

# Chapter 12

## The EU-Project “TROPOS”

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**Abstract** The global population is growing and the demand for food and energy is steadily increasing. Coastal space all over the world becomes increasingly limited and near-shore resources are often already heavily exploited. The use of offshore regions may provide new opportunities, but also involves major challenges such as the development of designs and technologies suitable for offshore condition. The floating TROPOS ‘Green & Blue’ modular multi-use platform concept introduced in this chapter is especially designed for offshore conditions and provides solutions for the problems and obstacles involved in “moving offshore”. The Green & Blue platform concept integrates fish and algae aquaculture with a wind farm. The floating multi-use approach allows for platform operation in deep waters and the promotion of synergies such as joint logistics, shared infrastructure and services, thereby making the use of offshore resources viable and profitable.

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## 12.1 Introduction

### 12.1.1 *Moving Offshore*

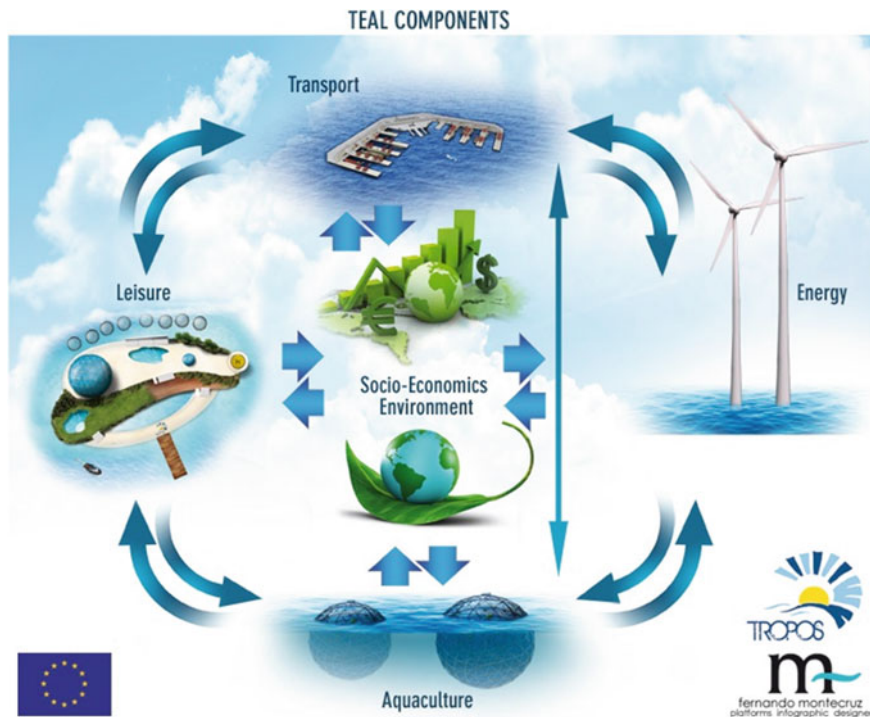
Coastal space all over the world has become increasingly limited and near-shore resources are often already heavily exploited. As a consequence, there is a growing call to move towards offshore aquaculture technologies. The advantages of offshore aquaculture compared to coastal aquaculture include, e.g., fewer restrictions (environmental, geographical, political), less competition for space with other activities (Ryan 2004), and better environmental conditions which result in improved fish growth, more efficient feed conversion, and a lower risk for pathogen infection (Ryan et al. 2007). Additionally, moving from protected areas of restricted water circulation to more exposed sea conditions allows farms with higher production capacity without increasing environmental impacts (Lu et al. 2014). However, moving offshore involves some major challenges, among others, high costs for the required infrastructure and transportation, more difficult access to services, supply and markets, and the need to adapt methodologies and procedures to offshore conditions. The best approach to overcome these problems is the development of shared solutions with other offshore sectors, i.e. to find and make use of synergies for a common use of sea space, infrastructure, resources (energy, water, supplies), services (maintenance, monitoring, surveillance) and transportation.

Accordingly, the European Union has launched the “The Ocean of Tomorrow” call in the 7th Framework Programme (FP7) for Research and Development, with one topic being “Multi-use Offshore Platforms” (OCEAN 2011.1). In total, three projects were selected and received funding for the design of multi-use offshore platforms: H2OCEAN, MERMAID and TROPOS. The latter one, the TROPOS project, is presented in this chapter.

### 12.1.2 *About TROPOS*

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*”. TROPOS had a total project duration of 3 years (January 2012–January 2015). 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 TROPOS project aimed at developing a floating modular multi-use platform system for use in deep waters, with an initial focus on Mediterranean and subtropical regions (Quevedo et al. 2012). Multi-use offshore platforms should allow for sustainable and eco-friendly uses and a synergistic exploitation of oceanic resources. A floating design facilitates access to deep sea areas and resources where deployment of conventional platform types is not possible. A modular multi-use



**Fig. 12.1** The TROPOS TEAL (Transport, Energy, Aquaculture, Leisure) components (Fernando Montecruz for the TROPOS project)

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; Fig. 12.1). *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 fight climate change, which has become one of the most critical global 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.

The development process involved successive iterations to find feasible solutions restricted by technical, environmental and socio-economic constrains. A multidisciplinary and cross sectorial team of specialists developed several tools to

explore suitable sites, combinations of resources, synergies, structural solutions and their technical, environmental and socio-economic viabilities. The analyses also included logistics, security, installation, operational, decommissioning and maintenance requirements. The outcome of the development process included different theoretical platform concepts, designed and specified in great detail based on simulations and models which were validated by experimental tests of realistic small-scale models. The developed TROPOS concepts included the so-called “Sustainable Service Hub”, “Leisure Island” and the “Green & Blue” concept. The latter one, the Green & Blue concept, integrates offshore aquaculture and renewable energies (Papandroulakis et al. 2014).

### ***12.1.3 Aquaculture in TROPOS***

Human population is growing and the demand for seafood is steadily increasing. Marine organisms are a source of high quality nutrients (proteins, essential fatty acids, vitamins, minerals, etc.) which are fundamental in human nutrition, but are also an important component in animal feeds and non-food sectors (e.g. cosmetic products). As the availability of natural resources is limited, an increasing amount of the demand has to be covered by aquaculture products. Aquaculture is the fastest growing economic area in the food industry sector and the proportion of the world’s food fish coming from aquaculture has risen in 2006 to almost half (FAO 2014). With the increasing demand for seafood the fish-farming industry will have to continue this trend (Cressey 2009). Accordingly, the integration of aquaculture in the TROPOS multi-use concepts was of major interest.

The European aquaculture sector has access to dynamic and cutting-edge research and technologies, advanced equipment and fish feed. Production currently meets the requirements for environmental protection, and the final products are traceable and meet high quality standards. The European Aquaculture Technology and Innovation Platform (EATiP) has set several objectives for the sector to achieve by 2030. Particularly for the Mediterranean, the target is to increase production by 200%. This production scenario will increase the current production from 230,000 to 690,000 t. To meet this objective, EATiP has defined the development of efficient technologies (such as developed in the scope of TROPOS) to support continued growth as one of its strategic goals.

Considering the expected growth of the aquaculture industry and the market globalization, the targeted species, regardless of group (i.e. fish, shellfish, algae), have to shift to those with global distribution and market. The target species should be a fast growing and well adapted to the environmental conditions offshore and clear oceanic waters. Among finfish, typical target species are large, fast growing pelagic and deep demersal species, such as the greater amberjack and the wreckfish; both species recently became targets for developing innovative and efficient rearing technologies.

In TROPOS, the main focus was not only on finfish but also on microalgae aquaculture.

Microalgae are not only of high interest in the food and feed sectors, but also for the production of biofuel (Enzing et al. 2014). The market volume and value of microalgae range over a broad scale from 1,000–5,000 €/t for high volume biofuels to 10,000–35,000 €/t for high value food. The value of microalgae used for pharmaceuticals is even higher. In the aquaculture industry microalgae are important as feed for early developmental stages of several species (larvae of molluscs, echinoderms, crustaceans, fish), with a worldwide annual production of approximately 10,000 t/year and a market value of about 30–250 €/kg. Approximately  $\frac{1}{5}$  of this biomass is used for larval stages of fish and shellfish reared in hatcheries (Muller-Feuga 2004). The most frequently used species are *Chlorella*, *Tetraselmis*, *Dunaliella*, *Isochrysis*, *Pavlova*, *Nannochloropsis*, *Phaeodactylum*, *Chaetoceros*, *Skeletonema* and *Thalassiosira* (Spolaore et al. 2006).

The greatest demand for microalgae lies in its potential to replace the current sources of PUFA (PolyUnsaturated Fatty Acids; Omega 3/6 fatty acids). The increasing public debate on the use of fishmeal for aquaculture puts microalgae in the focus as substitute for fishmeal, and Omega-3 industries increasingly produce concentrated EPA (eicosapentaenoic acid) and DHA (Docosahexaenoic acid) oils for human consumption.

Microalgae (and macroalgae) are also considered as possible substitute for fossil fuels. Despite a large body of research in the area of photosynthesis for carbon sequestration, little work has been done to develop practical algae production systems that do not ignore land availability limitations and can be installed at any location for the production of fuels, food and animal feed. Offshore algae production could fill that gap and allow the energy and cost efficient high volume conversion into biofuels.

## 12.2 The Conceptual Approach of TROPOS

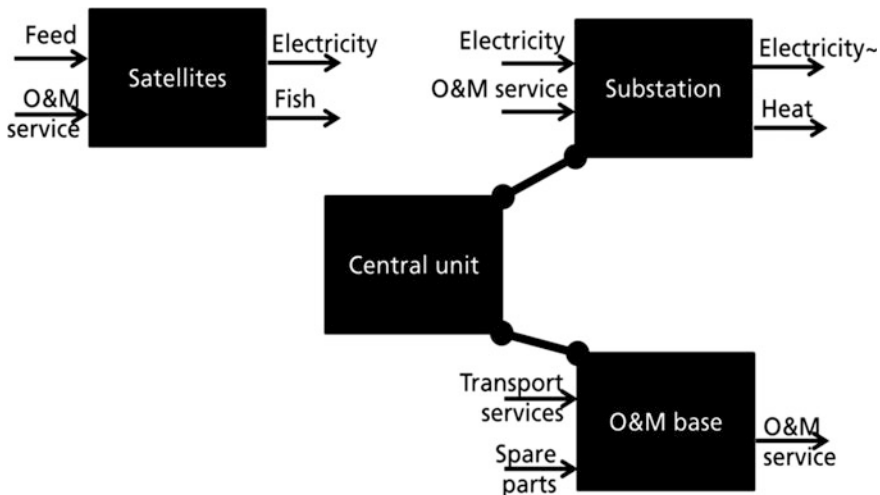
### 12.2.1 General Platform Design

The key characteristics of the TROPOS platform concepts are (i) the floating design which enables platform operation in deep waters, (ii) the multi-use concept which supports the integration of different functions and services at one site and facilitates synergies, e.g. by joint logistic, and (iii) the modular approach which allows for a flexible combination of different types of modules adapted to requirements. In this way, the TROPOS multi-use platform system is able to integrate a full range of functions from the four TEAL sectors (Fig. 12.1) and can be perfectly adapted and used in a much greater number of global geographical locations than a non-floating, non-modular and/or a single-use platform design.

The conceptual design of the TROPOS platform involves a central unit associated with modules and satellites (TROPOS 2013b, 2015). This floating central unit can be moored to the seafloor and builds the core of the platform. The lower part of the central unit is equipped with a double hull to prevent oil spills. Modules with different functions can be directly attached to 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.

In Fig. 12.2, a schematic representation of platform elements and their functional connections is shown as an example. In this example the platform is composed of the central unit, two modules (substation and operation & maintenance base) and one type of satellite (renewable energy and fish aquaculture). Functional units are shown as black boxes, with the specific inputs and outputs relevant for their functionality (TROPOS 2014b).

The design and engineering specifications of the platform concept considers extreme weather conditions and unplanned events to be prepared for all kinds of emergencies. Safety and security of crew and visitors, and protection of the environment, are the top priority in the design of the TROPOS scenarios.



**Fig. 12.2** Schematic example of TROPOS platform functional units and their connections. The example shows the main in and outputs of the satellite unit and two modules integrated into the central unit: a substation module representing the electrical connection between central unit and satellites, and an operation and maintenance (O&M) module (Source TROPOS 2014b)

Different concepts with different combinations of functional units from the TEAL sectors were developed in the project, among these, the so-called “*Green & Blue*” concept which is specified below.

### ***12.2.2 The Green & Blue Concept***

The Green & Blue concept is focusing on the use of physical and biological resources, intending to follow the strategies and actions of “Blue Growth<sup>1</sup>” as defined by the European Commission for the development of aquaculture and renewable energies in the EU. The Green & Blue concept integrates offshore aquaculture and renewable energies.

Depending on platform location and local conditions and dynamics, the renewable energy source to be harnessed might be wind, waves, solar or ocean thermal energy (Quevedo et al. 2013). Accordingly, the renewable energy component of the concept may be represented by a wind farm, wave energy converters, photovoltaic (PV) panels or an OTEC (Ocean Thermal Energy Conversion) plant.

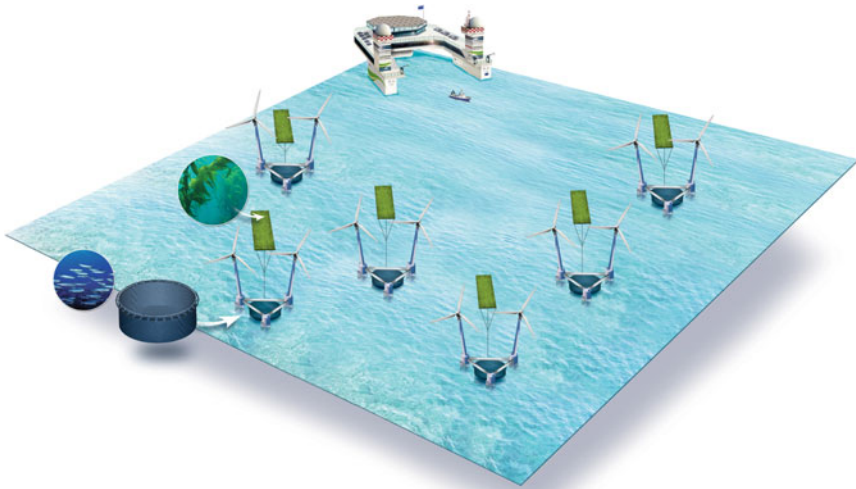
The aquaculture component of the Green & Blue concept primarily includes fish and algae aquaculture. Generally, the fish culture unit is planned in the form of floating, submerged or drifting cages. Depending on the location, secondary cultures around the fish cages may be developed for bivalves and/or macroalgae. Additionally, if the location’s depth allows such an activity, bottom cultures could be established. The algae culture unit can include several components, e.g. production of biomass (microalgae and macroalgae), products with high market value, and biofuel/gasification from macro and microalgae, and CO<sub>2</sub> fixation from flue gases. Wastewater e.g. domestic wastes from a central platform can be used to nourish algae, thereby combining algae biomass production with wastewater treatment. The source for the flue gas may be emissions from the satellite or the central platform or from on-shore emission sites as CO<sub>2</sub>-stripping at a biogas plant.

The aquaculture units (both fish and algae) take advantage of the facilities that the platform offers, namely energy, protection, anchoring and logistics with regard to installation, maintenance and operation. An example for a Green & Blue concept integrating offshore fish and algae aquaculture and wind turbines is shown in Fig. 12.3.

One Green & Blue case scenario, developed in TROPOS and designed to be located in the Mediterranean Sea in deep water locations, is described in more detail below.

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<sup>1</sup>“Blue Growth” refers to the European Commission’s long term strategy to support sustainable growth in the marine and maritime sectors.



Source: Papandroulakis, Fernando Montecruz, 2013a

**Fig. 12.3** Green & Blue concept integrating offshore fish and algae aquaculture and wind turbines (Fernando Montecruz for the TROPOS project)

## 12.3 The Green & Blue Concept in the Mediterranean

One Green & Blue platform was designed for a location north of Crete (southern Aegean Sea) at about 100 km distance from the shore in about 450 m water depth (Fig. 12.4). The site was chosen based on a GIS supported multi-criteria decision analysis, which also considered socio-economic and environmental aspects. Climatic, geographic and oceanographic characteristics and dynamics in this area were found to be appropriate for this platform concept (TROPOS 2013a).

In this particular scenario, fish and microalgae aquaculture are combined with wind turbines and some PV panels (see Fig. 12.3). The scenario includes six modules (integrated into the central unit) which aim to service, maintain and monitor the satellite units and to ensure smooth and optimal energy and biomass production flow. In all, there are 30 floating satellite units placed around the central unit, which comprise the wind turbines, some PV panels, as well as fish cages and algae floaters.

### 12.3.1 Central Unit

In this concept, the central unit extends over several decks and hosts all functions and services that are needed for the daily operational requirements of the platform. This includes, among others, the engine, diesel oil tanks, waste and wastewater





**Fig. 12.4** Approximate Green & Blue platform location in the Mediterranean, north of Crete (Map created by Fernando Montecruz for the TROPOS project)

storage and treatment plants, transformers, a desalination unit for freshwater production, freshwater tanks, different kind of workshops, maintenance and repair areas, air conditioning and storage rooms. Moreover the central unit hosts fire-fighting system, control, surveillance & monitoring rooms, and also offices, common and leisure rooms, laundry, kitchen and hospital (TROPOS 2014b). The energy demand of the platform will be completely met by the locally produced renewable energy; the diesel engine mainly serves as a backup in case of emergency or deficiency of the natural energy resource. Waste and wastewater produced during the operational phase of the platform will be treated following best practice and stored on board until it can be transferred to shore. Both aquaculture and energy production require specific facilities for proper operation. These facilities are organized in different modules on the central unit.

### 12.3.2 Modules

The major objectives of the modules integrated into the central unit in the Green & Blue concept are for monitoring, service, maintenance and processing of the energy and aquaculture production on the satellite units (TROPOS 2014a). These modules include

- The fish processing plant
- The aquaculture workshop
- The aquaculture support
- The algae biorefinery
- The substation
- Accommodation facilities

The fish processing plant provides all facilities required for processing the fish production. Generally, fish biomass produced in a farm may be either being processed on site or transported to another processing facility according to the business plan that will be followed. While for land-based or nearshore aquaculture the processing units are close to markets and the flow of product is continuous. This is not the case for offshore farms where connection with land is neither easy nor daily. Hence, an on-site processing unit is a requisite in order to prolong product's shelf life from days to weeks depending on the processing level. Also, the disadvantages of the offshore farms due to distance may turn to benefits with the production of value added products. Existing alternatives to this approach represent the use of a "boat-factory" which, however, presents some disadvantages related to dependencies on external services and the minimization of flexibilities for marketing.

In the plant, the harvested fresh fish can be directly processed without any delay. The module includes the processing facilities leading to 3 groups of products: (i) fresh fish on ice, (ii) degutted fish, subsequently IQF (Individually Quick Frozen), and (iii) processed fish (fillets or steaks) either IQF or packed in MAP (Modified Atmosphere Packaging). Special care is given to byproducts (estimated at ~20% of the biomass) that are also marketed. There are cooling and freezing rooms, storages, warehouse for packaging material and an ice-production unit.

The aquaculture workshop includes a maintenance unit for repairing equipment, warehouses for storage of harvesting equipment, nets and spare parts.

The aquaculture support module includes a central communication room for control, surveillance and monitoring of the aquaculture production and environmental parameters, and for operation and control of the automated feeding system. The module also includes laboratories both for biological analysis and electronics.

In the algae biorefinery, the harvested microalgae may undergo further processing, such as extraction of proteins, lipids, carbohydrates or pigments, and conversion to biofuel.

The substation is connected to the wind farm and serves as infield cable node, voltage transformation and/or current conversion system and export cable connector between the satellite units, the central unit and the onshore grid. To establish such connection, it is necessary for the substation to have specific power transmission capabilities in combination with distinctive voltage transformation functionalities.

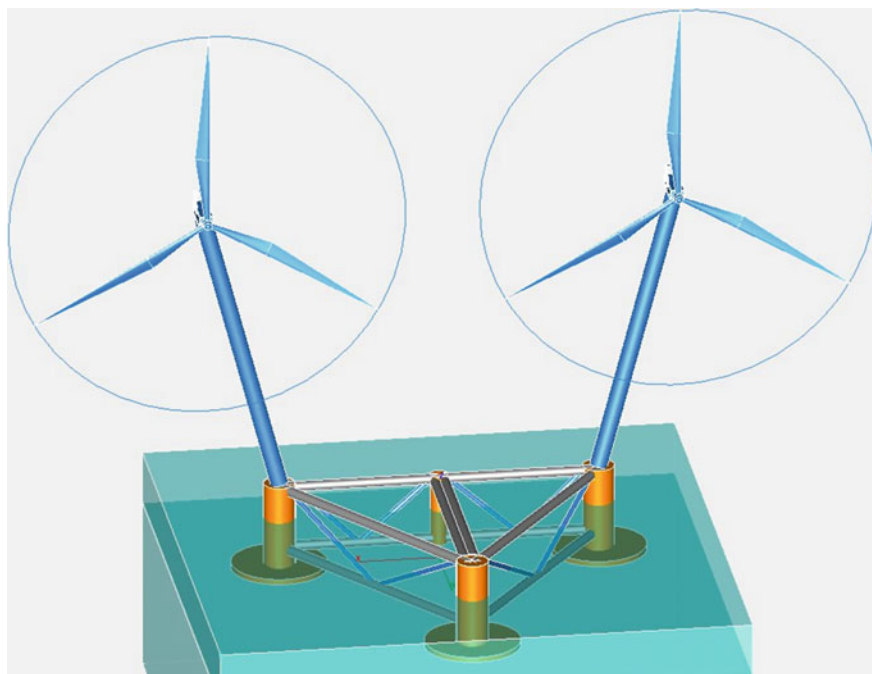
The accommodation module provides living space for crew and visitors.

### 12.3.3 Satellite Units

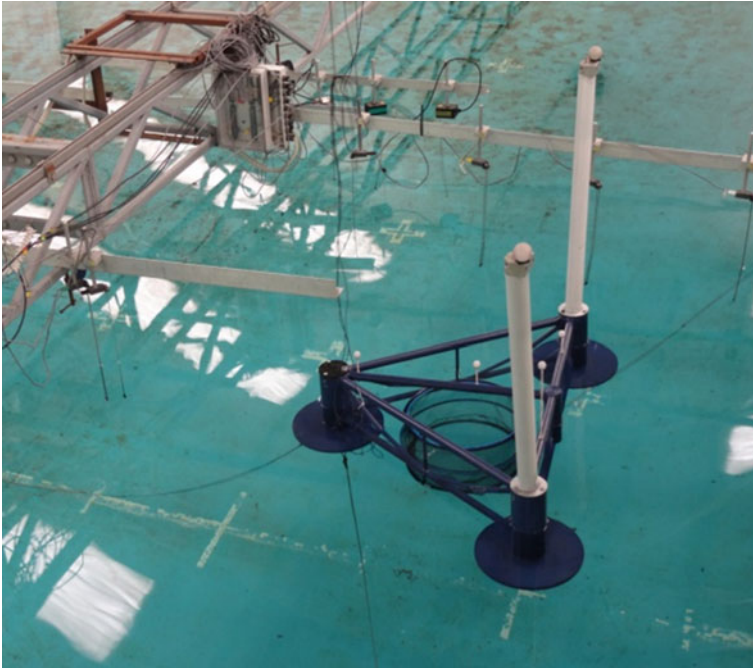
The Green & Blue scenario off Crete consists of 30 floating triangular satellite units. Each semi-submersible satellite unit is equipped with two 3.5 MW wind turbines (Fig. 12.5). Some units also include small 434 kW PV panels. The wind turbines have a rotor diameter of 112 m and total production of all 60 turbines (2 per satellite unit) was estimated with about 198 MW (TROPOS 2013c).

According to the design, 30 units will be installed allowing a maximum production capacity of 750 t fish per week. In each unit an open sea surface cage is integrated at the inert part of the triangular base (Figs. 12.4 and 12.6). All daily operational equipment including feed distributor, feed storage silos (66 t, 100 m<sup>3</sup>) and monitoring equipment are incorporated to the base, and are remotely controlled from the central platform. For the Green & Blue platform in the Mediterranean, the production plan includes the rearing of 3 different species in two-year rearing cycles: (i) the European Sea Bass (*Dicentrarchus labrax*), (ii) the Meagre (*Argyrosomus regius*), and (iii) the Greater Amberjack (*Seriola dumerili*).

The cage is a typical cylindrical floating offshore cage of 33/36 m (internal/external) diameter. The volume contained in the net cage is about 25,000 m<sup>3</sup>. In some of the units, the top of the fish cage is covered by solar panels for additional energy production (TROPOS 2013c).



**Fig. 12.5** 3D view of a floating wind satellite unit designed by EnerOcean S.L. for the TROPOS Green & Blue concept based on W2Power patented design (Source TROPOS 2013c)



**Fig. 12.6** A model of the Green & Blue satellite unit triangular base structure with the fish net cage inside; the model was tested at the UCC-BEAUFORT (HMRC)—National Ocean Wave Basin in Cork (Ireland), model scale 1:100 (Source TROPOS 2014c)

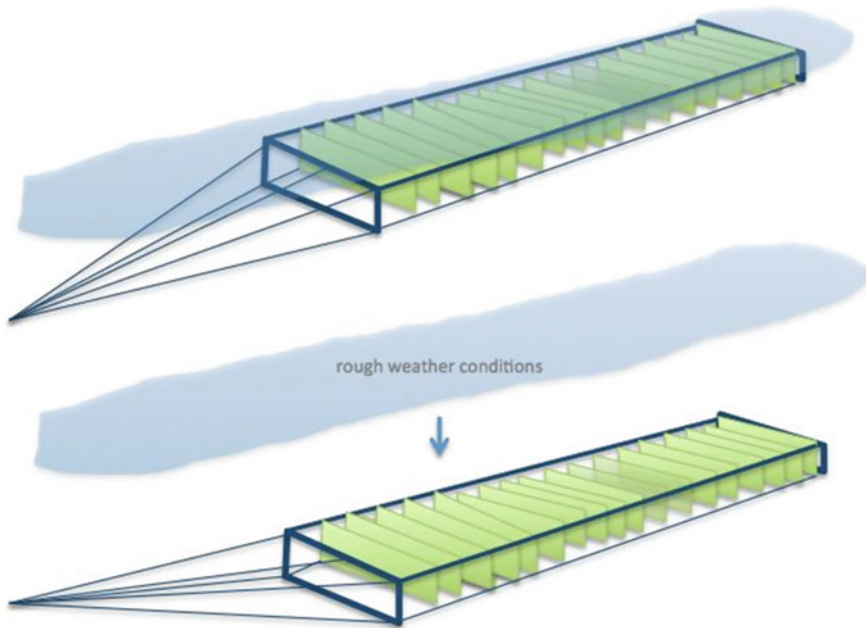
The microalgae production unit or floater containing the microalgae cultures is connected to the triangular construction, one floater per satellite unit, making a total of 30 algae floaters (Fig. 12.3). These photo-bioreactors are a closed system. The dimensions of a floater are  $50 \times 200$  m with an inserted phytoplankton unit of  $400 \text{ m}^3$ . Two thrusters, located at the end of the plant, help to manoeuvre the submersible culture system (Fig. 12.7).

The satellite units are unmanned and monitored, operated and controlled from the central unit. The fish cages and the algae photo-bioreactors are equipped with sensors for online control and monitoring from the aquaculture modules.

Energy demands of the sensors as well as of the automated fish feeding system are met by the local production from wind and/or solar energy. Service and maintenance are provided by a crew based on the central unit.

In summary, the final layout of the satellite is comprised of:

- Two turbines (3.5 MW each/90 m height) installed on a triangular shaped platform (column distance (base) 90 m/column distance (triangle legs) 80 m) and their auxiliary component to enable an appropriate grid connection.
- A cage for aquaculture moored between the triangular legs ( $25,000 \text{ m}^3$ /diameter 33 m/depth 30 m).



**Fig. 12.7** Algae aquaculture part of the Green & Blue satellite unit; the submersible algae floater is equipped with two thrusters (Source TROPOS 2014c)

- An Algae Production Unit connected to the wind satellite unit at a single point.
- An automatic feeding system (64 t in two silos with two different feeds and a distribution system located on the “vertical columns” of the triangle).
- An automatic feeding system for algae production (50 t CO<sub>2</sub> storage + nutrients).
- PV panels are installed on the top of the module for an additive 0.5 MW per satellite

### 12.3.4 Aquaculture Production Flow

Based on a theoretical production analysis the total aquaculture yield in the Green & Blue scenario in the Mediterranean is estimated to be 7,000 t of fish in a biannual production cycle and 2,000 t of algae in continuous production.

#### 12.3.4.1 Finfish Aquaculture

The fish production plan developed for this Green & Blue scenario involves the rearing of three different species in a two-year rearing cycles. Taking advantage of the different natural spawning period of the selected species and in order to avoid an

overlap in harvesting, stocking of cages is performed annually with half of the dedicated cages for each species as follows:

- European sea bass (*Dicentrarchus labrax*) a total of 8 cages; stocking 1 cage per month in February, March, April and May every year;
- Greater amberjack (*Seriola dumerili*) a total of 10 cages; stocking 5 cages in July every year;
- Meagre (*Argyrosomus regius*) a total of 10 cages; stocking five cages in October every year.

The 2 remaining fish cages serve as backup units. The stocking with fry will be followed by a rearing period of 2 years until market-size is reached (European sea bass 0.6 kg, greater amberjack 3 kg, meagre 2.5 kg). Fish will be fed with artificial feeds delivered by the automated feeding system. The amount of feed is based on the demand. Feeds will be transferred from cargo boats directly to the satellites and the silos will be loaded monthly.

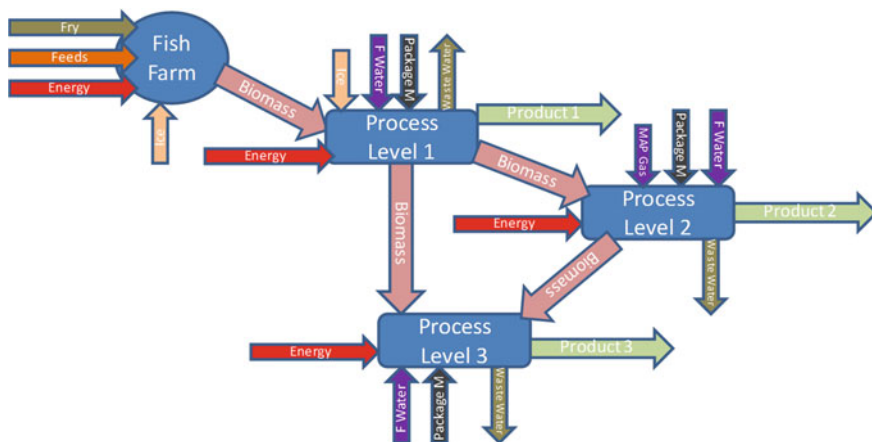
Fish harvesting from the cages will be performed with a fish-pump mounted on a working barge and the harvested biomass will be transported to the central unit. The same fish-pump is used to upload the fish to the aquaculture module on the central platform (TROPOS 2013c).

In Table 12.1 the results of a production analysis performed on a monthly basis are shown. For all three fish species the amount of required feed, energy, ice for

**Table 12.1** Production analysis (input/output table) of the complete Green & Blue fish aquaculture farm in the Mediterranean

	Species	Fish fry (1000 ind.)	Feeds (t)	Energy (kWh)	Ice (t)	Harvested fish (1000 ind.)	Harvested biomass (t)
January	European seabass	641	735	145,306	152	507	304
February		641	774	134,536	152	507	304
March		641	807	145,156	152	507	304
April		641	829	141,316	152	507	304
May	Greater amberjack		819	146,138	256	342	512
June		410	748	142,736	292	195	584
July		410	717	146,276	292	195	584
August		205	745	144,808	146	97	292
September	Meagre		763	142,598	256	427	512
October		513	706	146,372	304	243	608
November		513	657	142,832	304	243	608
December		256	678	144,856	152	122	304
Total		<b>4873</b>	<b>8980</b>	<b>1,722,930</b>	<b>2610</b>	<b>3892</b>	<b>5220</b>
Monthly average (t)		487	748	143,578	218	324	435

Source (TROPOS 2014b)



**Fig. 12.8** Fish aquaculture and processing plant flow chart including all inputs and outputs in the Green & Blue concept (Source TROPOS 2014b)

conservation of the final product, and the number and total biomass of harvested fish was calculated.

After harvesting, the fish biomass processing in the processing module is organized in 3 levels (Fig. 12.8):

- Process Level 1, Basic Processing—in this step fish are processed after harvest either as fresh product (product 1) or pretreated for further processing in process levels 2 or 3.
- Process Level 2, Filet Processing and Modified Atmosphere Packaging—in this step fish are processed to produce filets and other products that require packaging in a modified atmosphere.
- Process Level 3, IQF (Individually Quick Frozen) Processing—in this step the final product is frozen biomass. Biomass inputs to this process level 3 are whole fish from process level 1 and filet from process level 2.

The outputs from levels 2 and 3, apart from the final product include a significant amount of byproducts, which are not considered waste but as a primary material for other industries (e.g. fish meal production). Therefore, all byproducts are refrigerated and exported (TROPOS 2014b).

In terms of biomass, the total products from the Green & Blue fish aquaculture are about 25% fresh fish, 55% transformed (Individually Quick Freezing/Modified Atmosphere Product), 20% byproducts.

All the energy required for the operation of the fish aquaculture in the Green & Blue scenario will be provided by the local renewable energy production.

### 12.3.4.2 Microalgae Aquaculture

The algae production starts with the seeding of a microalgae starter-culture in the closed photo-bioreactors on the algae floaters. The key parameters for the algae production are irradiance, nutrients and size of installation. As the microalgae are in a closed system, the medium will be supplemented with some nutrients, such as nitrogen (9 t/year), phosphorus and micronutrients (1.5 t/year) (Table 12.2). CO<sub>2</sub> is also applied to enhance the production yield. This will be done by direct injection from a 50 t cryogenic CO<sub>2</sub> storage with assistance of an air blower.

The online control system allows monitoring and controlling of the production process inside the photo-bioreactors from board of the central unit. The unit is operating valves and pumps and measures, among other parameters, temperature, the pH value and the optical density in the system continuously. Environmental ambient parameters like irradiance and temperature are also recorded.

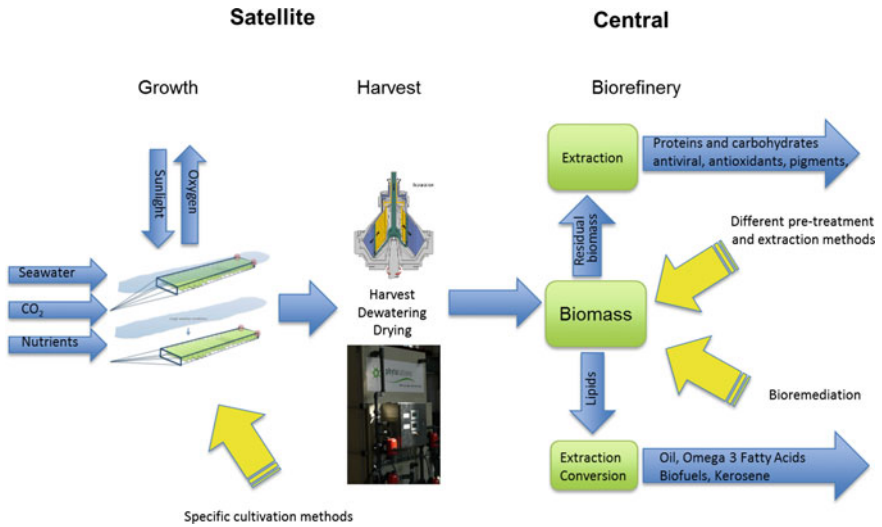
When the microalgae culture reaches the desired concentration the culture is harvested. The actual harvesting step of algae from the photo-bioreactors is carried out on the satellite and the biomass is then shuttled to the central platform for storage and further downstreaming. A two-step algae harvest is implemented with a first step consisting in a pre-concentration of the algae suspension followed by a second step of centrifugation. The dewatered algae biomass is then dried by spray-dryer or solar-dryer and either cold stored until transport to the shore or

**Table 12.2** Details on the algae aquaculture production unit, including dimension of floaters, inputs in terms of nutrients and output in terms of production as calculated based on a production analysis

Algae aquaculture				
Component	Subsystem	Number	Units	
Units	Number of units	30		
	Dimension	Length	200	m
		Beam	50	m
		Area	10,000	m <sup>2</sup>
	Production per unit	65	t/a	
Total production (6–8 months, 30 units)	1950	t/a		
Store nutrients	Nitrogen consumption per unit	9.0	t/a	
	Phosphorus and micronutrients consumption per unit	1.5	t/a	
	Volume per unit (Phytoplant)	400	m <sup>3</sup>	
Production capacity	Max. production per week	750	t	
	Production per day	300	t	

Source (TROPOS 2013c)





**Fig. 12.9** Algae aquaculture production and processing; flow chart including all inputs and outputs in the Green & Blue concept (© by Phytolutions)

**Table 12.3** Estimated microalgae production per month considering all 30 satellites units of the Green & Blue scenario

Months	Product (t)
Jan	60
Feb	80
Mar	130
Apr	150
May	200
Jun	280
Jul	290
Aug	250
Sep	210
Oct	160
Nov	80
Dec	60
Estimate per year	1950

Source (TROPOS 2014b)

directly further processed in the algae biorefinery module on the central platform. A flow model of the entire algae aquaculture production and processing is shown in Fig. 12.9.

In total, considering all 30 satellite units of the Green & Blue scenario, the annual production capacity of the facility was estimated with 1950 t/year (dry weight) (Tables 12.2 and 12.3).

Analysis of the economic impact confirmed that the Green & Blue concept in the Mediterranean has a strong economic case for development (TROPOS 2014d) and a virtual environmental impact assessment showed that the concept has minimal negative environmental impact (TROPOS 2014e).

## 12.4 Summary

Moving offshore involves a lot of advantages such as reduced competition with other activities compared to the near shore zone, optimum culture conditions in term of water quality and absence of pathogens, and rapid dispersal and dilution of any effluents to the wide open ocean (i.e. less negative impact on the environment; Lu et al. 2014). Moving offshore, however, also goes along with a major challenge, namely the suitable technology. Weather and wave conditions are often harsh in the open ocean and deep waters make the fixation of aquaculture facilities a difficult task. Moreover, the distance to the coast significantly complicates logistic service and supply, and operation and maintenance. A solution to overcome these problems and obstacles is represented by the TROPOS multi-use platform approach. The floating structure was especially designed for offshore conditions and allows for use in deep waters. As the annual offshore wind energy capacity will experience an average net increase of 21.5% every year until 2020, the combination of marine aquaculture farming with offshore wind energy exploitation seems obvious. The Green & Blue concept intends to integrate an offshore wind farm with aquaculture facilities for fish and algae, so as to create synergies among the activities: (i) Since many components of the system need energy (e.g. workshop, laboratory, feeding unit, etc.), aquaculture can achieve high levels of autonomy when combined with the wind turbines triggering the development of the offshore aquaculture further; (ii) Placing the cages between the turbines will save space and mooring lines; (iii) Since maintenance tasks have to be provided in a frequent basis for both fish and wind farm, the service infrastructure can be shared; (iv) Based on this, having a common accommodation unit on the platform, downtime periods will be decreased for both industries (since there will be permanently located personnel providing continuous inspections and routine maintenance tasks, and able to respond fast in case needed). Apart from this, sharing of divers and diving infrastructure, logistics, maintenance tools, workshops, environmental monitoring, etc. will reduce the service/maintenance costs.

## 12.5 Outlook

Multi-purpose offshore platforms are designed to incorporate modules of several compatible activities, and thus, provides the opportunity for the aquaculture industry to operate viably and profitably in offshore sites. Since mooring is one of

the major constraints for offshore aquaculture (the industry operates in depth <100 m), the synergy with the platform is vital for a feasible industry at deep offshore sites. The innovative synergies developed on modular multi-purpose platforms provide the opportunity for aquaculture to expand in offshore sites and meet future demands. Important constraints for success are the co-development and shared use of infrastructure, the selection of sites and technologies appropriate for environmental conditions, and the synergies in operational planning.

Until now, the aquaculture industry has moved offshore slowly and conservatively due to high costs and immaturity of innovative technologies. Some prototypes, consisting of submersible or semi-submersible cages, are currently available, allowing farms to be located farther from the coast than today. However, a significant research effort is needed on the development of new culture technologies as, although several prototypes have been proposed, few have been tested in commercial scale.

With its innovative design and technology the TROPOS concept represents an advanced solution for an integrated and synergistic offshore multi-use approach involving aquaculture and microalgae production. However, the next essential step is to move from theoretical approaches and modelled designs towards “real world” deployments. Even if financial support is possibly required at the beginning, pilot scale deployments are vital to proceed in the field of multi-use offshore installations.

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