Title of Proposal	**Sea states and atmospheric cHaracterisation toolbox for Offshore Wind in the MEDiterranean sea**
Acronym	**SHOWMED**
Call	H2020-LC-SC3-2018-2019-2020
Topic	LC-SC3-RES-31-2020: Offshore wind basic science and balance of plant

List of participants

Participant No (Type)	Participant organisation name	Acronym	Country
1 (Coordinator - SME)	France Energies Marines	FEM	France
2 (RTD)	Barcelona Supercomputing Center	BSC	Spain
3 (RTD)	Consiglio Nazionale delle Ricerche – Istituto di Science Marine	CNR	Italy
4 (RTD)	Center for Renewable Energy Sources and Saving	CRES	Greece
5 (RTD)	Croatian Meteorological and Hydrological Service	DHMZ	Croatia
6 (RTD)	Technical University of Denmark	DTU	Denmark
7 (RTD)	Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research	HZG	Germany
8 (RTD)	Institut français de recherche pour l’exploitation de la mer	Ifremer	France
9 (RTD)	Ruđer Bošković Institute	IRB	Croatia
10 (RTD)	Izmir Institute of Technology	IZTECH	Turkey

Table of Contents

1. EXCELLENCE 4

1.1 OBJECTIVES 6

1.1.1 Project objectives 6

1.2 CONCEPT 11

1.3 METHODOLOGY 12

1.3.1 Overall methodology 12
1.3.2 Position in the Technological Readiness Level scale: 17
1.3.3 National or international research and innovation activities 17

1.4 GENDER DIMENSION IN THE PROJECT 18

1.5 AMBITION 19

1.5.1 State of the art on the challenges faced and corresponding SHOWMED ambition 19
1.5.2 Innovation potential 21

2. IMPACT 25

2.1 EXPECTED IMPACTS 25

2.1.1 Offshore wind market in MCA 25
2.1.2 Contribution to the expected impact in the work program 27
2.1.3 Other substantial impact not mentioned in the work program 29
2.1.4 Limitations and barriers to consider for impact achievement 29

2.2 MEASURES TO MAXIMISE IMPACT 30

2.2.1 Exploitation 30
2.2.2 Dissemination 33
2.2.3 Communication activities 35

3. IMPLEMENTATION 37

3.1 WORK PLAN — WORK PACKAGES, DELIVERABLES AND MILESTONES 37

3.1.1 Overall structure of the work plan 37
3.1.2 Timing of the different work packages 38
3.1.3 Detailed work description 39
3.1.4 List of deliverables 54
3.1.5 Graphical presentation of the project 57

3.2 MANAGEMENT STRUCTURE, MILESTONES AND PROCEDURES 58

3.2.1 Organisational structure and decision making 58
3.2.2 Innovation management 59
3.2.3 Quality Assurance and Risk Management 60
3.2.4 List of milestones 62

3.3 CONSORTIUM AS A WHOLE 62

3.4 RESOURCES TO BE COMMITTED 63

REFERENCES : 67

Acronyms:

AEP: Annual Energy Production
AMO: Atlantic Multidecadal Oscillation
BSC: Barcelona Supercomputing Center
CAPEX: CAPital EXpenditure
CDEP: Communication, Dissemination and Engagement Plan
CNR: Consiglio Nazionale delle Ricerche
CRES: Center for Renewable Energy Sources and Saving
DHMZ: Croatian Meteorological and Hydrological Service
DTU: Technical University of Denmark
EC: European Commission
ETIP: European Technology & Innovation Platform
EU: European Union
FEM: France Energies Marines
FOW: Floating Offshore Wind
FOWT: Floating Offshore Wind Turbine
GIS: Geographic Information System
HZG: Helmholtz-Zentrum Geesthacht Centre for Materials and Coastal Research
IP: Intellectual Property
IPR: Intellectual Property Right
IRB: Ruđer Bošković Institute
IZTECH: Izmir Institute of Technology
KPI: Key Performance Indicator
LCOE: Levelized Cost Of Energy
LP: Le Planier (lighthouse, island)
MCA: Mediterranean Coastal Areas
ML: Machine Learning
MR: Marine Radar
NREL: National Renewable Energy Laboratory
NEWA: New European Wind Atlas
NWP: Numerical Weather Prediction
O&M: Operation and Maintenance
OPEX: OPerational EXpenditure
ORE: Offshore Renewable Energy
OW: Offshore Wind
PIV: Particle Image Velocimetry
QAP: Quality Assurance Plan
RDI: Research, Development and Innovation
SAR: Synthetic Aperture Radars
SO: Ship of Opportunity
SST: Sea Surface Temperature
SVS: Stereo-Video System
TRL: Technology Readiness Level
ULS: Ultimate Limit State
USA: Ultra-Sonic Anemometers
WBLM: Wave Boundary Layer Model
WP: Work Package

1. Excellence

Foreword

Shall we dare proclaim that *Mare Nostrum* is *terra incognita*? Indeed, if many indicators tend to suggest that offshore wind, and specifically floating offshore wind, is going to represent, along the Mediterranean coasts and in the near future, the complementary share of solar energy in the renewable energy mix, not enough is known today to assess its very specific wind resource and the metocean conditions to foster this development.

Global project context

The offshore wind (OW) outlook 2019[1], published by the International Energy Agency, estimates that the global offshore wind capacity is set to increase fifteen-fold from 2018 to 2040. Annual OW capacity additions are set to double over the next five years and increase at least fivefold by 2030 to over 20 and up to 30 GW per year. The European Union has the strongest ambitions for 2030, with targets in individual member states totalling 65-85 GW by 2030. In the European Union, OW is set to play a central role and has the potential to become the largest source of electricity supply with at least 10% of the electricity supply share by 2030 and up to 20% by 2040 in the sustainable scenario. Member states have made various commitments that underpin the future development of OW in the European Union. **Most of the commitments are related to Northern European countries** where fixed OW is a reality and commercial projects with floating OW turbines are soon to be released. France and Italy are the only countries in the **Mediterranean Coastal Areas (MCA)** that have included targets for development of OW in Southern Europe in their energy and climate plans at horizon 2030.

The market perspectives are also quickly broadening thanks to the success of the pioneering efforts of floating OW turbines developers. They show the path toward the exploitation of untapped wind resource lying in deep water, thus not accessible to bottom-fixed wind turbines.

The Mediterranean Sea is a striking example of a potential new Eldorado for the deployment of the floating OW industry. This area offers an exceptional wind potential, generally lying in deep water, combined with coastlines populated by about 250 million people. The Mediterranean Sea has further been identified as one of the hotspots for the climate change effect. Although the latter is a global problem, the development of power production means with a lower carbon footprint resonates in the Mediterranean Sea.

This trend can only be confirmed if there is a precise knowledge of the wind potential and sea-state conditions over the Mediterranean, as a prerequisite, as was performed over the North Sea prior to its present, impressive offshore wind deployment. SHOWMED has this primary goal over the Mediterranean Sea of setting the scene before a potential sizable investment.

Mediterranean Sea specificities for OW deployment:

One particularity of the Mediterranean basin is its enslavement within high and uneven reliefs that interact with the atmospheric flow and lead to intense and localized wind accelerations (e.g., Flamant, 2001, Guenard et al., 2005), that can certainly be exploited by the OW industry, when the wind channels reach the sea. Such situations occur under Mistral conditions in the Western Mediterranean basin, Bora winds such as in the Adriatic Sea, Meltem or Etesian winds in the Aegian Sea. The Mediterranean Sea is further exposed to **specific storm events** such as **Medicanes** (“Mediterranean Hurricanes”). Medicanes count among these extreme meteorological systems **that lack proper understanding and modelling** due to the obvious complexity to observe the relevant metocean parameters at sea under severe conditions. MCA flows are also often affected by land-sea thermal effects (Millot, 1979). Sea Surface Temperature (SST) is an important element in the dynamics of the Atmospheric Boundary Layer above the sea and affects the surface wind speed, shear, turbulence and gustiness.

1 Offshore wind Outlook 2019, Special Report, publication November 2019 – International Energy Agency

Offshore blowing winds result in short fetch steep young sea states with high breaking rates. The intense winter storms may further grow severe sea states made of steep and possibly breaking waves, particularly dangerous for any structure at sea. The high proportion of breaking waves in the MCA further intensify the coupling of the sea states and the atmosphere through the air-flow separation process that enhances the air-sea momentum flux (e.g., Kukulka et al., 2007).

The Mediterranean basin is characterized by a very steep continental slope. There, the water depth lying above the 50m-isobath corresponds to a negligible fraction of the basin. Both the water depth and high wind energy potential over the Mediterranean basin clearly suggest that floating technologies will be preferred in this region.

The hydrodynamic currents in the Mediterranean have velocities typically much lower than 1 m/s (e.g. Echevin et al., 2003), which makes their impact on the OW design and operation and **maintenance much less important than that of winds and waves. SHOWMED will then focus its efforts in the two latter metocean processes.**

These strong MCA specificities are the reason why SHOWMED's ambition is not only to apply a set of well-established approaches (data acquisition, modelling and guidance) to a new geographic area. SHOWMED has to develop new combinations of observations with higher resolution in space and time and of enhanced models with new relevant physical processes. These improvements are also, for the first time, mostly dedicated to fulfil the new requirements of the floating OW technology. A double challenge in some sense.

In the rest of the document will we use the denomination "Offshore Wind" (OW) to cover both the bottom-fixed and floating sector, keeping in mind that the latter will very likely be the preferred option in the MCA, and is as such the main target of SHOWMED.

Measure of project excellence

The rationale for the project is that the wind resource, wind and wave design conditions **and the weather forecasting** capacities lack dedicated efforts in the MCA, which faces very specific and challenging weather situations.

Indeed, previous efforts to enhance the forecasting capabilities of the metocean parameters have been conducted down to a scale that still does not reflect the accuracy in space and time needed for a floating OW farm project. Design, exploitation and maintenance plans highly rely on a perfect knowledge of the metocean conditions, which are overwhelmingly difficult to assess in the MCA. By connecting design with capital expenditure (CAPEX), and exploitation and maintenance with operational expenditure (OPEX), it is easy to understand the economic rationale of SHOWMED.

SHOWMED proposes to **accelerate** the deployment of **OW in Mediterranean Coastal Areas** by improving the characterization of their wind and wave conditions. The objective here is to **reduce the Levelized Cost Of Energy (LCOE) and increase market value of OW** in the target regions. To that purpose, SHOWMED proposes an integrated MCA-specific toolbox (see the details in the Objectives section below).

SHOWMED excellence can be further appreciated along different axes:

SHOWMED addresses a region with **excellent wind resource** that is currently underexploited. **SHOWMED intends to increase the OW market by further revealing the potential of the MCA** for the massive deployment of this technology (with a focus on floating wind). As such, SHOWMED will contribute to an intensified implementation of OW **in the European energy mix through the consolidation of OW growth in the countries already engaged in OW deployment and ignition of a fast development for the other countries**.

SHOWMED will also **demonstrate the practical assets of the MCA conditions,** especially the **offshore blowing winds conditions** that offer a decisive advantage for short-term forecasting derived from **coastal measurements**. It is expected that operation and maintenance (O&M) strategies as well as wind farm power optimization **will directly benefit** from the short-term forecasting tools developed in SHOWMED.

SHOWMED has a **relevant consortium** at different levels. First, the partnership disposes of a high-level of expertise regarding the monitoring and numerical modelling of metocean conditions. Second, and more importantly, **it features an excellent combination of Northern European teams** (DTU and HZG) holding a **considerable experience** in the deployment of applied research activities related **to industrial OW projects,** together with the other partners **owning an excellent knowledge of the metocean conditions in the MCA**. **This guarantees the success of the project but also skill transfers between the different institutes and countries** through a general collaborative effort, joint field experiments, numerical model developments and specific training sessions. This will provide a direct application of the project results in the MCA targeted by the project.

One of the major aims of SHOWMED is to ensure a **wide and durable implementation of the project outcomes within the industrial, scientific and institutional MCA OW communities.** A coherent set of workshops will thus be held across the **SHOWMED Mediterranean countries**. Actions regarding the presentation of SHOWMED's results through conferences, scientific papers, general dissemination, webinars or training sessions, will be strongly encouraged.

The dedicated communication and dissemination plans will allow to widespread the outputs and make the SHOWMED toolbox be adopted by a wide range of actors from the offshore wind sector. **This will contribute to the strengthening of the European industrial technology base, thereby increasing job growth and European competitiveness, particularly around the Mediterranean Sea.**

SHOWMED partners further intend to enhance **the industrial impact of the project** thanks to **a tailored advisory board made of OW key players** who are committed to providing industrial guidance throughout the project. This industrial impact will be strengthened by the **set of recommendations** to be produced by SHOWMED, aiming at **improving the applicability of the existing OW certifications standards** to the very specific MCA conditions.

1.1 Objectives

1.1.1 Project objectives

MCA can highly contribute to reach EU targets for renewable energy and improve value of the OW industry. Most of the Mediterranean countries acknowledge the potential but still need to get better confidence in the value of the OW and its potential for achieving affordable cost of Energy. These are the main motivations of SHOWMED.

SHOWMED aims at increasing the OW market value by:

- allowing to diversify areas of production from Northern Europe to MCA
- demonstrating the practical assets of MCA, namely the offshore blowing winds,
- transferring the knowledge of leading institutes involved in the development of the offshore industry to the MCA community,
- increasing the MCA OW market value by ensuring awareness of the MCA wind potential amongst the OW and local stakeholders.

SHOWMED targets a LCOE reduction through the generation of a MCA-specific metocean toolbox featuring:

- a MCA-specific sea-atmosphere coupled modelling system,
- observational (remote sensing and in-situ) databases of the MCA wind and wave conditions,
- a 25-year high-resolution numerical wind and wave hindcast database,
- decadal wind forecasts over MCA,
- recommendation regarding the wind and wave conditions in MCA to be implemented in certification standards,
- a fast data driven weather forecasting system.

The following specific objectives will be addressed during the course of SHOWMED project.

Objective 1: Increasing the MCA floating offshore wind (FOW) market value by allowing to diversify areas of production from Northern Europe to MCA

Problem to address: the MCA wind resource is highly influenced by OW channelled by the upstream orography and affected by interaction with the sea and especially the sea states. The current wind resource databases likely mispredict the wind resource because these channelling and air-sea interactions effects are not correctly captured. MCA have not been sufficiently taken into account for prospective development of OW in Europe.

Short response description: SHOWMED will develop a high-resolution air-sea coupled numerical modelling system to further capture the orographic effects and air-sea interaction to refine the resource assessment and likely reveals new hotspots in MCA.

Objective 2: increasing the MCA FOW market value by revealing the practical MCA assets

Problem to address: Definition of the weather windows for O&M, optimization of the power production of typical OW farms relies on numerical models since the cost of operating of an upwind station recording atmospheric parameters is prohibitive. Operational weather forecasts can not provide the information at the required time-space resolution for optimal power production and O&M planning.

Short response description: the MCA wind resource is often dominated by offshore blowing winds. In this context, the deployment of a cheap coastal monitoring strategy could be decisive in forecasting in the short term (typical 10 min to a couple of hours) the wind conditions at an OW farm located at a 10-50km distance. In addition, this information can be coupled to high resolution satellite products to statistically downscale the conventional weather forecasts.

Objective 3: Increasing the MCA FOW market value by building on the experience of northern Europe and specific MCA knowledge of the Mediterranean countries

Problem to address: The OW energy development has been led by the northern European countries. The fast and massive deployment of OW in MCA will require that the concerned countries develop a strong scientific and technological basis.

Short response description: SHOWMED will stimulate strong skill transfers between the northern partners who owns a considerable experience in deploying numerical models and instrumentation to support the massive deployment of OW in northern Europe. In the meantime, the Mediterranean partners have accumulated a considerable knowledge of the physical processes controlling the wind and waves in MCA. This will allow SHOWMED to provide the best observational and modelling tools to face the MCA challenges. This combination will contribute to build a solid scientific and technological basis in the MCA communities to accelerate and secure the OW deployment.

Objective 4: Increasing the MCA FOW market value by ensuring awareness of the MCA wind potential amongst the offshore wind and local stakeholders

Problem to address: up to now, OW has been only scarcely implemented in the energy mix of the Mediterranean countries. Part of the problem lies in the rapidly plunging bathymetries found in MCA and lack of visibility of the wind potential.

Short response description: SHOWMED will contribute to disseminating the potential for FOW farms deployment along MCA. WP6 is tasked with defining and implementing a programme of communication and dissemination activities. This will ensure that all key stakeholders are made aware of the project as it progresses and that all project results are made available. WP6 will also host stakeholder engagement events, and in particular local workshops will be organized in each Mediterranean country taking part in the project. A diverse range of stakeholders, including authorities, companies interested in developing businesses in FOW, students, researchers and broader communities, will be invited to these events.

<u>Objective 5: Lowering the MCA OW LCOE through reduction of the uncertainties in the resource assessment</u>

Problem to address: The complexity of the atmospheric patterns in the MCA induces significant uncertainties in the resource assessment, especially due to the fine wind structures induced by orographic effects and air-sea interactions. This results in high loan rates for the OW farm developers (for a decrease in uncertainty on the predicted mean wind speed at hub height of 0.1 m/s there is an estimated saving worth around £10 million for a large 25-year OW farm project, from Hasager et al., 2013).

Short response description: SHOWMED aims at providing the OW industry with a high-resolution accurate wind resource climatology covering the MCA of interest.

<u>Objective 6: Lowering the MCA FOW LCOE through reduction of uncertainties in the design conditions</u>

Problem to address: The fatigue and extreme design of the OW turbines and ancillary components (e.g. dynamic power cables, mooring lines) heavily depends on wind turbulence, gustiness and shear. Since we are mostly concerned with floating OW turbines, averaged and extreme wave conditions are a key component in the design but are lacking a correct description in MCA because the models were developed for open ocean condition rather than coastal areas and short fetch waves.

Short response description: Decisive description of the turbulence, wind gustiness and wave properties will be available through the SHOWMED experiments in the MCA. SHOWMED will propose MCA-relevant models of wind turbulence, gustiness and wave properties for potential implementation in the OW certification documents.

<u>Objective 7: Lowering the MCA FOW LCOE through optimization of power production and O&M windows, revealing the MCA assets</u>

Problem to address: Metocean conditions forecasting is crucial for the definition of O&M weather windows and the integration of the wind farm power into the grid. Real time wind farm control is key for optimizing wind production, reducing material fatigue and avoiding overproduction shutdown. However, it relies extensively on numerical modelling and complex instrumentation (horizontal lidar). Both components are very expensive.

Short response description: here we shall make the best use of the SHOWMED numerical and observational databases to provide the Floating Offshore Wind Turbine (FOWT) industry with a unique, affordable and fast data-driven forecasting system that is able to capture the fine wind features and associated wave fields using a combination of the high resolution numerical and observational databases and cutting-edge machine learning approaches. A gust forecasting method (30 - 60s ahead) will further be implemented based on the SHOWMED's X-band radar deployment.

Relation to the Horizon 2020 work programme

The call's topic targets specific research areas that are mainly addressed by the SHOWMED proposal.

Call research area	*How this is addressed?*
Atmospheric multi-scale flow modelling (from meso-scale to wind farm flows)	The partners will apply DTU's existing air-sea modelling system over nested meshes covering the coastal areas to produce a high-resolution wind and wave climatology covering the MCA. SHOWMED will also develop and validate a data-driven system able to downscale operational wind forecasts using machine learning and the SHOWMED's high resolution numerical and observational databases (featuring high resolution Synthetic Aperture Radar wind maps).

Call research area	*How this is addressed?*
Understanding and modelling key uncertainties and physical phenomena of OW energy design and operation (e.g. fluid-structure, soil-structure and electro-mechanical interaction, large motion prediction, turbulence, wave modelling, mooring line behaviour)	SHOWMED will target a fine description of the wind turbulence, gustiness and shear in the MCA thanks to the observations collected from profiling lidar, floating and fixed met-masts. The effort will focus on providing further understanding with regards to the changes in the turbulence, gustiness and shear properties at the land sea transitions. SHOWMED air-sea coupled modelling system will further involve a parameterization of the breaking waves effects on the air-sea momentum flux. Waves in the Mediterranean are known to be complex to model, mostly because state-of-the-art wave models are tuned for oceanic condition and not for the short fetch wave conditions, inherent to the MCA. Here we propose to implement in SHOWMED's modelling system, new sources terms for wave breaking dissipation, that is generally the greatest energy sink for waves in MCA wave. SHOWMED will also address the applicability to MCA of the wave energy spectrum shape proposed in certification standards and propose improved formulation, relying on SHOWMED's experimental efforts. This wind turbulence, gust, shear and wave information will be highly valuable to the OW industry to lower the LCOE of the wind power in MCA through reduction of uncertainties in the design conditions.
High performance computing and digitalisation (e.g. data processing, machine learning and data analytics methods for implementation in data‐driven design, digital twins and control and monitoring for O&M);	The project will massively rely on high performance computing for all the atmospheric and wave modelling tasks that require to run over several hundreds or thousands of cores in parallel, especially for the climatology productions. This also applies to the processing of thousands of satellite images, to be achieved in SHOWMED. In addition, machine learning will be intensively applied in SHOWMED: • To derive a system able to capture the wind speed from video and radar images of the sea surface, • To provide data driven short term forecasts fed by satellite and model atmospheric databases coupled to real time in situ observations. SHOWMED intends to transfer its short-term forecasts systems to the optimization of weather windows.
While OW must be the cornerstone of the proposal addressing any bullet point above, onshore wind may also be covered when synergies may be exploited from including both. This is just a possibility and not a requirement.	Different products of the project will benefit to the onshore wind industry. First, the configuration of the atmospheric model will cover the coastal Mediterranean land at a resolution high enough to capture the orographic effects that further propagate offshore in offshore blowing wind situations. The wind resource database will certainly be highly valuable for the developer of onshore wind farms close to the Mediterranean Sea. The data-driven downscaling and gust detection method to be developed in WP5 will have similar application and benefit for onshore and offshore wind and finally the data driven forecasting system could be useful for onshore wind farm close to the coastline and exposed to onshore winds in the Mediterranean Sea or elsewhere.

Call research area	*How this is addressed?*
	Direct application is envisaged for onshore wind farms deployed over low-lying islands such as those found in Croatia or Greece or Turkey to complement actions similar to the European Union funded TILOS project.
The proposals are expected to bring new technologies/models /methods to TRL 4-5 (please see part G of the General Annexes).	All the different components of the MCA specific toolbox that will be developed in SHOWMED (numerical models, statistical forecasting tool, dynamical downscaling system, wind resource climatology) will all be validated against real environmental conditions, therefore, matching at least TRL 4-5 in terms of technological maturity.
The contribution of offshore wind power to the energy mix is expected to increase significantly by 2030. Better knowledge of basic wind energy science and related areas contributes to the cost reductions required to achieve that goal.	According to the Wind Europe Association, 80% of the offshore wind resources in Europe are located in areas with a water depth more than 60m. Only floating offshore wind can significantly contribute to increasing the part of offshore wind in the energy mix. The potential in the Mediterranean Sea is huge and can be harvested at affordable cost by reducing uncertainties on resources and metocean characterization. The approach considered in SHOWMED fully contributes to achieve that goal. Currently, the generation of OW power in Europe is concentrated around the North Sea and United Kingdom with a real impact on the cost of electricity for the surrounding countries. In order to raise the market value of OW it is important to make new installations in other uncorrelated regions. The Mediterranean Sea, with its characteristic local wind regimes, is a perfect target for the development of new projects that diversify the wind electricity production and complement the current installations in Northern Europe.
Proposals should lower the Levelized Cost of Energy (LCOE); those addressing any of the first four bullet points above **should also aim to increase the market value of wind power.**	We believe SHOWMED will not only contribute to lower the LCOE through the three objectives exposed in section 2.1.2. It will also reveal the potential of the European MCA. Thanks to the planned communications efforts, we intend to demonstrate to all the countries partners of this project, the potential of OW along their coastline and how a more intense implementation of this technology could contribute to the energy mix at the European level. Finally, SHOWMED will also be an opportunity to demonstrate the industrial potential of the MCA to the advisory board of the project, composed of key players of the OW sector. Countries not involved in the SHOWMED proposal but influenced by similar Mediterranean wind regimes, such as Morocco, Algeria, Tunisia, Libya, Egypt, Lebanon, Israel or Syria will directly benefit from the tools and databases developed in this project for their current coastal onshore wind farms and future OW farms. More generally, different tools and techniques may find repercussion in the global OW sector. The SHOWMED numerical modelling chain and short-term forecasting systems could further be applied to other areas in the world with similar situations (e.g. offshore blowing winds).

1.2 Concept

SHOWMED motto is to improve the characterization of the metocean conditions in the MCA so as to increase the FOW market value and reduce the FOW LCOE. This will ensure a massive deployment of this technology in the Mediterranean Sea.

To achieve this, **SHOWMED will develop a specific observational strategy and numerical air-sea coupled numerical model** that will serve to produce observational and numerical wind and waves databases.

The exploitation of the databases in the project will serve for **wind resource assessment, definition of the design conditions and data driven weather forecasting.**

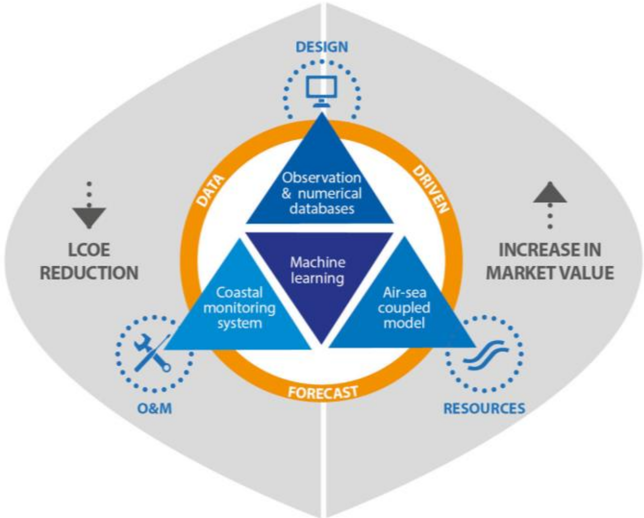


Figure 1.1: illustration of SHOWMED concept

Exploitation of the observational and numerical database

Resource assessment

The 25-year numerical wind hindcast will provide reliable information on the wind resource along the MCA thanks to the high spatial resolution and new air-sea coupling schemes implemented in SHOWMED's modelling system. We expect that it will also further reveal the exceptional wind energy potential of MCA through the accurate reproduction of the orographic channelling effects that accelerate the offshore blowing winds. Classical wind energy parameters, such as the wind power at hub height or the standard wind percentile P50 and P90 will be computed in order to provide direct guidance to the OW energy investors.

Wind design parameters

The numerical databases, together with the observations collected throughout the project (e.g. wind lidar and met masts) will be analysed to derive information regarding the wind turbulence, gustiness, shear (mean and storm) that that crucial for the design of OW turbines,

It is expected that the values found over the MCA will significantly differ from the typical range reported in the certification document or used in the wind farm siting softwares. Important efforts will be undertaken by the SHOWMED team to develop specific models for the MCA metocean conditions. These models target implementation in the certification standard and farm siting software such as DTU tool WAsP family.

Wave design parameters

The sea states found in MCA are generally younger and shorter than in the ocean. Here we shall evaluate the applicability of the JONSWAP spectrum for MCA and possibly define a more appropriate wave energy spectrum shape for MCA. Further efforts will concentrate on the directional spreading of the sea states that is generally disregarded by the industry, while in MCA conditions, it could strongly influence the fatigue and design of the wind turbines.

The statistics of extreme and rogue waves in MCA will be further explored in the project, since we anticipate they could differ from those found in open ocean conditions, due to the high wave steepness and large directional spreading. This is an important question both for ultimate limit state (ULS) design of the floating OW turbine but also for O&M (e.g. boat landing).

Again, the target will be to develop guidelines which shall be implemented in certification documents to optimize the design of OW turbines in MCA conditions.

Data driven weather forecasting

The strength of the project will be to provide the MCA OW actors with a forecasting system that will only rely on the databases generated through the project and exploited by fast and low computational cost machine learning algorithms. Hence, the MCA OW actors, will benefit from the highly accurate information produced by the advanced numerical and observational instrumentation deployed in SHOWMED without having to operate it. This data-driven forecasting system will be supplemented by a direct forecasting method of the gusts using X-band radar measurements.

Communication and dissemination

The final objective of SHOWMED is to ensure a proper dissemination of the project results, first to ensure that the MCA offshore wind energy potential is revealed and second that the metocean toolbox is optimally used by the key players of OW industry.

Workshops and training sessions towards FOW developers, technology developers, design offices, O&M companies will be organized towards the end of the project in order to properly disseminate the numerical toolboxes to the FOW value chain. In addition, local/regional workshops are planned around the Mediterranean (in Croatia, France, Greece, Italy, Spain and Turkey, Greece), targeting a large group of stakeholders to better inform about OW potential and their market value around MCA.

1.3 Methodology

1.3.1 Overall methodology

The objective of SHOWMED is to provide all the European countries surrounding the Mediterranean Sea with a **specific metocean toolbox and databases,** enabling significant reduction of the OW energy LCOE. To achieve this, the methodology is quite straightforward and follows the chart given in figure 1.2.

The motivation of this project is to refine the metocean condition characterization in MCA to boost the development of the Floating Offshore Wind sector. The lack of knowledge regarding the wind and wave conditions are due to:

- a general **lack of in-situ observations** compared to other regions where OW is well developed, such as in the North Sea,
- a **lack of in-depth validated MCA-dedicated satellite sources**, due to the insufficient in situ data necessary to develop accurate geophysical model functions to retrieve wind and wave properties from sea surface radar backscatter,
- the **absence of a specific monitoring strategy** to capture the rapid wind, turbulence and wave evolution in OW at the land-sea transition in presence of offshore blowing winds.

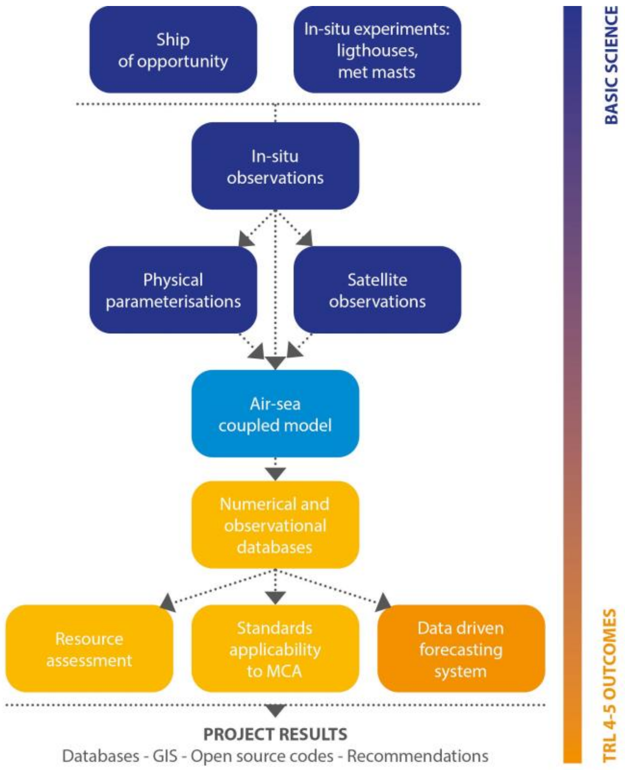


Figure 1.2: SHOWMED project methodology chart

These gaps in the description of the metocean conditions, impact the numerical model quality in particular due to the **lack of understanding of the dominant physical processes** that **prevent the developers from incorporating the relevant physical parameterizations** in the models and to calibrate and validate them accurately.

Finally, the outcomes of research projects dealing with the improvement of the physical description of the environment is generally made of metocean databases and/or numerical models. Hindcast databases are crucial for resource and design conditions assessment but are useless for forecasting purposes. Numerical models are crucial to develop accurate and operational forecasting system. However, in practice they require highly trained scientists and powerful computational means that often prevent their wide use by the initially targeted end users. SHOWMED intends to fill this gap by providing a data-driven forecasting system that will only rely on the project's database and on fast and easy to apply machine learning tools.

SHOWMED will therefore develop a work program starting from basic science aiming at improving the description and understanding of the metocean conditions through the development of specific monitoring strategies and coupled numerical modeling to provide accurate observational and numerical databases. These databases are the foundation of a data driven forecasting system able to downscale low resolution operational weather forecast.

Observational efforts

At the beginning of the project we intend to install different experimental sites for collecting relevant information regarding specific MCA conditions with a focus on offshore blowing winds. Existing experimental data (see Floatmast project in Greece) will be provided to the project to supplement the observational database.

In-situ efforts

French site

The French site will feature the deployment of X-band radars, met masts and profiling lidars on two lighthouses (**Cap Courone and Le Planier**) near Marseille. The two targeted lighthouses are aligned in the Mistral wind direction, spaced by a 20km distance. This makes the experiment very relevant to study the development of the atmospheric boundary layer and wave field over a distance relevant for the FOW sector. This setting is favorable for testing data driven atmospheric forecasting to be tested in WP5, especially under offshore blowing wind situations.

Le Planier is located on a shoal with a bathymetry rapidly plunging in rather deep waters (~ 80m). This situation is similar to the area surrounding La Jument lighthouse in the Iroise Sea (Brittany, France), where FEM, HZG and CNR operate stereo-video and X-band radar to capture the properties of storm waves and currents in the Atlantic Ocean (see Filipot et al., 2019; Guimaraes et al., 2020). We shall then be able to study the atmospheric flow and wave properties in the peculiar MCA situations, characterized by small yet intense storm systems. The site further features a permanent wave buoy (1 km in the South of Le Planier) owned by Cerema, France, that will be valuable for the calibration of the onsite remote sensing wave instruments deployed at the lighthouse.

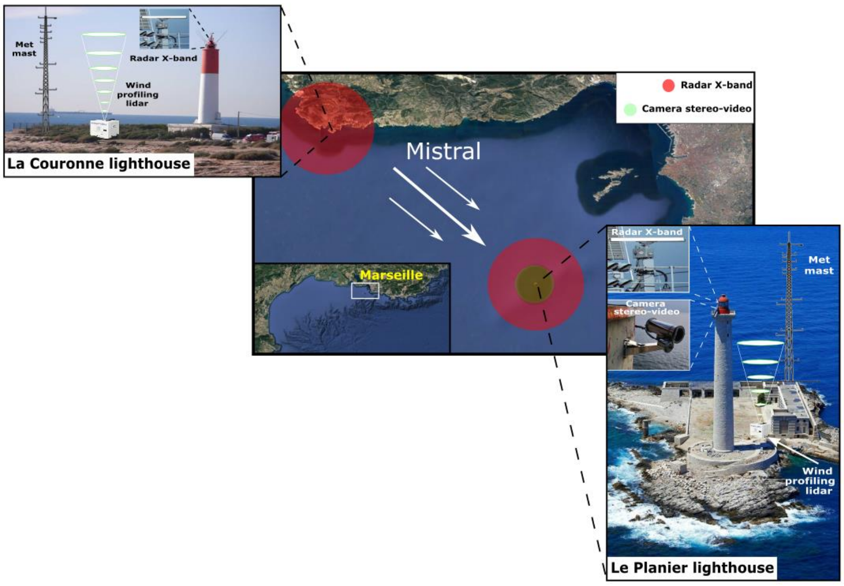


Figure 1.3: French experiment site and instrumentation

Innovative surface wind measurements techniques based on the breaking wave spectral statistics as well as the marine radar data (Dankert and Horstmann, 2007; Vicen-Bueno et al., 2013) will be further developed and will feed the improvement of wind retrieval algorithms based on satellite optical imagery.

Italian site:

The **Acqua Alta** oceanographic platform in the Northern Adriatic Sea (Italy; 15 km offshore the Venitian coast; 17 m water depth; 45.314350 N, 12.508317 E; http://www.ve.ismar.cnr.it/piattaforma/) will be used to study wave properties and air-sea momentum flux during young wave conditions driven by northeasterly short-fetch Bora Winds. Acqua Alta is managed by CNR, and it is equipped with sensors to monitor atmosphere (wind, turbulence, air temperature, air pressure), wave (stereo system and wave probe), and water body (sea surface temperature, current profile, bottom temperature). Observational data will be helpful to assess atmospheric model performance in the MCA.

Figure 1.4: Aqua Alta platform

Greek site

Figure 1.5: Floatmast deployed offshore Makronissos

The experiment will also benefit from the observations currently collected within the **FloatMast** project. The first Floating MetMast was installed off the coast of the island of Makronissos, Greece, at a water depth of 65 m and at a distance of 250 m from shore. FloatMast combines a mini tension leg platform with a met mast and a ZephIR 300 wind lidar. FloatMast is currently in operation and will provide meteorological data for a period of 12 months. CRES is currently running a profiling lidar on Makronissos for validation of the instrument deployed on the FloatMast. This site will be very valuable to understand the mean and turbulent flow modifications induced by the presence of islands for validation of the SHOWMED atmospheric model.

Turkish site

In Turkey, a conventional meteorological mast will be used for a 12-month wind measurement campaign. The instrumentation will be adequate for turbulence and wind shear measurements and consists of sonics, cups, vanes at multiple heights as well as atmospheric sensors. The measurement campaign is part of a local ongoing project in the city of Izmir, Turkey and funded by the Izmir Development Agency.

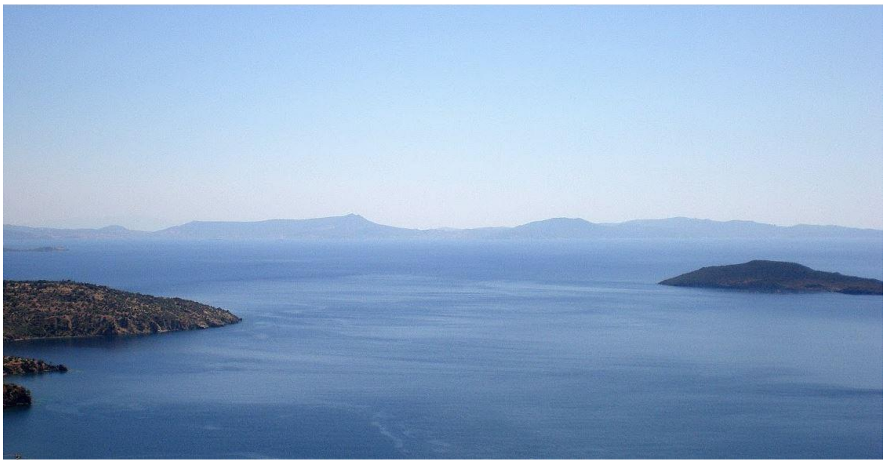


Figure 1.6: near-shore mast will be located at Dikili

The campaign is managed by IZTECH. SHOWMED will have full access to the data and the campaign will take place from July 2020 to July 2021, with a possibility of one to two-year extension. The site location has been chosen to be representative for the turbulence characteristics of a similar near-coastline location within the Mediterranean. The overall aim of the measurement campaign is to better estimate turbulence, wind shear and extreme winds under the near-coastline conditions and their possible deviations from current standards. The results will also be compared to industry standard software (e.g. WAsP, WAsP Engineering of DTU).

Ship of opportunity

As the properties of the wave and atmospheric conditions are characterized by strong spatial gradient in MCA conditions, especially in presence of offshore blowing winds, it is very complex to deploy an appropriate *in-situ* monitoring system at a reasonable cost.

In SHOWMED we propose to instrument the Carthage ship cruising routinely between Marseille and Tunis. This will be possible through a subcontracting with the National Institut of Sea Sciences and Technologies. The instrumentation will capture the spatial variability of the wind and wave properties at different fetches. Of course, this will also be of great value for the satellite and numerical model validation and in particular to investigate the relevance of the JONSWAP spectrum in MCA conditions.

Figure 1.7: Carthage ship

Satellite observation

Satellite Synthetic Aperture Radars (SAR) on-board the European satellites Envisat (2002 to 2012) and Sentinel-1 (2014-onwards) provide good coverage of the European Seas. The radar principle allows wind mapping at around 2 km spatial resolution (Horstmann et al., 2004), very suitable for offshore wind farm planning, in areas where no or limited other data are available (Christiansen et al., 2006; Hasager et al. 2020). There are two key important part of analysis: 1) retrieval of winds from radar backscatter (WP2.6) and 2) climate statistics at turbine hub-height (WP4.1). For the first, efforts will be undertaken to further understand the impacts of different non wind process (short fetch waves, breaking waves, biologic films, e.g.) on the measured signal. For the second the methodology is to first establish a long-term harmonized time-series of wind maps (Badger et al., 2019) followed by extrapolation from 10 m height to around 100 m using long-term stability correction with input from numerical models but maintaining the high spatial resolution on wind resource mapping (Badger et al., 2017). There is need to improve the wind mapping in the Mediterranean Seas beyond the New European Wind Atlas as there is a bias and uncertainty in this area due to lack of sufficient data (Hasager et al., 2020). Therefore, SHOWMED will focus on new relevant data collection in particular.

The methods used to relate the wind speeds to the wave breaking statistics, will further be the investigated for the analysis of visible imagery collected by satellite that will provide an additional valuable source of wind information for MCA.

Physical processes parameterization

He we shall rely on observations collected in short fetch wave environments by HZG prior SHOWMED (Buckley et al., 2018. See Figure 1.8 for illustration of the experimental set-up and observations).

This source of information will serve to increase the understanding of the physical processes controlling the atmospheric and wave evolution and feed the development of new MCA-dedicated, physical parameterizations to be implemented in the coupled numerical models, namely the air-sea momentum flux parameterizations, in relation with the specific MCA sea states and the high proportion of breaking waves, inducing a sheltering effect (air-flow separation).

The wave breaking statistics observations obtained from Le Planier, will be used to calibrate formulation developed by FEM for further implementation in the wave module of SHOWMED air-sea modeling system.

Numerical model developments

The MCA-specific air-sea momentum flux parameterization will be implemented in the WRF-WBLM-SWAN[2] model (Du et al. 2017, Larsén et al. 2019) to produce the first MCA-dedicated numerical tool. This model will be further calibrated and validated using a set of numerical experiment investigations of the average metocean conditions together with more challenging MCA-special weathers found over the areas of interest of the project. The test cases to be investigated will be:

- Bora winds in the Adriatic Sea, with observations from satellite and from the Acqua Alta platform, located in the Northern Bora jets,
- Mistral winds in the French Mediterranean Sea, using satellite data and the extensive dataset from the SHOWMED experiment conducted from the French lighthouses as well as from the ship of opportunity,
- Storm conditions, with a focus on the wave field and the wind turbulence from the measurements acquired from the open sea at Le Planier lighthouse,
- Etesian wind in Turkey, with large influence of the continental orography on the atmospheric flow and turbulence at sea, Estesian wind in Greece, featuring interactions between the atmospheric flow and islands.

This works will be strengthened by a numerical benchmark, involving a WRF-WW3[3] coupled model. This inter-comparison is expected to further help the team to understand the potential differences between the models and provide guidance for improving them by incorporating for instance a better understanding of air-sea fluxes under offshore fetch limited wind condition.

Application of the numerical models and observations: resource assessment and design conditions

Once duly validated the coupled numerical model will be applied to produce a 25-year numerical hindcast database with several high resolution (2 km) nest over the MCA (from Spain to Trukey). This will be exploited to produce standard resource information such as mean wind power at hub height as well as the 50-year wave height. This database will be further interfaced with a Geographic Information System (GIS) to ease the dissemination of the project results. This information will be completed by long term simulation aiming at capturing the multidecadal wind resource evolution over the Mediterranean Sea.

Based on the numerical and observational metocean database, SHOWMED will investigate the applicability of the wave and wind models proposed in the certification documents for:

- Wind turbulence, gust and shear, especially in presence of offshore blowing winds but also storms,
- Wave spectrum, and especially the applicability of the JONSWAP spectrum,
- Extreme wave statistics, with a focus on the effect of the directional spreading of the wave field.

Efforts will be undertaken to derive more appropriate formulations for future implementation in the certification documents.

Wind wave climatology production and data driven short term forecast

The modeling and satellite databases and the instrumentation deployed on the experimental sites will eventually feed the development of short-term data driven wind and wave forecasts.

[2] WRF: Weather Research and Forecasting model, WBLM: Wave Boundary Layer Model, SWAN: Simulation Wave Nearshore model
[3] WW3: WAVEWATCHIII wave model

Here we intend to produce high resolution wind forecast using a statistical approach fed by the high-resolution numerical databases, satellites databases and coastal measurements obtained within SHOWMED. The French experimental site will be the perfect playground to demonstrate the capabilities of our data driven forecasts, especially for the short term (10 min – 1 hour) and offshore blowing wind conditions using the 2 measurements stations deployed from the lighthouses spaced by 20km along the Mistral wind direction.

The data driven approach will be implemented in a smart data logger, which will allow to collect atmospheric information and provide a data driven forecast on the fly.

1.3.2 Position in the Technological Readiness Level scale:

SHOWMED targets the development of a set of numerical coupled models, satellite images prototype processor, a data driven forecast system that will all be validated against real world observation setting them at the 4-5 stage of the Technological Readiness Level. By the end of the project, further development will be necessary to support the full integration of the software with operational hardware and software systems.

1.3.3 National or international research and innovation activities

Completed Projects	*How will SHOWMED draw from this project?*
X-WiWa (National Funding, Denmark)	This project supported the development of the air-sea couple model chain WRF/WBLM/SWAN. This system will be further developed in SHOWMED to incorporate advanced air-sea coupling physical parameterizations.
NEWA: New European Wind Atlas (FP7)	This project will be used as a reference to measure the impact of SHOWMED in term of modelling accuracy. It also offers a convenient source for testing the data driven approach to be developed in WP5 before the release of the SHOWMED wind resource database.
MPC Sentinel-1 (ESA funding)	This project allows the Ifremer team to be in close contact with ESA team in charge of Sentinel-1 mission, one of the first data source for satellite measurements to be used in SHOWMED (WP2 and WP4).
FloatMast Blue (European Investment Project)	The wind observations currently collected by this platform deployed by 65m depth near Makronissos Island will be made available for exploitation in SHOWMED. The data will be available for the project, especially for the validation of SHOWMED model chain (WP3) and for the investigation of the wind properties in MCA (WP4).
Air-Sea Momentum flux at High Wind Speeds in the North Sea (National funding USA)	This experimental project provides measurements of the air-flow separation above breaking waves in short fetch conditions and corresponding momentum fluxes. They will be highly valuable for adjusting the air-sea flux parameterization to be implemented in WP3.
Wind at Dan Tysk (WvDT) (National Funding, Germany)	It will provide the basis for the development of a method to retrieve wind fields in space and time from marine radars to make a short term (30 to 60 seconds) wind speed prediction for an improved predictive control of offshore wind farms. This is part of SHOWMED's WP5.
HOMONIM (National funding, France)	This project provided the French operational models for the forecast of surges associated with waves, wind and reverse barometer currently operated by the French Met-Office. Both the open-source high resolution Digital Elevation Model (100m resolution) and the already implemented wave model will be useful in the WP3.

Ongoing Projects	*How will SHOWMED draw from this project?*
CARAVELE: Wind Characterization for Offshore Renewable Energy applications (FEM funding)	CARAVELE is a major FEM project, with strong involvement of Ifremer. It supports research dealing with the air-sea coupling (with a focus on wind-wave coupling and extreme conditions), addresses SAR images processing improvement and the data driven wind forecasting. The project results will be available for implementation in the development of the satellite wind prototype processor (WP2), model chain (WP3: wind-wave coupling) and data driven forecasting (WP5).
DiMe project (FEM funding)	This project involves an experiment from a lighthouse at sea to investigate the properties of breaking waves with stereo video and X-band radar systems operated by FEM and HZG. The protocol will be transposed on Le Planier lighthouse in SHOWMED (WP2). DiMe involves the development of new a breaking statistics model that will serve as a basis for the development of new air-sea momentum flux parameterization in SHOWMED (WP3).
Izmir Near Shore Wind Measurement Campaign (National funding, Turkey)	Izmir Development Agency has an agreement with IZTECH on making a measurement campaign between 2019-2021 at a location representing the Izmir territorial water. The data will be available for the project, especially for the validation of SHOWMED model chain (WP3) and for the investigation of the wind properties in MCA (WP4).
OceaniX (National Funding, France)	This project, in which FEM and Ifremer take part, will serve as breeding ground for the data driven approaches to be deployed in SHOWMED (WP5). They will be built on the Artificial Intelligence latest developments brought by the cutting-edge teams in presence in OceaniX.
Characterization of the French Mediterranean Sea (National Funding, France)	The French Government is funding a one-year deployment of 2 lidars in the Mediterranean Sea. At least one of them will be in the vicinity of SHOWMED's French experimental site. The data will be available for implementation in SHOWMED (WP2).
FloatMast (H2020 funding)	This project is currently supporting the deployment of a floating platform near the Makronissos island in Greece. The platform hosts a 40-m high metmast together with a profiling wind lidar. The data will be shared with SHOWMED and used in WP3 and 4.

1.4 Gender dimension in the project

All SHOWMED Consortium members, including the coordinator, partners and WP leaders have been brought together based on their respective expertise. No criteria other than scientific and technical expertise were evaluated to conjoin the best scientists and engineers in Europe to participate. Still the project team will be made of both male and female experts. Each individual is internationally recognized within their respective field and will make an important contribution to the project. The Consortium is aware of, and will comply with, the objectives set by Horizon 2020 on gender equality and, more specifically, with gender balance in research teams, decision making, and integrating sex/gender analysis in R&I content (Fact Sheet on gender equality in Horizon 2020, December 2013).

Therefore, the consortium partners of SHOWMED confirm that they will take the following actions:

- To promote gender equality by encouraging the active participation of females in the field of scientific research all around the European Union and within all processes of the project (evaluation, consultation, dissemination and implementation processes).
- To pay special attention and emphasis to attract female applicants or contracting additional staff in the project.

- To promote the equal balance of gender in the steering group or any advisory board of the project to the same extent.
- To balance the work and private life of all participants through the appropriate mechanisms (European, regional or local rules).
- To integrate the gender dimension in all areas of research.
- If appropriate, the promotion of the results of the project to a wider public of gender equality as a necessary tool to ensure the highest level of scientific quality.

In SHOWMED, the gender aspects will be considered by all consortium partners and monitored by the Project Coordinator. Any significant issues or deviations pertaining to the gender aspects will be reported to the Steering Group.

1.5 Ambition

The ambition of SHOWMED is to accelerate the development of OW in Europe and diversify areas of production enabling Mediterranean countries to take part of the future energy mix. In this way, it is intended that **SHOWMED will support MCA stakeholders in the reduction of offshore wind LCOE and large-scale deployment.** SHOWMED will perform innovative actions addressing the characterization of the wind resource, design conditions and the metocean conditions forecasting. Four main challenges are being tackled by SHOWMED, progressing beyond the current state of the art and revealing the ambition of the project.

1.5.1 State of the art on the challenges faced and corresponding SHOWMED ambition

Challenge 1: Wind resource assessment
Current State of the art
The closest initiative to SHOWMED is of course the New European Wind Atlas (NEWA) project that aims at reducing uncertainty of wind energy production and wind conditions to less than 10% at European scale. NEWA develops an innovative suite of modelling tools, featuring open source multiscale wind assessments numerical models and seasonal to decadal wind prediction. For the validation of the models, NEWA develops a monitoring strategy featuring lidar deployment from fixed stations on land and moving stations at Sea, in the Northern part of Europe. Still, Comparison of NEWA wind data with Satellite suggests underestimation of WRF-simulated winds by 1- 3 ms-1 in the MCA regions (Hasager et al., 2020). Part of the problem relates to a lack of observations to validate the ability of the atmospheric model to capture the coastal flow and the interaction with the ocean. In general, numerical modelling ability has always been questioned regarding storm conditions and coastal flows (Larsen et al., 2017; 2019). The storms are accompanied by fast developing met-ocean condition that requires a modelling system that is accurately designed for, which can adequately react. The requirement for the model setup for these conditions can often be different from that for a normal weather condition. The coastal area is characterized by contrasting thermal and dynamical conditions between land and sea, which generates local flow dynamics of a variety of scales. This imposes challenges for the modelling. Correct input forcing and high-resolution calculation are crucial for accurately capturing these dynamics. In MCA, sea states are often generated over short fetches (offshore blowing winds, or small-scale intense storm systems). This results in steep young waves with high breaking rate, which enhances the air-sea momentum fluxes through the air-flow separation occurring above the breaking crests (Reul et al., 1999, Buckley & Veron, 2016).
SHOWMED ambition
The ambition of SHOWMED is to generate a modeling chain, featuring downscaling capacities and a proper representation of the physical processes controlling the atmospheric conditions in the Mediterranean conditions including and focusing on wind-wave coupling. SHOWMED further endeavors to gather MCA-specific observations both for the development and validation of the modeling chain.

Challenge 2a: Design wave conditions
Current State of the art
Wave climate are produced by spectral wave models and have been mostly validated for oceanic conditions, i.e. for waves generated over long fetches (Jansen et al., 1997; Ardhuin et. al, 2010). In general, for the fatigue design, ultimate state design or wave tank testing of OW turbines, the frequency-directional wave energy spectrum is not available and engineers reconstruct a synthetic spectrum for the integral wave parameters (significant wave height, peak period, mean direction and directional spreading). For the frequency shape, the most widely used formulation is the so called JONSWAP spectrum that was empirically derived from observations mostly collected in intermediate water depth in the North Sea. For the ultimate state design, the wave extreme statistics are also considered, based on a single point location perspective and using statistical models validated using open ocean wave observations.
SHOWMED Ambition
SHOWMED ambition is to develop a spectral wave model version, able to capture the wave growth under short fetch conditions, with highly variable wind in time and space (e.g. gusts and squalls) and intense wave breaking. SHOWMED further intends to evaluate the applicability of the synthetic wave energy spectrum and extreme wave statistics and if required propose alternative in the certification standard.
Challenge 2b: Design wind conditions
Current State of the art
In the certification documents, different turbulence models are suggested, but none were validated in MCA conditions. For instance, "IEC 61400-1 Wind energy generation systems - Part 1: Design requirements" suggests two turbulence models for design load calculations and turbulence velocity calculations; (i) Mann uniform shear turbulence model and (ii) Kaimal spectrum and exponential coherence model. The Mann model is advised to be used. Both Eliassen and Obhrai (2016) and Cheynet et al. (2018) show the missing points of the turbulence models, which is the spatial distribution of the turbulence. Another related issue for the offshore or near-shore locations is the gustiness, where the incidences of gusts correspond to problems on offshore energy applications. Nevertheless, the statistics of velocity increments showed that they are highly intermittent. These anomalous (not Gaussian distributed) statistics explain an increased high probability of finding strong gusts (e.g. Boettcher, 2003). The gustiness can be affected by atmospheric eddies on a range of scales, including that of a meso-microstructure such as squalls as well as that of surface driven turbulence (classical turbulence concept). This provides turbulence scales ranging from 1 s to several hours and they are all relevant for turbines (loads and power output). Wind gustiness and shear in severe weather conditions need also careful examination for the Ultimate Limit State design, as pointed out by Worsnop et al. (2017).
SHOWMED Ambition
Thanks to a unique experimental effort, SHOWMED will explore the validity of the wind turbulence, gust and shear models proposed in the certification standards from a range of instruments (profiling lidar, X-band radar, sonic anemometers, met mast) in a variety of MCA regions: France, Italy, Greece, and Turkey. SHOWMED targets to implement the project finding in certifications document.
Challenge 3: Metocean forecasting
Current State of the art
To date, many wind forecasting approaches have been studied and proposed. Recent studies in the area of wind prediction are predominantly focused on the short-term wind predictions ranging from minutes to a few days due to the importance of these data on power systems. The different approaches can be classified into three categories: (i), physical models that are usually based on Numerical Weather Prediction (NWP) models, (ii), statistical methods, most of which are intelligent algorithms based on data-driven approaches and, (iii), hybrid physical and statistical models.

NWP models are essential tools in weather prediction and climate science (e.g., Done et al., 2004). However, there exist a variety of challenges by directly adopting NWP models for wind forecasting, such as the accuracy, spatial and temporal resolutions, domain and hierarchical importance of the physical processes

Statistical models follow the pioneering ideas from Lorenz (1956, 1977) and are trained using historical data. They usually outperform NWP models in very short-term forecasting (within one-hour ahead). Both linear and non-linear methods have been widely applied to wind forecasting. Linear models, such as autoregressive moving average methods, Box-Jenkins methods, Kalman filter, and Markov Chain model are most widely used in the literature. Artificial neural networks and support vector machine are the two most popular nonlinear methods for wind forecasting.

Data-driven downscaling is also a promising branch of statistical forecasting, using for instance historical SAR images to enhance the resolution of low-resolution operational forecasts (e.g., He et al., 2015).

SHOWMED Ambition

SHOWMED ambitions to provide the OW industry with a data driven forecasting tool able to outperform the conventional numerical wind forecasts produced by the operational services for short term forecasts. The product will be an integrated system integrating an atmospheric measurement unit feeding artificial intelligence algorithms learning the short-term weather forecast from the numerical and observation databases and information provided by a coastal measurement station. The system operators will be able to apply the improved forecasts in the real time security constrained unit commitment and real time security constrained economic dispatch to, (i), turn on/off generators in response to fluctuations, (ii), reduce the utilization of fast acting but expensive units, (iii), decrease the reserve levels and, (iv), reduce the wind curtailment.

Challenge 4: Proper implementation of the project results

Current State of the art

Many research projects develop cutting scientific knowledge but lack a proper application of the results in the reals world, either because the operation of the tools requires a high level of expertise (and often unaffordable computation power) or insufficient communication toward the end users.

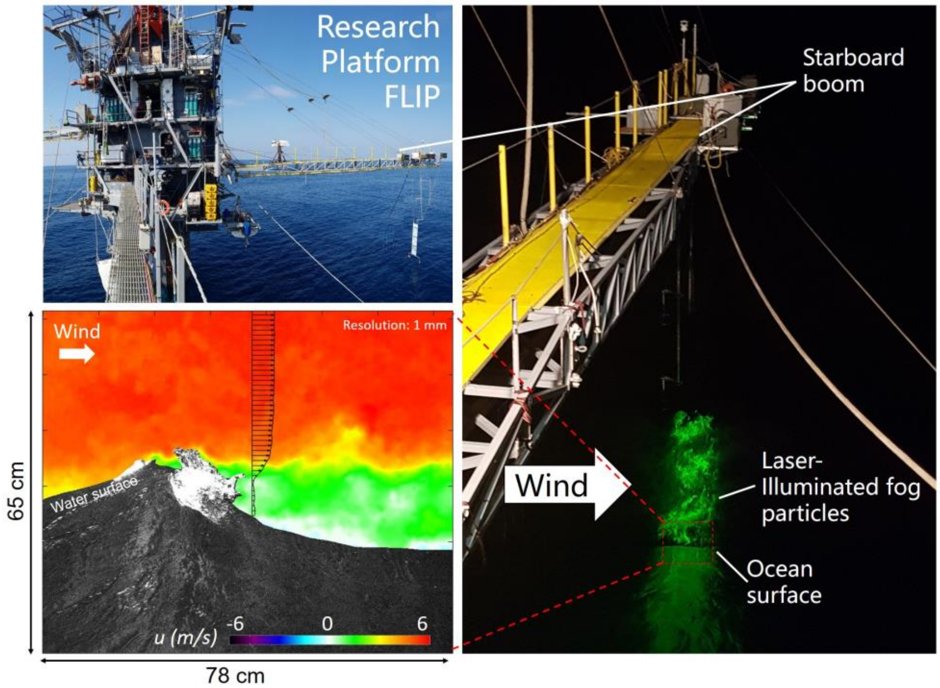
SHOWMED Ambition

SHOWMED ambitions to develop an open source code, free access database and fast machine learning algorithm for weather forecasting. On top of that, SHOWMED will ensure a solid implementation of the results in the partnership through technical training workshops (air-sea coupled model, X-band radar, stereo video imagery) and among the OW stakeholders thanks to organization of dissemination workshop in all the Mediterranean countries involved SHOWMED.

1.5.2 Innovation potential

Innovation is the core of SHOWMED. Important advances are expected to face the four main challenges exposed in the previous section.

Challenge 1: wind resource assessment	
Wind Wave Observations	**Land Sea transition experiment (WP2):** An experiment will be conducted to investigate the properties of the wind speed, shear, turbulence and wave fields at the land sea transition. It will feature deployments of wind masts, X-band radars, profiling lidars and stereo video systems deployed from two lighthouses, 20 km apart and aligned with the Mistral conditions. This will be supplemented by wind observations collected from the Acqua Alta platform in Italy (Adriatic Sea), the Floatmast platform deployed in Greece (Aegian Sea) and from a nearshore wind mast to be deployed in Turkey (Aegian Sea). This will offer a unique dataset covering different MCA climates.
	Wind measurements from sea surface optical observations (WP2): High resolution optical data from the video system deployed on Le Planier lighthouse will also allow to

	characterize the breaking waves spectral distribution as a function of wind speed to revisit the Beaufort scale and increase the potential of optical imagery for coastal wind products building on the recent results of Yurovskaya et al. (2019) with Sentinel 2. The current scientific knowledge will be further supported by a machine learning approach in order to integrate the significant amount of data now available from space.
	Wind and waves measurements from space (WP2-3): A Database of SAR wind maps covering the MCA will be generated in WP3 using the processing tools already available at DTU. The focus will be on the harmonization of Envisat, Sentinel 1a and 1b SAR data and generation of long-term data series. This database will benefit from an in deep validation against the observations collected in WP2. In addition, SHOWMED will develop several innovations regarding the monitoring of the air and sea properties to further improve our understanding of the contribution in the measurements with SAR and optical satellite images (WP2). This will contribute to test and implement new strategies for SAR data processing including wind and wave measurements and taking into account new possibilities offered by Copernicus high performance computing platforms.
Physical Processes **Parameterize-tions**	**Air-sea momentum flux:** Breaking waves are often omnipresent in the short fetch conditions typical of MCA. It is also well acknowledged that breaking waves may have an important contribution to the air-sea momentum flux, through the induced air flow separation that can support up to 50% of the sea surface form drag (see for instance, Kukulka et al., 2007). Here we will attempt to develop new parameterization extending the TOGA-COARE3.5[4] to incorporate this additional momentum flux in the SHOWMED model chain. This will be achieved using the wave breaking and air-sea coupled formulation currently developed by FEM building on past efforts (Filipot et al., 2010) and Ifremer (Kudryatsev et al., 2014), validated with existing air-sea fluxes measurements performed over breaking waves by HZG, in short fetch conditions.  *Figure 1.8: setup and results of the experiment conducted by Buckley et al. (2018). The associated observations will serve to validate the new air-sea momentum flux parameterizations.*

[4] TOGA-COARE: Tropical Ocean-Global Atmosphere-Coupled Ocean Atmosphere Research Experiment

Air-Sea Coupled Modeling	**Model development:** The corresponding new air-sea momentum flux parameterization will be implemented in the existing air-sea coupled system WRF/WBLM/SWAN already developed by (Du et al., 2017, 2019, Du 2017, Larsen et al., 2019). The new wave breaking parameterizations will be implemented in SWAN to explicitly provide the spectral distribution of the average crest length density per unit sea surface (Phillips, 1985) for the momentum flux computation in the atmospheric module.
Numerical Wind-Wave Hindcast	**Model downscaling:** The hindcast will not only benefit from the latest physical developments enabled by SHOWMED but will also feature a model downscaling approach to capture the wind and wave features at 2 km resolution using nest domains covering the MCA.
Long-Term Changes in Wind Resource	**Decadal prediction:** State-of-the art wind resource assessment methods assume that future wind conditions will be similar to past conditions. Assessing long-term changes in wind speed conditions is an innovation that SHOWMED will provide. Furthermore, those changes will be assessed from novel decadal prediction systems that exploit initialization of the whole climate state and provide information at timescales of the life of the wind farms, instead of employing non-initialized climate projections at longer timescales.

Challenge 2a: design wave conditions	
Wave modeling	**Wave breaking-induced dissipation (WP2):** The objective will be to improve the accuracy of the wave model to simulate young seas by incorporating an explicit formulation of the breaking statistics using current effort at FEM to extend the approaches from Filipot and Ardhuin, (2012); and Leckler et al., (2013). The new wave breaking statistics model will be further validated using the observations collected along the first month of the experiment from Le Planier lighthouse (stereo video system).
Wave Spectrum	**JONSWAP spectrum:** the dataset collected in WP2, and especially those obtained from the ship of opportunity will be analyzed to explore the validity of the JONSWAP spectrum in MCA conditions at different fetches. Among the research track to be followed to improve the JONSWAP shape, we anticipate that the wind gustiness (already mentioned by Hasselmann et al., 1973) could be incorporated in an MCA-specific JONSWAP version.
Wave Extreme	**Freak wave occurrence:** Here we shall build on the work from Benetazzo et al. (2017a) to study the influence of the spatial footprint on FOWT on the rate of occurrence of freak waves, together with in-depth investigation of the effect of the MCA wave field particularities (e.g., directional spreading, steepness). This work will heavily rely on the observational data collected during the experiment.

Challenge 2b: Design wind conditions	
Wind Shear, Turbulence and Gustiness	We shall here exploit the observational and numerical database to explore the properties of the wind shear, turbulence and gustiness as a function of the MCA regions and weather types. Focus will be drawn on the atmospheric properties during offshore flow (Mistral, Bora, Etesian) but also storm conditions (Medicane-like or extreme Bora events). In addition to the gustiness factor, the statistical distribution of gusts and squalls in MCA situations in average and extreme conditions will also be considered. Different gusts time scale will be investigated, from the very short-term gusts (few seconds) to squall type gusts (1 min – 1h).

Challenge 3: Weather forecasting	
Gust Prediction	A methodology relying on the X-band radar retrieved winds (Dankert and Horstmann, 2007) will be exploited to develop a very short term forecast on the arrival and force of gusts at a wind turbine. The system will be tested and demonstrated in the experiment at Le Planier lighthouse in France.
Data Driven Wind Forecasting	A short-term wind forecasting hybrid model will be used as a learning catalog, the 25-year numerical wind hindcast and satellite databases developed in SHOWMED. In addition, the wind measurements collected from coastal stations within SHOWMED will also be implemented in the data driven scheme of our hybrid method to further constrain the wind forecast at the wind farms. In offshore blowing wind conditions, this will offer a decisive asset. Five meteorological parameters will be used as inputs to our model: temperature, humidity, wind speed, wind direction and pressure and gathered through a smart logger implementing the data driven algorithms.

Challenge 4: Proper implementation of the project results	
Dissemination	SHOWMED will promote a transdisciplinary approach. The dissemination activities will rely on close cross-disciplinary collaboration between technical and scientific partners with experts in social sciences, communication and policy advice. Furthermore, the communication and dissemination activities will be grounded in a novel coproduction framework for Research and Innovation Actions. This framework engages stakeholders by raising awareness, involves them in the knowledge exchange and co-learning through participatory approaches and, when possible, empowers stakeholders through co-development of narratives and tailored information and knowledge.

2. Impact

2.1 Expected impacts

SHOWMED will generate innovative **observational, modelling, and forecasting tools** addressing specifically the peculiarities of wind and wave conditions in the MCA. These tools and associated databases will **highly contribute to lowering the LCOE** and widespreading the deployment of OW in Southern Europe, thus contributing to **increasing the value of OW power**. In particular, these tools will allow for a reduction of uncertainties in the resource assessment and design conditions, as well as an optimization of power production and O&M windows.

2.1.1 Offshore wind market in MCA

An overview of the OW deployment context in the Mediterranean Sea is given in order to further highlight the expected impacts of SHOWMED.

Croatian context

Currently, all 19 wind farms operational and integrated in the Croatian electric system through the Croatian Transmission System Operator are on land. However, the existing wind atlas of Croatia suggests that plenty of resources are available offshore (Horvath et al., 2011). Among 19 operational onshore wind farms, most of them are a few kilometers from the coast and one is on the Pelješac peninsula. Recently, several companies have been inquiring about offshore wind resources in the Adriatic (official communication of DHMZ with interested companies), evidencing raised interest in this aspect of renewable energy in Croatia.

French context

France benefits from the second highest OW production potential in Europe after the United Kingdom. All along the French coasts, including the English Channel, Atlantic and Mediterranean coasts, up to 140 GW could be exploited by floating OW and 80 GW by fixed offshore wind.

The attractiveness of the wind potential in the Mediterranean has been acknowledged by the French Government who has launched three pilot floating wind farm projects (near Leucate, Gruissan and Marseille). These projects will rely on 3 full scale 8-10 MW floating turbines, whose generated power will be injected in the French power grid by 2022-2023.

A call for tender should be released in 2021 for 2 commercial wind farms with power capacity over 250MW each. Both farms should further be extended by 500 MW at midterm. Moreover, the French energy plan proposes additional yearly calls for tender of 1 GW of OW, starting in 2024.

For the first floating wind farms planned in French MCA, target costs are set to a maximum of 110 €/MWh. In comparison, target costs for fixed offshore wind are set at a maximum of 50 €/MWh. By 2024, the government expects a convergence of costs for floating and fixed offshore wind farms. This means that LCOE for floating offshore wind is expected to be divided at least by two to be further considered as part of the energy mix at mid-term.

Greek context

The wind potential in the deep Greek waters exceeds 15GW, if the option of floating wind is used. The choice of floating OW turbines will have a positive impact on the economy and competitiveness of the country, given the considerable national potential in the maritime and naval sectors.

An additional critical synergy to OW development in Greece, may come from an extensive network of underwater high voltage lines (currently under development-construction) to connect the islands of the Greek archipelago, to the county's mainland grid. The capability for accommodating extra power from OW farms, along their route, is also included in the planning, since this will support the cost effectiveness of the projects and will also allow a higher renewable energy source penetration in the country's energy mix.

Italian context

At present, all the wind turbines in Italy are located onshore. But the government has planned to install capacity for at least 650 MW offshore, provided an estimated potential of 950 MW, thus projects are under authorization or construction. The most exploitable areas in the Italian waters are the south-west of Sicily and Sardinia, the Ionian sea and the Adriatic Sea. In this respect, the first OW farm in the Mediterranean Sea is being completed in Southern Italy, offshore of the Taranto harbour. It will start operating in 2020 and will consist of ten 3 MW wind turbines.

Spanish context

Spain is one of the leading countries in the world in terms of installed wind energy, with 25 GW installed at the end of 2019 and covering 20% of its electricity demand. Many Spanish companies have pioneered the construction of wind turbines and the development of onshore wind farms. In terms of offshore only two turbines are currently connected to the Spanish grid. This is partly due to the deep waters surrounding the Iberian Peninsula, which deepens beyond 50 m very fast. In 2009 the "Atlas eólico de España" determined that the potential for fixed-foundation wind farms was very scarce. Therefore, the Spanish offshore is in high need of affordable floating offshore technology. The first OW farm (an EQUINOR 200 MW project in the Canary Islands) will be operating by 2024. In the Spanish Mediterranean coast, the most suitable locations in terms of wind resource are located off the coasts of Almería, Castelló, and Tarragona, where the Cierzo (Mistral) blows very often, and also in the north of Girona, where Tramontana (north) winds are very strong. Some wind farm projects have been proposed in those locations, but have been paused or abandoned due to environmental or legislation problems. In this sense, the new "Plan Nacional Integrado de Energía y Clima" foresees an impulse to OW by setting a specific plan and facilitating administrative processes. Achieving cost-efficient floating offshore during the next years is therefore a crucial objective for Spain.

Turkish context

In 2018 the Energy ministry has published a licensing call for offshore for the first time. Three small projects, of 20MW, were announced for licensing bidding. Unfortunately, the bidding was not finalized on time because there were no investment groups willing to participate. The main reason the investors kept a distance to the bidding call is the large uncertainty for the selected locations because there are no measurements at sea over any of the seas that surround Turkey: Aegean, Mediterranean and Black Sea.

The high uncertainty in Turkish seas is not only coming from the lack of in-situ measurements but also the complex characteristics of sea-land interaction. Most of the locations, including the ones open for bidding, have frequent winds blowing from land to the sea.

A national wind atlas for Turkish offshore locations is not currently available. There have been two studies covering the coastline in the last 5 years (i) Global Wind Atlas (GWA) and (ii) New European Wind Atlas (NEWA). Both model results have no validation cases, since there are no on-sea measurements in Turkey yet.

An atlas study that answers the questions of the turbulence, downscaling the wake effects from islands could accelerate the investment of offshore in Turkey.

Mediterranean non connected Islands

Different initiatives are on-going to combine sources of renewable energies for non-connected Islands with the target to develop energy production in a sustainable way, ensuring self-sufficiency, lower prices for consumers, greater stability and a smaller ecological footprint replacing the oil stations. Tilos island (Greece) is the first non-interconnected autonomous 'green' energy island in the Mediterranean combining a solar park, onshore wind turbine and battery storage. SHOWMED will participate to deploy hybrid systems for Mediterranean islands by a better integration of wind turbines and lower costs.

MCA market potential for OW

The OW market in the MCA of European and associated countries is thus expected to reach a volume of 2.5 to 5 GW in terms of calls for tenders to be opened within the next five years. As FOW becomes competitive, an additional 0.5 to 1 GW per are expected in the period from 2025 to 2040. The **MCA market would represent at least 10% of new OW capacity to be installed in Europe within the next ten years**. In the Sustainable Development Scenario, the European Union's offshore installed capacity increases by almost 40% relative to the Stated Policies Scenario, reaching 175 GW by 2040. Cumulative investment in OW reaches € 500 billion over the projection period, or € 21 billion per year. Alone the **MCA market should thus represent around € 2 billion of investment in OW per year from 2025**.

2.1.2 Contribution to the expected impact in the work program

Impact on LCOE

The LCOE is based on an estimation of total cost of a project in regards to the total energy produced for the entire lifetime of the project. SHOWMED proposes to reduce the LCOE through:

- a better estimate of Annual Energy Production (AEP)
- a reduction of the CAPEX
- a reduction of the OPEX
- assurance cost and bank loan reduction

Annual energy production

The annual energy production is directly linked to the wind resource together with the turbine selected and related capacity factor. FOW projects such as Hywind Scotland (UK) and FLOATGEN (France) have shown an average capacity factor of 65 %, where bottom fixed is between 30 to 40% for the same period of the year (Tisheva, 2018). A better characterization of uncertainty in wind resource leads to better estimates of P50 and P90 values of annual energy production translating finally into higher debt capacity of projects (Mora et al., 2019). SHOWMED targets a reduction of the uncertainties in the resource assessment, leading to a reduction of uncertainties on annual energy production, directly reflected in the LCOE. Mora et al. (2019) investigated the impact of wind speed uncertainties on LCOE for different types of OW projects. They were able to show that for a baseline project, if the wind speed uncertainty is around 5 %, the LCOE is improved by 7 % compared to estimated LCOE for wind speed uncertainties of 10 %. The lower the main wind speed, the higher the impact on LCOE. By reducing uncertainties on wind speed for MCA by more than 5 %, **SHOWMED will lead to a LCOE uncertainty reduction of around 7 %**. Moreover, with a better prediction of operating windows, the production can be significantly improved which will be reflected on the operational expenditure.

Capital expenditure

CAPEX is related to the cost of the equipment, including installation and decommissioning. Estimates of CAPEX breakdown for FOW is shown in figure 2.1.

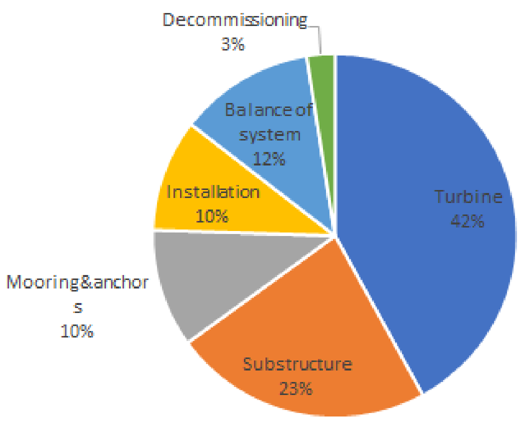


Figure 2.1: CAPEX breakdown estimates for floating OW[5]

SHOWMED will provide metocean and turbulence databases and models to technology developers (turbine and substructure) with a targeted uncertainty reduction of 10% on the wave and turbulence and gustiness parameters as well as a better characterization of extreme metocean events in MCA. Uncertainties in metocean conditions have a direct impact on turbine, substructure and mooring loads both for ultimate limit state (ULS) and fatigue design. In order to cover the uncertainties (including those related to metocean conditions), safety factors are applied in the OW Turbine design.

[5] Source: floating offshore wind market and technology review- Carbon Trust 2015

SHOWMED will contribute to optimizing safety factors on offshore wind turbine system designs, leading to a **CAPEX reduction that can be estimated to be around 3 to 5%**.

Operational expenditure

OPEX, directly related to installation, operation and maintenance of the OW farm, is expected to account for nearly one-third of offshore wind LCOE. Consequently, there is a large potential for reducing LCOE through advanced O&M strategies including the use of more accurate weather forecasts. As an illustration, the standby cost of a maintenance vessel for offshore wind can reach 100 k€ per day. A National Renewable Energy Laboratory (NREL) investigation (Maples et al., 2013) showed that a 12% decrease in O&M costs could be achieved, as increased sea state limits allowed for significantly reduced waiting periods. This reduction in waiting time has a substantial impact on the energy production, raising availability from 84.5% to 93.3%, an increase of nearly 12%. This increase in AEP is the primary contributor to the overall reduction in LCOE, which could be reduced by 14% in the investigated case. By improving operating windows by 20%, SHOWMED would allow to **improve the LCOE by around 7.5%.**

Insurance cost and bank loan

Insurance costs and bank loan interest (cost of capital) represent a significant amount of the LCOE for emerging technologies. Even if the maturity level of FOW has strongly increased thanks to pilot farms in Europe, it is still estimated that insurance and weighted average cost of capital represent around 25% of the LCOE for this technology. Improving financing conditions would significantly reduce the LCOE. This improvement can be achieved through reduction of uncertainties, both in design margin and annual production. Here the decadal forecasting study performed in SHOWMED will be decisive for bank and insurance. Overall, it can be expected that the reduction in cost for insurance and loan can reach at least 20% by the end of the project, leading to a **global impact of 5% on the LCOE**.

SHOWMED impact on LCOE

Taking all levers into account, the contribution of SHOWMED on **LCOE reduction is expected to be of around 15% for floating OW farms installed in MCA**. Half of the expected LCOE reduction is directly linked to the reduction of uncertainties in wind, waves and turbulences properties and half is coming from the improvement of the operating window. In addition, SHOWMED will strongly contribute to large scale deployment of OW in the Mediterranean Sea and thus indirectly support the important LCOE decrease due to scale effects.

Moreover, a change of the wind resource in the Mediterranean in the coming years could have a dramatic impact on revenues of operating wind farms compared to expectations, modifying the LCOE and the expected return on investment. SHOWMED will contribute to long term assessment of the AEP.

Impact on market value

SHOWMED's impact on FOW market value is tremendous even if the quantification is difficult to assess. Currently only few targets have been fixed in MCA to deploy OW in the Mediterranean Sea. Beyond the cost of electricity, large uncertainties on the wind potential in these areas affect the strategical decisions. SHOWMED will provide authorities from these regions with adapted tools and databases allowing to have a clear understanding of the potential and area that can support deployment of FOW. Moreover, large deployment is the first key driver to reduce LCOE for OW farms, as recognized by ETIP Wind[6].

Diversification is a key concept to increase the market value of OW (i.e. the revenue per energy unit of wind produced). With the current situation of OW being concentrated around the Southern North Sea and the United Kingdom, there is a high correlation of the generation of all European offshore farms. This means that whenever wind blows in that area, a lot of energy is fed into the grid and electricity prices drop accordingly.

[6] Source: ETIP Wind Roadmap, Offshore Balance of Plant 2019

In order to raise the market value of OW it is important to make new installations in other uncorrelated regions. The Mediterranean Sea, with its characteristic local wind regimes, is a perfect target for the development of new projects that diversify the wind electricity production and complement the current installations in the North Sea and United Kingdom.

SHOWMED focuses its research on OW in MCA. Results will also serve the onshore wind market of the MCA in all regions where similar wind conditions are observed. This is the case of Mediterranean islands and inland areas located in proximity of the coastline, which are already considered for **onshore wind** deployment. Results will also be transferable to other **world areas with similar wind conditions**.

Thanks to the specific knowledge supported by the northern institutes' expertise, the Mediterranean experts will further support the dissemination locally and support the creation of the value chain in countries where the OW market is still to be created. This will be strengthened by the collaborative essence of the project, and training sessions that will allow skill transfers from the northern to the Mediterranean partners regarding air-sea monitoring and modelling. This will ease the **proper implementation** of the project results in the Mediterranean countries thanks to the SHOWMED ambassadors.

Workshops organized in the MCA involved countries will further support the creation of the **value chain** by combining a wide range of stakeholders from authorities, to developers, technology suppliers, but also associations.

2.1.3 Other substantial impact not mentioned in the work program

Strategical decisions for defining the locations for deployment of future OW farms are taken based on the potential of production balanced by physical constraints (water depth, distance to coast...), other constraints coming from other activities in place or planned in the area as well as the environmental integration. The estimation of the production potential is based on the average wind speed coming from actual data and models. SHOWMED databases will be delivered to authorities in charge of the planning in Mediterranean Coastal Areas, allowing decisions to be taken based on accurate data for resource assessment. High resolution data provided could reveal areas that have not yet been identified as interesting in terms of resource potential. This will further increase the value of OW together with new market creation around the Mediterranean Sea for local suppliers.

It is commonly known that **bird migration** is directly affected by weather conditions and routes for migration are usually directly linked with wind direction (in order to reduce the effort over a long distance). Birds migration routes from Europe to Africa above Mediterranean Sea have not been well documented so far. Some data acquisition programs are still planned and coupling the results of bird migration routes with wind patterns will permit a global assessment of the ideal areas to install floating wind farms by maximizing the production, minimizing the LCOE and minimizing the risk of collision with birds. The superposition of the SHOWMED results with data acquired through dedicated campaigns will be done in a second stage.

2.1.4 Limitations and barriers to consider for impact achievement

SHOWMED alone cannot contribute to decreasing the LCOE by a factor as expected by authorities to deploy floating offshore wind in MCA. A limitation could come from technologies that will not be mature enough to contribute to the expected CAPEX reduction. However, this is more a question of time as pilot farms and improved design are being tested all around the world.

Barriers to the development of OW farms in MCA could come from the environmental integration. As an example, it is well known that bird migration from Africa to Europe twice a year, but unfortunately data are lacking to evaluate the risks of having a migration path from certain species where future farms could be installed, with a risk of collision. In France, the first floating wind pilot project is currently stopped due to an appeal from an association which pointed out the lack of data on bird migration above the Mediterranean Sea. FEM, with its offshore renewable energy (ORE) Environmental Integration team is currently coordinating a project aiming at evaluating the migration paths of birds but also of chiropters above Gulf of Lion. The final target is to propose a guide for collision impact assessment together with databases of migration path. As migration is strongly weather dependent, this data acquisition program will last at least three years, starting in July 2020.

2.2 Measures to maximise impact

The ultimate measure of success for the SHOWMED project will be the degree to which the impacts listed in Section 2.1 are achieved. The measures to maximize impact aim to:

- Ensure that all project results (including SHOWMED tools, reports, data generated and lessons learnt) are promoted and made available to stakeholders involved in the development of OW through appropriate dissemination and communication activities.
- Maximise the potential utilization of the outcomes of the project through a clear business plan and exploitation strategy to ensure that the interests in the consortium are suitably protected where appropriate.
- Foster the actual exploitation of methodologies developed in the project, ensuring that they are available to OW stakeholders and the potential replicability so they can be deployed in other locations facing similar physical conditions.
- Ensure efficient data and knowledge management integrating measures for data curation and preservation, protection of intellectual property and providing open access to peer-reviewed scientific publications resulting from the project.

To maximize its impact, the project has defined exploitation, dissemination and communication strategies outlined in this section as three distinct but complementary approaches. All these activities are mainly coordinated in WP6 led by the Barcelona Supercomputing Center that has a multidisciplinary team of knowledge transfer with extensive experience in user engagement and dissemination in research and innovation projects.

2.2.1 Exploitation

Main outputs

The main outputs of the project will be:

- **Databases** of the atmospheric and wave properties in MCA,
- **An air-sea coupled numerical model specifically** developed for the MCA (starting from the WRF-WBLM-SWAN modelling system from DTU),
- Reports and guidelines for certification implementing SHOWMED findings regarding wind turbulence, gustiness, shear, wave spectra and extreme wave statistics in the MCA environment,
- Atlas of the wind resource at high resolution over the MCA,
- **New data driven forecasting systems** interfaced for short term forecast, smart downscaling ant wind measurement.

These outputs will serve to develop service activities and propose new product to the market, allowing the partners to further develop their sustainability.

Databases and Atlas

Databases will be accessible through FEM offshore renewable energy (ORE) center, which is set to be inter-operable with other databases. FEMs resource center is taking the form of a web-based portal offering access to ORE sector information, including, but not limited to: reports, articles, databases, regulations, tools, etc. Searching tools will be available in order to identify pertinent information based on key words. GIS capability will also be enabled by assigning localization information to each resource. All resources will be described with metadata and access to them will either be direct (immediate upload) or clearly identified with localization and ownership information. Further inclusion in other software solution or GIS platforms will be discussed throughout the project to maximize the diffusion of the databases. In particular, a link is planned with NEWA (New European Wind Atlas), created with the support of the EU under FP7 program as well as PANGAEA [7].

[7] PENGAEA. Data Publisher for Earth & Environmental Science, https://www.pangaea.de/

The SHOWMED consortium fully supports the **open access to research data** as promoted by the H2020 program, and proposes to offer free access to the entire SHOWMED databases through GIS.
The Atlas will also be public and largely disseminated through an online GIS hosted by the FEM ORE resource center and possibly interfaced with dissemination platforms hosted by other partners (e.g. BSC). This will further support the visibility of all the partners involved in SHOWMED.

The promotion of free accessible maps and data can create new opportunities for partnership or service activities. It is expected that some refinements will be requested locally in order to support maritime planning and further strategical decisions. All Mediterranean partners are expected to have a key role to further support the development regionally based on their knowledge of metocean conditions and tools, and thus benefit from these assets through **specific contracts with local stakeholders**.

Numerical Models

The numerical models developed in SHOWMED will allow to deliver a service activity in particular for DTU and FEM. The partners will work with open source software and publish the models developed in scientific journals. The **service activity that can be created is related to training and design assistance** for resource estimation, turbulence, and metocean conditions. FEM and DTU are not design offices and prefer to support customers in their design rather than providing the full package including sets of calculations for large number of cases. Customers are expected to be floating OW developers, technology developers, and possibly also some design offices. For these training and design assistance activities, a typical revenue of 10 to 30 k€ can be expected for each offer. As the service will be available shortly after the project ends, it can be estimated that within five years after the project's completion, a total revenue of around 500 k€ should result from these services. It has to be mentioned that it is not planned to sell new software licenses, as the partners prefer to support the development of OW farms in MCA or regions with similar wind conditions with open source software and support to their usage rather than delivering new tools that will need time to enter the market, while expectation of growth from OW farms is on a mid-term plan.

Reports and Guidelines

Reports and guidelines for certifications can also further support the service activity proposed by FEM. FEM will not play the role of a certification body, but FEM can further **assist design offices or floating OW developers or technology developers** in the utilization of the guidelines through methodology and numerical tools. A service of assistance to design seems to be the most appropriate as it enables the design offices of developers to better take control of the methodologies and tools. FEM estimates that this service could be delivered around one year after the project ends. A typical revenue of 10 to 20 k€ can be expected for each offer. It can thus be estimated that within five years after the project ends, a total revenue of around 300 k€ should result from these services.

Innovative forecasting system

The innovative system for weather forecasting can be promoted as a new product created by CRES and FEM. At the current stage of the proposal, FEM and CRES are considering **transferring the results to a company or a start-up** which could promote commercially the product and deliver assistance for installation and further service activities for O&M. The business plan will be developed during the SHOWMED project, including the path to market and licensing. It is expected that search and activity will progressively enter the market after project completion and with an expected amount of 10 new contracts per year, which will result in a revenue of around 500 k€ in the fifth year of exploitation.

Research, Development and Innovation (RDI)

Thanks to training sessions and collaborative work in the project, the enhanced modelling tools will further help all the partners to set up successful research projects at National and European scale. Moreover, **direct RDI contracts** can be expected from local stakeholders to support further characterization or modeling activities in order to refine data supporting strategical decisions. These contracts can be estimated to reach a total value of more than 100 k€ for each Mediterranean partner during the next 5 years following the project end.

Market entry strategy and Business Plan

Through communication and dissemination activities under WP6, trainings, workshops, scientific and large audience dissemination, SHOWMED will largely disseminate towards a large group of stakeholders and **attract a wide user community.**

The **value proposition** of the Open Source data is to attract users and develop a large, loyal user community, while the value proposition of the value-added services is to persuade users to invest in tailored services as described above. Some of the proposed services will need further investments such as software upgrades and specific marketing actions on top of operating expenses for conducting the service activities, resulting in a net income that will grow progressively within five years after the project's completion. This leads to initial financial projections as shown in table 2.1.

Table 2.1: Initial financial projections for SHOWMED

SHOWMED P&L	2024	2025	2026	2027	2028	2029
TOTAL REVENUE	90	180	340	530	760	1050
Numerical Models: Training and assistance to usage	15	30	50	80	125	200
Reports and Guidelines : Assistance to certification	10	20	40	70	110	150
Weather forecasting system: New service	50	100	200	300	400	500
Overall results: Specific R&D contracts	15	30	50	80	125	200
TOTAL EXPENSES	90	160	240	320	410	520
Software upgrades	10	20	30	40	50	60
Operating expenses	40	80	130	180	240	320
Marketing	40	60	80	100	120	140
EBT	0	20	100	210	350	530
Taxes (considered 25% over EBT)	0	5	25	52,5	87,5	132,5
NET INCOME	0	15	75	157,5	262,5	397,5

Research data and knowledge management

A data management plan will be developed within WP6 with the target of making **data findable, accessible, interoperable and re-usable** (FAIR principle). The plan will describe what data will be generated or collected during the project, the standards that will be used, the level of confidentiality, how the data will be preserved and which datasets will be accessible and how. Metadata records will accompany the data files in order to describe, contextualize and facilitate external users to understand and reuse the data. One target is to integrated all metadata in FEM secured ORE resource center, ensuring that data will be accessible and findable after project ends in a sustainable manner. The consortium will also check the opportunity of further disseminating data on other European databases or atlas as NEWA or PANGAEA.

The consortium agreement, based on the DESCA (Development of a Simplified Consortium Agreement) template version 1.2 and signed by all partners during the negotiation phase, will regulate all legal matters related to knowledge management and protection. It includes detailed provisions for confidentiality as well as procedures ensuring that joint ownership of results can be managed in a fair and transparent manner. A summary of each participant background intellectual property rights (IPR) (i.e. pre-existing knowledge) will be detailed in the CA along with the terms of any proposed license.

The main principle regarding IPR, will be that each partner executing any task of the project work-plan owns the intellectual property (IP) limited to new data, new model, or deliverable generated by its own execution of this specific task. However, given the nature of collaborative project, it is likely that several partners will be involved in fostering new results. In that case, joint ownership of results may arise and joint ownership agreements will be negotiated separately from the CA and include rights for results exploitation.

Specific support will be given by the coordinator to partners regarding IPRs. Additionally, a review of produced innovations and intellectual property will be given at each general assembly in order to further support the partners with the right protection, dissemination and exploitation strategy. A review of TRL achievement will also be performed to correctly assess the outputs by the end of the project and prepare further development and exploitation.

2.2.2 *Dissemination*

SHOWMED has an ambitious dissemination strategy where engagement with users is a central part of the proposed activities. The dissemination strategy covers all WPs but is specifically addressed by WP6. Dissemination activities will be defined in the communication, dissemination and engagement plan (CDEP, D6.1) that will be delivered in the early stages of the project (M6) and updated later on (M18). The aim of the dissemination activities will be to ensure knowledge transfer to stakeholders that can best make use of them, explaining why and how the results of the project (including databases, software updates and issued forecasts) are reliable and usable for field applications. This will enhance stakeholder engagement, which is a pre-requisite step to maximizing the dissemination and impact of research, and will enable an adequate use and uptake of results by the project target audiences.

Audiences with strong interest in the floating offshore wind sector have already been identified as key regarding dissemination of the project results. These include industry, other key stakeholders of the OW sector (investors, policy makers, insurance companies, policy makers, etc.) and academia. Table 2.2 summarizes the different dissemination activities addressed to these target audiences together with the expected impacts.

Table 2.2. Dissemination and user engagement activities by target audience and expected impacts

Target audience	Activities	Expected impacts
OW industry (windfarm developers, technology developers, operation and maintenance services, project developers, specialised engineering consultancy firms, software developers)	Website LinkedIn posts Data repositories Meetings and seminars Industrial events and fairs Webinars Regional workshops Final stakeholder event Factsheets case study narratives Infographics	Showcase the application of project results in terms of improved wind resource assessment and systems design and optimization of the power production and maintenance of OW farms Encourage the uptake of project results by OW industry
Other OW key stakeholders (publics funders, private investors, policy makers, regulators, standard bodies, insurance providers, regional clusters and interest groups)	Website LinkedIn posts Data repositories Industrial events and fairs Webinars Final stakeholder event Policy brief Infographics	Showcase the application of project results as reliable tools to decrease LCOE of OW technologies Demonstrate their potential benefits for stakeholders beyond the OW industry
Academia (research organizations, universities)	Website ResearchGate posts Data repositories High-impact peer reviewed journals International conferences, meetings and seminars Webinars Regional workshops Final stakeholder event	Provide state-of-the-art scientific data and information of Mediterranean wind and wave modelling at high resolution

Project results in terms of data, software updates, and issued forecasts will be **included in data repositories** and made available to all target audiences. Whenever possible, **publications in high-impact peer reviewed journals** (e.g. Bulletin of the American Meteorological Society, Journal of Geophysical Research, Wind Energy, Renewable Energy, etc.) will be made available in open access. Publication of results in scientific journals will prove the cutting-edge character of the research conducted and ensure a proper implementation of the tools and databases developed by the OW industry.

Dissemination of further results will be completed by the presentation of project results in **international conferences (American and European Geophysical Union, Ocean, Offshore & Arctic Engineering, Torque, Wind Energy), meetings and seminars** through talks and posters, and attendance to industrial events and fairs, having stands or visibility when relevant. We will also ensure the presence of the project in **dedicated events from industry** such as FOWT and Wind Europe offshore conferences, the annual international events dedicated to offshore wind and FOW (with special focus on the Mediterranean) respectively. We will also be in events targeting policy makers such as as European Union Sustainable Energy Week (EUSEW) or the union for the Mediterranean annual energy platforms policy dialogue.

We will produce two **webinars** about topics of relevance for the project (e.g. how to use the tools developed in the project, such as the new WRF version and the data driven approaches applied to forecast wind and waves in MCA). Webinars will also be completed by the organization of a (one-day of half-day) **virtual workshop** about one scientific topic of relevance for the project.

In addition to virtual events, we also plan to organize face-to-face events. These include **five regional workshops** in different MCA countries around the Mediterranean (France, Turkey, Greece, Croatia and Italy). Workshops will target a large group of stakeholders from the project target audiences, and will be directed to better inform FOW potential and market value around MCA. At the end of the project, a **final stakeholder event** will be organized to present the main results of the project to potential users and the project advisory board, and to highlight their possible applications.

Key dissemination materials will be tailored to the specific audiences in terms of content, terminology and format. This involves the development of written material such as **factsheets on case study narratives**, and a **policy brief**, and also visual resources to help illustrate main project results, such as **infographics** to support the dissemination of key scientific papers and other dissemination material.

Although the project's website and professional social media (LinkedIn and ResearchGate) have been included as activities or channels for communication (section 2.2.3), they are also used for dissemination purposes.

A set of **key performance indicators** will be selected to evaluate the effectiveness of the dissemination (and communication) actions presented above. These indicators will be included in the Communication, Dissemination and Engagement Plan (CDEP) and monitored throughout the project. Adaptive strategies will be implemented according to the evaluation of these indicators, although the update of the CDEP in the midway point of the project will give the opportunity to make a major adaptation of the dissemination activities during the project.

Proposed indicators will include tangible results and will have explicit quantitative and measurable targets. Some examples of such indicators are set out in Table 2.3, but the full list of indicators will be developed in the CDEP.

Table 2.3. Example of Key Performance Indicators for Dissemination and user engagement activities

Dissemination tools/channels	**Indicators**	**Objective**
Professional social media	No. of views on LinkedIn / month	500
Publications	No. of submitted scientific papers	10
Events/Conferences	No. of presentations/posters at conferences	20
	No. of attended industrial events	9
Regional workshops	No. of organized events	5
	No. of participants/event	30

2.2.3 Communication activities

SHOWMED communication activities will be defined in the communication, dissemination and engagement plan (CDEP, D6.1), that will define the goals and objectives of communication. The plan will detail audiences, communication tools and channels, key messages and practical information such as branding project style, logo, templates, etc. The overall goal of communication activities is to establish a dialogue with an audience beyond the community of the floating offshore wind sector. Professionals that use the sea, environmental associations, media, and the general public living on the shores of the Mediterranean will be particularly targeted. The strategy will be to explain the global idea of the project and to develop consenting regarding offshore wind farms using the experiments carried out on lighthouses as real scientific mediation tools. Communication activities will be developed through the use of both traditional tools (e.g. general and specialized media) and multichannel tools (e.g. website, social media, newsletters, etc.). Table 2.4 summarizes the different communication activities addressed to these target audiences together with the expected impacts.

Table 2.4. Communication activities by target audience and expected impacts

Target audience	Communication tools/channels	Expected impacts
Professionals who use the sea (fishermen, sailors, tourism sector)	Website Communication kit E-newsletters Press releases	Provide reliable knowledge that can benefit to a wide range of sectors (knowledge transfer), facilitating decision-making, e.g. contribute to reduce shipwrecks
Environmental associations	Website Twitter Communication kit E-newsletters Press releases	Provide reliable knowledge that can be of interest for ecological issues relying on wave- and/or wind-related conditions, e.g. wind direction statistics to better understand bird migration
General public (citizens, youth)	Website Twitter Communication kit Press releases Science and society local events	Provide reliable knowledge that can benefit society at a whole Leverage the social value of lighthouses by using them to have a better knowledge of Mediterranean weather and to improve forecasts Motivate youth interest in science by showcasing its real-world application
Media	Website Twitter Communication kit Press releases	Ensure project visibility to the public and that it is reliably communicated
Other EU initiatives and projects	Website Twitter Communication kit E-newsletters Science and society local events	Increase synergies and avoid overlapping through knowledge sharing and clustering

We will set up and continuously updated a dedicated **website** that will provide a description of the project and its objectives aimed at general audiences. The website will contain information about the project's progress, news and dissemination material. It will also have a link to SHOWMED **social media** (Twitter, LinkedIn, ResearchGate). Targeted contents for social media will be prepared with a strong support from all partners. SHOWMED social media strategy for posting will leverage the activity and accounts of all partners while ensuring that they tag properly the handle of the project instead of creating new accounts, posts on social media.

A recognizable project **visual identity**, including the project logo, design elements, colours and fonts will be developed. The visual identity will be also applied to other project materials such as presentations, reports and newsletters. A **communication kit** will be provided following the project visual identity and containing communication materials directed to increase the visibility of the project among general audiences. The kit will include a leaflet, slideshows and a poster. It will be sent by e-mail when introducing the project to external stakeholders and will be made available on the project website.

Press releases will be prepared in close collaboration with other partners and distributed in each MCA to national and regional media through partners' press contacts. Press releases will include informative texts and visual materials developed as a result of communication and dissemination activities. In addition, **e-Newsletters** will be published biannually summarizing the main project advances and targeting stakeholders external to the project. Newsletters will be sent to project partners relevant contacts and to a mailing list managed by FEM with contacts collected from the project website.

Participation in **science and society local events** will be used as an opportunity for all project partners to raise awareness on the topic of the project. Potential events or initiatives to adhere are the European researchers night, science week, international day for women and girls in science, summer schools for teachers or journalists, pint of science, etc.

As for dissemination and engagement activities, a set of indicators will be selected to evaluate the impact of the communication activities and they will be regularly monitored forcing a review in the communication strategy if necessary. These indicators will include common performance indicators such as website visits, social media followers or media impacts after press releases.

3. Implementation

3.1 Work plan — Work packages, deliverables and milestones

3.1.1 Overall structure of the work plan

The work plan structure is results-based, with each work package mapping to a main objective of the project. This logic has been previously presented in sections 1.1.2 and 1.4.1.

WP1 focuses on project management to ensure the activities are conducted according to plan and to budget with high levels of quality and synergy between the partners. It includes a data management plan and a quality assurance plan.

WP2 produces the observational database necessary for the modeling chain development and validation and feed into the statistical forecasting undertaken in WP5.

WP3 deals with the development of a MCA-specific modelling chain incorporating new physics and validated over challenging weather conditions as well as the different regions of interest.

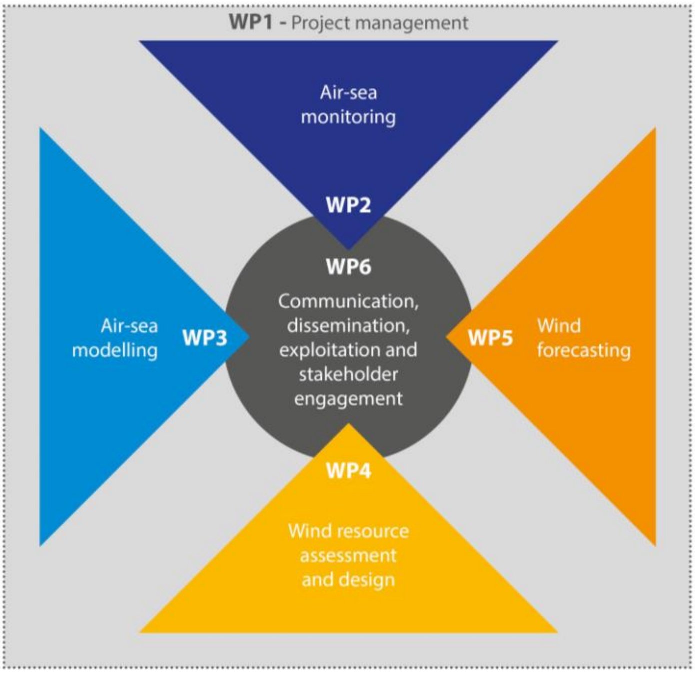


Figure 3.1: Visual presentation of work packages

WP4 exploits the modelling chain for the production of a 25-year wind-wave hindcast to be supplemented by a SAR wind database. These sources of information combined with the observations collected in WP2 will serve to explore the validity of the wave spectrum, extreme wave statistics, wind turbulence, gustiness and shear models in MCA conditions. This WP finally features a decadal wind prediction effort covering the region of interest.

WP5 aims to develop a data-driven forecasting system fed by the SHOWMED numerical database, coastal wind observations and integrated in a smart datalogger.

WP6 maximises the project’s impact on the deployment of OW in MCA by planning and deploying a comprehensive set of exploitation, dissemination and educational activities.

3.1.2 *Timing of the different work packages*

	WP and tasks	Lead	Month		Year 1												Year 2												Year 3												
			Start	End	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	
	Milestone		1	36							M1						M2, M3						M4, M5		M6	M7									M8						
WP1	**Project Management**	**FEM**	1	36																																					
T1.1	Project coordination	FEM	1	36				D1.1															D1.5, D1.7																		D1.9
T1.2	Project communication & reporting with EC	FEM	1	36				D1.2, D1.3															D1.6																		
T1.3	Quality assurance & risk management	FEM	1	36																																					
T1.4	Data management	FEM	1	36							D1.4																														D1.8
WP2	**Air-sea monitoring**	**HZG**	**1**	**27**																																					
T2.1	Collection of existing wind, waves and air-sea in situ measurements	FEM	1	6							D2.1																														
T2.2	Acquisition of wind, waves and air-sea measurements	HZG	3	18													D2.2						D2.3, D2.7																		
T2.3	Wind from video recorded breaking statistics, application to satellite optical imagery	HZG	3	18																			D2.4																		
T2.4	Development of an advanced satellite borne wind field processor	Ifremer	3	27																												D2.5, D2.6									
WP3	**Air-sea modelling**	**DTU**	**1**	**15**																																					
T3.1	New physical parameterizations in the air-sea model chain	HZG	1	6							D3.1																														
T3.2	Implementation of the SHOWMED air-sea coupled system configuration	DTU	3	12													D3.2																								
T3.3	Numerical experiments of MCA weathers	DHMZ	9	15																D3.3																					
WP4	**Wind resource assessment and design conditions**	**FEM**	**1**	**36**																																					
T4.1	Development of highly detailed wind resource statistics at turbine hub-height based on satellite SAR	DTU	1	36																					D4.1																D4.2
T4.2	Wind and wave climate from the SHOWMED modelling system	FEM	13	21																						D4.3															
T4.3	Decadal wind climate evolution over the Mediterranean Sea	BSC	6	30																															D4.4						
T4.4	Challenging the certification documents: design wind conditions	IZTECH	12	30																															D4.5						
T4.5	Challenging the certification documents: design wave spectrum	FEM	12	30																															D4.6						
T4.6	Challenging the certification documents: extreme wave statistics	CNR	12	30																															D4.7						
WP5	**O&M and power optimization applications: wind and wave forecasting**	**CRES**	**3**	**36**																																					
T5.1	Wind gust prediction	HZG	6	18																									D5.1												
T5.2	Data driven wind forecast from observations and numerical hindcasts	Ifremer	18	36																																					D5.2
T5.3	Development of a smart downscaling system	CRES	3	33																																		D5.3			
T5.4	Effect of the data-driven downscaling on the wave modelling	FEM	32	36																																					D5.4
T5.5	Definition of a suitable monitoring strategy for MCA wind measurements	FEM	30	36																																					D5.5
WP6	**Communication, dissemination, exploitation and stakeholder engagement**	**BSC**	**1**	**36**																																					
T6.1	Planification of the communication and dissemination of the results for stakeholder engagement	BSC	1	36							D6.1												D6.5																		D6.7
T6.2	Communication about the project	FEM	1	36				D6.2			D6.3																														
T6.3	Stakeholder engagement and dissemination of project results	BSC	6	36																															D6.6						
T6.4	Exploitation of the project results	FEM	6	36																			D6.4																		D6.8

3.1.3 Detailed work description

List of work packages

WP No	Work Package Title	Lead Participant No	Lead Participant Short Name	Person-Months	Start Month	End month
1	Project management	1	FEM	36	1	36
2	Air-sea monitoring	7	HZG	101	1	27
3	Air-sea modelling	6	DTU	112.7	1	24
4	Wind resource assessment and design conditions	1	FEM	129.9	1	36
5	O&M and power optimization applications: wind forecasting	4	CRES	59	3	36
6	Communication, dissemination, exploitation and stakeholder engagement	2	BSC	54	1	36
				492.6		

Table 3.1: list of Work packages

Work packages description

Work package No	1		**Lead beneficiary**		**FEM**					
Work package title	**Project Management**									
Participant number	1	2	3	4	5	6	7	8	9	10
Short name	**FEM**	BSC	CNR	CRES	DHMZ	DTU	HZG	Ifremer	IRB	IZTECH
Person/months	18	2	2	2	2	2	2	2	2	2
Start month	1			**End month**		36				

Objectives:

The focus of this WP is to deliver the **administrative, financial and legal management** of the project. The specific objectives are:

- The overall strategic and operational management of the project, including financial and administrative management, ensuring the accuracy, quality and timeliness of deliverables
- To ensure the seamless integration of the activities by reviewing and assessing the progress of the project activities towards the defined goals and objectives
- To coordinate and ensure the coherence of all the developments between Work Packages
- To establish the communication flow and methods for reporting, monitoring, quality assurance and innovation management
- The periodic identification, monitoring and assessment of risks together with implementation of contingency plans if needed
- To manage liaison with the European Commission and the production of periodic reports
- To manage knowledge and intellectual property (IP) rights, including legal documents such as the Consortium Agreement, access and exploitation of results and background IP

- To manage the public face of the project and encourage networking with other related projects, platforms and initiatives in coordination with WP6
- To promote gender equality.

Description of work

1.1 – Project coordination (M1-M36) – Lead: FEM; Participants: all

The objective of this task is to establish the governance structure in order to **coordinate, communicate and monitor progress** throughout project life. To support the coordinator in strategic decisions, a general assembly will be established composed of senior members from each partner organisation.

The **general assembly** will meet regularly on a 6 months period basis, and additional remote meeting will be planned at each milestone.

The consortium will be supported by an **advisory board** composed of offshore floating farm developers, floating technologies developers, O&M companies, regional/national authorities and intergovernmental organizations. Interactions with the advisory board are foreseen throughout the project via web conference meetings, in order to obtain advice on the strategy to be deployed and facilitate dissemination.

The project management task includes internal communication, reporting and monitoring with following objectives:

- Ensure **fluid communication** between project partners
- **Review project progress, deliverables and reports**, ensuring the quality of the project outputs
- **Follow up expenses** of each partner on a regular basis, ensuring the allocated budget allows to perform the envisaged studies
- **Follow up on planning and resource** allocation by each partner, ensuring deviations to initial targets have limited effects

The communication flow within the Consortium will be bottom-up and top-down, through typical communication methods. A **secured collaborative workspace** will be established to exchange documents and save latest versions and archives of project outputs.

1.2 – Project communication & reporting with European Commission (M1-M36) – Lead: FEM; Participants: all

This task aims to establish **fluent communication within the consortium and with the European Commission (EC)**. This will be facilitated by high quality internal and external (by the EC) monitoring of the project, to ensure production of deliverables and reports that meet the project's objectives, technical and non-technical commitments and EC requirements in due time and manner. The task will be the responsibility of the project manager and includes all reporting aspects as defined in the quality assurance plan and by the H2020 programme rules.

This task also includes the internal review of project deliverables and reports, their validation and subsequent submission, in order to ensure high quality in accordance with the contract's commitments, including evidence of the activities undertaken. WP leaders will be in charge of reviewing technical deliverables of their WP and the coordinator will be responsible for the final reviews, validation and submission to the EC.

Finally, all partners will keep updated records of their financial statements and provide documentation on expenses on a 6-month basis, for internal budget monitoring. The contractual reports include an interim report at month 18 (including a "technical periodic report" and a "financial periodic report") and a final report, at month 36, to summarise the project's activities over its full duration. This will cover the main aspects of the work undertaken, objectives, results, conclusions and future plans, especially regarding the exploitation plan to effectively bring the project results to the market.

1.3 – Quality assurance & risk management (M1-M36) – Lead: FEM; Participants: all

At the beginning of the project, a **quality assurance plan** (QAP) will be produced by the project manager to ensure a good quality and progress of work. It will include procedures for managing the quality, innovation, project risks and gender issues. The QAP will be reviewed at each project general assembly. It will serve as a handbook for SHOWMED project partners to assure the swift and coordinated management of all aspects described above. The project management plan will clearly document the work breakdown.

Management of the project risks will be performed through specific actions to identify risks, evaluating their impact and proposing mitigation measures. A risk register will be created and monitored on a monthly basis by the project manager, building on the risk register included in this proposal.

1.4 - Data management (M1-M36) - Lead: FEM; Participants: all

Partners of the consortium strongly believe in the concept of open science and in the benefits that the European innovation ecosystem can draw from allowing the reuse of data at a larger scale.

As SHOWMED will produce a large set of databases, the **data management plan** should target to make data **findable, accessible, interoperable and re-usable** (FAIR principle). The initial version of the data management plan will provide a first list of datasets and databases planned together with metadata information. The final version of the data management plan will focus on results obtained and sustainability in order to further exploit the data.

All metadata will be integrated at FEM ORE resource centre that will be available by end 2021. Other options (NEWA, PANGAEA) will also be used, in order for all data to be accessible after project end.

Deliverables (brief description and month of delivery)

D1.1 Project Management Plan – initial version (FEM, M3). The plan will address the governance and role of the partners, the agreed work plan and resources to be allocated, list of deliverables and milestones, agreed planning and budget.

D1.2 Quality Assurance Plan – initial version (FEM, M3). Handbook of procedures for project quality, risk, innovation and gender equality management.

D1.3 Risk register (FEM, M3) – Set up of the Risk register based on identification, evaluation proposition of mitigation measures

D1.4 Data Management Plan - initial version (FEM, M6) - Set up of the Data Management Plan based on the list of expected outputs of the project

D1.5 Project Management Plan – final version (FEM, M18). Final version of the Project Management Plan.

D1.6 Quality Assurance Plan – final version (FEM, M18). Final version of the Quality Assurance Plan.

D1.7 Interim Report (FEM, M18). Summary of progress against objectives, work plan and achievements. Review of deliverables, dissemination activities and project management actions. Any budget deviations and a forecast regarding activity for next reporting period will be available.

D1.8 Data Management Plan - final version (FEM, M36). Final version of the Data Management Plan listing metadata resulting from the project together with access right and further access solutions for stakeholders.

D1.9 Final report (FEM M36). Summary of all project achievements, work progress and objectives met. Deliverables, dissemination activities, project management activities, subcontracting and budget deviations will be reported. A final publishable summary report for wider dissemination will be included.

Work package No	2		Lead beneficiary		HZG					
Work package title	Air-sea monitoring									
Participant number	1	2	3	4	5	6	7	8	9	10
Short name	FEM	BSC	CNR	CRES	DHMZ	DTU	HZG	Ifremer	IRB	IZTECH
Person/months	13		3	16			49	10		10
Start month	1			End month		27				

Objectives:

WP2 will Collect and acquire of air-sea measurements for getting a better understanding of fetch-limited and offshore blowing wind conditions in MCA. This will allow to advance the modeling and forecast of wind, waves and turbulence conditions in coastal regions (WP3,4 and 5).

WP2 will contribute to the development of a new method to retrieve high resolution surface winds from tower and satellite based optical measurements.

Finally, a prototype wind processor will be developed for generating wind maps from satellite-borne Synthetic Aperture Radar (SAR) data. Use SAR (Sentinel-1), optical (Sentinel-2), multi-spectral and SAR-altimeter (Sentinel-3) high resolution sensors from the European Copernicus space component for earth monitoring.

Description of work

2.1 Collection of existing wind, waves and air-sea in situ measurements (M1 – M6) - Lead: FEM, participants: CRES, CNR, FEM, HZG, IZTECH

Collection of all available in-situ data in the Mediterranean Sea, which will be used for the validation and improvement of satellite products and numerical models (D2.1, M9). This will include, but will not be limited to : (i) wave data available through the French National Service for wave data archiving (ii) wind and wave observations collected by the 2 floating lidars to be deployed in the French Mediterranean Sea in preparation of the next FOWT call for tenders, and (iii) existing observations from the Aqua Alta platform in the northern Adriatic Sea,

2.2 Acquisition of wind, waves and air-sea measurements (M3 – M18) - Lead: HZG, participants: CNR, CRES, FEM, IZTECH

Mediterranean Sea:

A twelve-month experiment will be carried out in the Gulf of Lion, Mediterranean Sea, which will serve as basis to better understand, parameterize and model the coastal wind and wave situations. The experiment consists of two measurements sites near Marseille, France. In this area, strong northwesterly blowing winds, the Mistral, are predominating, making the Gulf of Lion one of the windiest areas in the Mediterranean. The lighthouse of Cap Couronne represents the situation at the coast on the main land. Approximately 20 km southeast (downwind) is the island of Le Planier (LP), which with the prevailing (Mistral) wind direction represents a fetch-limited situation.

Both land-based stations will be equipped with a vertically profiling wind lidar (up to 200 m), a mast with ultra-sonic anemometers (USA), air temperature, humidity and pressure sensors as well as water temperature. The mast on LP will be equipped with several USAs, at least two of which will be measuring 3D airflow velocities, thus yielding momentum flux data. In addition, both stations will be equipped with HZG's coherent on receive marine radars (MR), which allows to measure wind, waves and currents in space and time. LP will further host a stereo video system (SVS) to provide high level information on the wave spectra, breaking rates and individual wave statistics. The site further benefits from the deployment of a permanent wave buoy (1km south of LP) for calibration of the MR and SVS.

Ship of opportunity:

Additionally, it is planned to operate a SVS and MR from a ship of opportunity (SO) cruising routinely between Marseille, France and Tunis, Tunisia, capturing the wind and wave change from land to open sea at different fetches. The SO is already equipped with a FerryBox, which gives surface water temperature (important for air-sea fluxes).

Italian Adriatic Sea:

The experiments will take place in the northern Adriatic Sea (Italy) using instrumentation deployed onboard the Acqua Alta platform. The air–sea momentum flux assessment in conditions of Bora jet winds will use a 3D anemometer for wind stress, a SVS for directional wave field characterization, and barotropic (currents and water level) and baroclinic (sea temperature) measurements on the ocean side. Data will be used to assess the formulation of the drag coefficient for young/steep sea conditions and the interplay between the wave and turbulent boundary layers under strongly forced winds. SVS will face the Bora waves to maximise the 3D sea surface area directly observable by the cameras, and will be synchronized with other instruments. A wave probe mounted on the platform legs will provide supporting measurements. Measurement campaigns are planned to be carried out during year one of the project in close cooperation with other field experiments.

Greek Aegean Sea: the data collected during the ongoing one-year experiment conducted from the Floatmast platform, deployed near the Makronissos island, will be made available for the project. The platform hosts a 40 m met-mast and a wind lidar. The conditions will be used for air-sea coupled model validation (WP3) and for the investigating of the vertical structure of the wind and turbulence (WP3 and WP4).

Turkish Aegean Sea: An experiment is planned at the Aegean Sea, close to Turkish at the northern part of the city of Izmir. This initiative, funded by an external source, will allow the deployment of a met mast for at least 1-year (starting from year one of the project) from a small island lying 1.6 km from the mainland, located upwind (position: 26.81° N, 38.92° W). This will provide a rich source of information regarding the atmospheric conditions and their vertical properties in a location highly influenced by the upwind coastal orography.

All acquired data will be quality controlled and published via the FEM resource center as well as on the data center PANGAEA.

The availability of all the sites targeted by the project have been confirmed.

2.3 Wind from video recorded breaking statistics, application to satellite optical imagery (M3 – M18) Lead: FEM, participants: HZG, Ifremer

Here we propose to measure the surface wind from its dependence on the spectral distribution of the active breaking fronts using video imagery. We believe that this method is promising in the Mediterranean situations studied, where waves and wave breaking are highly related to the local wind. Direct parameterizations using the latest scientific knowledge will be tested together with data-driven methods. More specifically, we shall investigate the applicability of the Generative Adversarial Networks (Goodfellow et al., 2014), fed by the sea surface video images and X-band radar wind maps obtained from Le Planier lighthouse.

This knowledge will be transferred to the improvement of the wind retrieval techniques from satellite optical images, taking advantage of the time lag of Sentinel-2 optical acquisitions to capture the breaking fronts and their velocities as done by Yurovskaya et al. (2019). The application of this work will be threefold: i) it will help to improve the wind retrieval techniques from optical imagery, using wave breaking information (WP2.6), ii) it will help correct the noise introduced by wave breaking in the wind retrieval from SAR images (WP2.6), iii) it will provide relevant information for the validation of a MCA-dedicated wave breaking statistics formulation, to be implemented in the SHOWMED air-coupled numerical system (see WP3.1).

2.4 Development of an advanced satellite borne wind field processor (M3 – M27) - Lead: Ifremer, participants: DTU, FEM

Data from Copernicus Sentinel-1, Sentinel-2 and Sentinel-3 missions are routinely acquired over the Mediterranean Sea. They provide observations of the ocean sea surface at very high resolution together with a large coverage, offering the unique possibility to map the whole coastal area of the Mediterranean Sea.

Although established methods exist for deriving ocean surface wind field measurements from space-borne SAR such as Sentinel-1 (see WP4), several challenges remain when it comes to coastal measurements.

In particular, the impact of limited fetch on wave growth, breaking waves for strong offshore wind (e.g. Mistral, Bora, Meltem), biological films, wave-current interactions, or the influence of bathymetry on the measured signal can impact the accuracy of the surface wind measurements.

Optical, multi-spectral and SAR-altimeter data provide information on these possible disturbing phenomena. Case studies where all available information from the three Sentinel missions will be analyzed to assess these impacts on the wind retrieval and possibly define a new strategy for wind measurements. Optical data will be used for wave breaking characterization and to retrieve wave information from image cross-spectra between different channels (see WP 2.5). SAR-altimeter and X-band marine radar (see WP 2.2) will provide information on wave evolution with respect to fetch distance. Ocean color from Sentinel-3 OLCI multi-spectral sensor will provide information on biological films and ocean currents.

The potential of Sentinel-1 SAR new capabilities with respect to previous SAR missions (e.g. Envisat) will also be investigated. We will analyze the benefit of the dual-polarization for wind speed sensitivity, the higher resolution for direct wind direction estimates and non-wind features detection, the waves' signature in the high frequency part of the image spectrum and the geophysical signature of the Doppler. We will focus on complex meteorological situations (e.g. atmospheric front, offshore wind) to test new approaches for wind inversion from SAR in a new open source prototype wind processor and compare them with the existing method used in WP4.

Deliverables

D2.1 Database (and report) on the existing wind, waves and air-sea measurements (FEM, M6) This will be formatted in a well-organized database and a document providing a proper the description of the *in situ* data collected in WP2.1. When possible, the observations will be made publicly available through FEM resource center.

D2.2 Preliminary Gulf of Lion dataset for model validation (HZG, M12). A first dataset from the Gulf of Lion and Ship of Opportunity will be made available to the partners for the modelling work of WP3.3.

D2.3 Report on the Experiments in the French Mediterranean, Italian Adriatic Sea, Turkish site (HZG, M18). This report will provide all the necessary material regarding the experiments, including the type of instruments, settings, sampling frequency and period covered by the measurements.

D2.4 Video-based wind retrieval algorithm and report (FEM, M18). This is the algorithm developed to achieve the wind retrieval from video images of the sea surface, the description of the approach will be done in the attached report.

D2.5 Report on satellite wind analysis in MCA situations (Ifremer, M27). This document will present the analysis of the signature of non-wind features in the signal and the possible correction to be applied.

D2.6 Advanced SAR prototype wind processor (Ifremer, M27). The result will be an open source tool foreshadowing the next generation of SAR wind processor.

D2.7 Data publication of the Gulf of Lion Experiment (HZG, M18). The data set will be made publicly available through the PANGAEA platform and FEM resource center.

Work package No	3		**Lead beneficiary**		**DTU**					
Work package title	**Air-sea modelling**									
Participant number	1	2	3	4	5	**6**	7	8	9	10
Short name	FEM	BSC	CNR	CRES	DHMZ	**DTU**	HZG	Ifremer	IRB	IZTECH
Person/months	18	3	18	6	20	**17.7**		2	26	2
Start month	1			**End month**		24				

Objectives

The overall objective is to obtain a reliable calculation of wind and wave data, particularly within the coastal areas of the Mediterranean Sea, for offshore wind applications, including resource assessment (WP4), design parameters, operation (WP4) and data-driven weather forecasting for O&M activities (WP5). A directly relevant objective to this is to develop the modelling system that is most suitable for the meteorological conditions in this area, by incorporating specific physical parameterizations. To achieve this, a new air-sea momentum flux parameterization will be implemented in the modelling system.

Description of work

3.1 New physical parameterizations in the air-sea model chain (M1 – M6) - Lead: HZG, participants: DTU, FEM, Ifremer, HZG

The effort is focussed on developing a most suitable modelling system based on the current coupling approach of DTU (Du et al., 2019, where WRF is coupled to SWAN through a Wave Boundary Layer Model (WBLM) in SWAN).

The wave field in MCA is generally young and forced by high winds, which induces a large proportion of breaking waves. The breaking process is the main sink of energy for the waves and further supports a significant part of the air-sea momentum flux, through the sheltering effect (resulting from air-flow separation events above breaking wave crests.)

Our aim is to incorporate the state-of-the-art scientific knowledge being developed by FEM, Ifremer and HZG teams, to extend TOGA-COARE 3 type parameterizations and further implementation in SHOWMED's air-sea model chain.

FEM is currently improving the breaking parameterizations of the spectral wave models, extending the work from Filipot & al. (2012) and Leckler & al. (2013). Their breaking models, validated over different fetch conditions, will be implemented in SWAN to provide the spectral distribution of average density of breaking crest length per unit area (Phillips 1985).

Ifremer is actively working on the physical parameterization of the impact of wind-wave on air-sea fluxes (see Kudryatsev & al., 2014).

In parallel, HZG is currently using novel in situ particle image velocity (PIV) observations of the air-flow above breaking and non-breaking waves, together with air-sea momentum flux measurements, for the development of new process-based momentum and energy flux parameterizations, to be used within SHOWMED.

The three teams will work together to combine their wave breaking statistics, air-sea momentum flux parameterizations using the existing PIV measurements (HZG), and wave breaking (FEM) observations, and to adjust them to MCA-specific wind-wave conditions. Efforts will be made to integrate the wave breaking statistics collected during the first months of the field experiment from Le Planier lighthouse, into the calibration of the SHOWMED air-sea flux parameterization.

3.2 Implementation of the SHOWMED air-sea coupled system configuration (M3 – M12), Lead: DTU, participants: CRES, CNR, FEM, IZTECH

The starting point of the implementation is the state-of-the-art wind-wave two-way, online, coupled modeling system from DTU, namely WRF-WBLM-SWAN, where WBLM is implemented in SWAN (Du et al. 2017). In WBLM, as the interface of WRF and SWAN, the variation of stress and kinetic energy conservation equations are described. Here WBLM and SWAN share the same wind-input source function, ensuring that momentum flux from and to WRF is consistently calculated. This allows the new schemes derived from task 3.1 to have consistent impact on both atmospheric and wave modeling. There will be multiple modeling domains to cover the targeted MCA, using a two-way nested approach for both WRF and SWAN, with the inner domain having a spatial resolution of 2 km. The multiple domains also allow tests of area-calibrated new schemes from task 3.1. Sensitivity tests will be done in finding out the best forcing data, optimal domain displacement and size, vertical resolution, physics configurations (e.g. boundary layer schemes, radiation) and organization of simulation length etc. A variety of reanalysis data, including ERA5 and CFSR, will be tested for choosing the forcing data. Considering the Mediterranean coastal flows are often under the land-sea thermal effect, SST is an important element in the modeling. OSTIA SST in connection with ERA5 and OISST in connection with CFSR will first be examined. Sensitivity tests will be done in order to find out the uncertainties caused by the accuracy of SST data through modifications of the SST, as well as using selected high resolution satellite based high resolution SST data. All the tests will be performed together with verification using data from WP2, historical as well as new, to implement the new schemes from task 3.1.

3.3 Numerical experiments of MCA weathers (M9 – M15) - Lead: DHMZ, participants: DTU, CRES, CNR, FEM, IZTECH

The development of the modelling system will be done side by side with the investigation of special and normal Mediterranean weather conditions. Together with literature and measurements, we will examine various model performances in Mistral, Bora, land/sea breeze, storm (including Medicanes) conditions. Special cases will be identified first using historical measurements, open source reanalysis products as well as partners' in-house modelling data and the SHOWMED observations. Numerical experiments will be set up to investigate models' abilities for each of these phenomena. Selected cases studies will benefit from using ultra-high-resolution initial sea surface temperatures or coupling 2-way to suitable ocean model. To study the required resolution for resolving the coastal flow, as well we to understand the uncertainties related to the SHOWMED modelling system, in addition to push the mesoscale WRF model to high resolution limit (e.g. 300 m), microscale modelling will be conducted in selected coastal areas where measurements are available. The microscale models include WRF-LES and Ellipsys3D (Olsen, 2018). The effect of the very high wind resolution on the wave generation under offshore blowing wind will be further investigated using SAR wind maps and/or numerical model output conditions.

Training sessions will be organized before task 3.2 to train the partners in using the air-sea coupled systems so as to ensure a collaborative effort in 3.2.

Deliverables

D3.1 Report on the new air-sea flux parameterization scheme with effect of wave breaking (HZG, M6). This report will describe the development of the parameterization and the adjustments performed using the observations of wave breaking and momentum flux at hand. It will detail the technical implementation of the parameterizations for proper use by model end-users.

D3.2 Report on the definition of the SHOWMED air-sea coupled system configuration (DTU, M12). This report will detail the domain, nesting strategy, atmospheric and oceanic forcings at the boundary.

D3.3 Summary of reports on numerical experiments for special Mediterranean weather conditions (DHMZ, M15). Here each Mediterranean will be in charge to detail the validation cases investigated with the SHOWMED air-sea coupled system. They will detail the dataset used for validation, scores of the models and discuss the limitation and proposition of improvement of the model chain in view of its application in WP4.

Work package nb	4		**Lead beneficiary**			**FEM**				
Work package title	**Wind resource assessment and design conditions**									
Participant number	1	2	3	4	5	6	7	8	9	10
Short name	**FEM**	BSC	CNR	CRES	DHMZ	DTU	HZG	Ifremer	IRB	IZTECH
Person/months	15	35	16.3	8	12	27.6				16
Start month	1			**End month**		36				

Objectives:

This WP intends first to develop a wind-wave hindcast database covering MCA from the numerical chain developed in WP3 and from the analysis of SAR images. This source of information is supplemented by a study on the predicted evolution of the MCA wind climate at 5 to 10-year horizon.

The numerical and observational databases built in WP2 and 4 will be further analysed with regards to the design wind and wave conditions. In fine, this work intends to challenge the existing certification documents and if appropriate propose new models for the definition of the wind and wave design conditions.

Description of work

4.1 Development of highly detailed wind resource statistics at turbine hub-height based on satellite SAR (M01 – M36) - Lead: DTU

Satellite SAR wind maps from the DTU archive (https://satwinds.windenergy.dtu.dk/) with ¼ million processed wind maps will be the backbone of input, in addition to novel SAR products from WP2 task 2.5. Data from three European satellite missions (Envisat, Sentinel 1a and 1b) will be used with focus on achieving a harmonized long-term data series. This will involve analysis versus the buoy data in the Mediterranean Sea and versus the experimental data from (WP2 task 2.1 and task 2.2 link to radar, lidar, met-mast). The analysis will focus on ensuring long-term consistency as well as good spatial representation at all relevant sites in the Mediterranean Sea. Once an optimal wind map series from SAR multi sensors is available (surface winds at 10 m height) (see Deliverable D4.1), the extrapolation to turbine hub-height (100 m) will be performed. The methodology developed by Badger et al. (2016) will be revisited with analysis of how the stability climate in the Mediterranean Sea compare to novel observations of wind profiles and temperature profiles from (WP2 task 2.1). Furthermore, satellite scatterometer wind retrievals from the ASCAT instrument onboard the MetOp suite of platforms (A, B, C) at a 12.5 km spatial resolution will be used for the regions of interest to provide wind resource maps at 10 m and at hub-height. The added advantages of ASCAT winds include i) simultaneous retrieval of both wind speed and wind direction, ii) consistent temporal availability with at least 2 daily observations since 2007, while currently with 3 observing systems, parts of the Mediterranean can be observed up to 6 times per day. ASCAT winds will be further analyzed versus the same buoy data in the Mediterranean Sea, as used for the SAR analysis. Thus, ASCAT will be used as a separate source of remotely sensed winds to supplement the SAR wind resource statistics. The opportunity to improve the stability function based on modelling efforts on air-sea interactions and the response to the marine boundary layer stability climate (WP3 task 3.2) will be included in this analysis, to retrieve the detailed wind resource statistics at turbine hub-height.

An intermediate database will be made available at M20 for the development of the data-driven approaches in WP5. This will be Milestone (M6).

Finally, a comparison between the database and the wind derived from the prototype SAR wind processor develop in WP2 will be performed over some specific and challenging weather conditions. This will help set the priorities for the next generation of SAR wind processors, initiated through the open source prototype solution proposed in SHOWMED.

4.2 Wind and wave climate from the SHOWMED modelling system (M13 – M21) - Lead: FEM, participants:BSC, DTU, CRES, IZTECH, CNR, DMHZ, IRB

This task aims at applying the air-sea coupled model developed in WP3 to produce a 25-year hindcast of wind and wave conditions at High Resolution (2 km) over the MCA. This database will be extensively validated over each of the areas of interest, in Croatia, France, Greece, Italy, Spain and Turkey, using in situ measurements and the satellite databases generated through SHOWMED and existing high-resolution long term hindcasts from the partners. The database will be carefully organized using standard format (netcdf) and made freely available through FEM's resource center.

The wind speed information will be complemented with wind power at hub height and the derivation of standard statistical indicators, such as the P50 and P90 percentile.

4.3 Decadal wind climate evolution over the Mediterranean Sea (M6 – M30) - Lead: BSC, participants: FEM

In order to understand if currently observed trends will continue in the coming decades, the role that decadal oscillations play on those trends will be analyzed employing decadal prediction systems, i.e. initialized climate model integrations, (see Solaraju et al., 2019 and Smith et al., 2019) and twenty-century reanalyses (e.g. Wohland et al., 2019). The Atlantic Multidecadal Oscillation (AMO) is the main source of predictability at decadal timescales. First the skill of AMO forecasts in decadal prediction systems from CMIP6 DCPP-A will be assessed, and then the AMO impact on surface wind will be studied. Finally, multiannual predictions of surface wind 5 to 10 years ahead will be presented and accompanied by skill estimates based on past performance of the models.

4.4 Challenging the certification documents: design wind conditions (M12 – M30) - Lead: IZTECH, participants: DTU, CRES, FEM, HZG

The observations collected by the lidars, and met masts deployed in WP2, together with the numerical HR database will further be analysed with a focus on the wind shear and turbulence, gustiness and shear characteristics. Focus will be drawn on the testing and if appropriate, on improving the certification standards and wind farm siting softwares for MCA sites in offshore blowing winds and storm conditions for fatigue and Ultimate Limit State design purpose. We shall hence explore the validity of the turbulence, shear and gustiness models (see for instance DNV-GL-ST-0437, section 2.3.2 and 2.3.3) and propose specific parameterizations when appropriate to be implemented in certification documents and in the wind farm siting WAsP family software.

4.5 Challenging the certification documents: design wave spectrum (M12 – M30) - Lead: FEM, participants: CNR, Ifremer, HZG

In the MCA targeted by the project, the strong offshore blowing wind conditions lead to large coastal areas where the development of the sea is limited by the fetch. Even though the formulation of the JONSWAP spectrum formulation proposed by Hasselmann et al. (1973) introduces a dependence with the fetch compared to the Pierson and Moskowitz (1964) formulation, its application in the conditions of high wind speed fetch-limited waves of the MCA is highly questionable. Using the numerous observations of wave spectra obtained in the scope of the project, and especially those from the ship of opportunity, the applicability of the JONSWAP formulation shall be investigated, in particular regarding the spectral peak and its relation with the wind gustiness. Effort will be made to define a proper MCA-specific, fetch-dependent wave energy spectral shape. The directional properties of the wave field will be investigated in the same manner. As in WP4.3, the final objective is to provide guidelines in order to supplement the OW turbines certifications guidelines with MCA-specific wave spectrum description.

4.6 Challenging the certification documents: extreme wave statistics (M12 – M30) - Lead: CNR, participants: FEM, HZG

The wave field in MCA is generally made of young seas, that may be generated by offshore winds, sea breezes or intense but localized storms. In these situations, with large directional spreading and high wave steepness, the occurrence of rogue waves (single waves with height much larger than the typical ones defined by standard statistics) may deviate from what is expected in the ocean and predicted by the certification guidelines. Having a correct statistical description of rogue waves in MCA is important for the Ultimate State Design, but also for boat landing on a FOWT or installation process, even in milder conditions. In this task, we shall investigate the statistics of these rogue waves in the MCA with a focus on offshore blowing wind situations (O&M) and storm sea states. This will be complemented by an analysis of the rogue wave occurrence and magnitude over the typical floating OW turbine footprint. We intend here again to provide guidelines for further implementation of these results into the floating OW turbine certification standards. Data from all stereo wave measurement systems described in WP2 will be used for extreme value characterization. Rogue waves will be searched for by analysing the largest 3D wave trains passing within the stereo cameras field of view.

Deliverables

D4.1 Wind climate at 10 m from combined SAR wind data set (DTU, M20). This will be **a preliminary** database made of a long time series of SAR images covering the region of interest for use in WP5.

D4.2 Wind climate at 10 m from combined SAR wind data set (DTU, M36). This will be **the final** database made of a long time series of SAR images covering the region of interest.

D4.3 Wind wave 25-year hindcast produced by SHOWMED model chain (FEM, M21). This will be the SHOWMED numerical wind wave climatology for MCA, to be interfaced with a GIS in the FEM resource center.

D4.4 Report describing the expected decadal evolution of the wind climate over the MCA, over the wind farm lifetime duration (BSC, M30). This report will detail the modelling approach deployed and put into perspectives the results of the study, especially regarding the future OW projection over MCA.

D4.5 Guidelines report for implementation in OW standards documents of MCA-specific wind gust and wind turbulence models (IZTECH, M30). This report will challenge the existing certification guidelines for wind gust and turbulence and their applicability to MCA conditions. If required, more appropriate models will be proposed.

D4.6 Guidelines report for implementation in OW standards documents of MCA-specific wave energy spectrum shape (FEM, M30). Same as D4.3 for the wave energy spectrum.

D4.7 Guidelines report for implementation in OW standards documents of MCA and OW-specific rogue wave statistics (CNR, M30). Same as D4.4 for the extreme wave statistics.

Work package nb	5		**Lead beneficiary**		CRES				
Work package title	**O&M and power optimization applications: wind and wave forecasting**								
Participant number	1	2	3	**4**	5	6	7	8	9	10
Short name	FEM	BSC	CNR	**CRES**	DHMZ	DTU	HZG	Ifremer	IRB	IZTECH
Person/months	18		6	15			10	10		
Start month	3			**End month**		36				

Objectives:

With today's energy market regulations, a definite way of increasing the offshore wind power share in the energy mix is through accurate short-term energy forecasting of offshore wind farms.

Forecasting involves a suite of 'digitalization' steps, like cloud computing, data processing, machine learning (ML) and data analytics in order to assimilate the latest in situ observations into the forecasting models.

The present work package will investigate whether the advanced characteristics of wind coastal data as obtained from x-band radar, profiling lidars met masts and satellite images, can be coupled to model outputs to produce accurate forecasts using machine learning strategies.

More specifically, the following topics will be addressed:

- Wind gust forecasting using X-band radar,
- Server-side data-driven wind forecasting and hindcasting,
- In place adjustment of day-ahead weather forecasts by a smart data-logger with monitoring /alerting capabilities integrating the data driven forecasting tool,
- Wave forecasting taking as input the high resolution wind fields produced by the data driven approach,
- Definition of a suitable monitoring strategy for MCA wind measurements

Description of work

5.1 Wind gust prediction (M6-M24) - Lead: HZG, participants: FEM

A short term (30 to 60 s) wind forecast system will be developed for offshore wind farms, based on the experiment deployed from Le Planier lighthouse. The system is based on in situ wind measurements and in particular on marine radar data acquired from the location for which the forecast will be determined. Therefore, the marine radar data will be utilized to retrieve surface wind maps, which will be investigated with respect to surface wind extremes such as wind gusts. In a further step the propagation direction and speeds of the wind gust will be retrieved from the radar data and used to predict its time of arrival at the wind turbine by a simple wind speed prediction model. This will allow predictive control of the wind turbines to avoid power overshoots and reduce fatigue loading.

The possible use of optical imagery to infer wind gust from the breaking waves will be further explored in this task.

5.2 Data driven wind forecast from observations and numerical hindcasts (M18 – M36) - Lead: Ifremer, participants: FEM, CRES

Nowadays, ultra-high-resolution Large-Eddy simulation models, O(50 m) or less, can certainly deliver highly accurate low-level winds, needed climatologies, and/or seamless nowcasting capabilities. These ultra-high resolution model outputs can then be used to target spatial and/or temporal resolutions of available observations (satellite, in situ). However, already computationally prohibitive over extended domains, O(5 km) or more, and long periods, O(6 h) or more, the often needed ensemble forecast capabilities to assimilate these observations are certainly out of reach.

In this task, the objective is to consider new strategies to best process and down-scale ensembles of low-resolution wind field numerical outputs to match high resolution targeted resolution. All available high resolution atmospheric numerical outputs, satellite databases, and data from the coastal monitoring system produced along SHOWMED, will be aggregated. As foreseen, the strategy will extend the work of He et al. (2014). The proposed method will rely on Machine Learning techniques (such as Support Vector Regression and U-Net-type convolutional neural networks) to help encode important non-local flow characteristics of the input low-resolution fields. All additional multi-modal local data sources will be used to define generative models, best matching characteristics similar to the real data, especially to include additional key information related to the vertical stability and peculiar time-dependent land-sea complex wind transformation.

Finally, for the very short term (10 min - 1h) offshore blowing wind situations, the wind conditions from all local and non-local coastal stations will be integrated in the proposed data-driven generative schemes to provide accurate wind time-delay forecasts at the downwind wind farms. In that context, the generative models will be particularly tested to best reproduce the measurements acquired from the two French lighthouses, located 20 km away, along the Mistral wind direction.

5.3 Development of a smart downscaling system (M3 – M33) - Lead: CRES, participants: IZTECH, FEM

In this task, a smart data-logger will be developed and deployed, initially at the coastal 100m met mast of CRES and then at Le Planier lighthouse in France. Data-loggers with low-power consumption and good processing capabilities exist already and are able to combine both the non-stop data collection and the on-the-fly data analysis.

Such a system will, not only, be able to alert for some advanced flow properties (extreme wind shear, change in atmospheric stability states) that conventional data-loggers do not offer, but it will also be able to adjust the regular 6h, 12h, 24h weather forecasts of various services (GFS, ICON-EU, OpenWRF, etc) at the specific site. Typically, these forecasts are provided at a grid point, a few km away from the met mast location and need to be transferred.

The initial transfer functions inserted in the data-logger's ML algorithm, will originate from previous runs of a flow model (WAsP or CFD) and the data driven model of WP5.3 accounting for the topography effects (upwind land, surrounding islands, etc). After the first month(s) of measurements the continuously growing dataset (measurements and forecasts) "train" the logger-embedded ML algorithm to further improve the forecast results alone. The ML driving parameters are considered to be the wind speed and direction, air-temperature, pressure and the seasonal period.

5.4 Effect of the data-driven wind downscaling on the wave modelling (M32-36) - Lead: FEM, participants: Ifremer

Here we shall investigate the impact of using very high-resolution wind forecast, produced by the data driven approaches developed in WP5.2 and 5.3. This work will consist in running a wave model offline, over a fine mesh forced by high-resolution SAR wind field and comparing the model output to the observations collected in WP2 and to the output of the SHOWMED air-sea coupled numerical model.

This will help us conclude on the opportunity to plug the data driven wind forecasting system from WP5.3 and 5.4 into a wave model for operational forecasts to support O&M applications.

5.5 Definition of a suitable monitoring strategy for MCA wind measurements (M30 – M36) - Lead: FEM, participants: HZG - FEM

From the knowledge acquired through the project, a methodology will be defined for the deployment of an optimal but cheap coastal measurement network to feed into the numerical model validation and the data-driven forecasting system developed in this WP. The methodology will target the type of instruments to implement and the optimal locations to provide the best atmospheric information for the wind farms. Focus will be placed on offshore blowing wind situations, which offer the best setting for implementing the wind forecast at an offshore wind farm, from the knowledge brought by wind measurement stations located on the coast.

Deliverables

D5.1 A wind gust prediction methodology, based on X-band radar measurements (M24, HZG). This report will provide the guidelines to access wind gust forecasting from an X-band radar.

D5.2 A data driven forecasting algorithm (M36, Ifremer). The algorithm will able to predict the wind at high resolution and with high accuracy only from the knowledge of existing numerical and satellite databases coupled to real time in situ measurements.

D5.3 A smart box including local real time atmospheric information (M33, CRES). The smart box will be able to feed the data driven algorithms with local real time atmospheric information.

D5.4 A report detailing the impact of data driven downscaled wind on the wave modelling (M36, FEM)

D5.5 Guideline report for observational strategy (M36, FEM). Guideline report defining the best observational strategy to monitor MCA atmospheric conditions with application to wind forecasting for OW activities.

Work package nb	6	Lead beneficiary			BSC				
Work package title	**Communication, dissemination, exploitation and stakeholder engagement**								
Participant number	1	2	3	4	5	6	7	8	9	10
Short name	FEM	BSC	CNR	CRES	DHMZ	DTU	HZG	Ifremer	IRB	IZTECH
Person/months	10	30	2	2	2	2	2	1	1	2
Start month	1			**End month**	36				

Objectives

The main objective of this WP is to **maximise the project impacts on floating wind sector and particularly towards Mediterranean Coastal stakeholders**. It sets the framework for channelling and communicating information and results from other work packages towards targeted stakeholders that can be divided in three groups: offshore wind industry, other key stakeholders of the sector (e.g. publics funders, private investors, policy makers, regulators…) and academia. Exploitation will focus on new services and systems based on project results with potential for specific stakeholders involved in the offshore wind industry.

Specific objectives of this WP are:

- To set up and maintain effective online communication channels for transparent information and proactive visibility of the project;
- To ensure an efficient dissemination of project results targeting main stakeholders of MCA OW sector;
- To raise awareness and improve OW technology consenting among the general public;
- To foster the exploitation of SHOWMED results in accordance with Intellectual Property Rights;
- To contribute, upon invitation by the EC, to common information and dissemination activities to increase the visibility and synergies between H2020 supported actions;
- To monitor dissemination, communication and exploitation activities and to assess their effectiveness and impact.

Description of work

6.1 Planning of the communication and dissemination of the results for stakeholder engagement (M1-M36) - Lead: BSC; Participants: FEM

A Communication, Dissemination and Engagement Plan (CDEP) (D6.1, M6, BSC) will be developed at the beginning of the project to maximise the engagement of the stakeholders in MCA. This plan will be defined in accordance with the overall project management. It will evolve on the basis of the monitoring of Key Performance Indicators for the assessment of activities related to communication and dissemination of results. This monitoring will be carried out to ensure any required adjustment in the strategy (see Section 2.2). An intermediate report on communication, dissemination and engagement activities (D6.5, M18, BSC) will be delivered by mid-project so that by the time of the 2nd General Assembly in M24, corrective measures can be suggested for the last year of the project if needed.

A final report regarding the follow up and analysis of potential impacts of the communication, dissemination and engagement activities (D6.7, M36, BSC) will be presented at the end of the project.

6.2 - Communication about the project (M1-M36) - Lead: FEM. Participants: all

Communication activities will be carried out according to the Communication, Dissemination and Engagement Plan (CDEP) (D6.1, M6, BSC). Traditional and multimedia communication channels will be used to explain the original approach of the project and how its results will be translated into everyday life. The first channel to be set up will be the SHOWMED **dedicated website** (D6.2, M3, FEM), developed with the support of external services. In addition, a **communication kit** will be prepared including the project's visual identity, a leaflet, slideshows and a poster (D6.3, M6, FEM).

Besides the website that will be the main platform to share project results, an important part of the online communication activities will consist in posting **targeted contents on social media** (Twitter, LinkedIn and ResearchGate). Contents for these platforms will be prepared with strong support from all partners. SHOWMED's social media strategy for posting will leverage the activity and accounts of all partners while ensuring that they tag properly the handle of the project.

Several **press releases** will also be prepared in close collaboration with scientists from the consortium and disseminated in each MCA to national and regional generalist and specialised media using partners' press contacts. A **biannual electronic newsletter** (developed by FEM) targeting stakeholders outside the project will be published to summarize main advances.

All partners will also promote the project through **participation in on-going outreach initiatives** such as European Researchers' Night, Science Week, International Day of Women and Girls in Science or Summer Schools for teachers or journalists.

6.3 Stakeholder engagement and dissemination of project results (M6-M36) - Lead: BSC. Participants: all

Stakeholders engagement and dissemination of project results will target stakeholders from three main relevant communities: industry, government/policy and academia. To ensure a wide dissemination of the project results, several activities are already planned (see section 2.2 for more details) and will be carried out with the support of all partners in the consortium.

Project results in terms of data, software updates, and issued forecasts will be **included to data repositories** and made available to all target audiences. Whenever possible **publications in high-impact peer-reviewed journals** (e.g. Journal of Geophysical Research, Wind Energy, Renewable Energy, etc.) will be made available in open access. Project results will be presented in **international conferences, meetings and seminars**, such as Floating Offshore Wind Turbines (FOWT), International Offshore Wind Technical Conference, and WindEurope Offshore Conference, through talks and posters. Attendance to **industrial events and fairs**, such as WindEurope Offshore Exhibition, Offshore & Floating Wind Europe, All-Energy, and Offshore Energy, will be seek, having stands or visibility when relevant. **Events addressed to the policy community**, such as the European Sustainable Energy Week (EUSEW) or the Union for the Mediterranean annual Energy Platforms policy dialogue, will be targeted.

Two **webinars** will be organized (BSC, support from all partners) about topics of relevance for the project. A (one- or half-day) **virtual workshop** (BSC and FEM, support from all partners) about one scientific topic of relevance for the project will be organized.

Five regional workshops will be organized in different MCA countries around the Mediterranean: 1 in the Région Occitanie, France, close to pilot offshore wind farms (FEM with a Spanish stakeholder), 1 in Turkey (IZTECH), 1 in Greece (CRES), 1 in Croatia (DHMZ) and 1 in Italy (CNR). Workshops will target a large group of stakeholders from the project target audiences, and will be directed to better inform FOW potential and market value around MCA. At the end of the project, a **final stakeholder event** will be organized (M36, FEM) to present the main results of the project to potential users and the project Advisory Board, and to highlight their possible applications.

Written materials will be developed, including **case study narratives** shared as factsheets for industrial stakeholders (D6.6, M30, BSC, support from all partners), and a **policy brief** for policy and decision makers towards the end of the project (BSC).

Visual resources will also be prepared to support dissemination, including **infographics and figures** to support dissemination of key scientific papers or other dissemination material (BSC with design support of an external service).

SHOWMED aims to foster synergies with other projects and initiatives in the field (such as FEM's CARAVELE collaborative project) and will seek for opportunities to carry out joint or co-hosted activities to maximise the relevance and reach of dissemination activities.

6.4 Exploitation of the project results (M6-M36) - Lead: FEM; Participants: all
To ensure that SHOWMED impacts are maximized, the sustainability of the project outcomes must be secured. Expected exploitation will rely on the nature and robustness of the project results. SHOWMED is expected to deliver a system for short term weather forecasting that could have the potential to rapidly enter the market, although it will need further testing after the end of the project. Terms and conditions for its future exploitation will be evaluated. Other exploitable results could be related to the service activity relying on the modelling tools and databases produced. The exploitation and business plan basics are described in section 2.2. The objective of this task is to refine the latter based on results achieved in the project together with a better understanding of potential users' needs. The first version of the exploitation plan (D6.4, M18, FEM) will be based on a deep analysis of the exploitable results and include a first evaluation of potential markets. The final version will be delivered by project end (D6.8, M36, FEM).

Deliverables (brief description and month of delivery)
D6.1 Communication, Dissemination and Engagement Plan (CDEP) (M6, BSC). The plan will include targeted activities for communication and dissemination including KPIs to be monitored.
D6.2 SHOWMED website (M3, FEM). Online website used as communication channel for project presentation, structure and results.
D6.3 Communication kit (M6, FEM). Set of communication tools in line with the project visual identity, (leaflet, slideshows, poster, pull-up banner).
D6.4 Initial exploitation plan (M18, FEM). The plan will include the list of exploitable results targeted, how they can serve to develop a service activity and route to market.
D6.5 Intermediate report on communication, dissemination and engagement activities (M18, BSC). Mid-project_analysis of the effectiveness of the dissemination and communication activities and explanation of corrective actions, if any deviation.
D6.6 Case studies factsheets (M30, BSC). Explanation of main project results in the form of synthetic and illustrated factsheets.
D6.7 Final report on communication, dissemination and engagement activities (M36, BSC). Final analysis of the effectiveness and impact of the dissemination and communication activities.
D6.8 Final exploitation plan (M36, FEM). The final version of the exploitation plan will include market estimates.

3.1.4 List of deliverables

Del. No.	Deliverable name	WP No.	Lead partner	Type[8]	Diss. level[9]	Delivery date
D1.1	Project Management Plan – initial version	1	FEM	R	CO	M3
D1.2	Quality Assurance Plan – initial version	1	FEM	R	CO	M3
D1.3	Risk register	1	FEM	OTHER	CO	M3
D1.4	Data Management Plan - initial version	1	FEM	R	CO	M6
D1.5	Project Management Plan – final version	1	FEM	R	CO	M18
D1.6	Quality Assurance Plan – final version	1	FEM	R	CO	M18
D1.7	Interim report	1	FEM	R	CO	M18
D1.8	Data Management Plan - final version	1	FEM	R	CO	M36

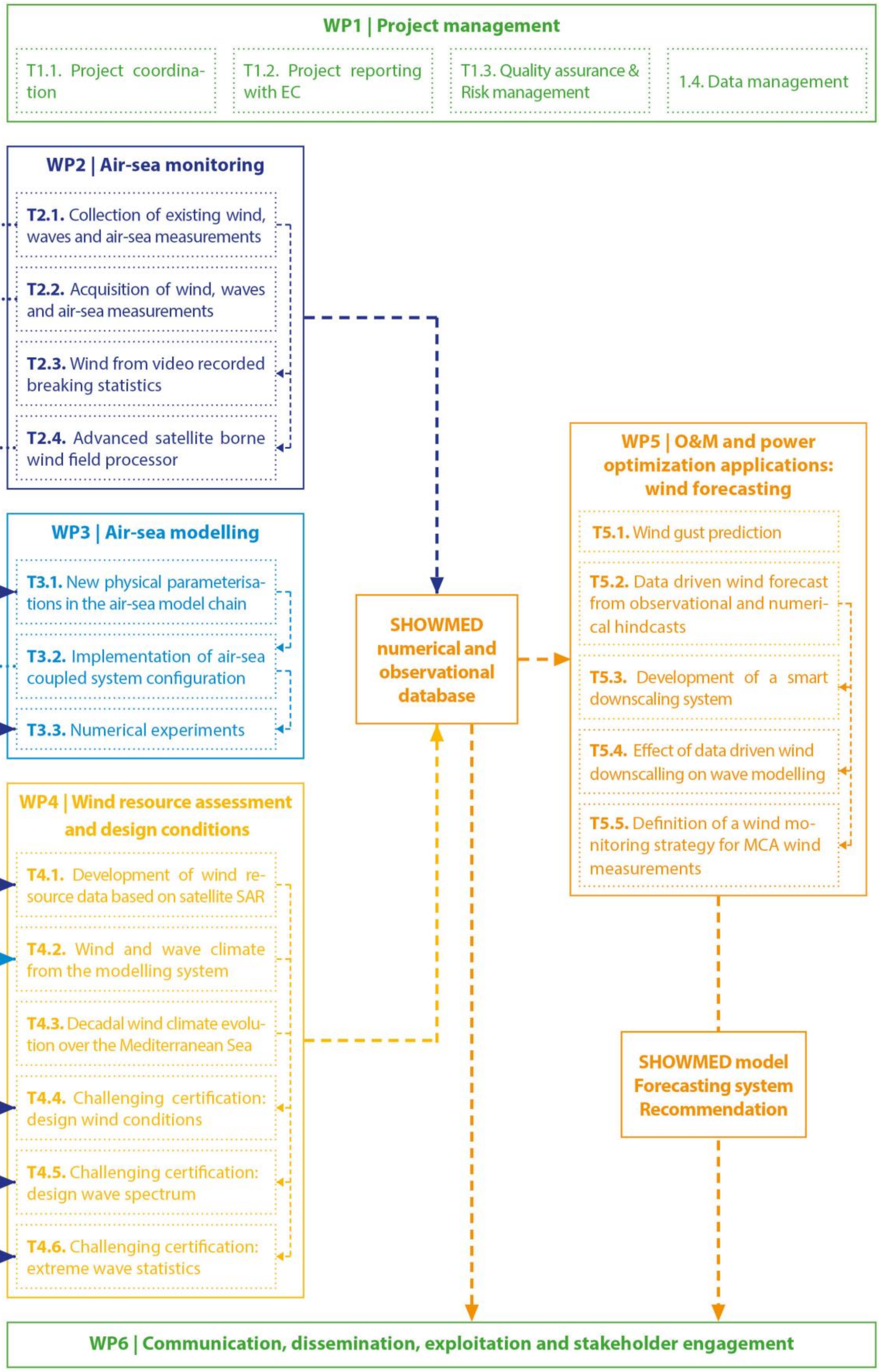
[8] Keys: R = Report, DEM = Demonstrator, DEC = Websites, OTHER = Software/data
[9] Keys: PU = Public, CO = Confidential

Del. No.	Deliverable name	WP No.	Lead partner	Type[8]	Diss. level[9]	Delivery date
D1.9	Final report	1	FEM	R	CO	M36
D2.1	Database (and report) on the existing wind, waves and air-sea measurements	2	FEM	R OTHER	PU	M6
D2.2	Preliminary Gulf of Lion dataset for model validation	2	HZG	OTHER	PU	M12
D2.3	Report on the Experiments in the French Mediterranean, Italian Adriatic Sea, Turkish site	2	HZG	R	PU	M18
D2.4	Video-based wind retrieval algorithm and report	2	FEM	R OTHER	PU	M18
D2.5	Report on satellite wind analysis in MCA situations	2	Ifremer	R	PU	M27
D2.6	Advanced SAR prototype wind processor	2	Ifremer	OTHER	PU	M27
D2.7	Data publication of the Gulf of Lion Experiment	2	HZG	OTHER	PU	M18
D3.1	Report on the new air-sea flux parameterization scheme with effect of wave breaking	3	HZG	R	PU	M6
D3.2	Report on the definition of the SHOWMED air-sea coupled system configuration	3	DTU	R	PU	M12
D3.3	Summary of reports on numerical experiments for special Mediterranean weathers	3	DHMZ	R	PU	M15
D4.1 a	Wind climate at 10 m from combined SAR wind data set	4	DTU	OTHER	PU	M20
D4.2	Wind climate at 10 m from combined SAR wind data set	4	DTU	OTHER	PU	M36
D4.3	Wind wave 25 year hindcast produced by SHOWMED model chain	4	FEM	OTHER	PU	M21
D4.4	Report describing the expected decadal evolution of the wind climate over the MCA, over the wind farm lifetime duration	4	BSC	R	PU	M30
D4.5	Guidelines report for implementation in FOWT standards documents of MCA-specific wind gust and wind turbulence models	4	IZTECH	R	PU	M30
D4.6	Guidelines report for implementation in FOWT standards documents of MCA-specific wave energy spectrum shape	4	FEM	R	PU	M30
D4.7	Guidelines report for implementation in FOWT standards documents of MCA and FOWT-specific rogue wave statistics	4	CNR	R	PU	M30
D5.1	A wind gust prediction methodology, based on X-band radar measurements	5	HZG	R	PU	M24

Del. No.	Deliverable name	WP No.	Lead partner	Type[8]	Diss. level[9]	Delivery date
D5.2	A data driven forecasting algorithm	5	Ifremer	OTHER	PU	M36
D5.3	A smart box including local real time atmospheric information	5	CRES	OTHER	PU	M33
D5.4	A report detailing the impact of data driven downscaled wind on the wave modelling	5	FEM	R	PU	M36
D5.5	Guideline report for observational strategy	5	FEM	R	PU	M36
D6.1	Communication, Dissemination and Engagement Plan (CDEP)	6	BSC	R	PU	M6
D6.2	SHOWMED website	6	FEM	DEC	PU	M3
D6.3	Communication kit	6	FEM	R	PU	M6
D6.4	Plan for Exploitation of Result	6	FEM	R	CO	M18
D6.5	Intermediate report on communication, dissemination and engagement activities	6	BSC	R	PU	M18
D6.6	Case studies factsheet	6	BSC	R	PU	M30
D6.7	Final report on communication, dissemination and engagement activities	6	BSC	R	PU	M36
D6.8	Final exploitation plan	6	FEM	R	CO	M36

Table 3.2: list of Deliverables

3.1.5 Graphical presentation of the project



3.2 Management structure, milestones and procedures

3.2.1 Organisational structure and decision making

Project Management deals with the governance structure, the role and responsibilities of the various actors and the contract with the EC. It includes the overall management, communication and coordination between the different partners, as well as the monitoring of the scientific and technical progress of the entire project, by means of the supervision of the achieved milestones, the management of the risks and establishment of contingency plans, gender equality, and other non-technical aspects. It also provides outputs for knowledge management and other RDI related activities, such as Intellectual Property Rights and dissemination, solving problems as they may arise. Besides, it promotes networking with other related projects, networks, and other initiatives. A specific Project Management Work Package (WP1) is included in the work plan.

The practical managerial framework, organizational structure and decision-making mechanisms, have been tailored to the size and complexity of the project. The general management structure is shown in figure 3.2.

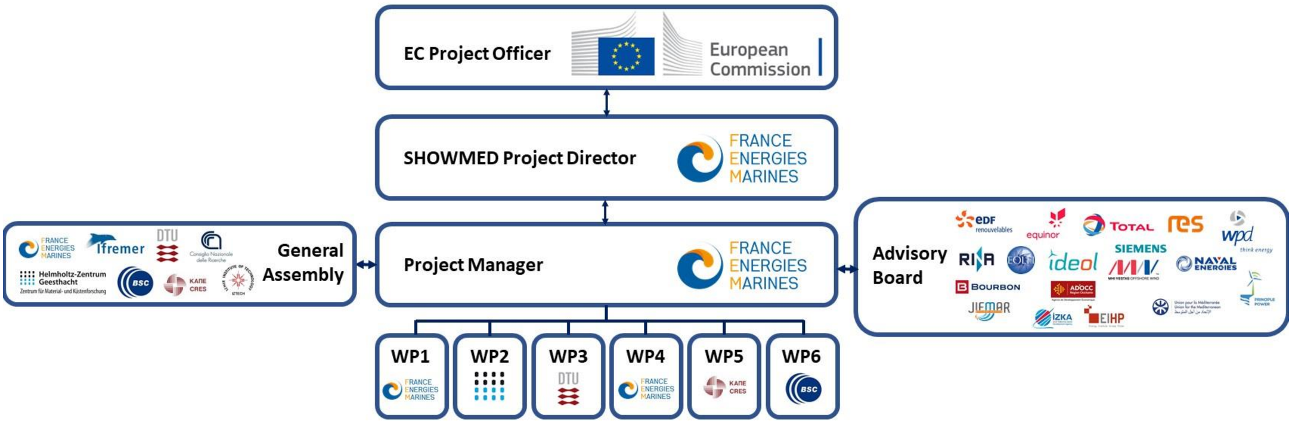


Figure 3.2: SHOWMED's general management structure.

The **Project Director** will lead the project and have overall supervision of its delivery. The Project Director will chair the General Assembly and act as the liaison to the EC Project Officer. It is the experience of the team and the project stakeholders that on a project of this scale, identifying a clear project lead provides clarity to the project team and external parties on the overall responsibility for the project's impact. Dr Jean François Filipot, Scientific Director at FEM, will be the Project Director.

The **Project Manager** will be responsible for the day-to-day coordination of the WPs via liaison with the WP Leads. The Project Manager will take care of monitoring the quality of deliverables, planning of tasks and following up on budget and risks using a suite of conventional management tools. The Project Manager will also report on project progress to the General Assembly and prepare the documentation they review at meeting. Where necessary, the Project Manager will feed back the outcomes of the General Assemblies to the WP Leads. The scale of this project requires a Project Manager with significant experience in delivering complex projects with a range of project partner types. Dr Fabien Leckler from FEM will fulfil this role and use his wealth of experience in contributing to complex collaborative projects.

The purpose of the **General Assembly** is to take strategic and high-value decisions in relation to the project. Members are responsible for monitoring progress of the project, checking the quality of the project outputs and reviewing the project risk register. The General Assembly is formed by senior members from each of the consortium organisations, such as Directors and Senior Managers. All General Assembly members will be responsible for the realisation of the technical activities of their team according to the work plan and timing established. They will also be responsible for requested activity periodic reports and cost breakdowns as scheduled, as well as solving the individual administrative issues. The General Assembly will meet regularly throughout the project to discuss and make decisions in relation to the project delivery. These meeting will be held on a six months period basis. The **General Assembly** will be governed by the General Assembly Terms of Reference within the Consortium Agreement, to which each organisation will be a signatory. The Terms of

Reference will fully set out the responsibilities of the General Assembly and the framework for decision-making, including threshold requirements for decisions making and voting rights.

WP Leads will be selected by their organisations based on their experience in working collaboratively in similarly complex project teams and their ability to deliver projects of scale. Their purpose will be to manage the day-to-day delivery of their WPs, ensuring the timely fulfilment of duties from the scientific and technical point of view, and to act as the point of communication for the Project Manager and the General Assembly. They will provide regular updates on the status of their WPs to the Project Manager, highlighting any potential issues (such as changes affecting the WP programme or budget) and successes. WP Leads assure the co-ordination between the different project teams that collaborate within the WP with the aim of exchanging intermediate results. They are also responsible for the consolidation of the reports and execution of the tasks within each WP.

The project will also be supported by an **Advisory Board** made up from 18 members from five groups of stakeholders directly interested by project outputs:

- ***Floating Offshore Wind farms developers and certification bodies***, who have a particular interest in methodologies, databases and systems developed throughout the project to better qualify the LCOE of future wind farms in Mediterranee. This group is represented by **EDF Renouvelables, Equinor, TOTAL, RES, WPD, EOLFI** and **RINA** who have experience and interest with floating offshore wind.
- ***Technologies developers*** and particularly turbines and floaters developers who will advise on the findings regarding the impact of the specific Mediterranean conditions on the turbine output and behaviour of the floating platform. This group is represented by world leader turbine suppliers (**Siemens Gamesa Renewable Energy and MHI Vestas**) as well as world leader experienced floating wind platforms developers (**Principle Power Inc., Ideol and Naval Energies**).
- ***Operation and Maintenance*** companies who can advise on the development of short-term prediction system. This group is represented by **Bourbon and Jifmar**.
- ***Regional/National authorities*** having a particular interest in databases and modelling results in order to support strategical decisions. This group is represented by **Occitanie Region development agency (Add'occ), Izmir Development Agency (IZKA) and Energy Institute Hrvoje Pozar (EIHP).**
- **Intergovernmental Organizations** bringing the perspective of the Mediterranean counties and fostering dialogue among stakeholders. This group is represented by **Union for the Mediterranean (UfM).**

The Advisory Board will give strategic advices to the General Assembly, Project Coordinator and WP leaders regarding: requirements, methodology, standardization, adequacy of the project outputs to the sector need for further exploitation and policy perspective at the Mediterranean level. The Advisory Board will meet remotely just after the KOM for a more detailed presentation of the project with the target to get advices on the methodology to be deployed. It is then planned to meet, within the same format after one year and two years of project, in order to present to the Advisory Board the project status and issues to get their advice.

Moreover, the Advisory Board will be invited to join the closure dissemination and knowledge sharing workshop at Month 36 in order to share the international experience and link the SHOWMED outputs with their developments and strategical decisions.

3.2.2 Innovation management

The process for managing innovation across the project's lifecycle is delivered through the organisational structure detailed above. The General Assembly members have been selected as experienced participants who understand both the markets and the technical issues and can identify new opportunities that may arise through the project. The regular meeting schedules defined for the General Assembly will allow time for these teams to discuss creative and visionary products, services or processes that can be spun out of this project and exploited for the benefit of the project team and wider industry. This process will be managed as a separate item in the meeting agendas and the products, services and processes that are identified for development will be taken through under the umbrella of the exploitation plan. Technology Readiness Level will also be estimated along with the exploitation plan for each product and model delivered throughout the project.

3.2.3 Quality Assurance and Risk Management

In accordance with the Consortium Agreement provisions for decision making, the **Quality Assurance Plan** will set the procedures, flows and rules for decision making, as well as for risk management, internal reporting and monitoring and reporting to the EC. In particular, following Quality Assurance aspects will be addressed to guarantee a timely accomplishment of the tasks:

- **Organisation**: Clear definition, agreement and update of roles and responsibilities
- **Planning**: Preparation of achievable and agreed statement of what the project is to produce, when and how it is to be produced, assigned to the different WPs and partners
- **Controls**: Regular review of the status and update of the work plan
- **Quality reviews**: Project deliverables will be reviewed according to the predefined procedures and criteria to ensure a standard high quality before delivery

Project Risks Register

The risks associated with this project have been carefully considered and assessed. Specifically, those which potentially involve risks of harm to the environment and to the health and safety of personnel. As Project Coordinator, these risks will be managed by FEM. All project team members will be actively encouraged to identify risks and suggest suitable mitigation through their WP Leads. The Project Manager will classify the risk with guidance from the General Assembly and seek out and manage the successful mitigation.

The Risk Register is a core document that will remain live across the project and is the heart of the project and will be reviewed at every General Assembly meeting. All new risks will be reviewed, and mitigations assessed to ensure that the risk is appropriately managed. An assessment of the critical risks identified for this project is provided in Table 3.3.

The criticality of the risk is estimated based on its probability to happen and impact on the project in case the risk is transformed into reality.

Green indicates that the project is on track. The identified risks are not expected to impact the other project results or overall outcomes.

Yellow indicates that some course correction may be required. One or more identified risks may impact the other project results or overall outcomes and some course correction may be required.

Risk criticity (C)		Probabiliy (P)		
		Low	Medium	High
Impact (I)	High	3	6	9
	Medium	2	4	6
	Low	1	2	3

Red indicates that significant course correction may be required. One or more identified risks may impact the other project results or overall outcomes and significant course correction may be required.

#	Description of risk	Risk level			WP	Proposed risk-mitigation measures
		P	I	C		
1	Losing critical staff or partners at a crucial point of the project	M	L	2	1	Identify critical overreliance and mitigate with collaborative approach within consortium. Use consortium network to identify alternatives.
2	Unexpected delay delivering project deliverables	M	M	4	1	Ensure rapid communication of delays within consortium and agree on support from partner with adequate resources.
3	WPs resources not well balanced	L	M	2	1	Monitoring of the work (quarterly reports and project meetings) and reallocation of resources in other WPs where necessary by the PSC

#	Description of risk	Risk level			WP	Proposed risk-mitigation measures
		P	I	C		
4	lidar operation failure in the Gulf-Lion experiment.	M	M	4	2	CRES has been warned by its lidar manufacturer (Leosphere) that the 1st generation lidars use some components that are not manufactured anymore. If such a failure occurs, CRES will adjust its budget accordingly (using personnel, equipment and other costs), so that a replacement unit (rental or new) is used and the measurement campaign is not put in danger.
5	Wind retrieval from wave breaking technique fails	H	L	3	2	Optical images will still be exploitable since (wind retrieval algorithms already exist) but with a lower level of accuracy.
6	Delay in implementation of the new physical parameterizations to be implemented in the model chain.	H	M	6	3	Part of the work will be based on existing air-sea measurements done with PIV at sea from the flip platform. This will be available from the beginning of the project. A specific and careful protocol will be followed so as to obtain samples of observations along the experiments.
7	The SAR and numerical databases are not ready on time for the development of the data driven downscaling approaches.	H	M	6	5	A preliminary SAR dataset will be delivered at M20. And use with the NEWA wind resource to start the development of the data driven forecasting systems.
8	Political, economic, social, technological, legal and environmental barriers to realise a sustainable impact	L	M	2	6	Invite all type of stakeholders to workshops and discuss with them sustainable impact strategies
9	Risk of a low impact of the outcomes of the project on the user community due to insufficient engagement or saliency that may result in a limited use	L	M	2	6	Work more actively in reaching out to potential users and ask engaged stakeholders to 'spread the word' (snowball effect). Ask the Advisory board for additional relevant events where the project outcomes can be showcased. Work in the production of dissemination material that clearly explains the advantages of the new results to encourage new users to try it.
10	Risk of a stakeholder engaged in the project activities claiming that their personal data have not been handled correctly	L	L	1	6	The Data Management Plan will have a section describing the procedures for personal data management in accordance with GDPR; registration to events and activities organised by the project will request explicit consent for personal data management including images or video. A privacy policy page available in the project website will provide clear instructions for consent withdrawal.

Table 3.3: Critical risks for implementation

3.2.4 List of milestones

Milestone number	Milestone name	WP	Due date	Means of verification
M1	Dataset of existing in situ observation database	2	M6	A dataset with a formatted and well organized data (D2.1)
M2	Preliminary Gulf of Lion dataset for model validation	2	M12	A preliminary dataset with a formatted and well organized data (D2.2)
M3	SHOWMED model chain with new air-sea flux parameterizations	3	M12	Model chain with source codes involving the development plan in T3.1. (D3.2).
M4	Wave retrieval from wave breaking statistics algorithm	2	M18	Clean and operational algorithm computing surface wind speed from spectral breaking statistics (D2.3)
M5	Observations from SHOWMED in situ experiment	2	M18	Publication of a formatted and well organized dataset (D2.7)
M6	Wind resource at 100 m based on SAR satellite data	4	M20	Preliminary SAR dataset to feed WP5 (D4.1).
M7	Wind wave database from SHOWMED model chain	4	M21	Numerical database with a formatted and well organize dataset (D4.3)
M8	Smart data logger for weather forecast data driven downscaling	5	M30	Validation of the system produced in WP5 (D5.4)

Table 3.4: SHOWMED milestones

3.3 Consortium as a whole

The challenges and opportunities of this project require a team with complementary abilities and areas of expertise and a shared ambition to develop floating offshore wind in Mediterranean Coastal Area. This team has to work together to match the project's objectives and bring the depth of expertise required to deliver core impacts targeted in this call. **The SHOWMEDs consortium is uniquely placed to achieve the project's objectives and to ensure a high impact according to the expectations of this call, in particular for supporting the development of floating offshore wind in Mediterranean coastal area at affordable cost**. A core feature of the consortium is that it contains the key partners from 6 Mediterranean countries together with partners from 2 countries leading the development of OW in Europe.

Main criteria for the selection of the consortium have been:

- **Expertise and complementarities** in the technical fields to fulfil project S&T objectives. The SHOWMED project includes a multidisciplinary consortium covering all the technical aspects required.
- **Geographical distribution**. Partners represent main Mediterranean Countries targeting to deploy Offshore floating wind and facing similar issues for being able to take strategic decisions. The project has a clear European dimension that will allow an easier pooling of competencies and a wider and faster impact achievement and results dissemination.

Experience in European projects and participation/coordination of relevant EU projects. All of the partners have experience in R&D collaborative projects most of them at European level.

Table 3.5 outlines the consortium members' main role and contribution to the project objectives. Further details on partners' expertise can be found in section 4.

Partner/Type	Main Role	Expertise/ Contribution
FEM (SME)	Project coordinator. WP1 & WP4 leader.	Project leader. Experience in collaborative R&D project management, extensive observation and modelling on coastal metocean conditions.
BSC (RTD)	Leader of WP6 and TP4.2	Expertise in modelling climate change impact on wind resource and experience in leading dissemination and communication of European projects.
CNR	Participation in WP3, 4 and 5	Expertise in wave observations and ocean-atmosphere coupled simulations.
CRES	WP5 leader Participation in WP2, 3 and 5	Academic partner of the Floatmast project. Expertise in wind measurement with lidars.
DHMZ	Participation in WP3	Experience in deploying operational weather forecasting models and very high-resolution models for the study of bora winds.
DTU	WP3 leader: modelling. Participation to WP4 on satellite remote sensing.	Expertise in offshore wind resources from satellite and other measurements. Expertise in wind-wave coupled modeling for resource and design parameters, as well as atmospheric turbulence modeling.
HZG	WP2 leader. Participation in all WPs	Expert in X-band radar measurements to retrieve, wind, waves and current properties.
Ifremer	Participation in WP2, WP3 & WP5	Expertise in SAR image analysis for wind retrieval, air-sea coupling and data driven weather forecasting.
IRB	Participation in WP3	Numerical expertise on wind-wave coupling and high-resolution wind wave modelling.
IZTECH	Participation in WP2, WP4 and WP6: data and analysis & workshop	Expertise and experience in the field of wind energy research and application.

Table 3.5: SHOWMED's partners role and expertise

3.4 Resources to be committed

Summary of staff effort

SHOWMED partners will allocate the necessary person/months (PM) as detailed in the tables of the work packages, in order to ensure the smooth progress of the tasks planned and the successful achievement of the project objectives. A summary is given in table 3.4a.

	WP1	WP2	WP3	WP4	WP5	WP6	Total PM
1/ **FEM**	**18**	13	18	**15**	18	10	**92**
2/ BSC	2		3	35		**30**	**70**
3/CNR	2	3	18	16.3	6	2	**47.3**
4/ CRES	2	16	6	8	**15**	2	**49**
5/ DHMZ	2		20	12		2	**36**
6/ DTU	2		**17.7**	27.6		2	**49.3**
7/ HZG	2	**49**			10	2	**63**

	WP1	WP2	WP3	WP4	WP5	WP6	Total PM
8/ Ifremer	2	10	2		10	1	**25**
9/ IRB	2		26			1	**29**
10/ IZTECH	2	10	2	16		2	**32**
Total PM	**36**	**101**	**112.7**	**129.9**	**59**	**54**	**492.6**

Table 3.6: Staff effort

Other direct cost

FEM

Participant Nr	1	Cost (€)	Justification
Travel		67 000	Project meetings including GA meetings & meeting with EC Travels to Le Planier (5 times two persons for one week) & other experimental investigations Participation to conferences Advisory board travel costs
Equipment		63 000	Amortizing costs for 2 years utilisation of lidar, stereo-video system, Inertial measurement unit
Other goods and services		89 000	Third party audit costs Installation, operation and maintenance cost for lidar, stereo-video system and inertial measurement unit including contribution to Phares & Balise support Training sessions, Workshops, printing of brochures and leaflefts Organization of a local workshop in Occitanie Region
Total		**214 000**	

CRES

Participant Nr	4	Cost (€)	Justification
Travel		21 500	Project's plenary & WPs meetings, Lidar deployment & maintenance (2persons/4month), Conferences for dissemination. Assuming 1500€/travel.
Equipment		18 000	Electronic devices for DAQ systems & dedicated sensors for outdoor operation
Other goods and services		33 000	Lidar deployment, operation and maintenance costs. Subscription to weather forecast services. Data analysis software, Dissemination event costs.
Total		**72 500**	

DHMZ

Participant Nr	5	Cost (€)	Justification
Travel		15 700	Project meetings (6k), 3 persons to Wind Europe conference (4.5k), 3 persons to EMS conference (4.5k), 2 persons to HRO CIGRE (Croatian national energy conference)(0.7k)
Equipment			
Other goods and services		11 400	Conference fees Wind Europe conference 3 persons (4.5k), conference fees EMS 3 persons (1.5k), conference fees HRO CIGRE (0.6k), external USA-NCAR expert travel to DHMZ (2.5k), external expert USA-NCAR training/consultancy fee (2k), minor amterial costs (flyer) 300EUR
Total		**27 100**	

DTU

Participant Nr	6	Cost (€)	Justification
Travel		34 228	Travel cost for 1 person to two project meetings per year, Travel cost for 1 person to two project meetings per year, Travel cost 2 persons to one conference per year.
Equipment			
Other goods and services		17 853	Audit cost consumables Five open access publications JHU software license
Total		**52 081**	

HZG

Participant Nr	7	Cost (€)	Justification
Travel		24 000	Project meetings Setup and maintenance of measurement sites Conferences
Equipment			
Other goods and services		27 200	Organization of project meeting, publication costs, consumables in particular for the experimental sites
Total		**51 200**	

For BSC, CNR, Ifremer, IRB, IZTECH other direct costs are below 25 000 €. These costs are related to travels and other goods and services and do not exceed 15% of the personnel costs.

Subcontractings

FEM

Participant Nr	1	Cost (€)	Justification
Subcontracting 1		30 000	Some of the instrumentation will be operated on a ship of opportunity (SO) cruising routinely between Marseille and Tunis, Tunisia, capturing the ch0anging situation from land to open sea. This will be achieved through a 30k€ subcontracting with the Institut National des Sciences et Technologies de la Mer of Tunis.
Subcontracting 2		5 000	We plan to work with a web agency for the web site development based on our specification

IRB

Participant Nr	9	Cost (€)	Justification
Subcontracting 1		60 000	Subcontracting Roland & Partner, for creation of high resolution unstructured coastal grids and application of a WRF/WW3 modelling system for benchmarking the WRF/SWBLM/SWAN model develop in WP3.

Repartition of the cost per WP

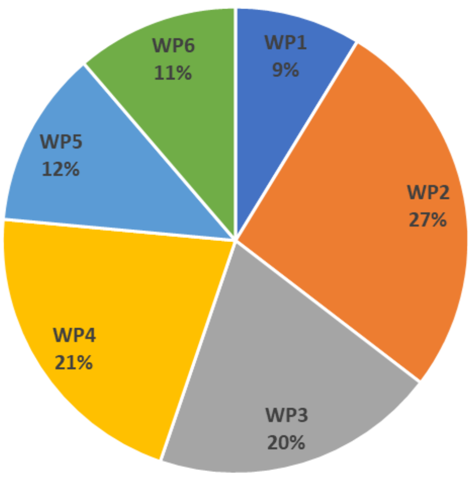


Figure 3.3: distribution of the cost per WP

Around 10 % of SHOWMED budget is dedicated to the project management, which seems reasonable for a 4M€ project with 10 European partners.

Scientific Work Packages (WP2 to WP5) account for 80% of the budget with a distribution that takes into account WP with experimental works and a WP that is more dedicated to integration.

Finally, an effort towards dissemination is reflected through the budget of WP6, enabling to promote the results to a large group of stakeholders and thus reach the impacts targeted through the call and through SHOWMED proposal

References :

Ardhuin, F., E. Rogers, A. V. Babanin, J.-F. Filipot, R. Magne, A. Roland, A. Van Der Westhuysen (2010). "Semiempirical dissipation source functions for ocean waves. Part I: Definition, calibration, and validation" *Journal of Physical Oceanography* 40, no. 9: 1917-1941.

Ayet, A., B. Chapron, J.-L. Redelsperger, G. Lapeyre, and L. Marié (2020). "On the Impact of Long Wind-Waves on Near-Surface Turbulence and Momentum Fluxes" *Boundary-Layer Meteorology* 174, no. 3: 465-491.

Badger, M., Peña, A., Hahmann, A. N., Mouche, A. A., & Hasager, C. B. (2016). Extrapolating satellite winds to turbine operating heights. *Journal of Applied Meteorology and Climatology*, *55*(4), 975-991.

Badger, M., Ahsbahs, T., Maule, P., & Karagali, I. (2019). Inter-calibration of SAR data series for offshore wind resource assessment. *Remote Sensing of Environment*, *232*, 111316.

Benetazzo, A., Barbariol, F., Bergamasco, F., Carniel, S., & Sclavo, M. (2017). Space-time extreme wind waves: Analysis and prediction of shape and height. *Ocean Modelling*, *113*, 201-216.

Boettcher, F., Renner, C. H., Waldl, H. P., & Peinke, J. (2003). On the statistics of wind gusts. *Boundary-Layer Meteorology*, *108*(1), 163-173.

Buckley, Marc P., and Fabrice Veron (2016). "Structure of the airflow above surface waves" *Journal of Physical Oceanography* 46, no. 5: 1377-1397.

Buckley, M. P., Savelyev, I., & Horstmann, J. (2018, June). Airflow Measurements Above Ocean Surface Waves Using PIV. In 23rd Symposium on Boundary Layers and Turbulence/21st Conference on Air-Sea Interaction. AMS.

Cheynet, E., Jakobsen, J. B., & Reuder, J. (2018). Velocity spectra and coherence estimates in the marine atmospheric boundary layer. *Boundary-layer meteorology*, *169*(3), 429-460.

Christiansen M.B., Koch, W., Horstmann, J., Hasager, C.B., & Nielsen, M (2006). “Wind Resource Assessment from C-band SAR: Optimising the Data Input” *Rem. Sens. Env.*, Vol. 105, pp.68-81, doi:10.1016/j.rse.2006.06.005

Done, James, Christopher A. Davis, and Morris Weisman (2004). "The next generation of NWP: Explicit forecasts of convection using the Weather Research and Forecasting (WRF) model" *Atmospheric Science Letters* 5, no. 6: 110-117.

DNV, G. (2016). DNV GL-ST-0437: Loads and Site Conditions for Wind Turbines. Standard, DNV GL, Høvik, November.

Du, J. (2017). Coupling atmospheric and ocean wave models for storm simulation, *Ph.D. thesis, Technical University of Denmark.*

Du, J., Bolaños, R., & Guo Larsén, X. (2017). The use of a wave boundary layer model in SWAN. *Journal of Geophysical Research: Oceans*, *122*(1), 42-62.

Du, J., Bolaños, R., Larsén, X. G., & Kelly, M. C. (2019). Wave boundary layer model in SWAN revisited. *Ocean Science*, *15*(2), 361-377.

Dankert, H., & Horstmann, J. (2007). A marine radar wind sensor. *Journal of Atmospheric and Oceanic Technology*, *24*(9), 1629-1642.

Echevin, V., M. Crepon, and L. Mortier (2003). "Interaction of a coastal current with a gulf: application to the shelf circulation of the Gulf of Lions in the Mediterranean Sea." *Journal of physical oceanography* 33, no. 1: 188-206.

Eliassen, L., & Obhrai, C. (2016). Coherence of turbulent wind under neutral wind conditions at FINO1. *Energy Procedia*, *94*(Supplement C), 388-398.

Filipot, J. F., & Ardhuin, F. (2012). A unified spectral parameterization for wave breaking: From the deep ocean to the surf zone. *Journal of Geophysical Research: Oceans*, *117*(C11).

Filipot, J. F., Ardhuin, F., & Babanin, A. V. (2010). A unified deep‐ to‐ shallow water wave‐ breaking probability parameterization. *Journal of Geophysical Research: Oceans*, *115*(C4).

Filipot, J. F., Guimaraes, P., Leckler, F., Hortsmann, J., Carrasco, R., Leroy, E.,... & Roeber, V. (2019). La Jument lighthouse: a real-scale laboratory for the study of giant waves and their loading on marine structures. *Philosophical Transactions of the Royal Society A*, *377*(2155), 20190008.

Flamant, C. (2003). Alpine lee cyclogenesis influence on air‐ sea heat exchanges and marine atmospheric boundary layer thermodynamics over the western Mediterranean during a Tramontane/Mistral event. *Journal of Geophysical Research: Oceans*, *108*(C2).

Guenard, V., Drobinski, P., Caccia, J. L., Campistron, B., & Bench, B. (2005). An observational study of the mesoscale mistral dynamics. *Boundary-layer meteorology*, *115*(2), 263-288.

Goodfellow, I., Pouget-Abadie, J., Mirza, M., Xu, B., Warde-Farley, D., Ozair, S.,... & Bengio, Y. (2014). Generative adversarial nets. In *Advances in neural information processing systems* (pp. 2672-2680).

Guimaraes, P. V., Ardhuin, F., Bergamasco, F., Leckler, F., Filipot, J-F., Yoo, J. & Benetazzo, A. (2020). A Data Set of Sea Surface Stereo Images to Resolve Space-Time Wave Fields, *Accepted in Nature Dataset*. https://doi.org/10.12770/AF599F42-2770-4D6D-8209-13F40E2C292F

Hasager, C. B., D. Stein, M. Courtney, A. Peña, T. Mikkelsen, M. Stickland, and A. Oldroyd (2013). "Hub height ocean winds over the North Sea observed by the NORSEWInD lidar array: measuring techniques, quality control and data management." *Remote Sensing* 5, no. 9: 4280-4303.

Hasager, C. B., Hahmann, A. N., Ahsbahs, T. T., Karagali, I., Sile, T., Badger, M., & Mann, J. (2020). Europe's offshore winds assessed with synthetic aperture radar, ASCAT and WRF. Wind Energy Science, 5(1), 375-390.

Hasselmann, K., Barnett, T. P., Bouws, E., Carlson, H., Cartwright, D. E., Enke, K.,... & Meerburg, A. (1973). Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP). *Ergänzungsheft 8-12*.

He, L., Fablet, R., Chapron, B., & Tournadre, J. (2015). Learning-based emulation of sea surface wind fields from numerical model outputs and SAR data. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *8*(10), 4742-4750.

Horvath, K., Bajić, A., & Ivatek-Šahdan, S. (2011). Dynamical downscaling of wind speed in complex terrain prone to bora-type flows. *Journal of applied meteorology and climatology*, *50*(8), 1676-1691.

Janssen, P. AEM, B. Hansen, and J.-R. Bidlot (1997). "Verification of the ECMWF wave forecasting system against buoy and altimeter data" *Weather and forecasting* 12, no. 4: 763-784.

Kukulka, T., Hara, T., & Belcher, S. E. (2007). A model of the air–sea momentum flux and breaking-wave distribution for strongly forced wind waves. *Journal of physical oceanography*, *37*(7), 1811-1828.

Kudryavtsev, V., Chapron, B., & Makin, V. (2014). Impact of wind waves on the air- sea fluxes: A coupled model. *Journal of Geophysical Research: Oceans*, *119*(2), 1217-1236.

Larsén, X. G., J. Du, R. Bolaños, and S. Larsen (2017). "On the impact of wind on the development of wave field during storm Britta" *Ocean Dynamics* 67, no. 11: 1407-1427.

Larsén, X. G., Du, J., Bolaños, R., Imberger, M., Kelly, M. C., Badger, M., & Larsen, S. (2019). Estimation of offshore extreme wind from wind- wave coupled modeling. *Wind Energy*, *22*(8), 1043-1057.

Leckler, F., Ardhuin, F., Filipot, J. F., & Mironov, A. (2013). Dissipation source terms and whitecap statistics. Ocean Modelling, 70, 62-74.

Leckler, F., Ardhuin, F., Peureux, C., Benetazzo, A., Bergamasco, F., & Dulov, V. (2015). Analysis and interpretation of frequency–wavenumber spectra of young wind waves. Journal of Physical Oceanography, 45(10), 2484-2496.

Lguensat, R., P. Tandeo, P. Ailliot, M. Pulido, and R. Fablet (2017). "The analog data assimilation." *Monthly Weather Review* 145, no. 10: 4093-4107.

Lorenz, E. N. (1956) "Empirical orthogonal functions and statistical weather prediction." Scientific report, Massuchetts Institute of Technology, Department of Meteorology.

Lorenz, E. N. (1977) "An experiment in nonlinear statistical weather forecasting" *Monthly Weather Review* 105, no. 5: 590-602.

Millot, C. (1979). Wind induced upwellings in the Gulf of Lions. *Oceanologica Acta*, *2*(3), 261-274.
no. 5 (1977): 590-602.

Maples, B, Saur, G., Hand, M., Van Pieterman, R., Obdam, (2013) "Installation, Operation, and Maintenance Strategies to Reduce the Cost of Offshore Wind Energy" National Renewable Energy Lab.(NREL), Technical Report, July 2013.

Monzikova, A. K., V. N. Kudryavtsev, A. G. Myasoedov, B. Chapron, and S. S. Zilitinkevich (2017). "Features of wind field over the sea surface in the coastal area." *Izvestiya, Atmospheric and Oceanic Physics* 53, no. 1: 76-83.

Mora, E. B., Spelling, J., van der Weijde, A. H., & Pavageau, E. M. (2019). The effects of mean wind speed uncertainty on project finance debt sizing for offshore wind farms. *Applied Energy*, *252*, 113419.

Olsen, B. T. (2018). Mesoscale to microscale coupling for determining site conditions in complex terrain.

Phillips, O. M. (1985). Spectral and statistical properties of the equilibrium range in wind-generated gravity waves. *Journal of Fluid Mechanics*, *156*, 505-531.

Pierson Jr, W. J., & Moskowitz, L. (1964). A proposed spectral form for fully developed wind seas based on the similarity theory of SA Kitaigorodskii. *Journal of geophysical research*, *69*(24), 5181-5190.

Reul, N., H. Branger, and J-P. Giovanangeli (1999). "Air flow separation over unsteady breaking waves." *Physics of Fluids* 11, no. 7: 1959-1961.

Sathe, A., & Bierbooms, W. (2007). Influence of different wind profiles due to varying atmospheric stability on the fatigue life of wind turbines. In Journal of Physics: Conference Series (Vol. 75, No. 1, p. 012056). IOP Publishing.

Smith, D. M., Eade, R., Scaife, A. A., Caron, L. P., Danabasoglu, G., DelSole, T. M., ... & Kharin, V. (2019). Robust skill of decadal climate predictions. *npj Climate and Atmospheric Science*, *2*(1), 1-10.

Solaraju-Murali, B., Caron, L. P., Gonzalez-Reviriego, N., & Doblas-Reyes, F. J. (2019). Multi-year prediction of European summer drought conditions for the agricultural sector. *Environmental Research Letters*, *14*(12), 124014.

Vicen-Bueno, R., Horstmann, J., Terril, E., Paolo, T. de, & Dannenberg, J. (2013): Real-Time Ocean Wind Vector Retrieval from Marine Radar Image Sequences Acquired at Grazing Angle. J. Atmos. Oceanic Technol., Vol. 30, p. 127–139, doi:10.1175/JTECH-D-12-00027.1

Yurovskaya, M., Kudryavtsev, V., Chapron, B., & Collard, F. (2019). Ocean surface current retrieval from space: The Sentinel-2 multispectral capabilities. Remote Sensing of Environment, 234, 111468.

Wohland, J., Omrani, N. E., Witthaut, D., & Keenlyside, N. S. (2019). Inconsistent wind speed trends in current twentieth century reanalyses. Journal of Geophysical Research: Atmospheres, 124(4), 1931-1940.

Worksnop, Rochelle P., Julie K. Lundquist, George H. Bryan, Rick Damiani, and Walt Musial. "Gusts and shear within hurricane eyewalls can exceed offshore wind turbine design standards." *Geophysical Research Letters* 44, no. 12 (2017): 6413-6420.