PROJECT FINAL REPORT

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The TROPOS Project — Modular Multi-use Deep Water Offshore Platform Harnessing and Servicing Mediterranean, Subtropical and Tropical Marine and Maritime Resources, has received funding from the European Union's Seventh Framework programme for research, technological development and demonstration under grant agreement number 288192 (Call Ocean of Tomorrow).

1. FINAL PUBLISHABLE SUMMARY REPORT

1.1 Executive Summary

The global population is growing and space and resources along the coast are limited. Therefore, the development of novel offshore technologies allowing for the exploitation of oceanic resources becomes more and more important. The TROPOS project aimed at developing a floating modular multi-use platform system for use in deep waters, with an initial geographic focus on the Mediterranean, Tropical and Sub-Tropical regions, but designed to be flexible enough so as not to be limited in geographic scope. The floating design facilitates access to deep sea areas and resources where deployment of conventional platform types is not possible. The modular multi-use approach allows integrating a range of functions from four different sectors: Transport, Energy, Aquaculture, and Leisure (in short: TEAL). Three different concepts were developed in the scope of TROPOS with various combinations of TEAL functions: the Green & Blue concept, the Leisure Island and the Sustainable Service Hub. Appropriate locations for the different concepts were identified and final TROPOS scenarios were defined with the help of a specifically developed GIS support tool: (1) Green & Blue scenario north of Crete, integrating wind energy exploitation and fish and algae aquaculture; (2) Leisure Island off the coast of Gran Canaria, combining leisure facilities with the use of solar energy; (3) the Sustainable Service Hub on the Dogger Bank (North Sea, UK), focusing on transport and energy related needs of the offshore renewable energy sector, i.e. it provides service for offshore wind farms. Additionally, two future scenarios were developed: a Green & Blue scenario in Taiwan, integrating aquaculture with OTEC; and the Offshore Container Terminal in Panama, serving as a central energy and transport hub. The design of the three official scenarios was specified in much detail and all scenarios were assessed by considering their particular logistic requirements, economic viability, and environmental and socio-economic impacts, and refined according to the results wherever necessary and feasible. The aim was to develop multi-use offshore platform concepts that allow for the sustainable and eco-friendly use and synergistic exploitation of oceanic resources.

On the following pages first the context and the specific objectives of the TROPOS project are presented, followed by a description of the main scientific and technical results obtained for each objective. The outcomes of TROPOS range from developed methodologies for decision support and impact assessments and design validation, to innovative technological solutions for the development of modular multi-use offshore platforms, and to the assessment and viability of each scenario and deployment strategy. In the end, the potential impact of the project's results on the society, the scientific and engineering community, the industry, and stakeholders, users and operators of future multi-use offshore platforms are discussed. The outcomes of TROPOS are expected to have a wider influence in different fields. The developed technological solutions and design specification provide a base on which future developers and the offshore industry may build. The developed methodologies may serve as guidelines and examples for future projects. The insight gained and lessons learned regarding logistic requirements, economic potential and limitations, environmental and socio-economic impact, identified gaps in regulations and obstacles may be of great use for future developments. Not only future developers and operators, but also regulatory bodies can build on this existing knowledge while avoiding problems and complications in designing and planning at early development stages. This will help the industry and the authorities to save time, efforts and costs. Finally, the TROPOS project significantly contributed to the advancement of knowledge about multi-use offshore platforms, not only among particular scientific communities, but also in terms of a better understanding of the wider public, developers and policy-makers about the possibilities of future marine activities and the implementation of large-scale offshore infrastructures. This enhanced awareness and knowledge will most likely increase the acceptance of future offshore multi-use deployments.

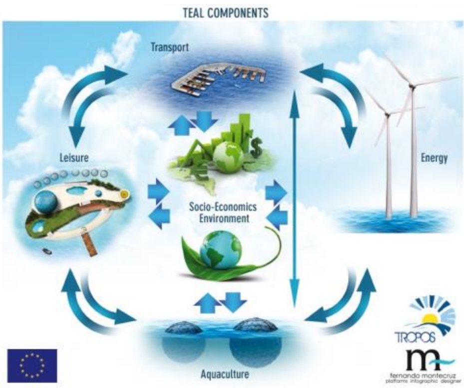
1.2 Project Context and Objectives

1.2.1 Context

The global population is growing and in Europe - as in most parts of the world - nearly half of the population lives in coastal areas. Space along the coast becomes increasingly scarce and on- and near-shore resources are limited and often already over-exploited. As a consequence, Research & Development activities are increasingly moving towards offshore technologies. To prevent spatial conflicts between novel maritime activities in offshore areas an integrated approach is required that allows for a shared use of space, infrastructures and logistics.

The TROPOS project aims at developing a floating modular multi-use platform system for use in deep waters. TROPOS had a total term of 3 years, from 2012 to 2015, and was funded by the European Commission under the 7th Framework Programme for Research & Development ("Ocean of Tomorrow", OCEAN 2011.1 – Multi-use offshore platforms). The project involved 20 partners from 9 different countries and was coordinated by PLOCAN (PLataforma Oceánica de las CANarias, Gran Canaria, Canary Islands, Spain). The full title of the TROPOS project is "*Modular Multi-use Deep Water Offshore Platform Harnessing and Servicing Mediterranean, Subtropical and Tropical Marine and Maritime Resources*".

The initial geographic focus for the platform systems was on the Mediterranean, Tropical and Sub-Tropical regions, but the aim was to design a system which is flexible enough for not being limited in geographic scope. The modular approach allows for the integration of a range of functions from different sectors. In the case of TROPOS, functions of four different sectors were integrated, namely Transport, Energy, Aquaculture, and Leisure (in short: TEAL). Marine Transport (T) provides critical services to the society ranging from building commercial and leisure ships, shipping of goods and fuel around the world, passenger transfer, to servicing offshore structures. The development of renewable Energies (E) is essential to address the dramatic depletion of fossil fuel reserves and to mitigate climate change which has become one of the most critical issues in recent years. Natural marine living resources are already heavily exploited, while the demand for these resources is steadily increasing. To reduce the fishing pressure on wild stocks, the demand needs to be increasingly met additionally by Aquaculture (A). The tourism industry represents the third largest socio-economic activity in the EU and space is needed for the development of new Leisure (L) activities. Not only in Europe, but all over the world there is an increasing demand for innovative, eco-friendly solutions in the tourism sector.



Accordingly, the overall aim of the TROPOS project was the development of multi-use offshore platforms that allow for sustainable and eco-friendly uses and a synergistic exploitation of oceanic resources.

1.2.2 Objectives

The main objectives of the TROPOS project involved:

- **To determine the optimal locations for multi-use offshore platforms in Mediterranean, subtropical and tropical latitudes, based on both numerical and physical modelling, including field validations**. The platform activities and services are expected to include and relate to: novel transport solutions and applications, offshore wind and ocean energy conversion, aquaculture facilities and services as well as offshore tourism and leisure activities.
- **To define and establish integrative and synergic relationships between the following oceanic activities and technologies:** renewable energy harvesting and offshore wind in particular, innovative systems for optimal offshore aquaculture and CO_2 sequestration, developing transport solutions for optimised installation and maintenance of the platform, operation and services to shipping and other innovative and integrated services, including offshore tourism activities and ocean environmental monitoring.
- **To develop novel, cost-efficient and modular multi-use platform designs** that enable an optimal coupling of offshore wind and ocean energy, aquaculture, offshore transport facilities, tourism activities and ocean environmental monitoring.
- **To determine logistical requirements**, including safety, construction, efficient installation, operation, maintenance, monitoring, specialized transportation, supply chain management and decommissioning of the novel platform.
- **To assess the economic feasibility and viability of the multi-use platform** as a novel way to deliver new sources of growth and sustainable jobs, including the comparison to non-multi-use platforms in the areas of interest.
- **To develop a comprehensive environmental impact methodology and assessment**, including a comparison to non-multi-use platforms.
- **To configure three complete solutions**, i.e. at least one for each of the Mediterranean, subtropical and tropical case-scenarios.

1.3 Main Scientific and Technical Results

Throughout the entire term of the TROPOS project there has been frequent interaction and exchange among the different groups and work packages to ensure a constant flow of information and feedback. The following sections present the main scientific and technical results for each project objective.

The TROPOS deliverables are available on the webpage (http://www.troposplatform.eu/Deliverables-Media/Project-Deliverables).

1.3.1 Optimal locations for multi-use offshore platforms

The TROPOS project has initially defined three zones as typical 'target regions' for the platforms, namely the Canary Islands (specifically Gran Canaria; Spain), Crete (Greece), and Taiwan (D2.3). In a later phase of the project, the central North Sea and Panama were also considered as a target region.

To identify the most suitable locations for multi-use offshore platforms within the target regions a Geographic Information System (GIS) tool was developed which integrates a multitude of data for a geographical assessment of different regions (D2.4). This application considers and integrates a multitude of data specific to a particular resource, but also data on water depth, seabed geology, distance to grid or distance to port, and data to be used in the definition of restricted areas. These represent areas where the implementation of the platform is potentially very sensitive or not possible at all due to administrative limitations based on e.g. fishing concessions, environmental protected areas, military exercise areas, underwater cables or shipping routes. The GIS application represents a resource-based decision support tool which significantly contributed to the selection process of TROPOS platform locations, while simultaneously serving as a pertinent database providing input to other objectives. The tool provided valuable support for the decisions on the most suitable sites for a given platform configuration, or, alternatively, on the most suitable platform configuration for a particular site.

Suitable locations for the TROPOS concepts which were finally chosen for the case studies include:

- North of Crete (southern Aegean Sea) at about 100km distance from the shore in about 450m water depth. This site is optimal for harnessing wind energy.
- Southwest of Taiwan, 3nm distance from Liuqiu Island in 300-400m water depth. The vertical temperature gradient along the water column in this area allows for the operation of an Ocean Thermal Energy Conversion (OTEC) plant.
- Southwest of Gran Canaria, 2nm from the shore in about 50m water depth. This is a suitable location for the exploitation of solar energy and touristic activities.
- In the North Sea on the Dogger Bank (UK), about 100km from the shore in about 30m water depth. This site suitable for harnessing wind energy.
- The Gulf of Panama in depths around 150 meters

1.3.2 Definition and establishment of integrative and synergistic relationships

TROPOS focused on different combinations of activities from the Transport, Renewable Energy, Aquaculture and Leisure (short: TEAL) sectors. To define and establish integrative and synergistic relationships among the TEAL sectors, it was important to start with the development of a methodology to define generic design benchmarks and selection criteria for the platform and components designs and their implementation. The first important output on the way towards achieving the objective was the development of a matrix establishing basic levels of compatibility between the different TEAL components (D2.1). The developed methodology based on multi-criteria analysis was designed to provide an informed decision on the most suitable TEAL components to be integrated in the TROPOS platform at a specific site. This represented the backbone of the decision support methodology implemented in the GIS tool to identify the optimal platform locations (D2.4) and to deliver useful input to the design and dimensioning of the platform.

Based on the established definitions, fact sheets with concise key information on the different TEAL components were prepared (D2.2). A review of technical and techno-economical specifications was performed for each potential module of the TEAL components and integrated in the defined decision criteria defined. These specifications, together with the geographical assessment of resource, constraints and preliminary market potential in the different target regions (D2.3), helped to define most suitable combinations of TEAL components for different locations.

This work, together with the outcomes of the overall deployment strategy (D5.8), finally resulted in the definition of the different TROPOS concepts (D3.5, D4.3):

- Leisure Island - focusing on leisure facilities in combination with renewable energies.
- Green & Blue – combining offshore aquaculture with renewable energies.
- Sustainable Service Hub – focusing on transport and energy related needs of the offshore renewable energy sector
- Offshore Container Terminal - serving as a central energy and transport hub

1.3.3 Development of novel, cost-efficient and modular multi-use platform designs

The first step towards this goal was achieved by developing a methodology and detailing the landscape of marine transport, energy, aquaculture and leisure for the overall deployment strategy (D5.1). The main impacts of the TROPOS platform on each of the TEAL industries were identified:

- The TROPOS platform offers a unique scenario for reducing O&M costs in the marine transport, energy and aquaculture sectors;
- The shipping industry would benefit from the construction of ship repairing facilities at medium sized floating harbours (these can also be used as fish processing plants);
- Further investment and R&D in stable, floating platforms and structures will facilitate the development of floating wind turbine structures;
- The implementation of photovoltaics and solar heating / cooling systems can decrease the overall cost of the technology;
- The implementation of OTEC within the platform structure can decrease construction costs of a plant;
- Although tidal energy devices and resources are usually located in relatively shallow waters, the platform could act as a servicing hub for the device, or as a satellite platform which contains the device, thus promoting the innovation of tidal energy technologies;
- There are currently high costs of electricity for remote and isolated regions, the integration of a wave energy device can work towards reducing these costs;
- The platform can work towards operating multidisciplinary activities which are in accordance with strategies and actions defined by the EU to help promote tourism,
- The construction of a TROPOS platform will aid the development of offshore aquaculture technologies and will enable the exploitation of deeper water fishery resources.

After a final selection of the platform composition suitable for different deployment areas, the integrated concept platform design was completed (D3.5). The design solution of the modular multi-use approach involved a floating central unit platform which is fixed to the seafloor by a catenary mooring. Modules with different functions can be directly integrated into the central unit, and/or satellite units can be indirectly connected (via undersea cables), each according to requirements. Satellite units are fixed with their own mooring. Central unit, modules and satellites were designed and specified in great detail. The initial design developed in the beginning of the project was completely revised during the second half of the project to meet all requirements. The design was adapted and its suitability was verified by using different modelling approaches. A novel joint system to connect the floating modules to the central unit was developed and patented. The design (in particular regarding seakeeping) of the satellite units, integrating wind turbines and aquaculture facilities, was tested in experimental tanks. The synergies of combining fish aquaculture cages with algae bioreactors were tested offshore in a pilot scale cage facility in the Mediterranean. This approach provided useful “real-world” data and helped to significantly improve the design of the bioreactor.

A validation methodology was developed to verify the design of the TROPOS concepts, which was particularly dedicated to multi-use offshore platforms to support the validation process performed by a certification body (D4.4). The methodology is generic enough to address any of the systems proposed in the TROPOS project and other possible concepts. The proposed methodology combines the use of existing standards from related sectors such as shipping, offshore oil & gas, wind energy, aquaculture etc. with a risk-based approach for the most innovative and unknown parts of the multi-use offshore platform. This methodology is mainly intended for project owners, certification bodies, national authorities, designers and manufacturers, but also insurers, bankers, investors and others.

1.3.4 Logistical requirements

The first step in determining the logistical requirements of the floating TROPOS platform concepts was the compilation of a technical concept dossier for the central unit which assessed conceptual specifications and the design (D3.2). During this work it became apparent that the different platform concepts require individual central unit designs to meet the specific requirements. Accordingly, a scalable, semi-submerged barge providing sufficient functional space for the particular requirements was developed as the central unit. Life Cycle Assessment (LCA) of embedded carbon associated with the service life of a multi-use platform was carried out for each function (TEAL) area (D5.4). This exercise was performed by using different case studies to represent examples of potential TEAL uses of a platform. These case studies were then used to inform and refine the TROPOS platform options and to allow informed decisions on the final designs for the TROPOS platform.

The logistic requirements related to the manufacturing, installation, operation and maintenance were investigated for the three TROPOS ICS concepts (D5.5): Leisure Island, Green & Blue ‘Crete’ and Sustainable Service Hub. To identify the high level logistical requirements of the TROPOS concepts, flow diagrams were created focusing on Operation & Maintenance (O&M). Based on the assembled information, suitable vessels, ports and electrical grid infrastructure capable of fulfilling the requirements were identified and discussed while focusing on the identification of gaps and conflicts between the logistical requirements of the TROPOS concepts and the capabilities of the existing logistical solutions. Moreover, existing legislation, regulation, design standards and trainings that are fully or partially applicable to the TROPOS concepts were identified.

Challenges and gaps are mainly expected to emerge from the Green & Blue ‘Crete’ concept and the satellite units in particular: On the part of “hard” infrastructure, the large dimensions of the satellite units massively reduce the number of dry docks capable of manufacturing such structures and performing their heavy maintenance. In particular, considering the large numbers of required satellite units this poses a problem for the deployment of such platforms. A second major challenge is the lack of actual field experience with complete farms of floating and grid connected offshore wind turbine units like those on which the Green & Blue ‘Crete’ satellite unit farm is supposed to be based. On the part of “soft” infrastructure, gaps in legislation, regulation and training are to be expected originating from the introduction of the novel technological application of floating offshore algae farming but also from the novel way of co-locating the otherwise known and partially rather ordinary applications of floating fish cages and floating wind turbines. Regarding Leisure Island and the Sustainable Service Hub it was shown that, in general, these concepts resemble already existing applications., In more detail, recent leisure cruise ships and offshore wind substations, and consequently the deployment of such platforms, can heavily rely on existing logistical solutions on the part of hard infrastructure as well as proven regulations and legislations of the soft infrastructure part, without any expected serious gaps and challenges (D5.5).

The LCA showed that only the Sustainable Service Hub ICS scenario is feasible when examining embedded carbon (D5.4). The Sustainable Service Hub scenario uses >60% less embedded carbon than the return-to-base strategy much of which are savings from the use of fuel.

A series of recommendations for policy-makers was provided regarding the needs of the industry (D5.5). These policy recommendations include:

- Adaptation of existing standards from relating sectors regarding the design of platforms.
- Personnel should be trained in multiple disciplines so that they are able to carry out the cross-cutting functions of multi-use platforms.
- Further examination of the existing synergies between the Sustainable Service Hub and substation modules.
- Standardization of training and certification for multi-use platform workers.

1.3.5 Economic feasibility and viability of multi-use platforms

The first step towards the assessment of feasibility and viability of the TROPOS multi-use offshore platforms involved the development of a framework and methodology for the overall deployment strategy (D5.1). The deployment strategy considers policy, cost and commercialization aspects of the sector in order to display and put these wider influences into context. The deployment strategy is aimed at policy-makers, project developers, governmental bodies, investors (public and private), legislators, the supply chain providers and consultants in order to aid a coherent progression of the sector.

The analysis of technology pricing of multi-use platforms completed a system pricing exercise to identify cost reductions, efficiency and benefits associated with the deployment of multi-use platforms in Crete, the Canary Islands and Taiwan (D5.3). The analysis revealed that an Offshore Wind Service Hub is already cost effective for wind farms of >200 MW. For the Leisure Island the analysis gave negative “Return-Of-Investment” (ROI) values. For an offshore aquaculture unit, sharing a platform is particularly important because most costs are caused by aquaculture services.

An assessment of the impact on local and regional economic conditions in the different TEAL areas was conducted by using an input-output approach (D5.2). In the Transport (T) sector, a significant increase in FTE (Full Time Employment) and Gross Domestic Product (GDP) is expected to the Canary Islands. In the Energy (E) sector, FTE and GDP are significantly higher in the Crete case study than in the Canary Islands or Taiwan. For Aquaculture (A), CAPEX, OPEX and total CAPEX output impacts are similar for all locations. For Leisure (L) the Crete scenario offers the largest increase in GDP and FTE jobs.

Based on the technical and viability strategies, the overall Deployment Strategy for multi-use offshore platforms was developed, and analysed the overall needs of the industry to create a number of final policy recommendations for initial deployments up to 2040 (D5.8). The most important policy recommendations for the different key deployment research areas include:

A. Finance

- Tax exemptions for income from platforms.
- Continued investment in R&D for innovation to decrease costs.
- Provision of capital grants for first builds.

B. Infrastructure

- Aim to develop a built-for-purpose fleet of vessels for the industry.
- For initial deployments: utilising existing port infrastructures. For 2040 deployments: updating facilities for mass manufacturing of platforms.
- Utilising mobile floating substations and converter stations until further testing and development of floating offshore substations is completed.

C. Regulation & Legislation

- When adopting design standards that align with the ICS Concepts, it will be necessary to examine the full needs and capabilities of the platform. Applying too constraining standards could cause additional costs or prevent the occurrence of critical activities.
- For initial deployment: adopting/adapting existing health and safety standards from existing industries. For commercialisation: developing fit-for-purpose industry standards.
- Ensure that appropriate EIA are carried out, and provide and carry out necessary mitigation plans.

Deployment targets for 2020 should be realised by considering existing standards and regulations, infrastructure, financial mechanisms and the knowledge of existing offshore platforms. In order to reach the commercialization of the sector, the implementation of many of the developed recommendations must be carried out through both changes in policy as well as updating the physical infrastructural requirements of the industry.

The examination found that a combined functionality of the TEAL areas has the potential to provide increased productivity, a better use of resources and an increased efficiency to the wind and aquaculture industries, whilst the Leisure Island offers an alternative holiday experience with the luxury of access to exclusive areas of interest.

The final key conclusions regarding the feasibility and viability of offshore multi-use platforms are (D5.8):

- In the case of the ICS concepts there is no single support mechanism that offers financial support necessary for the commercialisation of multi-use platforms. All concepts will require a number of support mechanisms to progress the market from demonstration projects in 2020 through to commercialisation in 2040.
- Regarding 2020 deployments, existing infrastructures can meet the needs of the industry, however, in order to reach the commercialisation stage, built-for-purpose vessels, ports and harbour facilities and grid connection will be required in order to reduce costs, reduce emissions and increase the productivity of the sector.
- Many skills and training required for the initial deployments will be adopted and adapted from other industries. As the sector develops towards commercialisation, purpose built skills and training standards will be developed.
- Addressing the technical challenges identified during the TROPOS project will help to achieve increased productivity throughout the lifetime of the platform.
- Regulation and legislation regarding platform structure, health and safety and environmental planning for initial deployments will be adopted from existing industries. Over time, it will be necessary to fully develop a set of standards that specifically apply to the offshore multi-use platform industry in order to ensure that the correct requirements of the industry are addressed.

1.3.6 Environmental impact methodology and assessment

When planning and designing any kind of offshore installation, the potential effects on the environment need to be considered. In Europe an Environmental Impact Assessment (EIA) is mandatory for projects likely to have significant effects on the environment (Directive 2014/52/EU). In TROPOS environmental considerations were involved from the beginning of the project to ensure that most sustainable and environmentally friendly options are integrated in early conceptual design stages.

Methodologies considering the specific concept and platform location were not only developed for the assessment of environmental (D6.2) and socio-economic impacts (D6.4), but also for the comparison between multi-use and single-use platforms (D6.5). The developed methodological approaches may serve as guidelines / examples for the assessment of future “real” floating multi-use offshore installations or similar projects. Potential major impacts on the environment and the society, and the most sensitive receptors in each scenario were also identified. The platform scenarios considered for the environmental impact assessment include the three official ICS concepts, Green & Blue in Crete, Leisure Island in Gran Canaria and the Sustainable Service Hub in the North Sea, as well as one future concept, the Green & Blue scenario in Taiwan. The assessment of the socio-economic impacted focused on the Leisure Island scenario and the Green & Blue scenario in Taiwan.

A multitude of potential environmental impacts were identified for each scenario, most of them of only minor or moderate significance (D6.2). The Green & Blue scenario off Crete is not expected to have major detrimental effects on the environment; however, the impact of the wind turbines and the aquaculture units need to be monitored rigorously. Noise from vessel traffic and the operation of leisure facilities and artificial lighting from bars and restaurants have been identified as the most critical effects of the Leisure Island scenario. The results from the socio-economic impact assessment clearly showed that the majority of people are open-minded and positive towards such innovative platforms, but also have their concerns, in particular regarding the impact on the environment (D6.4). Acceptance also differed between interest groups: stakeholders related to the tourism industry were much more positive towards the Leisure Island development compared to people promoting conservation. Noise, artificial lighting and waste are supposed to be the most significant stressors on the natural environment caused by the Green & Blue scenario in Taiwan (D6.2). Despite a general acceptance and support of the platform, people raised again a number of concerns related to environmental impacts and uncertain effects on local fishing and fish processing industries (D6.6). Offshore aquaculture facilities alone are more appealing to local residents than the multi-use approach with aquaculture and leisure facilities. In contrast, the majority of tourists are willing to support the offshore platform development in a multi-use approach, i.e. if leisure facilities and renewable energies are involved. Interestingly, in both, Gran Canaria and Taiwan, people show a positive willingness to pay for a sustainable development such as the TROPOS concepts, but only in Gran Canaria the willingness to pay overweight the costs (not in Taiwan). The most severe effects to be expected from the Sustainable Service Hub scenario are caused by noise and vibration, and emissions from vessel and helicopter traffic (D6.5, Annex). However, given that the Service Hub serves to reduce traffic and movement between an offshore wind farm and the shore, this TROPOS concept in fact helps to reduce the impact of these stressors on the local environment. In terms of socio-economic conditions, the Sustainable Service Hub seems to be beneficial for the region, without obvious negative impacts. The social acceptance of this concept, however, is difficult to predict (D6.5, Annex).

Based on the information from the environmental impact assessment, appropriate negative impact mitigation strategies were developed (D6.2) and specific monitoring programmes were adapted to each of the scenarios to minimize/avoid adverse effects on the environment and society (D6.3). The monitoring strategies particularly considered elements likely to be affected by the platform. To compare the impacts of the TROPOS multi-use platforms to single-use deployments, a precautionary approach was developed and applied (D6.5). The comparison showed that in most cases the adverse effects on the environment are reduced in the multi-use platform deployments. Taking the Green & Blue ‘Crete’ concept as an example, an analytical approach for the assessment of cumulative effects was developed, providing a valuable basis for the analysis of multi-use platform effects over large spatial areas and long temporal boundaries.

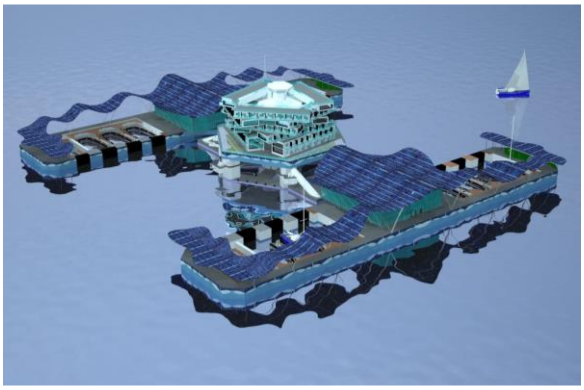
Within the scope of this objective based on impact assessments of multi-use offshore platforms, a close cooperation with the other Ocean of Tomorrow projects, in particular with MERMAID, was initiated. A key achievement in this cooperation was the generation of the shared database, the *HMT EIA Library* which was used by all three projects, H2OCEAN, MERMAID and TROPOS. The second significant output of this cooperation was the very close collaboration in the socio-economic impact assessment of the Taiwan scenario and the submission of a joint TROPOS/MERMAID cooperation deliverable (D6.6).

1.3.7 Complete solutions/final configured scenarios

The final TROPOS modular multi-use offshore platform scenarios were configured while considering all different aspects regarding site characteristics, economy, environment, technology, design, logistics and society.

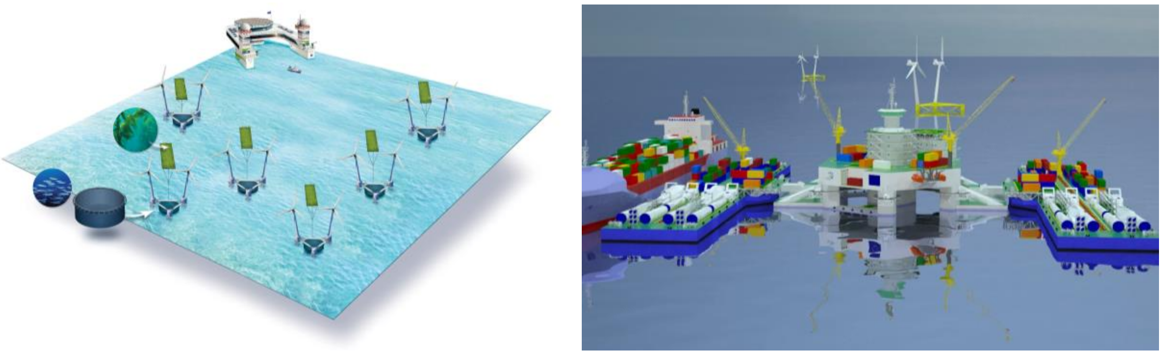
Three official final solutions were defined by the Interdisciplinary Cohesion Subcommittee (ICS), the TROPOS ICS scenarios (D4.3):

- **Leisure Island, Gran Canaria**. This scenario, located southwest of Gran Canaria Island, involves a multitude of leisure facilities for tourists and local residents, including the full range of hotel services. Energy demand of the platform is partially met by a photovoltaic (PV) plant; as backup additional electricity might be provided via an HVAC cable from land. This scenario does not involve satellites, but several modules integrated into the central unit platform: a visitors' centre, food & beverages, accommodation, monitoring, energy storage, and a marina. Visitors as well as staff are transported via daily shuttle transfers between Gran Canaria and the platform. Visitors can also approach the platform with private yachts by entering the marina.

Leisure Island – Conceptual design (left) and Engineering design (right)

- **Green & Blue, Crete**. In this scenario, situated north of Crete, fish and microalgae aquaculture are combined with a floating offshore wind farm. The aquaculture units are part of 30 floating satellite units, each consisting of one fish cage and one algae floater. Each satellite unit is equipped with two 2-3.3 MW wind turbines; some also include small photovoltaic (PV) units. Aquaculture units, wind turbines and PV units are controlled and monitored online from the central unit. The central unit includes a workshop, a fish processing unit, an algae biorefinery, storage facilities, accommodation for staff, and a substation for the electrical connection between wind turbines, central unit and onshore grid.



Green & Blue Crete – Conceptual design (left) and Engineering design (right)

- **Sustainable Service Hub, Dogger Bank**. This scenario, located in the central North Sea, focuses on transport and energy related needs of the offshore renewable energy sector and serves as an offshore wind hub for a wind farm assembled around the platform. The service hub consists of 4 modules: a quick reaction maintenance base, a substation, and an accommodation module for service staff and a helipad. The electrical energy generated by the wind turbines directly supplies the electrical power consumers of the entire facility. Due to the accommodation infrastructure for the workforces, this concept has capacity to host a large number of people. The infrastructure is also available for external visits (controlled and following strict security measures). The waste heat of the electricity generation is used for heating purposes.

Sustainable Service Hub – Conceptual design (left) and Engineering design (right)

According to the project title, the TROPOS Project aims at developing a floating modular multi-use platform system for use in deep waters, with an initial geographic focus on the Mediterranean, Tropical and Sub-Tropical regions. The Dogger Bank is neither a deep water habitat, nor it is located in a sub-tropical or tropical region. Nevertheless, the TROPOS platforms are designed to be flexible enough so as not to be limited in geographic scope, and the Dogger Bank Zone with its huge wind farm developments is the perfect site for the Sustainable Service Hub.

These three ICS scenarios were designed and specified in detail. Additionally to the official ICS scenarios, two future scenarios were developed:

- **Green & Blue, Taiwan**. In this scenario, located southwest of Taiwan close to Liuqiu Island, fish and macroalgae aquaculture are combined with a floating Ocean Thermal Energy Conversion (OTEC) for energy supply. The 8 MW OTEC plant, operated as a closed cycle system, uses the ocean's naturally available vertical temperature gradient to produce electrical energy. Beside the type of renewable energy source, another difference to the Green & Blue scenario in Crete is that the Liuqiu Island scenario platform also includes some (limited) leisure facilities, such as cafés, bars, restaurants and observatories for the public, and provides accommodation for visitors.

Green & Blue Taiwan – Conceptual design

Fish and macroalgae aquaculture units are located on 30 floating satellite constructions. The macroalgae floaters are located downstream of the fish cages, allowing for recycling of nutrients from fish excrement by the algae.

- **Offshore Container Terminal**. The constraining factor for the size of a vessel is the limitation in the dimensioning of ports. Today, many ports are excluded from direct services, due to their size, as they do not have infrastructures to cater for large container ships. But, in the best case, these ports are integrated into the global feeder routes. The feeder routes carry the cargo in small vessels towards some main port nodes where it is trans-shipped to large vessels to transport the payload to a hub port. This is the reason why the TROPOS project considered an offshore container terminal as an appropriate solution to overcome these challenges. The principal services which are provided by this platform concept include the provision of means and the organisation for container exchange, container loading/unloading and storage, receiving and shipping of containers, and staff accommodation.

Offshore Container Terminal – Conceptual design

Fresh water is generated by a desalination unit for all five TROPOS scenarios. Waste water is filtered and purified in a septic plant before being discharged. In case of the Leisure Island scenario, sewage will be transported to the shore as no discharge is allowed in the area. Solid waste is treated on board the central unit following best practice, including compacting, high quality incinerator and subsequent transport to shore (D3.5).

In order to compensate the lack of specific and comprehensive standards and approval procedures for multi-use offshore platforms, a new validation methodology particularly for multi-use offshore platforms was developed (D4.4). This methodology is applicable to any multi-use offshore platform concept developed within or beyond the TROPOS project.

1.3.8 Conclusion

During the TROPOS project a multitude of highly valuable insights were gained and novel inventions were made. The output involves innovative designs, optimum locations and advanced technological solutions for modular multi-use offshore platforms which were developed by taking environmental, social and economic aspects into account. The different scenarios developed in the scope of the project allowed for site- and concept-specific assessments and the comparison of social, environmental and economic impacts and logistic requirements of different multi-use offshore platform concepts. All the developed scenarios are feasible in terms of technology and logistics, and acceptable in terms of their environmental impact, provided that mitigation strategies are pursued and strict monitoring is applied. All scenarios have the potential to be built at least at pilot scale in the near future. However, the Sustainable Service Hub concept has currently the highest potential for near-term development. Considering all different aspects examined in the scope of the TROPOS project, the Sustainable Service Hub turned out to be the most economically viable and ecologically sustainable concept. The analysis revealed that an Offshore Wind Service Hub is already cost effective for wind farms of >200 MW. The Sustainable Service Hub will significantly contribute to a reduction of the impact of offshore wind farms on ecosystems as the amount of traffic will be significantly reduced through the presence of the Service Hub, and most of the traffic will occur in a limited area within the wind farm site.

The next essential step, which is urgently required now, is to move from the theoretical approach and modelled designs towards "real world" deployments. Even if financial support is possibly required at the beginning, pilot scale deployments are essential to proceed in the field of multi-use offshore installations, to work on and solve problems (e.g. in legislation or standards, as raised above), to test and improve the developed installations in reality and to monitor (positive and negative) effects of multi-use offshore platforms on the society, regional economy and environment.

1.4 Potential Impact

The TROPOS project is expected to have wide and lasting impacts on several levels and in different fields.

First and most obvious, innovative, **advanced technological solutions** for modular floating multi-use platforms are provided through the TROPOS project. This novel technology opens new possibilities and new areas. The floating construction allows for the operation in deep waters and for the exploitation of oceanic offshore resources where conventional platforms fixed at the seafloor with piles or tripods are not deployable. The entirely novel modular multi-use design also provides much room for synergies between different sectors and activities. The concept designs developed in the scope of the TROPOS project enable an optimal coupling of renewable energy exploitation, offshore aquaculture, maritime transport and leisure activities in a sustainable and eco-friendly manner. Compared to conventional offshore installations, the technological solutions and the multi-use approach allow for more activities of different sectors at one place while requiring less space and causing less negative impacts on the environment. This technological and conceptual development is an important step for the progress of all future offshore developments and makes an important contribution to the offshore industry.

Different **methodologies** were developed or adapted in TROPOS, which were then used as decision support tools and for evaluation purposes. These include the GIS decision support tool which serves the identification of optimum locations for multi-use platforms, the validation methodology developed to verify the platform design in the absence of specific standards and approval procedures, the methodological approaches developed to assess the environmental and socio-economic impacts of multi-use offshore platforms, and the development of appropriate environmental monitoring strategies. These methodologies may serve as guidelines and examples for future projects, facilitating and significantly accelerating decision and evaluation processes.

The multitude of **insights gained and lessons learned** during the project will significantly and positively influence future developments. There are not only insights concerning technological solutions for floating modular multi-use offshore platforms, but also with regard to economy, logistics, environment, society and regulation and legislation. Economic and logistic viabilities and potentials as well as limitations of the TROPOS scenarios were analysed: potential environmental impacts were identified and evaluated; negative impact mitigation strategies and monitoring programmes were developed; social perceptions and concerns were investigated, and existing gaps and requirements in regulations and legislation regarding multi-use platforms were identified. Not only future developers and operators, but also regulatory bodies can build on this existing knowledge, while avoiding problems and complications in designing and planning offshore platforms at an early stage. This will help the industry and the authorities to save time, efforts and costs.

In order to make sure that all the achievements of the project are **disseminated and available to the public**, TROPOS was represented on several national and international conferences by oral and/or poster presentations. Moreover, flyers and brochures illustrating the project and its progress were regularly updated and distributed, e.g. at conferences and meetings, and to various institutes and companies. In total, 6 newsletters were published to inform about news and the progress of the project. The public TROPOS website was regularly updated and provides detailed information about the project, news and events, and links to the deliverables and further information material. The efforts and achievements of the project have not only been published in newsletters and information material, but also in scientific journals. Details about the project were also distributed in face-to-face discussions during the socio-economic surveys.

With all these dissemination activities the TROPOS project enormously advanced the knowledge about multi-use offshore platforms, not only among confined scientific communities, such as engineers and environmental scientists, but also in terms of a better understanding of the wider public, developers and policy-makers about the possibilities of future marine activities and the implementation of large-scale offshore infrastructures. The dissemination activities and the socio-economic surveys contributed to a deeper comprehension of socio-economic impacts and indicated likely social implications of offshore platforms. It is expected that the TROPOS project also made large contributions to raising public awareness of offshore platforms. However, although TROPOS is a project of international scope that involves various stakeholders and geographic areas, distinct effects towards public awareness raising are certainly not limited to but more likely to be recognised locally where the TROPOS case studies are situated.

The possibly largest social implication is related to **awareness** raising in several regards. Different public activities of the TROPOS project made various stakeholders aware of the offshore industry, novel offshore infrastructures and future uses of the marine space. Local people at the case study sites have become more conscious of the novel infrastructures, learnt about what could happen and that such projects are technically feasible. People have not only discerned the technical viability of large-scale offshore platforms, but may have also come to the conclusion that offshore platform solutions are potentially desired and have slowly been launched by policy-makers. But in more detail it is also expected that local people have also become more aware of the opportunities that different uses of offshore platforms may entail as well as their potential impacts. The TROPOS project raised awareness of multiple uses of the offshore space in general and the possibility of integrating and combining specific uses of energy, aquaculture, leisure and transport activities in various platform concepts in particular.

With regard to potential benefits of multi-use offshore platforms, the TROPOS project has not only led to a greater awareness of the purposes of particular platform concepts *per se*, but affected stakeholders may have also become more aware of broader notions, such as sustainability. TROPOS may have prompted an increased awareness of sustainability among local stakeholders, and advanced the knowledge of how sustainable concepts can be implemented and integrated in large-scale projects. Another benefit, at a more notional level, is the sustainable conception of various platform modules which can also result in a greater awareness of adequate local responses to climate change which do not normatively undermine but particularly focus on local economic activities. Instead of imposing predefined and fixed platform concepts on certain areas, the TROPOS approach based on multi-use solutions demonstrated some flexibility to respond to local activities and needs. In general, the public relations activities and local consultation efforts with residents, tourists and local experts are also hoped to have demonstrated that local input and tacit knowledge is desired and required to achieve a better fit of various platform concepts and local settings, which has been proven with the Leisure Island and Green & Blue concepts for Gran Canaria and Taiwan. Therefore, the **acceptance** of real future installations might be higher in these locations as people have been made aware of these kind of developments due to the preparatory work of TROPOS, especially when they feel their interests and concerns were sufficiently taken into account. However, these efforts have to be maintained and extended when it comes to the real planning stage.

In contrast to the early favourable uptake of such projects, and when being confronted with potential environmental and socio-economic impacts of the platforms, local people have certainly become more conscious about the potential ambivalence of local benefits and impacts. Local people involved in TROPOS should now be more aware of the fact that direct local benefits of the platform concepts, e.g. job creation, may also entail potential impacts on the environment and traditional economic foundations of local areas, such as fishing and tourism businesses. But an increased awareness of impacts also comprises considerations of how these impacts can be most adequately addressed and mitigated. This leads again to questions of how such developments can be most effectively integrated and embedded in the local context. The diversity and partial ambivalence of expected or perceived impacts have been reflected in the results of the social acceptance study, demonstrating a large initial acceptance of such hypothetical projects in both Gran Canaria and Taiwan, but also some site-specific concerns. Knowledge about and awareness of local characteristics and potential impacts clearly influences the articulation of concerns. This implies a need for a continuous information provision about the progress of such projects as a crucial factor that can shape people's attitudes towards a certain offshore platform project and concept.

Moreover, knowledge, awareness of and experience with such novel projects can influence how certain people evaluate the technology. Knowledge about how such a development works, what purposes and modules it involves and what effects it might have can influence the perception of costs, risks and benefits of a multi-use offshore platform and indirectly shape its acceptability. Although experience is related to knowledge and awareness of projects, awareness does not necessarily include experiences. Only real-life experience can reshape the perception of previously expected costs, risks and benefits, which rather remain hypothetical, theoretical and perhaps contested until novel platforms are in place. But this also means that attitudes towards such a project can change after its implementation, and, in turn, that acceptance may influence the uptake of provided project information.

Likewise, feeding information back to people on how their consulted input has been regarded and may have influenced the project development, design and mitigation strategies can result in a greater acceptance and ultimately in a more appropriate local embeddedness of a platform at later stages. Questions related to procedural justice including perceived unfairness and inadequacy of the planning process have often been stated to be a crucial factor influencing social acceptance of novel infrastructures. By taking account of local concerns and opinions of particular and possibly affected stakeholders at early stages, the TROPOS project took a first important step for not repeating the deficiencies that have emerged from early development stages of other offshore developments, such as wind farms. However, this initial good practice has to be perpetuated at potential later planning stages to have an even greater positive impact and not to nullify the efforts of the TROPOS project.

Another meaningful implication of the TROPOS project accrues from the examined **perception of socio-economic impacts** of large-scale offshore platforms at various locations. Drawing on learning points and findings from studies focusing on social implications of offshore renewables, findings from the TROPOS project hint at more positive socio-economic repercussions through a strengthening of the economic position of the local areas by attracting visitors, generating income and jobs and boosting the image of the area due to the innovative and sustainable nature of the offshore platform. But despite largely positive economic impacts, initial results also suggest potential adverse economic and environmental effects that also need to be carefully taken into account when going ahead with the planning of offshore platforms. Potential socio-economic impacts emerging from the construction of other offshore infrastructures refer to local property values, tourism businesses and fishing communities. Results from the TROPOS assessments of perceived impacts indicate that these groups also feel affected by the development of offshore platforms and their specific uses.

The TROPOS project has also helped to **target particular audiences** from the offshore industry, developers and policy-makers. It determined the future directions for developing multi-use offshore platforms and also pointed out issues to be taken into account. In doing so, TROPOS delivered detailed information about the compatibility of multiple uses in a platform. This is of particular relevance to potential future developers. The TROPOS project not only provided information on mere conceptual solutions, but also detailed strategies on how offshore platforms could be developed, designed, constructed and maintained. The different work packages of the project carved out development strategies and provided evidence of what is required when implementing such a project from the technical side of things, pointed out planning-related issues, and suggested various modules and requirements for the use of offshore platforms. This is not only expected to provide learning points for developers of offshore platforms, but also for any developers or decision-makers involved in the development of offshore infrastructures. New stakeholder networks have been created through TROPOS and its sister projects which offer valuable opportunities for the transfer of knowledge between different scientific communities, industry sectors and international policy-makers. TROPOS paved the way for harnessing sustainable offshore resources and provides a robust foundation and knowledge base for an innovative offshore economy in the future.

Collaborations and interactions of different communities from academia, industry, policy-making and the public underpinned the combined value of multi-disciplinary input and expertise. Therefore, TROPOS also provided a clear indication of what is required and what should be considered when planning and building infrastructures in such a unique environment. Given the scope and size of such infrastructure projects potential impacts should be considered from the very beginning in order to avoid later pitfalls and obstacles arising from impacts and possible conflicts. As reflected by the assessments of the TROPOS project, developers and decision-makers are well-advised to consider and address impacts on the landscape/seascape and marine ecosystems as well as values and practices of fishing communities, the tourist sector and local residents. From a social acceptance point of view good practice should therefore include a thorough engagement of and dialogue with all relevant stakeholders and communities as well as a steady information provision and the dissemination of progress reports.

Finally, the TROPOS project has shown **that strengths and effects of proposed offshore platforms** are highly concept- and site-specific. Although offshore platforms are anticipated to bring numerous socio-economic benefits, the findings of the TROPOS project also suggest that local concerns are often related to the purpose of the platforms (tourism/leisure and fishing/aquaculture) which overlap with traditional economic foundations of local areas. On the one hand, multi-use offshore platforms would secure the competiveness of local areas by adding innovative and novel structures that complement local socio-economic conditions, enhance the quality of life as well as community cohesion, and add to the values of local people. On the other hand, this must not be achieved at the expense of but in line with traditional and possibly vulnerable local businesses that may have the same economic focus as the platform concepts.

1.5 Contact

Public website address: http://www.tropos platform.eu

The following table shows the involved partners in the project and a contact person per organization:

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