compulsory geological (bibliographical) study (DTS) Constitution of the initial geological model Optional geophysical and/or geotechnical reconnaissance
Preliminary	Conceptual design	Project draft	Major risks assessment Confirmation of tenders in the French context Validation of the technical options Validation of the financial assessment Drawing up of the general building principles Choice of the structures and foundations type Constructional implementation Pre-dimensioning of foundations Installation feasibility of foundations and cables	Compulsory preliminary geophysical and geotechnical reconnaissance. Objectives: Identification of the major geotechnical hazards Definition of the stratigraphy and lithology Constitution of the stratigraphic and geological site models Definition of the geotechnical parameters for the pre-dimensioning of foundations for each geological province Preliminary characterization of cable routes and installation conditions
Project	Basic design FEED	Design	Significant risks assessment Validation of the construction means, of costs and of schedule Dimensioning for each group of wind turbines Investment decision and switch to construction stage	Compulsory detailed geophysical and geotechnical reconnaissance Objectives: Identification of the significant hazards Definition of the stratigraphic profiles and of the geotechnical parameters profiles for the dimensioning of the foundations Constitution of the geotechnical model Definition of the cable laying and burial conditions If necessary, feasibility tests regarding installation or burial

Project stage	Project sub stage	Activity	Objective of the project stage Assessment of geotechnical risks	Geological studies, geophysical and geotechnical recon-naissance to be carried out
Project	Detailed design	Detailed construction studies	Minor or localised risks assessment Detailed study of each wind turbine. Dimensioning for each foundation. Burial predictions. Detailed installation procedures for foundations and cables. Remediation procedures	Additional specific reconnaissance(s) if required Objectives: Identification of minor or localised hazards
Project	Installation	Installation	Installation follow-up	Implementation of monitoring
Operation	Inspection Mainte-nance	Inspection Mainte-nance	Ensuring the long-term stability and safety of the structures Organizing the feedback regarding the behaviour of structures	Scour monitoring (bathymetry) Instrumentation set up and data analysis

7.3.2 Preliminary geophysical site investigation for wind turbines

The proposed extent and the recommended resolution of the preliminary geophysical investigation by multi beam echo sounders, side-scan sonars and boomers or sparkers is described in the guidance of the CFMS, too. The summary of these recommendations is given in Table 4 which is taken from the CFMS-guidance (CFMS 2019b).

Table 4: Recommended extent and resolution of the geophysical site investigation

Objective	Method	Grid	Penetration	Notes
Seafloor topography	Bathymetry with multi beam echo sounder (MBES)	Full field coverage with a 50 % to 100 % overlap T: 20 % overlap	N/A	Processing of MBES data by backscattering is recommended Single-trace echo-sounder to calibrate the MBES
Seafloor morphology Nature of surface sediments	Side Scan Sonar (dual frequency)	Full field coverage with a 50 % to 100 % overlap	N/A	R: collect samples to calibrate sediments nature: grab sampler (or gravity corer)
Stratigraphy	Single- or multi-trace seismic reflection Source: boomer or sparker for significant penetrations; R: to be complemented with pinger/chirp for shallow penetrations	250 m x 1000 m (cross lines) grid	Typically: 50 -100m (depending on soil/rock conditions) Resolution: < 1m in depth Pinger/chirp: Resolution < 0.3m	Full field coverage Surface seismic reflection required on all cables routes, see ch. 5.6.5 of (CFMS 2019b)

Abbreviations: R = specific recommendation, T = tolerated, N/A = not applicable

7.3.3 Preliminary geotechnical site investigation for wind turbines

For the specification of the recommended equipment, the implementation and the quality requirements of the preliminary geotechnical site investigation, the CFMS guideline (CFMS 2019b) refers to an international set of rules (ISSMGE 2005) and (ISO 2014). Generally, the following scope of Table 5 is recommended for the preliminary geotechnical site investigation.

Table 5: Recommended scope for preliminary geotechnical site investigation

Objective	Method	Programme	Penetration	Notes
Stratigraphy Nature of soils and identification Basic geotechnical properties Typical geotechnical profile for each geological province Assessment of the geotechnical properties of materials and their spatial variability	Coring and boreholes with in-situ tests, such as CPTU, PMT or HPDT and/or with well logging (natural radioactivity, pressure wave velocity, shear wave velocity)	Achievement of twin boreholes*: 1 borehole with continuous coring/sampling 1 borehole with in-situ tests At least a couple of boreholes for each geological province and/or Single boreholes such as: Alternated bore-hole** for CPTU/coring/sampling borehole with CPTU as continuous as possible, if relevant Borehole with continuous coring/sampling and well logging To be distributed on the whole field to establish the spatial variability of the site	Sufficient to: cross the main formations and understand their configuration at the scale of the site establish pro-files of geotechnical parameters along the part influenced by foundations	* Prioritize twin-boreholes if relevant and low number of provinces ** Alternated boreholes may prove financially attractive in the preliminary stage

7.3.4 Main geophysical site investigation for wind turbines

The recommended extent of the main geophysical site investigation is summarized in the following Table 6 that is taken from (CFMS 2019b).

Table 6: Recommended extent of the main geophysical site investigation

Objective	Method	Grid	Penetration	Notes
Seafloor topography	Bathymetry with multi beam echo sounder (MBES)	Coverage of each structure location with overlap of 100 %	N/A	Size depends on the type of structure (wind turbines, meteorological mast, transformation substations and cables)
Seafloor morphology Surface obstructions	Side Scan Sonar (dual frequency)	Coverage of each structure location with overlap of 100 %	N/A	Size depends on the type of structure (wind turbines, meteorological mast, transformation substations and cables)
Stratigraphy	Single- or multi-trace seismic reflection source: boomer or sparker for significant penetrations chirp for small shallow penetrations	Two perpendicular lines for each structure	Depending on the type of foundation and on specific objectives	
Measurement of pressure wave velocity by seismic refraction	Refraction (dragged on the seafloor or static)	On structures locations: to be defined according to objectives Cable route: continuous profile	5 to 20 m depending on objectives 5 m	
Measurement of shear wave velocity by surface wave	Multichannel analysis of surface waves (MASW)	On structures locations: to be defined according to objectives	5 to 15 m depending on objectives	

Abbreviations: N/A = not applicable

7.3.5 Main geotechnical site investigation for wind turbines

The recommended extent of the main geotechnical site investigation is summarized in the following Table 7 that is taken from (CFMS 2019b).

Table 7: Recommended extent of the main geotechnical site investigation

Objective	Method	Type of founda-tion	Programme	Penetration
Final dimensioning of foundations Installation studies	Coring/sampling boreholes Boreholes with in-situ tests such as CPT/CPTU Boreholes with in-situ deformation tests (PMT, HPDT) Mixed boreholes with alternating coring/sampling and in-situ testing	Piled Monopile Gravity base Shallow with skirts Anchoring	Piled: 1 borehole at the centre of each wind tur-bine location Monopile: 1 borehole at the centre of each location Gravity base: 1 borehole at the centre of each location + 3 boreholes on the periphery* Shallow foundation with skirts: 1 borehole at the centre of each location + 3 CPT boreholes on the periphery* Anchoring: 1 borehole at each anchor location	Piled: Anticipated pile length + 3 times pile diameter as a minimum Monopile: Anticipated monopile length + 0.5 times pile diameter as a minimum Gravity base: 1.5 times foundation width but penetration of at least 2m in the substratum Shallow with skirts: At least 10m penetration or until refusal (CPT) 1.5 times foundation width but penetration of at least 2m in the substratum Skirts height + 2 m; min. 5m Anchoring: Depending on the anchor type and nature of soils

* in case of a strong geological or geotechnical heterogeneity

In addition to the commonly performed cone penetration tests and borings, pressuremeter testing and gamma ray testing are addressed in the CFMS guidance (CFMS 2019b). This type of testing is also briefly addressed in the ISO standard on marine site investigations (ISO 2014).

Pressuremeter tests, such as the Pressuremeter Ménard Test (PMT) or the High Pressure Dilatometer Test (HPDT) can be a supplementary testing method to investigate the in-situ stress-strain relationship of the soil in particular for hard material such as hard clays, dense sands or rock. The gamma ray testing is proposed as a specific type of in-situ testing of rock material to determine the stratigraphy and the in-situ density of the rock, see section 5.4.2.2 of the CFMS guidance (CFMS 2019b).

7.3.6 First phase of site investigation for cable routes

A two-phase site investigation is recommended for cable routes, as outlined in two separate chapters of (CFMS 2019b). The first phase is intended to:

- Guide the choice of the layout of cable corridors
- Evaluate the risk to the cables and define their level of protection
- Define the target burial depth
- Determine the feasibility of the installation methods.

The proposed extent of the site investigation is summarized in the following Table 8 that is taken from (CFMS 2019b).

Table 8: Recommended extent for the first phase of the site investigation for cable routes

Objective	Method	Grid	Penetration	Notes
Seafloor topography	Depending on Table 5.8 of (CFMS 2019b)	Depending on Table 5.8 of (CFMS 2019b)	Depending on Table 5.8 of (CFMS 2019b)	
Seafloor morphology Nature of surface sediments	Depending on Table 5.8 of (CFMS 2019b)	Depending on Table 5.8 of (CFMS 2019b)	Depending on Table 5.8 of (CFMS 2019b)	
Stratigraphy	Depending on Table 5.8 of (CFMS 2019b). Prioritize accuracy over penetration on the first 5 to 10 metres.	Depending on Table 5.8 of (CFMS 2019b). Prioritize accuracy over penetration on the first 5 to 10 metres.	Depending on Table 5.8 of (CFMS 2019b). Prioritize accuracy over penetration on the first 5 to 10 metres.	
Characterization of the nature and strength of soils and rocks over the anticipated depth of cable burial	Depending on context: Gravity coring, vibro coring, rotary coring, CPT/CPTU carried out from a seabed frame	Typically: 20 to 30 borehole locations for a 100 km^2 site	Most often: 2 to 3 metres depending on the planned burial depth, exceptionally up to 5 metres	Often carried out during the geotechnical preliminary reconnaissa nce
Thermal insulation	Thermal conductivity measure: made in-situ by using a probe set by push penetration or on sampled cores	A few measures for each geological province	Most often: 2 to 3 metres depending on the planned burial depth	

7.3.7 Second phase of site investigation for cable routes

The second phase of the site investigation for cable routes is intended to:

- Allow cable routing in previously defined corridors
- Confirm and specify the target burial depths according to the required degree of protection and their variation along the route
- Determine the installation technique that is suitable for the soil conditions, for example the appropriate type of machines and tools, power requirements
- Predict operational conditions and their variation along the cable route
- Locate areas requiring special treatment for cable installation and cable protection

This second phase of the site investigation is carried out in the design phase. The recommended extent of the second phase of the site investigation is summarized in the following Table 9 that is taken from (CFMS 2019b).

Table 9: Recommended extent for the second phase of the site investigation for cable routes

Objective	Method	Grid	Penetration	Notes
Seafloor topography	Multibeam bathymetry (MBES)	200 m corridor* centred on the cable axis, with a 50 % to 100 % overlap	NA	*Corridor width to be defined in dependency of the heterogeneity of the subsurface geology and amount of obstructions
Seafloor morphology Nature of surface sediments if appropriate signal processing (backscattering)	Side scan sonar	200 m corridor* centred on the cable axis, with a 100 % overlap	NA	*Corridor width to be defined in dependency of the heterogeneity of the subsurface geology and amount of obstructions
Stratigraphy	High resolution seismic reflection source: to be defined depending on geology (pinger /chirp)	One run on the cable axis and two runs at a 100 m distance from each other. Even transversal cross-checks (about 300 m to 500 m)	Prioritize accuracy on the first 3 to 5 metres	
Characterizing continuously the soil conditions over the burial depth by using pressure wave	Ultra high resolution seismic refraction implemented very close to the seafloor (system	One run on the cable axis	3 to 5 metres	Seismic streamers will be of the short type (typically: 24 m) with a minimum of 24 geophones spread

Objective	Method	Grid	Penetration	Notes
velocity or shear wave velocity	dragged on the seafloor or towed just above seabed) Optional: combined seismic refraction and MASW			so that they will collect as many information as possible on the first 2 to 3 metres
Characterizing punctually the nature and strength of soils and rocks over the foreseeable burial depth	CPT/CPTU carried out from a seabed frame Gravity coring, vibro coring, rotary coring from underwater boreholes	One borehole every 300 to 1000 m depending on the complexity of the subsurface geology	Most often: 2 to 3 metres depending on the planned burial depth, exceptionally up to 5 meters	
Thermal insulation	Thermal conductivity measurements: in-situ with a probe installed by push penetration or on samples	A few measurements for each geological province	Most often 2 to 3 metres depending on the planned burial depth	

* if needed and not obtained during the preliminary stage

7.3.8 Site investigation for substations

The recommended site investigation for substations is briefly outlined in the separate section 5.6.6 of the CFMS-guidance (CFMS 2019b) with reference to the relevant chapters of the site investigation for wind turbines. According to (CFMS 2019b) the site investigation for substations should be combined with the site investigation for the wind turbine locations. With reference to the recommended site investigation for wind turbine foundations, the extent of the site investigation for substations shall be adjusted to the intended foundation type and the soil conditions.

7.4 Germany

Since the Offshore Wind Energy Act (Windenergie-auf-See-Gesetz, WindSeeG) came into force on 1 January 2017, the subsidy for offshore wind energy has been determined on a competitive basis. Tenders have been introduced for all offshore wind farms that will start operation from 2021 onwards. After a transitional phase for wind farms that start operation from 2021 to 2025 the tender will be issued in the so-called 'central model' for wind farms that will start their operational phase from 2026 onwards. According to the government's plan a cumulated capacity of up to 15 GW will be installed in the North Sea and the Baltic Sea by 2030. According to current planning, a cumulated capacity of 7.7 GW will be connected to the grid in the North Sea and the Baltic Sea by 2020 (BNetzA 2019).

In Germany the connection of the wind farm to the land-side electrical grid (landfall) is built by the assigned TSO. In particular, Tennet, who acts on behalf of the German state, provides the grid connection for wind farms in the North Sea. The grid connection comprises the export cables and the required substation that compiles the electricity of a wind farm cluster into an export cable. The intended areas for offshore wind energy and the timeline for their development including grid connection within the 'central model' are defined in the national site development plan 'Flächenentwicklungsplan' (BSH 2019f). This plan is a bundled continuation of the national planning previously carried out using several instruments, beside others for example the former 'Bundesfachplan Offshore' (BSH 2017). In 2018 and 2019 the Site Development Plan will be prepared for the first time and will be updated in the following.

The competent agency for the allocation of the connection or promotion is the Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (Bundesnetzagentur BNetzA). The competent agency for permits regarding the marine spatial planning and the construction of the wind farm in the EEZ is the Federal Maritime and Hydrographic Agency (Bundesamt für Seeschifffahrt und Hydrographie BSH). For offshore wind farms within the territorial waters of the 12 nm zone in the North Sea these permits are granted by the local authorities of the relevant Federal states, which are Lower Saxony and Schleswig-Holstein, respectively.

In the German territorial waters of the 12 nm zone the procedures for the site investigations are defined by the mandatory national standards which are issued by the German institute for standardization DIN. As certain standards and regulations are not automatically valid in the EEZ, the procedure for site investigations in the German EEZ is specifically regulated by the Standard Ground Investigations (BSH 2014) that has been elaborated by an expert group on behalf of the BSH. Due to its supplementary guidance on the specific requirements for offshore wind farms, this standard is usually also applied for site investigation within the German territorial waters. In the future, the recently published part 4 of the DIN standard 18088 (DIN 2019) will provide bundled requirements for the site investigations, once officially introduced as a mandatory standard by the competent authorities. However, in the German EEZ the Standard Ground Investigations (BSH 2014) will remain the main mandatory standard for ground investigations.

7.4.1 Site investigations - Phases

The standard ground investigation (BSH 2014) defines a detailed and stepwise procedure for the site investigation that has to be carried out in parallel to different project development phases and the permit procedure. Thus, a defined milestone of the permit procedure requires the completion of a corresponding milestone of the site investigation. The key phases of the ground investigation are depicted in the following tables that are taken from (BSH 2014). In particular, the BSH standard (BSH 2014) does also specify a certain range of investigations for the operational phase of the wind farm to monitor the structural integrity of the foundations.

In addition to the requirements on the surveys and the testing, also the minimum requirements on the reporting and the presentation of the results are defined in the BSH standard (BSH 2014).

Table 10: Site investigation for the development phase according to BSH standard

Phase	Measure	Purpose and objective of exploration	Type of exploration	Work steps/supporting documents
Develop-ment	Detailed clarification for the site; Planning including preliminary design of the structure of the plant	Preliminary investigation of the area; Site selection and preliminary planning of structures; The preliminary investigation aids decision-making as to whether the planned offshore structures can be built with regard to the ground conditions, and if necessary also which general requirements are essential for the foundation concepts, the foundation structure and the construction process and which measures are important for site investigations. Fundamentals for invitations to tender on foundation planning and construction	Review, assessments and evaluations of available supporting documents; Geological survey in the entire area of the construction site; Preliminary geotechnical investigations, i.e. representative exploration by means of direct and indirect exposures (a coarse grid over the construction site) and representative determination of the essential parameters and characteristics of the ground conditions.	Evaluation of available supporting documents; Geological survey; Preliminary geotechnical investigations (drilling and/or probing, laboratory and/or field tests); Supporting documents to be submitted with the design basis and the preliminary design: Geological report, Preliminary geotechnical site investigation report, Soil and foundation expertise (Development phase). All documents audited by an inspector

Table 11: Site investigation for the construction phase according to BSH standard

Phase	Measure	Purpose and objective of exploration	Type of exploration	Work steps/supporting documents
Construc-tion	Fundamental design (basic design)	The scope of the geotechnical investigation and studies, and the choice of investigation methods is determined by the type, size and importance of the construction of the wind energy plants/substations, the uniformity of the structure of the ground conditions, the morphology of the seabed and existing ground types. The area under investigation must also take possible deviations from the plan into account with regard to the location of structures. The structure of the ground conditions and the sediment characteristics must be individually recorded for each construction site.	Review and assessing available supporting documents; Direct explorations by drilling at the sites of the offshore structures; Indirect explorations by probing at the sites of the offshore structures; Laboratory tests via sediment samples on sites	Main geotechnical investigations (drilling and/or probing, laboratory and/or field tests); Supporting documents to be submitted in connection with the basic design: Main geotechnical site investigation report, Soil and foundation expertise, (Construction phase) Supplementary report regarding soil behavior under cyclic loading, Evidence on the geotechnical and structural safety and suitability for use All documents shall be audited by an inspector
	Implementa-tion planning	Final design of the structure; The necessary studies depend on the type of foundation. They must be suitable in type and in scope for establishing all dimensions of the foundation and to keep all records appertaining to structural safety and suitability for use	Supplementary direct exposures at the sites of the foundation elements; Supplementary indirect explorations at the sites of the foundation elements; Laboratory tests via sediment samples on sites; In certain circumstances pile driving and pile load tests may be carried out	Supplementary exploration and investigation Supporting documents to be submitted in connection with the final planning documents: Supplementary report regarding cyclical loads in the context of the Standard Design audited by an inspector

Table 12: Site investigation for the execution and operational phase according to BSH standard

Phase	Measure	Purpose and objective of exploration	Type of exploration	Work steps/supporting documents
Execution	Erection	Production of the foundation elements; Inspection of the ground conditions with regard to consistency with the design; inspection of production of the foundation body; monitoring of the development of excess pore water pressure in the load-bearing part of the foundation; monitoring of subsidence and tilting of the foundation body.	Pile driving log/pile driving report, manufacturing report regarding in-situ concrete piles; Eventual deformation measurements, as far as is reasonable; Eventual excess pore water pressure measurements, as far as is reasonable;	Monitoring in the construction phase Supporting documents to be submitted in connection with the inspection documents: Reports of findings and assessments in the context of Standard Design audited by an inspector
Operations	Operations maintenance and monitoring	Monitoring structural behavior under working loads; It should be made possible to be able to take counter-measures in good time against behaviors, which differ from those in the design. Monitoring sediment dynamics in the cable route corridors within and outside the windfarm.	Deformation measurements on selected offshore structures within the offshore wind farm; Monitoring scour at regular intervals on each foundation	Operations monitoring (geotechnical monitoring) Supporting documents to be submitted in connection with the inspection documents: Reports of findings and assessments audited by an inspector

According to (BSH 2014) the site investigation (field works, lab testing, reporting) is divided into a geological and a geotechnical site investigation.

Geological investigations shall be carried out to obtain a general overview of the site conditions in the wind farm area. As an example, by use of geophysical surveys heterogeneous ground conditions, seabed features or potential obstacles can be identified. The minimum methods and requirements for geological surveys with geophysical methods are described in (BSH 2014):

- Echo-sounding measurements
  Objective: Bathymetric of the seabed / water depth within the windfarm area
- Side scan sonar (SSS) investigations
  Objective: Topography of the seabed
- Seismic investigations
  Objective: General subsoil conditions
- Magnetometers or active metal detection systems
  Objective: Detection of wrecks, cables, unexploded ordnance devices 'UXO' etc.

The geotechnical investigations are divided into two phases, the preliminary investigation in the development phase and the main investigation in the construction phase.

In the preliminary phase, at least 10% of the planned turbine locations shall be investigated by geotechnical testing (BSH 2014). Often, the wind farm layout is not finished at this stage of the project. Therefore, the corners of the wind farm and additional locations within the wind farm area are usually explored.

In the construction phase at least one site investigation has to be carried out at each turbine location. For offshore substations usually a minimum of four site investigations shall be carried out (corner areas or locations of pile foundations).

Besides the described two 'main phases' for site investigations, which belong to the development phase and the construction phase of the project, the site investigation shall also be carried out during the operational phase of the wind farm to monitor the foundation's behavior. For this reason, the site investigations in operating phase is focused on geophysical measurements, e. g. to monitor potential scour development or to confirm the integrity of an optional scour protection system.

The BSH standard (BSH 2014) provides detailed requirements on the degree of accuracy and the extent of the site investigations. In addition to the requirements that are already specified by the governing Eurocode 7 and the relevant national standards the requirements on geophysical investigations are summarized in part B of the standard. The following tables that are taken from (BSH 2014) provide a summary thereof.

Table 13: Requirements on echo sounding (BSH 2014)

Phase	Geological survey	Inspection
Objectives	Detection of local depth changes (potential scour)	
Scope	Full coverage	In the local surroundings of the foundation elements of the offshore structures
Timing	Once	In the initial years after completion check once per year, early on in the year
Method	Multi-beam echo sounder (MBES) Positioning better than 5m +5 % of water depth as well as accuracy for reduced depths in accordance with IHO (2008) for Order 1b surveys	Multi-beam echo sounder (MBES) Positioning better than 5 m + 5 % of water depth as well as accuracy for reduced depths in accordance with IHO (2008) for Order 1a surveys
Presentation of results	Bathymetric map of the areas surveyed Water depths must be adjusted for water sound propagation and illustrated based on CD (LAT) (Tidal correction) Data must also be submitted in digital format and with sufficient supporting documentation	Bathymetric map of the areas measured Water depths must be adjusted for water sound propagation and illustrated based on CD (LAT) (Tidal correction) Data must also be submitted in digital format and with sufficient supporting documentation

Table 14: Requirements on side scan sonar (BSH 2014)

Phase	Geological survey	Inspection
Objectives	Summary of the present sediment types and sediment structures. Validation and calibration of the findings by means of ground truthing.	Detecting erosion areas, scour or obstacles. Validation and calibration of the findings by means of ground truthing.
Scope	Sections in accordance with seismic measurements or extensively over the offshore construction site Extensively within areas with heterogeneous sediment cover	In the local surroundings of the foundation elements of the offshore structures
Timing	Once	In the initial years after completion check once per year, early on in the year
Method	Frequency of 100 kHz or higher Measured area is a maximum of 2 x 100 m Recognition of objects > 1 m in grid spacing* Digital recording Cruising speed max. 4 kn, provided that the equipment used does not demonstrably allow for higher cruising speeds Positioning of the equipment is better than 10 m	Frequency of 100 kHz or higher Measured area is a maximum of 2 x 75 m Recognition of objects > 1 m in grid spacing Digital recording Cruising speed max. 4 kn Positioning of the equipment is better than 10 m
Presentation of results	Digital SSS mosaic of the section (horizontal resolution from 0.5 m) Map with interpretations of the side scan sonar sections Data must also be submitted in digital format and with sufficient supporting documentation (internal format)	Digital SSS mosaic of the section (horizontal resolution from 0.5 m) Map with interpretations of the side scan sonar sections Data must also be submitted in digital format and with sufficient supporting documentation (internal format)

Table 15: Requirements on seismic investigations (BSH 2014)

Phase	Geological survey
Objectives	Detecting the type and location of geological units
Scope	Use of grids for exploration of the offshore construction site, recommendation: spacing of the seismic grid of 500 m in longitudinal and transverse directions. In case of differences in similar grid positions due to certain features of the construction site, a maximum spacing of 1000 m must not be exceeded.
Timing	Once
Method	Boomers or alternative systems with comparable or better performance and sufficient signal penetration, resolution of at least 1 m required close to the surface Supplementary sub-bottom profilers or chirp sonar for areas close to the surface (e. g. along the planned cable route corridors), vertical resolution of at least 0.5 m Cruising speed: max. 4 kn Usage up to sea state of 4, when systems are used together with a so-called ‘motion sensor’ then usage up to swell 5 or 6 is justifiable
Presentation of results	Section with interpretation (i.e. geological longitudinal sections and transects) Map with the geographical location of geological units and structure elements (e. g. isolines map) Data must also be submitted in digital format and with sufficient supporting documentation (internal format).

Table 16: Requirements on magnetometers or active metal detection systems (BSH 2014)

Phase	Geological survey
Objectives	Primary inspection of the study area for wrecks, cables in and out of operation, metal parts and other hazardous objects such as e. g. ordnance (provided it can be detected)
Scope	Depending on necessity in accordance with the findings of the Desk Study (Stage 1, see Table 1) In any case within ammunition prone areas and areas close by, sections corresponding to the seismic profile grid or covering the whole area if necessary
Timing	If required
Method	Magnetometer If ordnance is suspected, or within areas where munitions are suspected, then within a gradiometer arrangement Resolution < 0.1 nT Alternatively: an active metal detection system which measures total intensity Cruising speed: max. 4 kn Use up to a maximum sea state of 4 The altitude of the magnetometer over the ground should be chosen depending on the geophysical study findings. If ordnance is suspected, then lower than 4 m.
Presentation of results	Map with investigation findings List of anomalies discovered incl. comparison with the findings of SSS investigations. The data must also be submitted in digital format and with sufficient supporting documentation.

The required depth of investigation is indirectly defined by a reference to DIN EN 1997 part 2 (DIN 2010). According to annex B.3 of (DIN 2010), the geotechnical investigation for piles shall be carried out down to 3 times the pile diameter below the expected pile tip or rather a minimum of 5 m below the expected pile tip. It is assumed that this recommendation applies primarily to axially loaded piles. For shallow foundations, the site investigation should be carried out at least up to 1.5 times the shorter foundation length below the foundation base. In individual cases, a well-founded deviation from this recommendation is possible, e.g. by taking the dominant direction of loading and the existing subsoil conditions into account.

7.4.2 Site investigations for cables and substations

Analogue to the site investigation for offshore structures, part D of the BSH standard (BSH 2014) defines minimum requirements on the site investigations for cable routes for the inter-array cables and the export power cables (BSH 2014).

7.4.3 Responsible body for site investigations

Until 31 December 2025 the applicant or the owner of the wind farm is responsible for all parts of the preliminary and main site investigation campaign as described in (BSH 2014).

For wind farms that start operation from 01 January 2026 onwards and beginning with the 'centralized auction model', on behalf of the BNetzA the BSH will take over the following scope within the preliminary geotechnical investigations for wind farms in the EEZ:

- Desk study
- Geophysical survey
- Preliminary geotechnical investigation
- Geological report

The associated factual reports and raw data will be forwarded to each of the applicants. The interpretation of the provided data will be part of the applicant's work.

The main geotechnical site investigation, the preparation of the geological report, the preliminary and main soil investigation reports and the preliminary and main soil and foundation expertise reports fall under the responsibility of the auction winner.

7.4.4 Geotechnical expert

According to the (BSH 2014) and based on the requirements from DIN 4020 the works related to the geotechnical investigations will be carried out by a suitably qualified and independent geotechnical expert with documented experience in this field of works. The geotechnical expert acts on behalf of the applicant or holder of the wind farm license, respectively.

The geotechnical expert:

- Plans the preliminary geotechnical site investigation and the main geotechnical site investigation
- Accompanies the execution of the preliminary geotechnical site investigation and the main geotechnical investigation,
- Prepares the geotechnical site investigation report (development and construction phase)
- Prepares the soil and foundation expertise report (development and construction phase)

For geophysical investigations, a comparable position, namely a 'geophysical expert', is not defined in the relevant standards.

7.4.5 Geotechnical investigations

The scope of site investigations (number of locations, depth, method, soil samples, quality of specimen, type and number of geotechnical lab tests etc.) is specified by the 'Geotechnical Expert', see section 7.4.4 of this report. The minimum requirements on geotechnical investigations as a basis for planning and designing for offshore structures are described in (BSH 2014):

- Planning of field investigations: investigation methods, direct explorations by drilling and sampling, indirect explorations by soundings and in-situ measurements
- Soil and rock sampling
- Supplementary investigations

Furthermore, the minimum requirements for geotechnical laboratory testing are regulated in (BSH 2014).

- Standard laboratory tests for assessing non-cohesive soils and cohesive soils
- Tests to analyze the soil behaviour under cyclic loading and requirements for the determination of the relevant cyclic load level

7.4.6 Exemplary scope of geophysical investigations

The exemplary scope of geophysical investigations is taken from (BSH 2019a) and (BSH 2019e). For the considered areas N-3.7 and N-7.2 already some geophysical data exist from previous investigations that shall be completed by supplementary investigations. The scope for the geophysical survey of the areas N-3.7 with approximately 21 km^2 and N-7.2 with approximately 94 km^2 comprises

- Sub-bottom profiler survey including sound velocity profile
  - Maximum cruising speed relative to ground < 4 kn
  - Investigation of the upper approximately 15 m of the ground
  - The allowable lateral deviation from the pre-defined survey lines is limited to 10 m
  - The required recording window is 35 ms from seabed level
  - To ensure sufficient quality of the recorded data the survey can be carried out up to a maximum significant wave height 1.5 m
  - Data processing: transformation into SEG Y data exchange format
- Single channel seismic survey
  - Maximum cruising speed relative to ground < 4 kn
  - Maximum offset between source and receiver perpendicular to direction of travel < 10 m, in direction of travel < 5 m
  - Investigation of the upper approximately 30 m of the ground
  - The allowable lateral deviation from the pre-defined survey lines is limited to 10 m
  - The required recording length is 250 ms

- To ensure sufficient quality of the recorded data the survey can be carried out up to a maximum significant wave height 1.5 m
- Data processing: transformation into SEG Y data exchange format

► Multi channel seismic survey

- Maximum cruising speed relative to ground < 4 kn
- Investigation of the upper approximately 100 m of the ground
- Maximum offset between source and nearest receiver perpendicular to direction of travel < 10 m, in direction of travel < 10 m
- Maximum offset between source and farthest receiver perpendicular to direction of travel < 10 m, in direction of travel < 10 m
- The allowable lateral deviation from the pre-defined survey lines is limited to 10 m
- The required recording length is 500 ms
- To ensure sufficient quality of the recorded data the survey can be carried out up to a maximum significant wave height 1.5 m
- Data processing: transformation into SEG Y data exchange format

► Overall aims of the geophysical survey

- The surveys contribute to the preliminary site investigation for selected areas of the German ‘site development plan’
- The surveys shall be carried out in accordance with the BSH standard on ground investigations (BSH 2014)
- To establish a complete and grid-shaped geophysical survey of the ground as a data basis for the Geologic Report
- To derive a 3D ground model of the identified geologic strata
- Determination of locations for further geotechnical investigations by boreholes and cone penetration testing
- The investigation for wrecks, "UXO", archaeological heritage and other obstacles is explicitly not an intended scope of the preliminary site investigation that is provided by the BSH to the bidders of an auction process. Thus, the gathering and interpretation of information about these issues is solely in the response of the project developers.

According to the BSH standard (BSH 2014), the lateral distance between the survey lines for detecting the type and location of geological units should not exceed 500 m in longitudinal and transverse directions. The geophysical surveys described above will have a grid line spacing between 150 m to a range of about 400 to 600 m. The total length of the survey lines is approximately 298 km for N-3 and approximately 1302 km for N-7 (BSH 2019e).

7.4.7 Exemplary scope for geotechnical investigations

The exemplary scope for the geotechnical preliminary site investigation is taken from (BSH 2019c), (BSH 2019d) and (BSH 2019f). The entire scope for the geotechnical investigation of the four areas N-3.5, N-3.6, N-3.7 and N-3.8 with a total area of approximately 99 km^2 comprises:

► Boreholes

- 10 borehole locations with soil sampling according to DON EN ISO 22475-1
- Target depth for geotechnical investigation is 80 m below seabed

- Cone penetration testing (CPT)
  - 10 CPT locations, CPT according to DIN EN ISO 22476-1, the location of each CPT shall be as close as possible to the belonging borehole
  - Various modes: continuous from seabed, down-the-hole
  - Target depth for cone penetration testing is 80 m below seabed

- Geophysical testing at boreholes or CPT locations
  - Geophysical testing at 10 locations, either at the CPT locations or at the borehole locations
  - Measurement of P-wave velocity, in case of dense soil or rock material, additional measurement of S-wave velocity
  - Target depth for geophysical testing is 80 m below seabed

- Laboratory testing
  - Pocket penetrometer test, 5 tests at each of 100 samples
  - Particle size distribution by dry sieving analysis according to DIN EN ISO 17892-4, 175 tests
  - Particle size distribution by wet sieving according to DIN EN ISO 17892-4, 17 tests
  - Particle size distribution by combined sieving and sedimentation according to DIN EN ISO 17892-4, 33 tests
  - Particle size distribution by sedimentation according to DIN EN ISO 17892-4, 17 tests
  - Particle shape according to DIN EN ISO 14688-1, 60 tests
  - Water content according to DIN EN ISO 17892-1, 45 tests
  - Atterberg limits according to DIN EN ISO 17892-12, 50 tests
  - Shrinkage limit according to DIN 18122-2, 50 tests
  - Lime content according to DIN 18129, 122 tests
  - Loss of ignition (organic content), DIN 18128, 61 tests
  - Bulk density according to DIN EN ISO 17892-2, 160 tests
  - Particle density according to DIN EN ISO 17892-3
  - Density of non-cohesive soils for maximum and minimum compactness according to DIN 18126, 28 tests
  - Water permeability according to DIN 18130-1(in May 2019 replaced by DIN EN ISO 17892-11) , 28 tests
  - Oedometer test with 8 increments of loading and unloading according to DIN EN ISO 17892-5, 45 tests
  - UU triaxial testing according to DIN EN ISO 17892-8 and -9, 22 tests each of 3 individual tests
  - CU and CD triaxial testing according to DIN EN ISO 17892-8 and -9, 60 tests each of 3 individual tests
  - Direct shear tests at cohesive soil according to DIN EN ISO 18137-3, 30 tests each of 3 individual tests
  - Direct shear tests at non-cohesive soil according to DIN EN ISO 18137-3, 85 tests each of 3 individual tests
  - Unconfined compression test according to DIN EN ISO 17892-7, 22 tests
  - Laboratory vane test, analogue to the principles of DIN 4094-4, 22 tests

7.5 Ireland

The planned strategic development of offshore wind energy in Ireland is outlined in the Offshore Renewable Energy Development Plan that was published in 2014 by the former Department of

Communications, Energy and Natural Resources (DCENR 2014). An interim review of this plan was published in May 2018 by the Department of Communications, Climate Action and Environment (DCCAE 2018).

Generally, at present the offshore wind energy is at present focused on pilot projects or demonstration projects. The establishment of large-scale commercial projects and the related official requirements including those on the site investigation procedure, are still in the preparatory development phase.

In particular, at present no specific requirements on the applicable standards and the extent of the site investigation are published by the relevant authority DCCAE.

The General Scheme of the Maritime Area and (Foreshore) Amendment Bill was published 2013 to adapt the consent system to the future challenges that are involved with the envisaged promotion of offshore wind energy (DHPLG 2013).

The 'maritime area' comprises the foreshore, the exclusive economic zone and the continental shelf area. According to the updated bill of 2013 the planning and development in the 'maritime area' requires a consent from the An Board Pleanála, which is an independent statutory planning board or from planning authorities. In addition, a project will furthermore require consents from the Irish state in accordance with other legal requirements.

The 'An Board Pleanála' is the competent authority for projects that

- Are strategic infrastructure projects
- Require an Environmental Impact Assessment (EIA) or Appropriate Assessment (AA)
- Are beyond the 12 nautical miles zone.

In addition, the 'An Board Pleanála' is the competent authority for projects that are entirely beyond the nearshore area. The 'nearshore area' is defined as "the bed and the shore, below the line of high water of ordinary or medium tides and above the line of low water of ordinary or medium tides, of every tidal river and tidal estuary and of every channel, creek and bay of the sea and of any such river or estuary", excerpt quote from (DHPLG 2013).

The planning permission from the relevant planning authority will be required for projects that are entirely within the nearshore area or partially on land and partially in the nearshore area, and that neither are considered as strategic infrastructure projects nor require an EIA or AA. Depending on the location of the project one of the following will be the competent planning authority: the counties of Louth, Meath, Fingal, Dun Laoghaire-Rathdown, South Dublin, Wicklow, Wexford, Carlow, Kilkenny, Cork, Kerry, Clare, Galway, Mayo, Sligo, Leitrim and Donegal or the cities of Dublin, Cork and Galway and Waterford City and County and Limerick City and County, see (DHPLG 2013).

The recently published general scheme of the Marine Planning and Development Management Bill (MPDM) is outlined by Beauchamps (2019).

7.6 Luxembourg

Luxembourg does not have territorial waters or an exclusive economic zone within the North Sea. Therefore, no offshore wind farms are planned in areas that fall under Luxembourg's responsibility.

7.7 Norway

In Norway offshore wind energy is considered mainly as an export market for the Norwegian offshore industry. According to the Norwegian energy minister, the focus is to strengthen the supplier industry rather than to install offshore wind farms in Norway (Windpoweroffshore 2018). Even more, since Norway has large areas suitable for onshore wind and without the need to go offshore. Norwegian companies developed and tested floating concepts for offshore wind energy turbines as for example Equinor's 'Hywind' project in Scotland (Equinor 2019).

7.8 The Netherlands

7.8.1 Roadmap and tendering scheme

The legislative framework for offshore wind energy in the Netherlands is made of four main acts, namely

- The Water Act ('Waterwet')
- The Offshore Wind Energy Act ('Wet windenergie op zee')
- The Economic Affairs Subsidies Framework Act ('Kaderwet EZ-subsidies')
- The Electricity Act ('Elektriciteitswet 1998').

These acts are supplemented by several governmental decrees, in particular the Water Decree ('Waterbesluit', namely paragraph 6A), the Stimulation of Sustainable Energy Production Decision ('Besluit stimulering duurzame energieproductie') and the Decision compensation scheme for offshore grid ('Besluit schadevergoeding net op zee'). The legislative framework is illustrated for example in (RVO.nl 2017a).

The roadmap of the Dutch government schedules tenders of 700 MW each year from 2015 to 2019 and future tenders for additional 6,100 MW from 2020 to 2026 (RVO.nl 2016a), (RVO.nl 2016b), (RVO.nl 2017a), (RVO.nl 2018a), (RVO.nl 2019a), (RVO.nl 2019b). The tendered wind farm zone Borssele V is intended as a special innovation site. The planned wind farm zones are summarized inTable 17.

Table 17: Road map for wind farm zones in the Netherlands

Wind farm zone	Installed power (rounded)	Date of tender	Year of commissioning
Borssele I + II	752 MW	2016	2020
Borssele III + IV	731.5 MW	2016	2020
Borssele V	19 MW	2018	2021
Hollandse Kust (zuid) I + II	740 MW	2017	2022
Hollandse Kust (zuid) III + IV	700 MW	2019	2023
Hollandse Kust (Noord)	700 MW	2019	2024
Hollandse Kust (West)	1400 MW	2021	2024 to 2025
Ten Noorden van de Waddeneilanden	700 MW	2022	2026
IJmuiden Ver	4000 MW	2023 to 2025	2027 to 2030

The developer of a wind farm is provided by the Dutch government with the permit for building the wind farm, the preliminary site data of the wind farm, the connection to the electrical network and - if required – with a subsidy.

Each developer that intends to build an offshore wind farm in the Dutch territorial waters or the Dutch exclusive economic zone has to provide a proposal for the tendered wind farm zones. The tender process is organized by the Rijksdienst voor Ondernemend Nederland (RVO.nl) on behalf of the Dutch Ministry of Economic Affairs and Climate Policy. The evaluation of the submitted tenders is based on defined criteria that are for example outlined in (RVO.nl 2017b), (RVO.nl 2017c). Based on a scoring system the RVO will award the contract to the tenderer that best meets the following six criteria.

- Social costs: The higher the estimated annual net electricity generation the more efficient is the use of the offshore grid and the lower are the social costs that are involved with the project. The lower the social costs the higher the score.
- Knowledge: The larger the track record of the involved companies and suppliers in offshore wind the larger the score
- Design quality: The more specific the project plan and the more precise the relevant milestones are specified the higher the score.
- Capacity: The higher the offered capacity of the wind farm the higher the score
- Risks: The more detailed potential risks that are associated with e. g. a changed price of electricity, the construction of the wind farm, the operation of the wind farm are analyzed the higher the score.
- Measures: The more comprehensive the applied risk mitigation measures are the higher the score.

Following the general trend in offshore wind, subsidy-free tenders won the recent competition, thus the subsidy is not the main criterion for the evaluation of the bids any longer.

For preparation of the tender preliminary site information is provided by the RVO to the tenderers. Exemplarily, reference is made to the Borssele wind farm site III and IV, for which the reports about the geophysical survey, the geotechnical investigations, the morphodynamics and the met ocean desk study are published at the RVO's website (https://offshorewind.rvo.nl). The provided site investigation data comprise laboratory test results, maps of geologic cross sections, maps of geo hazards, borehole logs, CPT logs to name the most important ones only. In dependency of the final wind farm layout additional site investigation has to be performed by the successful tenderer at the final turbine locations.

7.8.2 Site investigation data provided by RVO

The RVO provides the developers with comprehensive information about the site conditions in the course of the tendering process. The objective and the extent of the provided information are exemplarily outlined for Hollandse Kust site III and IV (RVO.nl 2018a), (RVO.nl 2018b) and Borssele sites III and IV (RVO.nl 2016b), (RVO.nl 2016 c). Generally, the investigation comprises a geophysical investigation and a subsequent geotechnical investigation.

According to (RVO.nl 2018b) the main objective of the geophysical site investigation is to

- Obtain data for the wind farm development, in particular but not limited to the foundation design and the cable burial
- Determine the accurate sea floor elevation
- Provide information about seabed features, natural and man-made objects, unexploded ordnance devices 'UXO' and other obstacles, albeit without the provision of 'UXO' clearance certificates but on the level of a desk study
- Provide geological interpretation of the ground, locate structural complexities or geohazards like for example shallow gas, channels, faulting
- Provide input for the specification of the geotechnical sampling and testing

According to (RVO.nl 2018b) the main objective of the geophysical site investigation is to

- Further develop the ground model of the site, determine the spatial variation of the seafloor and the ground conditions
- Provide geotechnical data for, but not limited to, the design of foundations and cables
- Development of the geologic ground model to 100 metres below lowest astronomical tide (LAT)
- Avoid the need for future sampling boreholes

In view of this objective, it is considered appropriate to designate the entire investigation as a 'preparatory' investigation rather than a 'preliminary' investigation. The objective of avoiding future sampling boreholes is particularly noteworthy. If, contrary to expectations, an additional geotechnical investigation should become necessary at individual locations, comparatively inexpensive CPT should be sufficient to provide the missing information.

The Dutch authorities have not specified a minimum scope for the site investigation. However, the site survey shall comply with acknowledged standards. The geophysical survey shall comply with

- The Dutch Standard for Hydrographic Surveys for the multi beam echo sounder acquisition, which is based on IHO recommendations (Rijkswaterstaat 2009)
- The SEG Y rev 1 for trace headers (SEG 2002)
- The IHO Manual on Hydrography (IHO 2005)
- The IHO Standards for Hydrographic Surveys (IHO 2008)

Seabed cone penetration testing shall comply with

- EN ISO 22476-1
- EN 1997-2
- ISO 19901-8
- BS 5930
- BS 1377
- Or client approved equivalent

Downhole seismic cone penetration tests and the data processing shall be in accordance with

- ISO 19901-8
- ASTM D7400-08
- Or equivalent

Downhole piezo cone penetration tests and the data processing shall be in full accordance with

- ISSMFE reference test procedures (ISSMFE 1989)
- EN ISO 22476-1
- EN 1997-2

The boreholes shall be performed in accordance with

- EN 1997-2 and ISO 19901-8

The borehole logs shall be compiled in consideration of

- EN ISO 14688-1 and EN ISO 14688-2

The equipment and the procedure for sampling shall ensure for good core recovery and high quality samples according to EN 1997-2 and ISO 19901-8. Soil samples of quality class 1 or 2 for cohesive soils and quality class 3 or 4 for non-cohesive soils are required. According to EN 1997-2 the sample quality is characterized by 5 'quality classes', whereas according to ISO 19901-8 the term 'application class' is used for the identical classification system of sample quality.

In practice, the preliminary site investigation and the corresponding reports may for example base on ISO-standard combined with British Standards to comply with the above requirements, like for example

- ISO 19901-8:2014. Petroleum and natural gas industries – specific requirements for offshore structures – part 8: marine site investigations (ISO 2014). See for example (RVO.nl 2016c)
- BS 1377-7:1990. Methods of test for soils for civil engineering purposes. Shear strength tests (total stress). See for example (RVO.nl 2016c). Note: meanwhile this British standard is replaced by BSI ISO 17892-7:2018 (BSI 2018a) and BS EN ISO 17892-8:2018 (BSI 2018b).
- BS 1377-8:1990. Methods of test for soils for civil engineering purposes. Shear strength tests (effective stress). See for example (RVO.nl 2016c). Note: meanwhile this British standard is replaced by BS EN ISO 17892-9:2018 (BSI 2018c).
- BS 5930:1999+A2:2010. Code of practice for site investigations. See for example (RVO.nl 2016c). Note: meanwhile the current version is BS 5930:2015 (BSI 2015).

The provided preliminary site information is reviewed by an acknowledged certifier to confirm the adequacy of the provided data for the preparation of a design basis in accordance with relevant offshore standards such as for example (DNV 2014) which is meanwhile replaced by (DNV GL 2018). The relevant statement of the certifier is provided with the geotechnical site investigation report as for example in (RVO.nl 2016c). The quality assurance by an independent review and the subsequent statement on the suitability of the preliminary site data as input for an auction process are unique in Europe.

The amount of borehole locations and seafloor CPT locations of the preliminary site investigation for selected Dutch offshore wind farms is summarized in the table below. The data of Borssele III are taken from (RVO 2016b) and (RVO 2016c). The data of Borssele IV is taken from (RVO 2016d) and (RVO 2016e). The data of Hollandse Kust Zuid sites III and IV is taken from (RVO 2018b), the data for Hollandse Kust (Noord) is taken from (RVO 2019c).

Table 18: Amount of borehole locations and exploration depth of recent preliminary site investigation for Dutch offshore wind farms

Offshore wind farm	Borehole locations with soil sampling and/or CPT (including PPDT, SCPT etc. if applicable)	Depth of boreholes below seabed, TD = target depth	Locations with seafloor CPT (including PPDT and SCPT etc., if applicable)	Depth of seafloor CPT below seabed
Borssele III	12	44.9 – 80.9 m	25	4.9 – 50.3 m
Borssele IV	11	49.9 – 60.0 m	24	8.6 – 49.6 m
Hollandse Kust Zuid, site III	9	TD = 50 – 65 m	25	26.1 – 51.1 m
Hollandse Kust Zuid, site IV	10	TD = 50 – 65 m	28	28.9 – 50.8 m
Hollandse Kust Noord	28 5	60 – 80 m 100 m	78	2.1 – 53.0

7.9 United Kingdom

Overall, the Department for Business, Energy & Industrial Strategy (BEIS) is the competent authority for offshore wind energy in the UK. For offshore wind farms in England, Wales and Northern Ireland a lease from the Crown Estate, which manages the seabed around England, Wales and Northern Ireland is required.

Generally, the regulatory regime in the UK separates the electricity production (i.e. the wind farm including the inner array cables) from the operation of the transmission system (i.e. the substation and export cables). The transmission system between the offshore wind farm and the landside electrical net can be built by either Offshore Transmission Owners (OFTO) or by the generator of electrical energy. However, if the transmission system is planned and built by the electricity generator in the course of the construction of the wind farm, which is the usual case, the transmission system has to be sold after completion of the construction. The necessary tender process of the transmission system is managed by Ofgem, the Office of Gas and Electricity Markets (Ofgem 2019).

The UK government is the competent authority for the subsidy regime in the UK. The recent subsidy system includes 'contracts for difference', abbreviated as 'CfD', which are granted to the successful applicant through an auction process. In this system, companies interested in the generation of offshore wind energy must take part in a competition procedure and provide a bid about the unit price for the generated electricity they are required to receive from the state or the Low Carbon Contracts Company (LCCC), respectively, that acts on behalf of the state. The difference between the selling price of the electricity on the electricity market and the guaranteed price ('strike price') demanded by the bidder is compensated by the contract. If the market price is below the strike price, the difference is paid to the generator by the LCCC. If the market price is above the strike price, the generator has to pay the difference to the LCCC. The contract between the generator and the LCCC, that is owned by the BEIS, is based on private law. The LCCC is the counterparty to the contracts awarded in CfD allocation rounds (auctions) and its primary role is to issue the contracts, manage them during the construction and delivery phase and make CfD payments. The Electricity Settlements Company (ESC), that is also owned by BEIS, oversees the settlement of the capacity market and ensures by contracts with capacity providers that sufficient capacity is available even at times of stress in the electrical system (LCCC 2019).

The existing CfD including the agreed strike prices are published in the CfD register that is published on the website of the LCCC.

7.9.1 Relevant authorities in England and Wales

Offshore wind farms of more than 100 MW, which is usually the case, are considered as nationally significant projects. For this type of projects that require a 'development consent' according to the Planning Act 2008, the Planning Inspectorate is the responsible government agency that administers the planning process. The Planning Inspectorate evaluates the planned project and gives an advice to the Secretary of State to either provide or to refuse the requested consent. According to its website (Planning Inspectorate 2019) "the Planning Inspectorate deals with planning appeals, national infrastructure planning applications, examinations of local plans and other planning-related and specialist casework in England and Wales. The Planning Inspectorate is an executive agency, sponsored by the Ministry of Housing, Communities & Local Government and the Welsh Government", excerpt quote from (Planning Inspectorate 2019).

The Marine Management Organisation, abbreviated as 'MMO', is the competent public body for the consent of offshore wind farms of more than 1 MW but less than or equal to 100 MW. The MMO is an executive non-departmental public body sponsored by the Department for Environment, Food & Rural Affairs. According to its website the MMO is responsible to "license, regulate and plan marine activities in the seas around England so that they're carried out in a sustainable way", excerpt quote from (MMO 2019). The inshore and offshore waters of England are divided into 11 plan areas as depicted in the map (MMO 2014).

7.9.2 Relevant authorities in Scotland

The Crown Estate Scotland manages the leasing of the seabed within the 12 nm zone and holds the rights to offshore renewable energy up to 200 nm from the coastline (Crown Estate Scotland 2019). In addition, the Crown Estate Scotland is the relevant authority for consents of short term activities like site investigations within this area.

The UK government is responsible for the subsidy regime that is relevant for offshore wind farms in Scotland whereas the Scottish government is responsible for the marine planning in Scotland. The relevant Scottish authority for the strategic marine planning, the environmental considerations, the regulatory compliance and the assessment of consent applications for projects is Marine Scotland. The integrated management of Scotland's seas is the main objective of Marine Scotland (Marine Scotland 2018) and (Marine Scotland 2019). In addition, Marine Scotland is responsible for the marine renewable energies and the sustainable economic growth of the marine renewable industry.

The Crown Estate Scotland provides the lease of a seabed to an applicant only if Marine Scotland has issued all of the necessary consents for the project in question. With regard to the design of the planned structures Marine Scotland requires a third party verification for test designs and a third party certification for commercial developments where 'type certification' is available for off the shelf products, see Annex B to (Marine Scotland 2018). The degree of the verification or certification is not prescribed by Marine Scotland but shall correspond to the degree that the investor requires for insurance purposes. The verification or certification, respectively, shall be carried out by an "independent accredited agency of recognised international standing and reputation" (excerpt quote) with sufficient experience. In particular, the applicable standards for design and the degree of detail for the following verification or certification shall be agreed between the applicant and the engaged verifier or certifier. Marine Scotland requires that the engaged independent certifier issues a certificate that clearly describes the level and the limitations of the performed review. The main objective of this independent review is to provide evidence to the Scottish ministers, the authorities and relevant stakeholders that reasonable due diligence has been undertaken. However, no specific requirements about the applicable standards for design or site investigation are defined by Marine Scotland. Rather, it is assumed by this approach that the mandatory engagement of an internationally recognized independent certifier will ensure the technical reliability of the planned offshore structures.

7.9.3 Relevant authorities in Northern Ireland

In Northern Ireland the Department of Agriculture, Environment and Rural Affairs is the responsible authority for consents (DAERA 2019).

7.10 Sweden

Currently, five operating offshore wind farms exist in Sweden, producing a total capacity of 202 MW by 86 offshore wind turbines. At present, no additional offshore wind farm is planned to be installed in Swedish waters within the next decade, leading to a forecast of approx. 300 MW total capacity installed offshore Sweden in 2030 (most likely by repowering).

In April 2018 the Swedish competition authority Konkurrensverket has announced, that it has rejected the proposals from the Swedish Ministry of Environment and Energy to provide financial support for the offshore wind power (e.g. by abolishing partly or completely the costs for grid connection to the mainland power station). The Swedish competition authority found that special support for offshore wind power would distort competition in the market for renewable electricity generation.

For this reason and due to the fact that Sweden has a large amount of areas suitable for the generation of onshore wind energy, it is not expected that new offshore wind farms will be installed in Swedish waters in near future.

At the end of 2018 four offshore wind farms with at total 79 turbines were connected to the grid (WindEurope 2019a). The youngest of these four wind farms was commissioned in 2013.

Based on these interim results there are no special national requirements for site investigations for an offshore wind farm in Sweden. Instead our understanding is, that the amount of geotechnical investigations and geophysical surveys is within the responsibility of the developer.

8 Comparison

This chapter summarizes the results of the comparison of the individual procedures for site investigation. The comparison is based on the criteria defined in (Fichtner 2018):

- Objective and scope of site investigation
- Hierarchy of standards
- Mandatory techniques
- Responsibility and bearing of costs
- Quality assurance
- Interfaces to the overall consent procedure
- Time specifications for the soil investigation

Due to largely varying approaches in the individual countries, not all of these criteria are subject to binding regulations that can be directly compared with one another. The differences are mainly in the regulatory requirements of the individual countries and less in the technology used.

Due to the different level of information on the practice in individual countries, only a fundamental consideration is possible for some criteria.

8.1 Objective and scope of site investigation

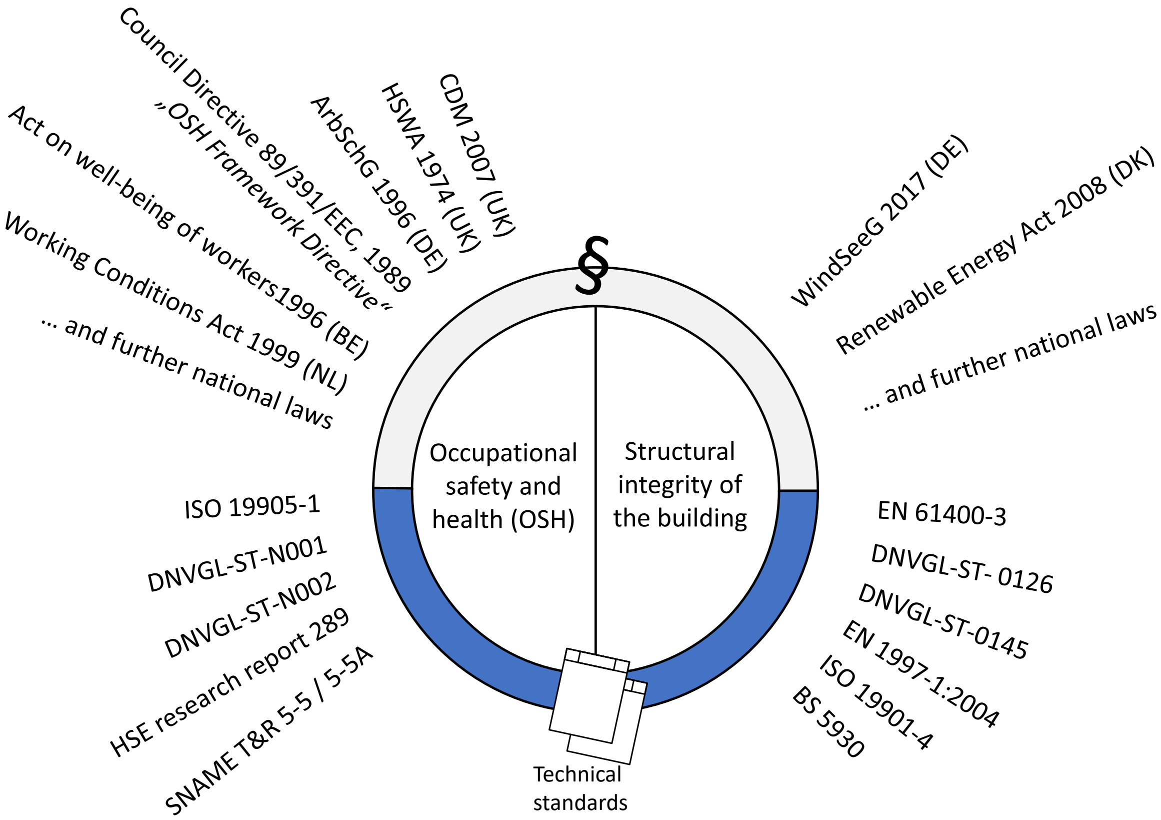
Generally, site investigation and in particular soil investigation provides fundamental information as a contribution to occupational safety and health as well as to the structural integrity of the building. Hazards can arise from man-made objects as well as from the natural soil conditions.

Without aiming for completeness, some of the relevant legislative bases and technical standards are depicted in Figure 3. The documents are assigned based on their predominant purpose, although a clear distinction is difficult in some cases. The council directive 89/391 (Council of the European Communities 1989) as an overarching document for occupational safety and health in the EU member states lays down the general principle of risk prevention. Even if not explicitly addressed in this directive, adequate soil investigation is a measure for preventive risk mitigation at construction sites. Furthermore, adequate measures for occupational safety and health are required by national laws. Soil investigation as a measure of occupational safety and health is addressed in further standards and guidelines such as for example the SNAME-guideline which is almost identical with ISO 19905 part 1.

In addition, soil investigation provides an essential basis for the project development and is therefore also important from a commercial point of view.

According to the assigned scope of this study, this report is focused on soil investigation aiming for the structural integrity of the building. This objective is covered by the exemplary technical standards that are depicted in the lower right quadrant of Figure 3. However, the importance of soil investigation with regard to occupational safety and health shall not be put in question.

Figure 3: Exemplary legislative bases and technical standards for soil investigation



Source: Own illustration, Fichtner Water & Transportation GmbH

In the North Seas Countries under consideration, only in Germany minimum requirements on site investigations are defined in detail by the authorities, see (BSH 2014). In addition to ensuring a meaningful soil investigation, the use of a consistent set of standards from the initial soil investigation to the final foundation design is also ensured by this approach.

The BSH standard requires a geophysical investigation to derive a geologic model of the site in advance of the geotechnical investigation. The geophysical investigation shall identify the elevation of the seabed, relevant features at the seabed and below the seabed, the layering of the main soil strata as well as potential obstacles like for example man-made objects and existing cables. To ensure a sufficient degree of detail for the geophysical investigation, requirements on the distance between the survey lines and the arrangement of perpendicular crossings are specified by the BSH standard. The information of the geophysical investigation is compiled into a geologic model that serves as a basis for the planning of the geotechnical investigation.

As a minimum, each turbine location shall be investigated by at least one type of geotechnical field testing, maybe indirectly by cone penetration test or directly by drilling and sampling. In case of foundations with a large footprint like for example jackets, the BSH standard recommends to perform geotechnical testing at multiple locations across the proposed footprint. A combined interpretation of the geophysical investigation and the geotechnical investigation shall take place to establish a sound geologic model of the site.

The required depth of the geotechnical investigation is indirectly defined in the BSH standard by a reference to part 2 of the Eurocode 7, see chapter 7.4.1 of this report. The investigation for axially loaded piles shall usually be carried out down to 3 times the pile diameter below the expected pile tip and at least 5 m below the expected pile tip. For shallow foundations, the site investigation should be carried out at least up to 1.5 times the shorter foundation length below the foundation base. Particular emphasis is put on specific laboratory testing to assess the soil behavior under cyclic loading.

In all other countries, no mandatory requirements are defined for the scope of the site investigation for offshore wind farms. In most of the countries the basic requirement to provide a meaningful basis for the development and the construction of the wind farm is governed by the expertise and experience of the market players. Mostly, the planning of the site investigation is based on ISO 19901 (ISO 2014), supplemented by DNV GL standards (DNVGL 2018) and specific guidance on geophysical investigations like for example (IHO 2008).

Section 7.3 of DNVGL-ST-0126 (DNVGL 2018) provides guidance on the recommended scope for site investigations. Similar to the general requirement of the BSH standard, at least each turbine location shall be investigated by geotechnical field testing. The recommended investigation depth is 0.5 times below the expected pile tip for laterally loaded piles and 3 times the pile diameter below the expected pile tip of axially loaded piles.

The DNVGL standard (DNVGL 2018) recommends a geophysical investigation to identify the layering of the main strata, the elevation of the seabed, seabed features and geological features. The detailed scope of the geotechnical investigation shall be derived in dependency of the foundation type and in consideration of the results from the geophysical investigation. In particular, drilling and sampling, downhole testing and laboratory testing including cyclic laboratory testing should be carried out. Furthermore, it is recommended to correlate the results of the geophysical investigation with the results of the geotechnical investigation.

All in all, the employed type of technique for the soil investigation in the North Sea is similar in the individual countries, regardless the regulations defined by each country. This interim result was confirmed by the conversation with some of Europe's leading project developers. Regardless the country in which the offshore wind farm is located and assuming similar soil conditions, a similar scope of soil investigations will most likely be carried out by an experienced wind farm developer. Based on their experience gained in numerous projects and with reference to the trend towards sophisticated methods of foundation design, established developers are aware of the importance of a comprehensive site investigation and take it into account in the project development.

A defined minimum scope ensures even in the case of an inexperienced wind farm developer, that a meaningful site investigation is carried out from the outset. The procedure for site investigation practiced in most of the North Seas Countries requires an experienced developer who plans a meaningful scope for the site investigation on his own initiative. In the worst case, the acceptance of an inadequate site investigation would be denied by the certifier at a later stage of the project. In the meantime, however, the offshore wind market is dominated by experienced project developers. New project developers, who perhaps only want to carry out initial project phases in the first instance, are the exception.

Furthermore, the role designated to the authorities in the approval process must be taken into account. Whilst in most countries detailed requirements intentionally have not been issued, the authorities in Germany are obliged to a certain extent to carry out a technical plausibility check. Therefore, the defined minimum scope for soil investigation supports to fulfill this obligation.

In the table below the number of borehole locations and CPT locations of the preliminary site investigation of recent wind farms in the Netherlands and in Denmark is compared with the ‘10 % criterion’ that is decisive for the preliminary geotechnical site investigation in Germany (BSH 2014). According to the 10 % criterion the total number of borehole locations and CPT locations of the preliminary site investigation shall correspond to 10 % of the planned number of wind turbine locations.

In the absence of more definitive information, for the planning of the preliminary site investigation of future offshore wind farms in Germany, the expected number of turbine locations is estimated based on the potential area of the wind farm. According to (BSH 2019b) it is assumed that one turbine will be installed per 0.5 km^2 of the wind farm area. This approach appears conservative in view of the resulting number of turbines, since for recent Danish wind farms one turbine is planned per 2 to 3 km^2. For comparison, the last column of Table 19 provides the resulting number of investigation points for the preliminary site investigation according to the 10 % criterion for the estimated spatial density of one turbine per 0.5 km^2 of the wind farm.

Table 19: Comparison of the preliminary geotechnical site investigation with the '10 % criterion'

Offshore wind farm	Borehole locations	CPT locations	Wind farm area	Number of turbine locations	Total number of borehole locations and CPT locations	Required number of investigations acc. to 10 % criterion
Horns Rev 3 (DK)	12	28	145 km²	49 x 8.3 MW	40	29
Kriegers Flak (DK, Baltic Sea)	17	42	170 km²	72 x 8.4 MW	59	34
Vesterhav Nord (Dk)	3	12	60 km²	21 x 8.4 MW	15	12
Vesterhav Syd (DK)	2	12	50 km²	20 x 8.4 MW	14	10
Thor (DK, planned)	15 - 20	60 - 80	180 - 220 km² out of 440 km²	800 – 1000 MW in total	75 - 100	36 - 44
Borssele III (NL)	12	25	64 km²	77 x 9.5 MW cumulated at site III and IV	37	13
Borssele IV (NL)	11	24	58 km²	77 x 9.5 MW cumulated at site III and IV	35	12
Hollandse Kust Zuid, site III (NL)	9	25	46 km²	76 x 10 MW cumulated at site III and IV	34	9
Hollandse Kust Zuid, site IV (NL)	10	28	64 km²	76 x 10 MW cumulated at site III and IV	38	13
Hollandse Kust Noord (NL)	33	78	94 km²	n. a.	111	19
Area N-3.7 (DE, planned)	4	4	18 km²	n. a.	4 (boreholes and CPT at same locations)	4
Area N-03W	6	6	150 km²	n. a.	6 (boreholes and CPT at same locations)	30

The number of borehole locations and the number of CPT locations that was carried out for the preliminary geotechnical site investigations is well above the amount of geotechnical investigation points that are required according to the 10 % criterion.

8.2 Hierarchy of standards

Regarding the hierarchy of standards, a clear distinction between the regulations in Germany and the regulations in other North Seas Countries can be made.

In Germany the hierarchy of standards is defined in the mandatory BSH Standard Ground Investigations (BSH 2014). According to this standard the Eurocode standard and the national application standards by DIN have to be applied. With regard to the soil investigation, Eurocode 7, which is the DIN EN 1997 series in Germany, and supplementary national standards like for example DIN 4020 are decisive. The German approval authority reserves the right to exclude individual standards or parts thereof from the obligation to apply the above standards. Deviations from the established standards and requirements are possible if the deviations are justified for example by scientific research or with regard to the specific conditions of the project.

In all other countries the planning of the site investigation is widely based on part 8 of the ISO 19901 (ISO 2014) and supplemented by recommendations taken from additional guidance for offshore wind energy such as for example the DNV GL standards (DNVGL 2018), see Figure 4 below.

This approach is not mandatory, thus no predefined hierarchy of standards exists in these countries. However, it is common practice in the industry to base the site investigation on these acknowledged standards.

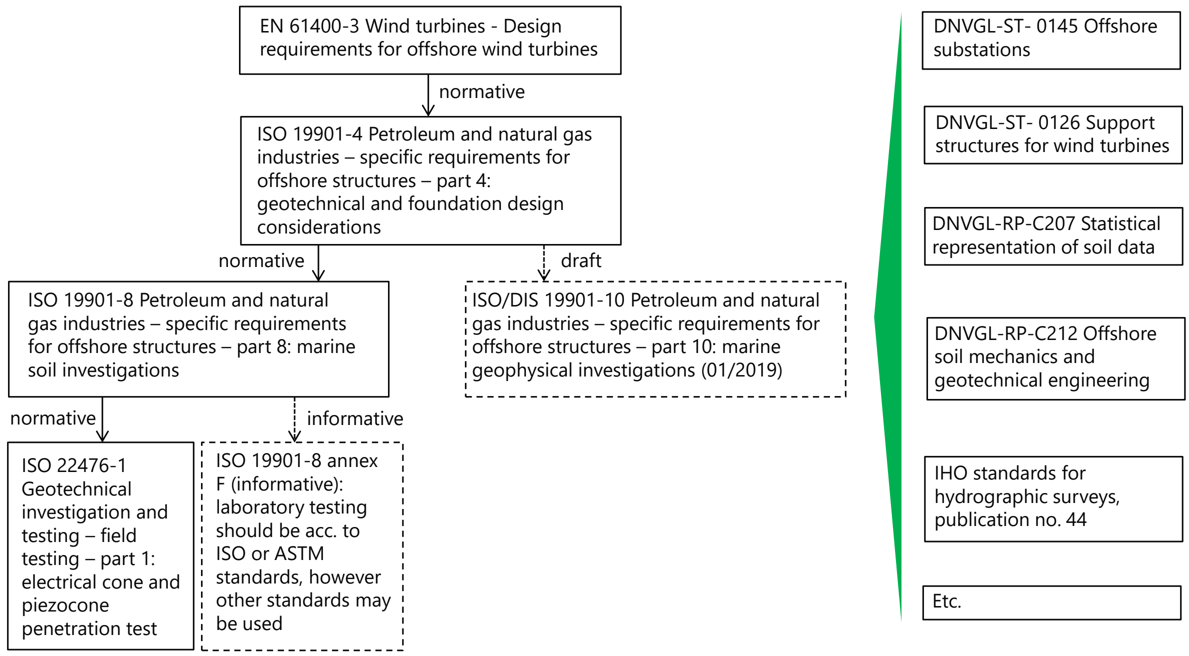
The framework for planning and execution of the soil investigation according to ISO 19901 and EN 1997 ('Eurocode 7'), respectively, is depicted in the following figures. Formally, the ISO standards as well as the EN standards are to be implemented as corresponding national standards by the national standardization bodies. For reasons of clarity, only the direct normative references that are given in the respective standards are shown in Figure 4 and Figure 5 below. Of course, there are further relevant standards of the corresponding family of standards.

It is worth to note that ISO 19901 and Eurocode 7 finally refer to quite the same standards for soil testing. The deliberate restriction to the directly referenced standards already illustrates this with the examples of ISO 14688, ISO 14689, ISO 22475, and ISO 22476. In addition, with reference to Germany, the former national DIN-standards for soil testing are successively replaced by transposed EN ISO standards as indicated in Figure 5 below.

Even though there are still national standards for individual issues that are not based on the direct transposition of an international standard, these examples illustrate the development towards a Europe-wide standardization that is as uniform as possible. Regardless of this process there are, however, fundamental differences in the extent to which these standards are mandatory for the planning of offshore wind farms.

Figure 4: Framework for soil investigation based on ISO 19901

Site investigation based on ISO 19901

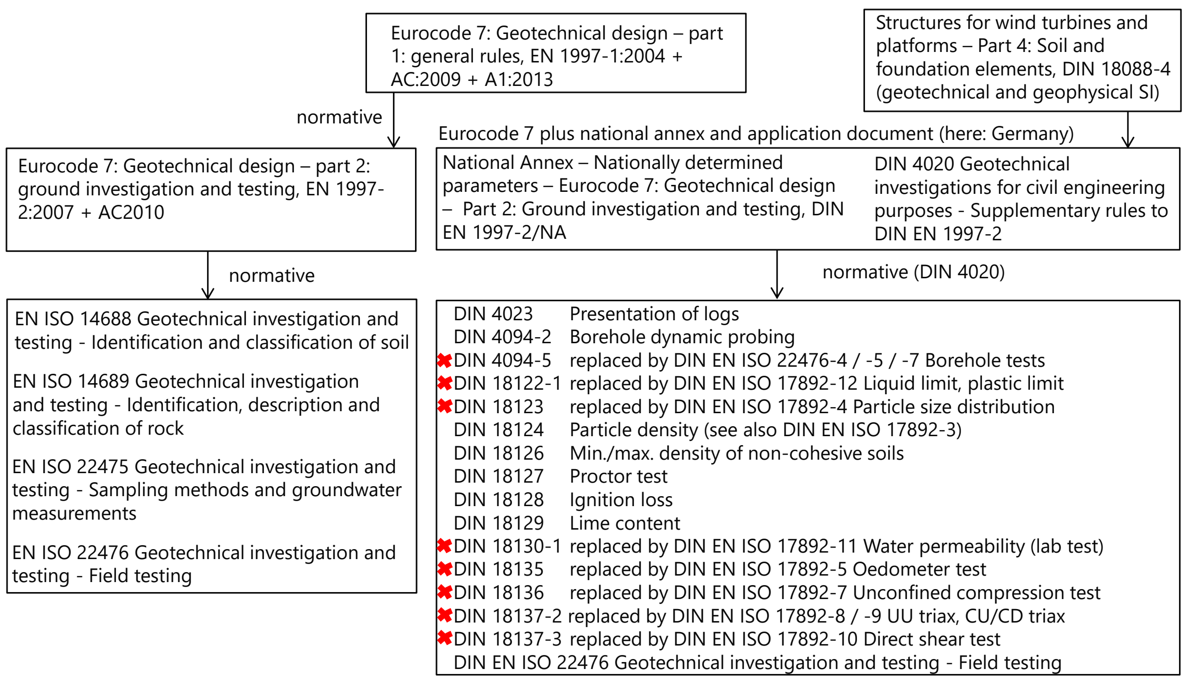


For the sake of clarity, only the direct normative references are listed.

Source: Own illustration, Fichtner Water & Transportation GmbH

Figure 5: Framework for soil investigation based on Eurocode 7 with national annex for Germany

Site investigation based on Eurocode series



For the sake of clarity, only the direct normative references are listed.

Source: Own illustration, Fichtner Water & Transportation GmbH

In Figure 5 the national annex and the application document to Eurocode 7 are exemplarily shown for Germany, since the use of Eurocode 7 is a mandatory requirement in Germany, The use of Eurocode 7 as the basis for soil investigation for offshore structures has been established in Germany by the published DIN 18088, too.

8.3 Mandatory techniques

Only in Germany mandatory techniques are defined to a certain extent for some parts of the soil investigation (BSH 2014). For example, minimum technical requirements on the towing speed, the frequency and the resolution of geophysical devices are defined to ensure a meaningful resolution of the subsoil and the seabed features. Of course, the decision about the most appropriate device and the detailed execution of the site investigation is with the wind farm developer.

In all other countries, special techniques are recommended based on the expected subsoil, but the use of these specific techniques is not a mandatory requirement.

A more in-depth comparison of the employed techniques will be added in the further course of the project.

8.4 Responsibility and bearing of costs

In view of responsibility and costs, there are two different approaches for site investigations in the North Seas Countries.

- Approach 1: All phases of the site investigation are carried out by the developer or on behalf of the developer. The developer, respectively the company contracted by him, defines the scope to be executed in consideration of the relevant requirements, ensures the timely execution of the works and bears the related costs. So far, this approach has been usual practice for example in the United Kingdom, Belgium and Germany. In Germany, the upcoming 'centralized auction model' will change this approach. In the United Kingdom and Belgium there are thoughts to change the current approach as well, but so far there is no information about concrete measures decided upon.

- Approach 2: The preliminary site investigation is performed by the competent authority or on behalf of the competent authority. The authority, respectively the contracted company, defines the scope to be executed and ensures the timely execution of the preliminary site investigation. In principle, interested developers can participate in the definition of the scope by comments. The data of the preliminary site investigation is provided to the interested developers that have to apply for implementing the wind farm in the course of an auction model. The successful tenderer has to complement the preliminary site investigation on his own in the course of a detailed site investigation, if applicable. This approach is currently applied for example in Denmark and in the Netherlands.
  In Denmark, the costs of the preliminary site investigation must be borne by the successful tenderer of the auction. In the Netherlands, the costs of the preliminary site investigation are borne by the state. In Germany, the successful tenderer of the auction process for offshore wind farms that will be commissioned from 01 January 2026 onwards, will have to bear the costs of the preliminary site investigation.

Approach 1 involves a financial risk for the developer during the preparatory project phase, for example if the developer abandons the project or does not achieve the required licenses. In particular, this approach is not suitable for auction models where it is deliberately not clear at the outset which of the interested developers will finally implement the project.

Approach 2 usually implies an auction model for the wind farm development. In the course of the auction process the preliminary site investigation provides fundamental input data for the preparation of the individual bids. With a sustained trend in the North Seas Countries towards auction models as a measure for cost reduction by increased competition this approach will be more and more applied.

In Denmark and in the Netherlands, and in future also in Germany, the competent authorities provide the developers with factual data of the preliminary site investigation. Beside differences in the detailed amount of data provided, these countries have in common that the interpretation of the site data and thus, the associated risk, is with the developer. Thus, the cost reductions that can be finally achieved by auctions also partly depend on the willingness of the bidders to take risks driven by the competition as well as on the bidders' individual experience with the project implementation. Of course, the sound project preparation is always necessary in order to ensure the economic success over the entire life cycle of the wind farm, in particular with regard to the submission of 'zero-subsidy' bids. As a result, the competing developers have an increased interest in a meaningful site investigation as a measure for risk management and economic optimization.

The scope of the preliminary site investigations that are provided by the competent authorities to the potential bidders as input for the auction processes differ between the Netherlands, Denmark and Germany particularly in view of the provided information about wrecks, 'UXO', archaeological heritage and other obstacles. While in Denmark and in the Netherlands desk studies about these topics are provided to the potential bidders, in Germany these topics are explicitly excluded from the intended scope.

However, for both approaches the main site investigation of the final farm layout is always in the responsibility of the wind farm developer. In all three countries in the course of the main site investigation, the successful bidders have to check the finally determined park layout in view of UXO and other obstacles, regardless of whether the bidders have been provided with initial desk studies in advance or not.

8.5 Quality assurance

Even if a project certificate is required for the approval procedure in some countries, the separate review of the site investigation is not a mandatory requirement of the approval procedure in most of the North Seas Countries. However, in most of the North Seas Countries an additional quality assurance for the site investigation is implemented by the voluntary engagement of an acknowledged independent certifier.

Usually, the independent review of the soil investigation data is initiated by the wind farm developers as part of their risk management. In the Netherlands, a voluntary independent review of the site data takes place before the data are forwarded by RVO to the bidders of the auction process. This independent review additionally increases the confidence in the provided site data and thus supports the preparation of cost-effective bids.

The review of the scope and the derived results provides an overall evaluation of the site investigation in addition to the quality assurance that has been carried out by the contractors for the individual work packages of the site investigation. Usually, the requirements from insurance companies, the established industry practice and the standards of DNVGL form an integral part of this review. The independent certifier documents the performed check of the site investigation and the derived soil parameters by a statement.

In Germany, a mandatory quality assurance is implemented by the engagement of a 'Geotechnical Expert' in addition to the mandatory engagement of an acknowledged independent certifier. The duties and the obligations of this 'Geotechnical Expert' are defined in the BSH standard (BSH 2014), see section 7.4.4 of this report. Furthermore, the BSH and its supporting Federal agencies carry out a plausibility check of the provided technical documents, too. Thus, a large set of mandatory 'quality gates' and control mechanisms is introduced into the approval process by the authorities to minimize the risk.

8.6 Interfaces to the overall consent procedure

So far, in most of the North Seas Countries no regulative requirements are identified that define mandatory milestones within the site investigation process that are directly linked with the consent procedure.

In Germany, several milestones of the step-wise site investigation are directly linked to the overall consent procedure of the wind farm. The technical planning and the execution of the site investigation is adjusted to the step-wise consent procedure.

The interfaces between the site investigation and the overall consent procedure in the individual countries will be elaborated in more detail during the further course of the project.

8.7 Time specifications for the soil investigations

In none of the considered countries, specific time constraints are defined by the authorities for the site investigation itself. The available time for the site investigation is governed by the project development schedule and the overall time schedule for the construction of the wind farm.

8.8 Concise overview

Table 20 provides a concise overview about the main findings of the comparison.

Table 20: Main findings of the comparison

Criterion	BE	DE	DK	FR	IR	NL	NO	SE	UK
Mandatory minimum scope of soil investigation (SI) defined by authorities?	No	Yes	No	Regulation is in progress by authorities	Regulation is in progress by authorities	No	N/A (offshore wind will marginally contribute to the future energy supply)	N/A (offshore wind will marginally contribute to the future energy supply)	No
Mandatory hierarchy of codes defined by authorities? / employed main standards for SI	No / ISO, DNVGL	Yes / EC, DIN	No / ISO, DNVGL			No / ISO, DNVGL			No / ISO, DNVGL
Mandatory requirements about the techniques for SI defined by authorities?	No	Yes	No			No			No
Responsibility and bearing of costs for SI	SI by developer (thoughts to adapt the preliminary SI similar to e.g. NL, DK)	For projects from 2026: preliminary SI by national agency, main SI by developer,	Preliminary SI by national agency, main SI by developer, cost for preliminary SI			Preliminary SI by national agency, main SI by developer, cost for preliminary SI			SI by developer

Criterion	BE	DE	DK	FR	IR	NL	NO	SE	UK
		cost for preliminary SI must be borne by the developer	must be borne by the developer			must be borne by the state			
Quality assurance of the SI is mainly performed by	Certifier (at the developer's discretion), contractors	Certifier (obligatory), 'Geotechnical Expert' (obligatory), contractors	Certifier (at the developer's discretion), contractors			Certifier (preliminary SI: voluntary check on behalf of national agency; main SI: at the developer's discretion), contractors			Certifier (at the developer's discretion), contractors
Mandatory interfaces to the overall consent procedure?	No	Yes	No			No			No
Mandatory time constraints for the site investigation itself defined by authorities?	No	No	No	No	No	No	No	No	No

Note: The quality assurance measures also carried out to a certain extent by the developers are not listed separately in the upper table.

9 Potential for alignment

In this section best practices and the potential alignment of the soil investigation procedures is evaluated as a contribution to the North Sea Energy Cooperation's overall aim. The consultation with individual developers, a stakeholder workshop (WindEurope 2019b) and meetings with WindEurope and the Carbon Trust were performed to get a more insight into the different regulations and the industry's view.

According to its own information, the industry association WindEurope represents more than 400 members including for example wind turbine manufacturers, component suppliers, research institutes, national wind and renewables associations, developers, contractors, electricity providers, finance and insurance companies, and consultants (WindEurope 2019d).

The Carbon Trust is a company limited by guarantee that assists governments, multilateral organizations, businesses and the public sector to reduce carbon emissions (Carbon Trust 2019). In particular, the Carbon Trust initiates acknowledged joint industry projects that support relevant developments of the offshore wind industry. Its work is supported by leading wind park developers. Thus, the exchange with WindEurope and the Carbon Trust shall enable access to information about the bundled view of the industry as a supplement to the other sources of information.

To evaluate the economic significance of a potential alignment in the field of soil investigation, in section 9.1 of this report the relation between the direct costs for soil investigation and the total investment for an offshore wind farm is considered. Subsequently, the influence of the soil investigation on the follow-up phases of the project development is discussed.

In section 9.2 of this report the possibilities for further alignment of procedures for soil investigation are summarized based on the results from the dialogue with market participants and the European support group SG 4.

9.1 Economic significance of soil investigation

As usual, costs are mostly considered as confidential information by project developers and contractors. This is especially relevant for the offshore wind industry, which is subject to an increasing market competition. For this reason, the dialogue with market participants only provided isolated information on the costs and in particular on the quantitative evaluation of individual boundary conditions of the soil investigation for offshore wind farms.

The authors of this study are aware that a reliable cost estimate must take into account a variety of contractual and technical constraints. However, in most cases either no detailed information is available on these constraints or individual projects cannot be easily compared because their individual boundary conditions differ too much from each other.

In order to assess the financial relevance of the site investigation for the project development, however, at least the share of the direct costs of the site investigation in the total investment costs of a wind farm can be estimated roughly from the available information.

The information about costs is mainly derived from information that has been published by Danish and German authorities in the course of the auction scheme. Supplementary information is taken from the dialogue with market participants and the authors' experience with geotechnical testing.

The figures below provide information about the direct costs for soil investigation and the total investment, which of course highly depend on the specific constraints of the individual projects.

Therefore, these figures may only be considered as a rough guidance, whereas project-specific costs can be different.

For the UK, the provided costs include the offshore transmission asset, which in dependency of the specific project comprises the offshore substation, the onshore substation and the export cables. For the other countries these costs are not included in the figures. Therefore, the provided costs related to the installed capacity are higher in the UK than in the other countries.

Table 21: Investment in European offshore wind farms in 2018 (final investment decision), (WindEurope 2019a)

Country	CAPEX in million Euro	Financed new capacity in MW	CAPEX in million Euro per MW	Number of projects
UK	5400	1858	2.91	3
NL	1400	732	1.91	1
DK	1100	605	1.82	1
BE	1800	706	2.55	2
DE	400	258	1.55	2
total	10100	4159	2.43	9

Table 22: Investment in European offshore wind farms in 2017 (final investment decision), (WindEurope 2018)

Country	CAPEX in million Euro	Financed new capacity in MW	CAPEX in million Euro per MW	Number of projects
UK	3700	1400	2.64	2
NL	0	0	0	0
DK	0	0	0	0
BE	0	0	0	0
DE	3800	1100	3.45	4
total	7500	2500	3.00	6

Table 23: Investment in European offshore wind farms in 2016 (final investment decision), (WindEurope 2017a), (WindEurope 2017b) and public information

Country	CAPEX in million Euro	Financed new capacity in MW	CAPEX in million Euro per MW	Number of projects
UK	10493	2594	4.05	4
NL	0	0	0	0
DK	1000	400	2.50	1
BE	2300	679	3.39	2
DE	4289	1235	3.47	3
total	18082	4908	3.68	10

Note: in Finland the final investment decision was made for one 40 MW project, too.

Table 24: Investment in European offshore wind farms in 2015 (final investment decision), (EWEA 2016)

Country	CAPEX in million Euro	Financed capacity in MW	CAPEX in million Euro per MW	Number of projects
4 countries	13300	3000	4.43	10

The above figures allow only a rough comparison of the investment costs. For a more detailed assessment the project-specific cost factors, which are not provided in detail in the published data, need to be taken into account. Nevertheless, there is a clear trend towards a reduction of the capacity-related investment, which is according to Table 21 roughly around 2 million Euro per installed Megawatt, except for offshore wind farms in the UK.

This assessment is supported by the findings from (Energinet 2018), whereas the capacity-related nominal investment excluding grid connection is about 2.05 million Euro per Megawatt for projects with final investment decision in 2017 and 1.92 million Euro per Megawatt for projects with final investment decision in 2020. Both figures are primarily valid for Danish projects and are fixed 2015 prices.

Data from (PBL 2019) which are summarized in Table 25 indicate somewhat lower investment costs than the above values. The costs for grid connection are not included in these numbers, but they are given in (PBL 2019) together with the estimated OPEX of these projects.

Table 25: Investment per Megawatt for Dutch offshore wind farms excluding grid connection (PBL 2019)

Offshore wind farm	CAPEX in million Euro per MW
Hollandse Kust (Zuid) III&IV	1.60
Hollandse Kust (West)	1.75
Hollandse Kust (Noord) V	1.70
IJmuiden Ver	1.85
Boven de Wadden Eilanden	1.90

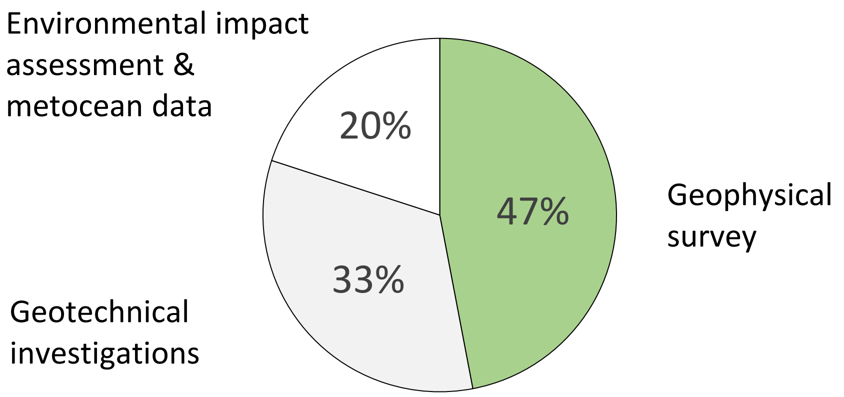
The tender conditions for Danish offshore wind farms are one of the few public sources of information. The pre-investigations for nearshore wind farms (ENS 2016b) and Kriegers Flak (ENS 2016a) comprise an environmental impact assessment, preliminary geophysical and geotechnical surveys and gathering of meteorological-oceanographic data. Therefore, the costs that are related to the geophysical survey and the geotechnical survey, respectively, cannot be derived directly from the published total costs for the pre-investigations. In addition, a reliable assessment would require to consider the detailed scope of the surveys, too. Therefore, from the figures of Table 26 only an approximate order of magnitude of the costs can be estimated and this can also only be used for preliminary soil investigation. The designated size of the wind farm area that is given in Table 26 is most often only one part of the potential wind farm area that has been investigated in advance. For the five 'nearshore areas' of Table 26 at total 350 MW are planned at two or more sites of the 'nearshore areas'.

Table 26: Costs of pre-investigations and environmental impact assessment reports for recent Danish wind farms (ENS 2016a), (ENS 2016b)

Offshore wind farm	Area	Planned capacity	Costs in million DKK excluding VAT	Costs in million Euro 1 Euro = 7.467 DKK
Nearshore areas, site North Sea (South) 'Vesterhav Syd'	up to 44 km²	up to 200 MW	not more than 23.8	3.2
Nearshore areas, site North Sea (North) 'Vesterhav Nord'	up to 44 km²	up to 200 MW	not more than 26.1	3.5
Nearshore areas, site Bornholm	up to 11 km²	up to 50 MW	not more than 23.3	3.1
Nearshore areas, site Sæby	up to 44 km²	up to 200 MW	not more than 23.3	3.1
Nearshore areas, site Smålandsvarvandet	up to 44 km²	up to 200 MW	not more than 25.6	3.4
Kriegers Flak (Baltic Sea)	179 km²	600 MW	not more than 80.0	10.7

According to the dialogue with the Danish Energy Agency 'Energistyrelsen' the following indicative cost share between the environmental impact assessment and gathering of meteorological-oceanographic data ('metocean data'), preliminary geotechnical investigations and preliminary geophysical surveys is derived. The cost share depicted in Figure 6 provides an averaged indicative estimate for the preliminary site investigations that were carried out for the preparation of the auction process in Denmark.

Figure 6: Indicative cost share for preliminary site surveys of recent Danish offshore wind farms



Data: Energistyrelsen - Danish Energy Agency

Source: Own illustration, Fichtner Water & Transportation GmbH

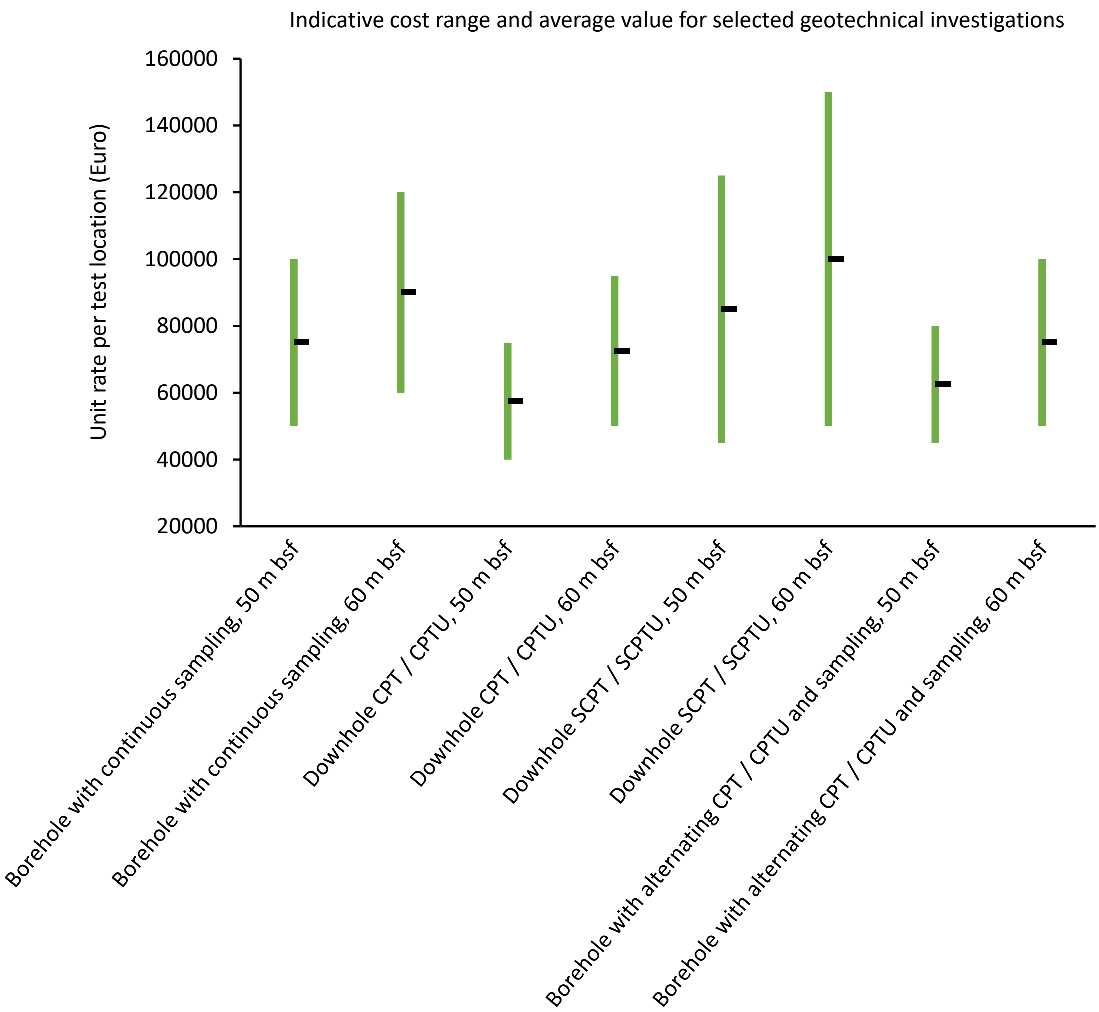
For comparison the published costs for the preparatory site investigation of planned German wind farm areas are summarized in Table 27.

Table 27: Costs for preliminary site investigation for planned German wind farms (BSH 2019c)

Offshore wind farm	Area	Costs in million Euro excluding VAT	Remark
Geophysical survey for area N-3 and N-7	115 km²	1.30	Scope: see section 7.4.6 of this report
Geotechnical investigations for areas N-3.5, N-3.6, N-3.7, N-3.8	99 km²	< 10.13	Scope: see section 7.4.7 of this report

In addition to the published costs for certain site investigation campaigns, market participants were asked about the costs. As a result, an indicative cost range was derived for selected test types. Of course, these cost ranges can only serve as a rough orientation. In particular, the relevant project-specific boundary conditions, the market situation and the consideration of individual contract conditions regarding mobilization, demobilization, specifications for soil sampling, risk of weather downtime and so on cannot be considered in them. The resulting cost ranges are depicted in Figure 7.

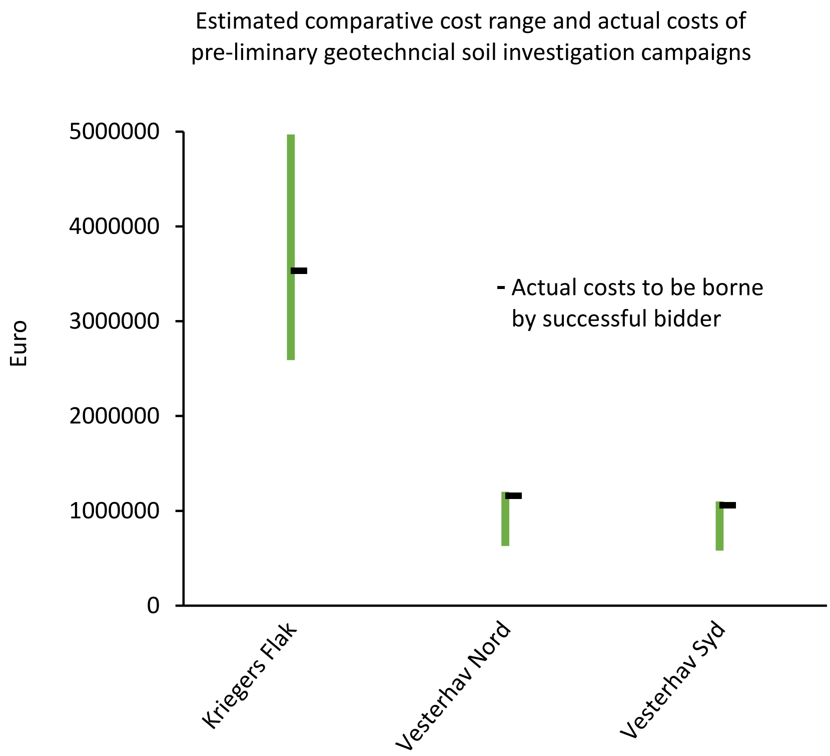
Figure 7: Indicative cost range for selected types of geotechnical investigations



Source: Own illustration, Fichtner Water & Transportation GmbH

Overall, the order of magnitude of the cost for the geotechnical investigations of Danish projects coincides with the cost range of boreholes and soundings indicated by market participants. The comparison of is not intended to serve as an evaluation of the individual contract price, even more since the detailed contract conditions are unknown to the authors, but merely as a general plausibility check within the framework of this study.

Figure 8: Estimated comparative cost range and actual costs for preliminary geotechnical investigation campaigns



Source: Own illustration, Fichtner Water & Transportation GmbH

Generally, the costs for the laboratory test programme are significantly lower than the costs for the site investigation works at sea. It is therefore not expected that the necessary consideration of these costs will lead to a fundamentally different magnitude of the estimated comparative cost range than in Figure 8.

It is emphasized once again that due to the multiple influencing factors, all above cost estimates should be treated with caution. As an overall result from the above figures the direct costs related to site investigation are usually in the range of a single-digit percentage of the total CAPEX, even though it is expected that further site investigation might become necessary in addition to the so far addressed preliminary soil investigation campaigns.

For example, (Wood and Knight 2013) indicate the cost for site investigation with about 1 % of the total investment for an offshore wind farm. In view of recent cost developments the relative share may be assumed somewhere in the range of 1 % to 2 % of the total investment, which confirms the above general assessment.

Even though developers will most likely appreciate a reduction of the direct costs for soil investigation, it is clear from these figures that the direct costs for soil investigation contribute only a relatively small share of the total investment.

From the point of view of project financing, it should be noted that these site investigation costs are incurred at an early stage of project development, without these costs being balanced by current revenues from electricity generation. Thus, site investigation costs are a significant proportion of the project development costs. However, when considering the entire project lifecycle, including the operating phase, a comprehensive site investigation contributes to the realization of cost savings. In particular, the optimization of the foundation design and the minimization of geological risks should be mentioned here.

All in all, it is obvious that the direct costs for site investigation is not considered as the foremost measure for a significant cost reduction of offshore wind energy, even more since soil depicts only one part of the entire site investigation.

The site investigation does not only serve to characterize the overall site conditions, for example to bypass areas of complex geology during the planning of the park layout, but must also provide the input values for the numerical simulation of the foundations. In this context it should be noted that advances achieved in the numerical simulation of foundations, using for example sophisticated constitutive models in finite element analyses, maybe accompanied by increased requirements on soil testing as well as on the soil sampling technique. Therefore, the improvements in the geotechnical foundation design, which finally lead to an overall reduction in costs, must always be seen in connection with the resulting requirements on the preceding site investigation.

As outlined previously the reduction of the direct costs for soil investigation is not considered as the foremost contribution to an overall cost reduction for offshore wind energy. Even more important is the reduction of follow-up costs arising for example from

- The required preparatory time to consider significant differences between the regulatory framework for soil investigation within the individual project plan
- The possibility to enable efficient adjustments of the park layout by use of digital ground models, preferably even if turbine locations should change after completion of the geotechnical offshore survey
- The cost savings by improved foundation design which is based on up-to-date calculation models and relies upon comprehensive soil parameters
- The efficient project implementation through largely schematized internal workflows of the respective project developers

Obviously, different national regulations about subsoil investigation, its documentation and the approval procedure lead to additional efforts in time and costs for project developers. For example the project development will require additional time to familiarize itself with the relevant regulations and to prepare a tailored project plan. This is particularly the case if the first project is developed in a country with whose regulatory requirements the respective project developer does not yet have any practical experience. However, these additional efforts are likely to decrease with in an increasing number of implemented projects.

The use of digital ground models, and in particular those derived from '3D seismic surveys' as a supplement to existing boreholes and CPT data, is considered as a potential future trend in park layout planning. Although, the use of '3D seismic' is not yet a standardised survey method and can be subject to stricter sea state restrictions than conventional seismic survey methods, it offers the perspective to enlarge the available time window for the optimisation of the park layout during the project development phase. Provided that a reliable interpretation of the '3D seismic' survey is possible for the encountered ground conditions, the location of individual turbines may be changed even after the geotechnical investigation of the initially planned turbine locations. However, '3D seismic' cannot completely replace the geotechnical investigation by boreholes or CPT. The interpretation of seismic surveys will always require geotechnical investigations for calibration purpose and for the determination of soil parameters. In fact, '3D seismic' could be used for a cautious assessment of the soil conditions between existing geotechnical investigation points. Thus, the cautious supplementary use of this sophisticated seismic survey technique with its required interpretation algorithm could provide more insight into the ground conditions and could assist to optimize the park layout.

Economic advantages by an improved foundation design that is based on up-to-date calculation models can only be achieved for an offshore wind farm project if the required soil parameters are available during the design phase. The economic advantages can be, for example, a shorter embedment length of piles compared to previous calculation models or a more accurate prognosis of the operating behaviour of the wind energy plant. Recently developed calculation methods, for example the monopile calculation model (Byrne 2018), require additional soil parameters which exceed the standard set of soil parameters that is usually determined so far. Beside others, the model of (Byrne 2018) considers the small strain stiffness of the soil that is derived from the velocity of the shear wave 'S-wave' in the ground. The determination of the shear wave velocity by borehole geophysics is part of recent preliminary geotechnical investigation campaigns (RVO.nl 2016b), (RVO.nl 2019), (BSH 2019c), to name only some of them and without order of precedence.

In industrialized processes, which also include the construction of power plants at sea, standardised workflows lead to a reduced error rate and an increased productivity. Leading international project developers endeavour the internal standardisation of workflows for the effective project implementation. The site conditions represent project-specific input variables for these processes. Analogue to the first bullet point, significant differences in the national regulatory requirements might cause additional effort for adjustments within these internal workflows or even interfere with the internal workflows practiced so far. Generally, from this point of view the as far as possible alignment of regulatory requirements would be beneficial. In the absence of more detailed information from market participants on the financial impact on project development and implementation, this aspect is not further explored in the study.

9.2 Discussion on possible alignments and proposed way forward

Different regulatory requirements about for example the detailed scope of the surveys, the format of reporting and the sequence of the surveys will obviously cause additional efforts on the developer's side with an increased risk for misunderstandings or misinterpretations of the prevailing rules. Aligned regulatory requirements would ease the project development, reduce the risk for project delay and would contribute to the overall aim of the North Sea Energy Cooperation. In fact, however, leading project developers have meanwhile adapted to the fact of different regulatory requirements about soil investigation in the individual North Seas Countries. This is certainly also due to the fact that the non-European markets in any case require a certain adaptation of the internal work processes of the project developers to different national regulations.

Most of the North Seas Countries have deliberately not issued detailed regulatory requirements about the site investigation to achieve cost-reductions by enabling flexibility for the project developers, see for example (RVO.nl 2017d). In the North Sea countries, the concept of deliberate flexibility in the selection of technical regulations and the concept of a binding, consistent hierarchy of standards are in contrast to each other. In view of the installed wind farms in Europe, it appears that both concepts are working in practice. The fact of fundamentally different regulatory approaches in the individual countries also became clear from the dialogue within the European support group SG4.

Since most of the North Seas Countries did not issue binding regulations about details of the soil investigation procedure to achieve cost reduction through flexibility for the project developers, a ‘harmonization’ in the meaning of aligned standards is hardly possible. Thus, rather than seeking harmonization, an ‘exchange of best practices’ is currently seen as an advantageous measure.

In particular, this exchange on best practices should facilitate the recognition of innovative techniques, such as for example multichannel seismic, three-dimensional digital ground models or seismic cone penetration testing in all of the North Seas Countries.

The small share of the direct costs for soil investigation at the total investment costs that is described in the previous section strengthens the finding, that soil investigation itself and its relevant regulatory requirements should not be considered as the foremost cost driver for offshore wind farms. In fact, the information derived from a comprehensive soil investigation for the follow-up project phases is the key driver to mitigate geological risks and to enable a cost-effective foundation design. The long-term resulting financial benefit for the project will in most cases balance the relatively small additional effort for a sophisticated and comprehensive soil investigation.

Beside the recognised overarching requirement for meaningful and reliable site data, the following three aspects appear also important for the soil investigation of offshore wind farms:

- Availability: Determination of investigation technique that is available to a preferably large amount of contractors, provided that this technique can provide the required type and the required quality of the data. Two examples thereof are the determination of an adequate soil sample diameter and the timely tendering of the works to secure the availability of suitable vessels for the planned investigation period.

- Flexibility: Enabling as much flexibility as possible for the contractors to comply with the ‘functional requirements’ of the soil investigation rather than focusing on detailed norms for individual testing. In this context ‘functional requirements’ should describe the envisaged overall aim of the soil investigation, for example, the determination of certain in-situ soil parameters or the provision of soil samples suitable for a certain type of laboratory testing. At foremost, the scope should meet the requirements of up-to-date calculation models and innovative design approaches, which however undergo a continuous development.

- Familiarity: Reduce the amount of requirements which do not correspond with what has been established for most part of the international market. The preferably wide use of already known, routine workflows contributes to reducing the risks and thus the costs of project implementation.

Partly, a European alignment of the standards for individual types of field tests and laboratory tests already takes place, as outlined in section 8.2 of this report.

Irrespective of the consent scheme, a kind of "best practice" was identified on a technical level for the preliminary soil investigations carried out for the auction processes in Denmark, the Netherlands and Germany. This ‘best practice’ is very likely to evolve and its present features should therefore serve as a starting point for further improvements:

- Stepwise investigation by a preceding geophysical survey and subsequent determination of the relevant geotechnical investigation points based on the findings from the geophysical survey.

- Combined interpretation of the geophysical survey and the geotechnical investigations. This principle is already described in relevant standards like for example (ISO 2014) and (BSH 2014). In addition, the importance and benefits of this combined interpretation became more and more obvious for the park layout planning. Exemplarily, reference is made to preliminary soil investigations for Dutch and Danish wind farms, where digital ground models are handed over to the bidders (Energinet 2014), (ENS 2019a), (RVO.nl 2018a), to name only some of them.
- On a technical level, a future point for practical alignment could be to agree on a standardized data format for the exchange of three-dimensional (3D) digital ground models. In principal, such an alignment would be analogue to the 'standardized' SEG Y data format (SEG 2002) which is used for the exchange of geophysical survey data, see for example (Rijkswaterstaat 2009), (BSH 2019e), and (ENS 2019b).
- The established close dialogues between the competent authorities and the potential project developers during the planning of the preliminary soil investigation campaigns as input for the auction schemes in the Netherlands, Denmark and Germany is considered as a relevant measure in order to fit both, the needs of the investors and the needs of the public.
- The future use of innovative investigation techniques, like for example '3D seismic' surveys, could improve the future planning of the park layout. However, this technique is not yet a standardized investigation method. The reliable interpretation requires extensive experience and might not be possible for very complex ground situations. The potentials of such innovations should be harnessed for the offshore wind industry, while an appropriate critical assessment should not be omitted.

10 Excursus on further relevant framework conditions in Germany

During the work on this study, further information was gained, that appear relevant for the future implementation of offshore wind energy in Germany.

The implementation of the envisaged expansion target for offshore wind energy does not solely depend on the defined regulatory requirements for site investigation. Apart from the fact that the recommendations of the BSH standard (BSH 2014) have only in Germany been formally introduced as a binding minimum requirement, the content of the recommendations is also applied to wind farms in other North Seas countries. Since for example in Denmark and in the Netherlands at least a comparable scope of site investigation is carried out for the preparation of auctions, the minimum scope of site investigation prescribed by the BSH Standard cannot be the key issue for a potentially different growth rate of the installed capacity.

A site investigation campaign for a wind farm, even for the preliminary site survey, usually requires a total period of several years starting with initial preparations, tendering, executing the field testing at sea, laboratory testing onshore and the subsequent evaluation of the investigation results. In comparison with this experience, the budgetary resources of the competent authority in Germany are predominantly limited to the respective financial year, as it turned out from the dialogue with the BSH.

In the worst case, a preliminary site investigation campaign of a wind farm area would be divided into several lots that are distributed to different financial years. Each of these lots is tendered separately and without the possibility of long-term chartering of adequate vessels. From this perspective, the preliminary site investigation that is split into several lots would be performed in an ineffective and costly manner. Generally, the tendering of relatively small lots without binding charter of vessels well in advance of the field works, tendentially leads to rising costs for the site investigation.

The present budgetary regulations for the BSH might turn out as an obstacle for the future expansion of offshore wind energy in Germany, if these budgetary regulations would cause a delay of the preliminary site investigation for potential offshore wind farm areas. With a view to the desired expansion of offshore wind energy, the possibilities for improving the present budgetary regulations should be checked by the competent authorities.

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