FRANCE ENERGIES MARINES

Scientific et Technological Roadmap

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Table of contents

Context & objectives

France Energies Marines is the Institute for Energy Transition (ITE) set up to promote and support the deployment of Marine Renewable Energies (MRE) in France. In this emerging sector, for which Europe is leading the international competition, our action must, first and foremost, contribute to ensuring the proper implementation of the Pluriannual Energy Program (PPE), which provides for the massive deployment of MRE technologies. The following schedule and volumes for offshore wind turbines have already been prescribed as below:

Objectif d'augmentation des capacités installées d'éoliennes en mer et mesures pour les atteindre

	2016	PPE 2016 objectifs 2018	2023	2028
Objectif éolien en mer (GW)		0,5	2,4	5,2-6,2

Mesure : lancer les appels d'offres ci-dessous pour les éoliennes en mer, avec des prix plafond supérieurs de 10 à 20 €/MWh aux prix cibles.

Date d'attribution de l'AO	2019	2020	2021	2022	2023	>2024
Eolien flottant 750MW			250 MW *Bretagne Sud* (120 €/MWh)	2 x 250 MW *Méditerranée* (110 €/MWh)		1 000 MW par an, posé et/ou flottant, selon les prix et le gisement, avec des tarifs cibles convergeant vers les prix de marché sur le posé
Eolien posé 2,5 à 3 GW	600 MW *Dunkerque* (45 €/MWh)	1 000 MW *Manche Est Mer du Nord* (60 €/MWh)*	500 – 1 000 MW *Sud-Atlantique*** (60 €/MWh)		1 000 MW (50 €/MWh)	

** Pour ce projet, la date de 2020 est la date de lancement de la procédure de mise en concurrence.*

***Dans ce cadre, un projet éolien en mer au large d'Oléron pourrait être attribué.*

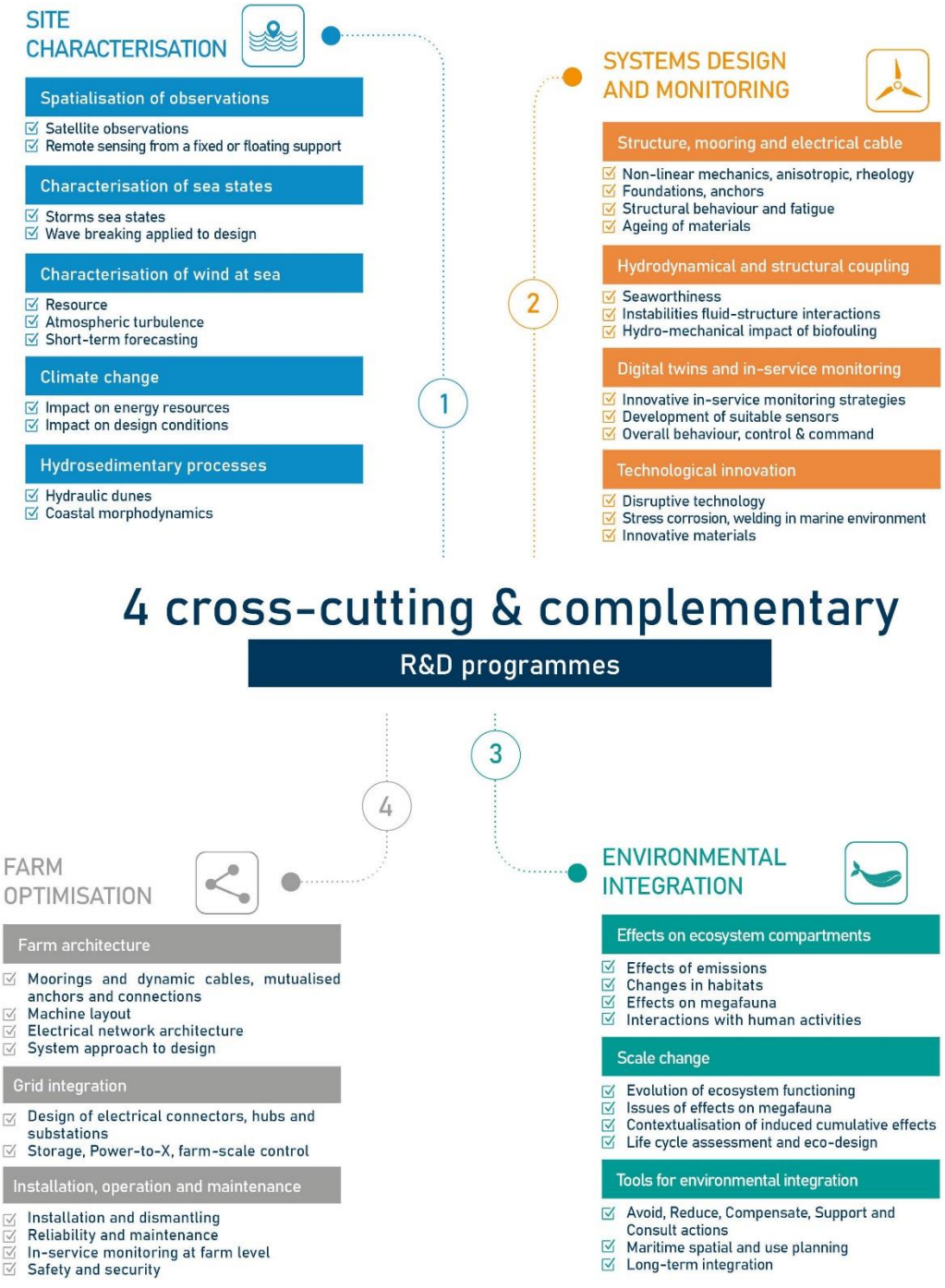
Table extracted from the "Programmation Pluriannuelle de l'Energie" presenting the targeted projections for the deployment of offshore wind technologies

The results of ITE's R&D programs are also intended to stimulate the French industry, which has international ambitions. The global growth of the MRE sector is strong and although France may not be at the forefront in the field of land-based wind energy, it is positioned as a leader in the floating wind energy sector, thanks in particular to the four pilot farms planned on the Atlantic and Mediterranean coasts.

This vision is perfectly consistent with the strategic roadmap for the development of energy technologies ("SET-Plan"), a pillar of the European policy of technological innovation in energy and climate, and with the energy component of the National Research Strategy (SNRE), through its challenge "Clean, safe and efficient energy". Applying the recommendations of the SNRE to intensify the development of MREs, FEM pursues inter-disciplinary research, in close connection with the regions and the industrial sector, associating with civil society and contributing to building a critical mass of French cutting-edge skills with international visibility and application.

R&D Programs

Taking into account these issues arising from the PPE, and translating them into the objectives of national industrial players, has led to definition of cross-cutting research programs covering upstream research to pre-competitive research. They complement other aspects of the national program, including calls for tenders for commercial farms, pilot farms or technological components supported by ADEME. Submitted to the ANR, the scientific and technological roadmap of France Energies Marines is divided into four complementary and cross-cutting research programs:



While this document reflects the pragmatic will of the State and members of FEM to quickly bring offshore wind technology to the forefront, with a focus on the floating MRE sector that has the greatest deployment potential and concentrates the greatest need for innovation, it is anticipated that a large part of the results obtained from this technology will be transferable to the other MRE sectors. These mutual benefits are clearly identified and anticipated in the four R&D programs described in this document and assists in FEM's action contributing to the emergence of all MRE technologies.

R&D activities are also part of a FEM development strategy based on the deployment of infrastructures at sea, of an experimental nature or for the purpose of acquiring data and knowledge specific to the needs of MRE, as proposed in the FOWRCE_SEA project. These R&D activities are also intended to be implemented, for those based on offshore experiments, as well as pilot and test sites, in order to consolidate development of the MRE sector in the most pragmatic and relevant manner.

The FEM S&T Roadmap presented in this document is an evolution of the initial document produced in 2016. This revision allows us to adapt our R&D programme to the needs of the sector for the period 2021-2026. The document is the result of a close collaboration between FEM and its members, structured by working groups contributing to a joint draft. According to the ITE process, the S&T Roadmap has also been reviewed by the eight international members of the Scientific & Technological Council and must be validated by the Administrative Board. For its implementation, FEM will rely primarily on the skills of its teams and members, while encouraging collaboration with teams displaying complementary expertise.

Likewise, although structured according to the four research programs already mentioned, the presentation of the S&T Roadmap highlights several themes which will be addressed by pooling resources from different programs, this transdiscipliniarity being encouraged by the size of FEM and its exclusive dedication to subjects related to MRE.

Site Characterization Program

The dynamics of the French MRE sector are strongly focused, in terms of R&D and innovation, on i) floating offshore wind as a breakthrough technology, and ii) land-based wind to optimize its adaptation to the French market. FEM has been involved in this effort since 2016, and in particular through the Site Characterization program.

To support the growth of the sector, the R&D activities of this program will focus on:

- **Reducing the uncertainties influencing wind resource and design conditions** (wind and turbulence under average and extreme conditions) and impact the LCOE (Levelized Cost of Energy) of this sector. The ITE will strive to fill the gap in observations by setting up observatories with dedicated *in situ* measurement campaigns. These efforts will be complemented by intensification of FEM actions in the use of satellite images. These *in situ* and satellite observations should also help refine understanding of air-sea interaction processes that are currently poorly represented in numerical models that simulate the climatologies used by engineers to estimate resource and design conditions in the context of climate change.
- **The reduction of uncertainties on sea state parameters for the design of MRE systems**, by consolidating the knowledge and expertise accumulated through the DiMe, DIMPACT and CARAVELE projects on the observation and modelling of storm sea states and in particular breakers. Based on its observatory at the La Jument lighthouse in Brittany and the one that will be deployed on the Zefyros floating wind turbine in Norway, FEM will continue to build databases dedicated to the documentation of these events. The development of specific wave models for the simulation of storm conditions will also be extended as part of the research efforts to develop a coupled Ocean, Wave, Atmosphere modeling chain (CASSIOWPE project).
- **The development of short-term wind and wave forecasting tools** to reduce the OPEX costs of MRE projects. FEM will seek to implement structural means of characterizing wind and wave conditions in the short term (from a few minutes to a few days) to make maintenance operations more reliable and to widen the windows of secure access, a know-how that can also be applied and adapted to other technologies.
- **The Characterization of interactions between coastal and littoral morphodynamics and MRE activities**. The ITE will also extend its efforts to characterize morphodynamics launched by the PHYSIC and DUNES projects to the characterization of the coastal zone, in a context of climate change. Cable landing operations, which are often at the centre of acceptability issues during the consultation phases prior to the deployment of offshore wind farms, concentrate questioning on possible alterations to the coastline.

All the R&D axes and sub-axes that structure the "Site Characterization" R&D program are listed below and described in detail in the rest of the document.

Spatial the observations

- SO1: Satellite observations
- SO2: Remote sensing from a fixed or floating support

Sea state characterization

- CE1: Storm sea states
- CE2: Wave breaking and MRE design

Wind characterization at sea

- CV1: Wind resource at sea
- CV2: Atmospheric turbulence at sea
- CV3: Short-term forecast of offshore wind

Climate change

- CC1: Impact on energy resources
- CC2: Impact on design conditions

Hydrosedimentary processes

- PH1: Sedimentdunes
- PH2: Littoral morphodynamics (including landing zone)

Designed and monitoring of ORE systems Program

This program addresses all MRE systems (land-based wind, floating wind, floating and fixed tidal devices, wave energy convertors, ocean thermal energy and auxiliaries) but focuses primarily on floating wind, which represents the greatest opportunity for the French sector due to the deep nature of its coasts, the metocean diversity of its marine and ultra-marine territories, its historical naval expertise and its delay in the development of land-based offshore wind energy.

FEM aims to develop tools, methodologies, technological building blocks and innovative testing means, so improving current standards to enable the French sector to become competitive and robust. The strategy of this program is to prioritise themes aiming to optimise the performance/cost ratio and to make their components reliable over 20-25 years in the marine environment.

FEM has built its scientific roadmap in focusing on a complementary philosophy to the actual investigations of French industry players around components and R&D issues specific to MREs.

Finally, in its applied research approach, FEM works to address these different themes in a progressive and pragmatic manner with the following main objectives:

- A detailed understanding of the physics through bench, tank and laboratory tests;
- Development of analytical and numerical models for the simulation of these phenomena;
- Validation of these models by measurements at sea on a reduced scale, or full-scale prototypes depending of the technology TRL and representativity constraints;
- Integration of certification offices to improve standards.

FEM has therefore identified four major areas of technological investigation:

- **Structure and materials** with a focus on **anchor lines**, **export cables and foundations**. These former components constitute the bottom-surface link and are identified as sensitive because of their small size in relation to the floats, so sustaining strong imposed dynamics, in addition to the ambient fluid loadings. Their small size and weight also make them sensitive to environmental variations such as biofouling. Once, it comes a strong challenge to describe the complex behaviour of these components, which leads to new materials whose behaviour and ageing in a marine environment are still poorly understood. Finally, certain components such as electrical cables so suffering of electro-thermal-mechanical coupling stresses are currently studied in this representative coupling way but very few feedbacks exist and no certification process include such approach. Therefore dynamic cable life and degradation modes are poorly understood, thus preventing design optimisation of this key component.
- **Hydrodynamic-structure interactions** are also a key issue for any floating system. Many tools exist today but limitations are clearly identified on the representativeness of non-linearities as well as their quantification from measurements at sea. The same is true for floating measurement devices, which are outside the standard assumptions due to their small size and large motions. Finally, biofouling has been identified as an element likely to have an impact on the behaviour of bottom/surface connections and potentially influence the appearance of fluid/structure instabilities, for which understanding and modelling are still in the research area. Therefore, this theme makes it possible to optimise the design of floating systems but also to improve their monitoring and maintenance by feeding the third axis;

- **The Digital twin and in-service monitoring** axis aim to improve the representativeness of the numerical models of systems deployed during operation through a hybrid methodology of measurements at sea and numerical modelling. The objective is to go beyond the simple alert level by proposing system health diagnostics to optimise maintenance.
- Finally, as the aim of FEM is to support and facilitate **technological innovation**, the last axis focuses on this aspect at the scale of technological bricks and not of entire systems.
- All of these themes are approached in a multidisciplinary manner with the three other programs, which constitutes the DNA of the institute.

Most of these themes require long-term immersion on representative sites in order to reach degrees of maturity (TRL) ensuring a representative and useful return for the industry. As the authorisation requests are cumbersome and sometimes uncertain, it is necessary for FEM to have test sites (owner or partnership) on several maritime facades, such as the MISTRAL site.

The four priority areas mentioned break down as follows:

Structure, Mooring and Export Cable

- SAC1: Non Linear-Mechanics, anisotropy, rheology.
- SAC2: Fondation / Anchor. (P4: AF1)
- SAC3: Structural behavior / Fatigue.
- SAC4: Material Ageing.

Hydro-Structure Interaction

- CHS1: Sea-keeping (non-linear, 2nd order).
- CHS2: FSI Instabilities (VIV, VIM, GALLOP…).
- CHS3: Hydro-Mechanical Impact of Biofouling.

Digital Twin / In-service Monitoring

- DTS1: Innovative Monitoring Strategy / Digital Twin.
- DTS2: Adapted Sensors Development
- DTS3: Overall Behaviour Optimization / control command (FW).

Innovative Technology

- INT1: Technological Breakthroughs.
- INT2: Stressed Corrosion / Welding in Marine Environment
- INT3: Innovative Materials

Farm optimization, operations and maintenance Program

This program aims to develop methodologies and tools that will optimize the implementation of commercial ORE farms and their integration into the electrical grid from a technical and economic point of view, as well as the operating phase (Operations & Maintenance). Three aspects are thus defined in this approach:

- The architecture of the farms, including the optimization of the layout of the machines, the inter-array and export cable network, the bottom-to-surface links, and an integrated system approach of the farm design.
- Grid integration, with the aim of developing tools and methodologies to optimize integration into the electrical grid, both at sea and on land, with a particular focus on alternatives to electricity for transporting the produced energy.
- And finally, the issues of installation, Operations & Maintenance, and decommissioning of ORE farms.

This program, which addresses all ORE applications in a transverse manner, is closely linked to the three other ITE research programs on many aspects, initially studied on a reduced scale and extended to the entire so-called commercial farm in this program. It is broken down into the three axes mentioned above:

Farm architecture

- AF1: Optimization of bottom-surface links, anchors, and mutualized connections.
- AF2: Optimization of the layout of the machines - AEP layout.
- AF3: Design of the electrical network architecture - IAC & export cable.
- AF4: System approach of the farm design (integrated design, innovative optimization methods, other disciplines).

Network integration

- IR1: Design of connectors, hubs and substations.
- IR2: Storage, Power-to-X, farm-scale control.

Installation and Operation & Maintenance

- EX1: Installation and decommissioning.
- EX2: Reliability and Maintenance.
- EX3: Monitoring at farm scale.
- EX4: Safety & Security.

Environmental Integration Program

This program concerns scientific research into the effects of marine renewable energy on marine ecosystems and human activities. The issues studied are those raised by the industry, experts and citizens' associations. In a pragmatic and rigorous approach, this program contributes to the development of MRE by ensuring a virtuous integration into the environment, a guarantee of acceptability.

As with the other programs, the Environmental Integration program focuses mainly on supporting the development of offshore wind farms, both fixed and floating. Although wind farms, their components and associated human activities, which generate effects on marine ecosystems, represent the bulk of R&D projects currently underway in the program, the results, protocols or recommendations may be, in part, transposable to other MREs.

The work conducted in the program has several objectives:

- Identify the ecological and socio-economic issues to be taken into account in the installation, operation, maintenance and decommissioning phases of MRE projects.
- Develop tools and methodologies to measure, qualify, analyse and predict the effects of MREs on marine ecosystems and human activities with regard to the issues identified.
- Pooling R&D and knowledge acquisition efforts on a larger scale than that of a MRE farm.

- Contribute to the standardization and production of recommendations for the assessment and monitoring of the effects of MREs on marine systems, but also the avoid-minimize-mitigate (or Reduce)-compensate (AMMC/ ARC) sequence.
- Enhance knowledge towards the industry and citizens.

Since its first version, the roadmap of the program has evolved and two changes can be specified. First of all, the term "Environmental Integration" has gradually replaced the term "Environmental Impact". Environmental integration seems to correspond better to the objectives of the program and reflects a desire for a sector developing a low-carbon energy to best assess the effects generated by MRE projects, to report to public action and society, and then to limit them to a maximum. The second major change in the program's roadmap is the disappearance of the dichotomy between environmental and socio-economic effects. The holistic ecosystem approach first developed in the TROPHIK project, and currently pursued in the APPEAL and WINDSERV projects, has placed the human in the ecosystem and it is the whole that can now be considered and named also socio-ecosystem. In this same perspective, the LIF-OWI project, which is interested in the life cycle assessment (LCA) of wind energy projects, proposes to combine the classical approach with the development of a social LCA and indicators related to marine ecology.

This program is divided into three axes, the first dealing with the effects of MREs on the compartments of marine socio-ecosystems, both in their natural and human dimensions, the second considering a change of scale towards a more macro consideration of the effects and the last proposing tools for the integration of MREs in these ecosystems. The boundary between these axes is not hermetic, it is indeed a better global knowledge of the effects of MRE projects on ecosystems that will provide elements to improve their integration.

Regarding the environmental and socio-economic integration of MREs, FEM's mission also extends to actions that are not related to R&D issues but are just as essential and are not detailed in this document: creation of a steering committee for expertise on the environmental challenges of MREs, methodological summaries, recommendation reports, teaching, participation in consultation and public debates...

The three program axes include 11 sub-axes listed and described below:

Effects on ecosystem compartments

- ESE1: Effects of emissions (noise, EMF, nutrients, pollutants...)
- ESE2: Habitats modification

- ESE3: Effects on megafauna (avifauna, marine mammals and large fish)
- ESE4: Interactions with human activities

Change of socio-ecosystemic, spatial and temporal scale for the consideration of effects

- CEE1: Evolution of ecosystem functioning.
- CEE2: Macro issues of effects on megafauna.
- CEE3: Contextualization of cumulative effects induced by MREs.
- CEE4: Life Cycle Assessment and Ecodesign.

Tools for environmental integration

- OI1: Avoid, Minimize, Mitigate, Compensate, Consult and Support.
- OI2: Marine spatial planning.
- OI3: Long-term integration of MREs.