TEC4SEA

Scientific Roadmap
2022-2027

1. THE TEC4SEA RESEARCH INFRASTRUCTURE

The Infrastructure

The TEC4SEA Research Infrastructure, recognized by FCT in the National Roadmap of Research Infrastructures, is a pioneer platform in Europe to support research, development, and test of marine robotics, telecommunications, and sensing technologies for monitoring and operating in the ocean environment.

The goals

As a direct result of the nature of the founding partners and of the role envisaged for TEC4SEA within the Portuguese National Ocean Strategy (PNOS), this RI was designed to serve not only the academic community, but also the industrial community, fostering and promoting R&D and technology transfer, and helping the intended growth of a sustainable blue economy sector.

The nature

TEC4SEA is a geographically distributed infrastructure, with physical presence from the North to the South of Portugal. It is open to the entire scientific and enterprise/industrial community, with a free access policy for researchers affiliated with the research units that ensure its maintenance and sustainability.

In an attempt to rally the vast set of skills, resources and competences needed to successfully tackle the challenge posed by its self-defined mission and, in particular, by the particularly difficulties inherent to the dimension and depth of the Portuguese Sea, the TEC4SEA Research Infrastructure (RI) was created as a highly multidisciplinary platform, capable of supporting research, development, and test of marine technologies. This eclecticism and multidisciplinary nature, required for the effective and self-sustained development of technologies for monitoring and operating in the ocean environment, are well

Strategic alignment

reflected in the diversity and scope of the defined scientific objectives defined in this roadmap.

TEC4SEA is also a vertically integrated infrastructure, in the sense that it possesses a set of skills and resources ranging from pure conceptual research to sea going missions, with strong industrial and logistic competences in the middle tier of prototype production. It can thus support researchers in all phases of technology development, from conception and theoretical analysis, to prototype development, field test deployments, and technology validation. This large scope in the nature of the TEC4SEA activities is again well reflected in the diversity of the defined scientific objectives defined in this roadmap.

2. THE STRATEGIC FAMEWORK

The motivation

The drive to develop technology for the ocean environment is not the only driver of TEC4SEA. Equally important, and identically ingrained in its founding DNA, is the recognition that the usefulness of technology is measurable by the impact it has on the surrounding economic and social fabrics. As such, TEC4SEA attributes high priority to programs and projects with the potential to empower leading Portuguese companies, by increasing their capacity to innovate in the sea economy arena.

Being technical education a vital component of the technological empowerment of industry and, in general, a key factor in the technological capabilities of societies, the TEC4SEA infrastructure is also highly committed to the provision of advanced education programs.

The **Scientific Roadmap 2022-2027** presented in this document is the result of the previous three motivation vectors (*technology* *development*, *technological empowerment*, and *advanced education*). Being intended as a guiding document for the TEC4SEA scientific activities and goals within the next 5 years, it was developed in full compliance with the defined strategic map and objectives of the **TEC4SEA Strategic Plan** for the same period.

A great deal of effort was also put into guaranteeing that this roadmap was kept aligned with the **Portuguese National Ocean Strategy** (PNOS), so that it might become an useful asset for the promotion of national blue growth. The NPOS was not, however, the only national strategy which was considered.

At the European level, the alignment is also completely preserved. Being deeply rooted in the Atlantic Ocean, the largest sea basin in terms of gross value added (GVA), it directly addresses an assets representing 36% of the EU blue economy GVA. Since the new PNOS was already fully aligned with the European relevant documents, namely the European Commission's **Atlantic Maritime Area**, and given TEC4SEA´s capability to address to address and support the challenges of all four pillars of the **Atlantic Action Plan 2.0**, the strategic alignment at the national level mostly implied the alignment at the European level.

As a result of this alignment, all orientations and choices present in this Scientific Roadmap are deeply rooted in both the geostrategic nature of Portugal as a maritime axis Nation, and the particular characteristics of the Portuguese Sea.

The Portuguese Sea. Contextual problems

Portugal has the 3rd largest Exclusive Economic Zone (EEZ) of the EU and the 10th largest EEZ in the world. With the new reality brought by the Continental Shelf Extension proposal, currently under appreciation by the United Nations's Commission on the Limits of the Continental Shelf (CLCS), the Portuguese territory becomes approximately 4 million km^2 wide (roughly equivalent to 91% of the European Union's land area), with the vast majority of this North Atlantic area being constituted by deep and ultra-deep sea

These two characteristics (*dimension* and *depth*) combine to create considerable technical difficulties to the national capability for both exploration and exploitation of these vast underwater domains.

This roadmap and the scientific objectives it establishes are, therefore, products of the need to address the technical and scientific challenges presented by these two characteristics of the Portuguese Sea. Whatever we accomplish, we should be able to accomplish in deep and ultra-deep sea; whatever we do or deploy, we should be capable of doing or deploying in remote areas of the Atlantic, far from the commodities afforded by the proximity of land. In this regard, this Scientific roadmap can be seen as the natural and coherent successor of the previous one.

Dimension

This problem of dimension creates technical and scientific areas in many different areas, both directly and indirectly. Coverage of such a vast area of water and soil is not easily done, be it for exploiting, exploring, or simply monitoring purposes. No amount of ships, personnel, or money, can produce short-term results, if physical presence on site is required.

The use of satellite technology can, in some functional areas (e.g. surface monitoring), mitigate the problem, but even if the costs of such an alternative are acceptable, it still leaves many areas uncovered.

The response to this problem to which TECSEA aims to contribute is: *automation*. Projects such as Argos have already shown the usefulness of mass automation to map and collect massive amounts of data, without the need for human physical presence on site. But, as an approach to this problem, automation faces many indirect challenges which are again posed by the sheer dimension of the Portuguese Sea: communications at sea, platform endurance, mission deployment, energy harvesting, effective swarming, the need for low cost platforms and sensors (if the needed mass replication is to be achieved), etc. In turn, each one of these general technical challenges may be subdivided into smaller challenges.

Depth

The vast majority of the Portuguese Sea is constituted by deep and ultra-deep sea, a fact that poses tremendous additional challenges. The most direct and obvious challenges posed by depth are related with structures, materials, and the need to maintain dry compartments under enormous water pressures. But many indirect technological problems arise. Vehicles take a long time to reach the bottom, which means long periods without bottom Doppler and, thus, without a critical component of actual UUV (Underwater Unmanned Vehicle) navigation. This creates very serious navigational difficulties, for which no satisfactory solution is yet known. Many other indirect difficulties are posed by depth.

Attractiveness for European Researchers

To fully achieve the role of Europe’s scientific doorway to deep sea, thus constituting a strong attractor for researchers operating in deep sea related scientific fields, TEC4SEA needs to further build up and deploy some of its capabilities: deep sea persistence present (via a semi-fixed underwater observatory), mission deployment assets, fixed test-beds for prototype testing, etc.

3. THE SCIENTIFIC ROADMAP 2022-2027

Mission related Lines of Action

The lines of action (LOA) established for TEC4SEA are a result from the intersection of the previously presented goals, motivations and framework, and the set of skills, competences, resources and scientific interests of the founding institutions. The established lines of action are:

LA1. To become a reference on experimentally-driven, multidisciplinary research on technology for the ocean, supporting research, development, and testing of new technologies along 4 major research lines:

- Marine robotics, addressing the development of solutions for long term deployments, deep water operations, autonomous inspection and intervention, intelligent data harvesting, and safe operation of unmanned platforms;
- Technologies and systems for underwater monitoring, namely fiber optic sensors and imaging systems for measuring physical, chemical and biological parameters and enabling smart infrastructures;
- Broadband wireless communications systems for ocean environments, including radio systems for over water communications and acoustic, optical, and radio systems for underwater communications;
- Acoustic systems for ocean monitoring and exploration

LA2. To advance the technological envelope underlying the development of robotic operations in the ocean environment;

LA3. To support the specification and testing of draft standard technologies for the ocean environment;

LA4. To integrate with international infrastructures. TEC4SEA should aim at integrating with related and complementary RIs, benefiting from the setup of new partnerships, and the attraction of new users;

LA5. To support technical training of human resources, as well as advanced education programs.

Services

As a research Infrastructure recognized by FCT in the National Roadmap of Research Infrastructures, TEC4SEA has the dual role of not only pursuing its own scientific interests, but of also constituting a platform, open to both the academia and industry, capable of supplying a pre-defined set of services.

As such, the scientific roadmap did also take into consideration the need to maintain and develop the skills, resources and competences necessary for provision of services of excellence in the pre-defined areas.

The currently offered services to be pursued can be grouped as:

Service	Brief description
ACCESS TO SEA AND DEEP SEA	Provision of access to the maritime environment, and oceanic equipment deployment. The vessels acquired by the project support missions of up to 4 days, for 8 researchers, up to 60 nmi from land, covering depths up to 4000 m. Global ocean access is possible using chartered vessels.
DESIGN, FABRICATION, AND OPERATION OF AUTONOMOUS	Customized design, construction and operation of surface and subsurface vehicles for mission-oriented

VEHICLES	applications. Payload integration in pre-existing vehicles.
3D MAPPING AND RECONSTRUCTION OF UNDERWATER ENVIRONMENTS	3D optical and acoustic mapping of underwater volumes. Reconstruction and dimensional analysis of the 3D collected data.
DESIGN AND CHARACTERIZATION OF UNDERWATER ACOUSTIC SYSTEMS	Design of customized underwater acoustic systems.
CALIBRATION OF ACOUSTIC SYSTEMS AND DEVICES	Analysis, characterization, and calibration of acoustic equipment.
DESIGN AND IMPLEMENTATION OF UNDERWATER EXPERIMENTAL SETUPS	Design and implementation of experimental setups for underwater acoustic research and development, according to the defined specific research goals.
MARITIME COMMUNICATION NETWORKS FOR CUSTOM APPLICATIONS	Design, test, and deployment of maritime communication networks to support client-specified applications.
ANALYSIS AND CHARACTERIZATION OF RF, MICROWAVE, AND OPTOELECTRONIC DEVICES	Analysis and characterization of RF, microwave, and optoelecronic devices in a wide set of frequency ranges. Anechoic chamber measurements and analysis of radiating equipment and devices.
OPTICAL SENSOR DESIGN, FABRICATION, CALIBRATION, AND CHARACTERIZATION	Fast fabrication and implementation of prototypes with optical sensor integration, both isolated and surface-volume distributed, and their performance characterization. Production of high-precision mixtures with CO_2 and N_2, for testing sensors in water.

OPTICAL CHARACTERIZATION OF MATERIALS AND DEVICES	Non-invasive mapping of the 3D microstructure of opaque materials. Fluorescent response of materials. Optical absorbance of transparent samples. Optical fiber transmission, reflection and attenuation response. Identification of materials using mass spectrography and LIBS.
PRESSURE TESTS IN HYPERBARIC CHAMBER	Verification of the structural resistance, water tightness, and capability of continued operation in high-pressure liquid environments. Pressures up to an equivalent depth of 4000 m.
DEPLOYMENT AND RECOVERY OF UNDERWATER EQUIPMENT	Deployment and recovery of underwater equipment up to depths of 2000 m.
ADPTATION OF EQUIPMENT TO MARITIME ENVIRONMENTS	Adaptation of pre/existing equipment to above-water or underwater maritime environments
DESIGN, CHARACTERIZATION AND VALIDATION OF NAVIGATION AND POSITIONING SYSTEMS	Design, characterization and validation of positioning and navigation system for air, surface, or subsurface vehicles.
UNDERWATER VEHICLES ATTITUDE MEASUREMENT AND CONTROL	Analysis of the attitude of underwater vehicles in controlled environment. Performance evaluation of attitude control systems.
COMMUNICATION NETWORKS PERFORMANCE ANALYSIS	Analysis of the performance of communication networks by simulation with context and environment replication.
COMMUNICATION PROTOCOL PARAMETRIZATION AND OPTIMIZATION	Parametrization and optimization of the communication protocol parameters for specific environments and/or applications.

ELECTROMAGNETIC SPECTRUM MONITORING AND ANALYSIS	Analysis and monitoring of the VHF/UHF/SHF electromagnetic spectrum in maritime environments.
SUPPLY OF TEMPORARY TCP CONNECTIVITY	Supply of temporary TCP connectivity for maritime applications.
DESIGN OF RF AND MICROWAVE CIRCUIT AND DEVICES	Design of RF and microwave circuit and devices.
COMPUTER AIDED DESIGN OF MICROWAVE ANTENNAS AND DEVICES	Computer-aided-design of microwave antennas and devices supported by 3D field simulations.
OPTOFLUIDIC DEVICE FABRICATION	Fabrication of optofluidic devices by direct imprinting with sub-micron resolution.
FABRICATION OF 3D POLYMERIC MICROSTRUCTURES	Fabrication of 3D polymeric microstructures by 3D photopolymerization, with sub-micron resolution.
FABRICATION OF FIBER-OPTIC/BASED BRAGG NETWORKS	Fabrication of fiber-optic-based Bragg networks with a ≈200 nm maximum resolution.
FABRICATION OF OPTICAL-FIBER-BASED DEVICES	Fabrication of nanofibers and metallic nanowires, couplers or WDM.
SIMULATION OF OPTICAL SENSORS AND SYSTEMS	Software-based (Zeemax / Comso) simulation of optical sensors and systems.

Table 1 – Offered services.

Scientific Objectives

In the internal plane, TEC4SEA has also its own scientific objectives, and they all relate to proposed solutions to some of the above identified challenges. The prosecution of these internal scientific objectives is also reflected in this Scientific Roadmap.

This choice of internal scientific objectives does not, however, necessarily reflect the relative importance of the particular problem addressed by it. In fact, it results from a careful consideration of the problem, its scientific, technological and economic impact, the resources required for its solution, and last but not least, the capability of TEC4SEA to address it. The solutions to problems for which TEC4SEA has no attack tools and no realistic hope of obtaining them, are not considered as objectives, the importance or relevance of the underlying problems notwithstanding.

The established Scientific Objectives (SO) for the period 2020-2027 are presented in Table 1. Each one of them was derived as an answer (solution or mitigation) to one of the contextual problems posed by the particular characteristics of the Portuguese Sea. Each one of these Scientific Objectives is detailed below (Table 2), framed against the underlying contextual problem and the particular technical/scientific challenge that it poses and needs to be addressed.

Contextual challenge: Dimension					
Answer	Technical/Scientific challenge				Objective
Massive Automation	Cooperative swarming	Cooperative autonomy			
		Adaptive/Efiicient sampling			
	Complex mission capability	Autonomous intervention		Increasing the level of functional intelligence of unmaned vehicles	**SO1**: Prototype capable of autonomous bottom inspection
					SO2: Prototype capable of autonomous pick & place
	Low cost platforms and sensors	Sensors	Geomagnetic		
			Geobiochemical	Development and inegration new sensors (fluorescence, LIBS)	**SO3:** New developed sensor integrated onoperational unmaned plataform
			Hydrocarbons	Low power methane detection	**SO4:** Develop an acoustic detector of methane ascending plumes
				Fiber optic based hidrocarbon sensor	**SO5:** Develop a prototype fiber optic methane detector
			Accoustic	Directional accoustic vector sensors	**SO6:** Develop a short span vector sensor prototype
				Distributed beamforming	**SO7:** Distributed beamforming technology demonstrator.
				Polymer based accoustic sensors	**SO8:** Polymer based accoustic sensors technology demonstrator
				Simultaneous ADCP and ABS sensor	**SO9:** Develop a prototype sensor simultaneously capable of ADCP and ABS measurements
			Minerals		
	Long term deployment				

Contextual challenge: Dimension				
Answer	**Technical/Scientific challenge**			**Objective**
Longer endurance	Energy	Charge on dock		
		Wireless power	Charging UxV batteries without physical connection	**SO10:** Wireless power technology demonstrator.
		Harvesting		
		Underwater high voltage power lines	Development on new sensors for control of underwater smartgrids.	**SO11:** Demonstrator of the use of optical technology with totally dielectric elements.
		Maganement		
		Passive transponders	Underwater RFID	**SO12:** Working demonstrator of powerless sensor underwater readout
	Permanent observatory			**SO13:** Bulid and deply a permanent (but redeployable) underwater observatory,to be used as technology demonstrator and test bed.
	Materials	Sensors resilient to corrosive and polluted environments	Development of new metamaterials, capable of the necessary antibiofouling, hydrophobicity, etc), utilizing deposition tecnhiques (thin films, self assembly, etc)	
		Corrosion	Development of new materials and encapsulating tecnhiques for corrosive environments.	

Contextual challenge: Dimension				
Answer	Technical/Scientific challenge			Objective
Oceanwide Communications	Long range links		Data links on HF	**SO14:** Capacitity to control unmaned vehicles via HF shore-ship link
	Near surface RF data communications		RF near surface penetration	**SO15:** Point-to-point technology demonstrator
				SO16: Working test-bed for "near-surface" communications, with multiple fixed and mobile nodes
	Data mules			**SO17:** Ad-hoc opportunistic network prototype of 10 nodes.
	Short range underwater optical data comms		Underwater optical data transmission	**SO18:** Working test-bed capable of short range high debit
				SO19: Working test-bed capable of (100m) data transfer.
	Short range underwater RF data comms		Underwater RF data transmission	**SO20:** Working prototype capable of (100m, horizontal) data transfer.
	Comand relaying			
Better navigation	Homing			
	Inertial (cost/precision)			
	Multi-layers		Eliminate the need for USBL Ship	**SO21:** USBL. 3x USV, + 1 UUV, deployable
	Static			
	Relative			
	SLAM			
	Collision avoidance			

Contextual challenge: Depth				
Answer	**Technical/Scientific challenge**			**Objective**
Better navigation	Homing			
	Inertial (cost/precision)			
	Multi-layers		Eliminate the need for USBL Ship	**SO21**
	SLAM			
	Collision avoidance			
Light, resistant structures	Pressure resistance	Pressure		
	Deformation and vibration		Sensors capable of whithstanding mechanical agression, and corrosion.	**S22:** Development of new, fiber optical based sensors, for deformation and vibration.
Contextual challenge: Attractiveness				
Answer	**Technical/Scientific challenge**			**Objective**
Permanent underwater observatory	Create a permanent underwater deep-sea observatory and technological test-bed			**SO13**
Operational, deployable unmaned systems and swarms	Deployable UsV based mapping and pick&place system, whitout the need for an USBL ship			**SO1, SO2, SO21**
Esay to use communications test beds	Underwater communications test bed			**SO13, SO18, SO19, SO20**
	Long range communications operations support and test-bed			**SO14, SO16, SO17**
Scienftific productions	To become a respected reference in the area, in training, scientific productivity and quality.			**SO23**
Areas of operations	To establish marine areas reserved for TEC4SEA operations (TUPEMs)			**SO24:** To establish marine areas reserved for TEC4SEA operations

Table 2 - Scientific Objectives

Strategic objectives

As stated, this Scientific Roadmap is fully aligned with the TEC4SEA Strategic Plan 2020-2027, and thus shares many of its motivations. In particular, the defined Scientific Objectives are key contributors to the Strategic Objectives defined on the Strategic Plan. Their relation can be seen in Table 2, which also identifies the principal Line of Action to which each Scientific Objective contributes, and functional areas where the greatest impact of the SOs is foreseen.

The Strategic Objectives, and their supporting Operational Objectives, have been defined in the **TEC4SEA Strategic Plan 2022-2027**:

STRATO 1 -	Becoming a reference institution in sea technology development and test
STRATO 2 -	Becoming a relevant tool in the National Ocean Economy, empowering enterprises, and fostering a sustainable blue economy
STRATO 3 -	Becoming the European gateway to deep sea: the Atlantic Ocean Laboratory
STRATO 4 -	Providing European science and researchers with easy access to deep sea and related assets, thus fostering European technology in the area
STRATO 5 -	Supporting technical and advanced education programs in sea technology
STRATO 6 -	Supporting the industrial sector
STRATO 7 -	Supporting research in other scientific areas
STRATO 8 -	Providing tools to mitigate the main technological challenges posed by the Portuguese Sea
STRATO 9 -	Becoming a node of the relevant European networks producing technology for the sea
STRATO 10 -	Maintaining a vertically integrated structure capable of internally supporting the full R&D, prototyping, deployment and testing processes
STRATO 11 -	To be a useful, shared resource for sea technology development
STRATO 12 -	To be a useful, shared resource for sea technology development
STRATO 13 -	Long term, deep water, autonomous robotics
STRATO 14 -	Improved fiber optics sensors and imaging systems
STRATO 15 -	Resilient underwater deployable bases
STRATO 16 -	Broadband wireless maritime communications, and underwater communications
STRATO 17 -	Restricted sea areas dedicated to technology development and test
STRATO 18 -	Versatile systems for underwater monitoring and exploration

Table 3 . Strategic objectives

The relation between Scientific Objectives, Lines of Action, and Strategic Objectives can be seen in Table 4 below.

Scientific Objective	Line of action	Strategic objective
SO1: Prototype capable of autonomous bottom inspection	LA 1, LA 2	STRATO 1, STARTO 13, STRATO 8, STRATO 18
SO2: Prototype capable of autonomous pick & place	LA 1, LA 2	STRATO 1, STRATO 8, STRATO 13, STRATO 18
SO3: New developed sensor integrated on operational unmaned plataform	LA 1, LA 2	STRATO 1, STRATO 8
SO4: Develop an acoustic detector of methane ascending plumes	LA 1, LA 2	STRATO 1, STRATO 8
SO5: Develop a prototype fiber optic methane detector	LA 1, LA 2	STRATO 1, STRATO 8
SO6: Develop a short span vector sensor prototype	LA 1, LA 2	STRATO 1
SO7: Distributed beamforming technology demonstrator.	LA 1, LA 2	STRATO 1, STRATO 8
SO8: Polymer based accoustic sensors technology demonstrator	LA 1, LA 2	STRATO 1
SO9: Develop a prototype sensor simultaneously capable of ADCP and ABS measurements	LA 1, LA 2	STRATO 1, STRATO 18
SO10: Wireless power technology demonstrator.	LA 1, LA 2	STRATO 1, STRATO 8, STARTO 13, STRATO 18
SO11: Demonstrator of the use of optical technology with totally dielectric elements.	LA 1, LA 2	STRATO 1
SO12: Working demonstrator of powerless sensor underwater readout	LA 1, LA 2	STRATO 1, STRATO 18
SO13: Bulid and deply a permanent (but redeployable) underwater observatory,to be used as technology demonstrator and test bed.	LA 1, LA 2	STRATO 3, STRATO 8, STRATO 13, STRATO 16
SO14: Capacitity to control unmaned vehicles via HF shore-ship link	LA 1, LA 2	STRATO 8, STRATO 16, STRATO 18
SO15: Point-to-point technology demonstrator	LA 1, LA 2	STRATO 16
SO16: Working test-bed for "near-surface" communications, with multiple fixed and mobile nodes	LA 1, LA 2, LA 3	STRATO 16

Scientific Objective	Line of action	Strategic objective
SO17: Ad-hoc opportunistic network prototype of 10 nodes.	LA 1, LA 2, LA 3	STRATO 6, STRATO 16
SO18: Working test-bed capable of short range high debit	LA 1, LA 2, LA 3	STRATO 6, STRATO 16
SO19: Working test-bed capable of (100m) data transfer.	LA 1, LA 2	STRATO 6, STRATO 16
SO20: Working prototype capable of (100m, horizontal) data transfer.	LA 1, LA 2	STRATO 6, STRATO 16
SO21: USBL. 3x USV, + 1 UUV, deployable	LA 1, LA 2	STRATO 18
SO22: Development of new, fiber optical based sensors, for deformation and vibration.	LA 1, LA 3	
SO23:	LA 1, LA 5	STRATO 1
SO24: To establish marine areas reserved for TEC4SEA operations	LA 3	STRATO 1, STRATO 2, STRATO 3, STRATO 4, STRATO 9, STRATO 10, STRATO 12, STRATO 15, STRATO 17

Table 4 – Relations between Scientific Objectives, Lines of Action, and Strategic Objectives.