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Research article

Environmentally-driven design of a floating desalination platform (Case study: reverse osmosis floating desalination platform of ras gharib, Egypt)

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Abstract: Floating desalination plants are fairly new technologies and are not as common as the traditional land-based desalination plants. Almost none of the proposed nor installed projects' designers indicates that the design is environmentally driven, and only few designs are environmentally assessed. This paper aims to highlight the significant role of the environmental practices to achieve a sustainable design, where most of the environmental impact assessment procedures are performed prior to the design phase. Throughout the research, comparing alternatives and analyzing the baseline provided reliable technical help in the tasks of selecting the proposed project's location, desalination technology, power source and platform configuration. Thus, detailed technical descriptions of different systems are presented. Finally, environmental impacts associated with the operation of the proposed floating desalination plant in the selected location are assessed to give guidance on the monitoring and mitigation processes necessary to enhance the process performance, minimize the adverse environmental impacts and ensure the project's sustainability.

Keywords: floating desalination platforms; wind energy; solar energy; environmental impact assessment; sustainable design

1. Introduction

Even though water covers 70% of the Earth, the United Nations Development Programme (UNDP) reported that 40% of the world population suffers from water scarcity. The World Health organization (WHO) also estimated that 785 million people lack access to basic drinking water service and at least 2 billion people drink water contaminated with fungus that can transmit diseases such as diarrhea, cholera, dysentery, typhoid, and polio**.** Within the next fifty years, the world population will increase by another 40 to 50%, and this growth in population will increase water demand and worsen the problem [1]. Therefore, the UN declares ‘clean water and sanitation’ as its sixth sustainable development goal to ensure safe and affordable water for all by 2030. Desalination process evolved into a viable alternative technology to increase the availability of freshwater and meet water demand. Data suggests that there are approximately 15,906 operational desalination facilities that produce around 95.37 million m^3/day water for human use and are located across 177 countries [2]. The global distribution of desalination plants and capacities in (million m^3/day) indicates that 34% of the facilities are located in the Middle East and North Africa region, more statistics can be found in [3]. A big concern for the desalination units remains to be their environmental impact and contribution to climate change [4]. The average of desalinating 1000 cubic meters of freshwater consumes about 5 tons of crude oil which produces around 10 tons of CO_2 emissions [5] and discharges up to 3000 cubic meters of brine. Many researchers have started to integrate the desalination plants with renewable energy sources such as solar, wind and ocean waves; and several systems are successfully installed and operated. Record of some renewable energy desalination systems in Greece, Japan, Spain, Morocco and Scotland are found in [4]. The Egyptian water authorities reported the installation of 3 Reverse Osmosis (RO) desalination plants in 3 different cities with total production of 365 m^3/day powered by renewables (Solar PV and wind power) between 1985 and 1996.

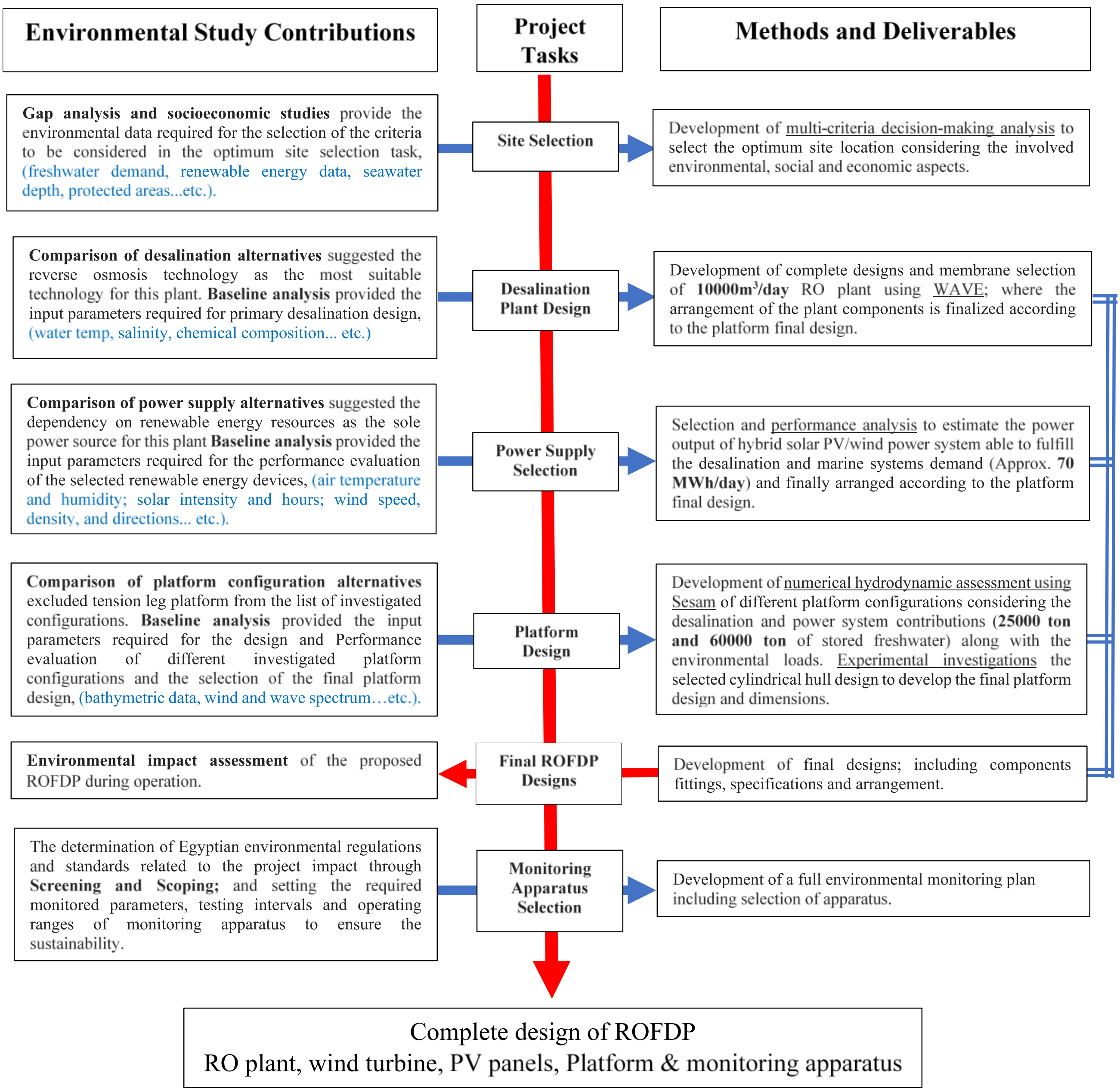
Desalination is an expensive process which can only provide the highly stressed regions with domestic and municipal use [6]. The large land area required for the renewable energy devices to fulfill the desalinating power demand made the process sometimes more expensive. Floating Desalination Platforms (FDPs) are fairly new technologies and are not as common as the traditional land-based desalination plants. Even though, there are several researchers who investigated FDP concept, only less than 10 plants have been successfully installed worldwide and most of them were powered by fossil fuels and were utilized as a temporary solution. In 2008, Saudi Arabia introduced a floating desalination facility until a permanent land-based facility was built, while the Cypriot government built one temporarily from 2008 to 2013 [7]. Table 1 presents a list of FDPs that have either been proposed by researchers or been successfully installed. FDP shows advantages compared to land-based desalination plants as the cost of transferring seawater to the plant onshore (feed-water intake) and the price of the land area holding the plant will be significantly reduced in addition to the strategic advantage of being easily moved (towed) to other areas. Also, the floating concept, according to Al-Othman, offers safety features that is well prepared it for tsunamis and earthquakes in comparison with the conventional plants on land [8]. The CEO of the WSC Company has stated that the cost of protecting the coastal environment is less when the plant is built offshore, because seawater can be used for the process of diluting waste liquid [7].

Table 1. List of proposed and installed FDPs.

Design Name/ Researcher's Name	Location	Capacity (m^3/day)	Energy Source	Status	Ref.
Shoaiba Barge	Saudi Arabia	52,000	Fossil Fuels	Installed	[7]
Rumaith	Abu Dhabi	2,500	Fossil Fuels	Installed	[9]
Ydriada MUP	Greece	N/A	Wind Turbine	Installed	[10]
Jonathan Davis	Greece	N/A	PV-electrode	Research Scale	[11]
N/A	Cyprus	20,000	Fossil Fuels	Installed	[7]
N/A	Thailand	4,000	Fossil Fuels	Installed	[7]
BY Chouski	Western Mediterranean Sea	N/A	Fossil Fuels	Research Scale	[12,13]
BY Vasjukov et al.	*Not designed for a specific location*	N/A	Nuclear Power	Research Scale	[14]
BY Pieter Stuyfzand	*Not designed for a specific location*	5,000–500,000	Renewable Multi-Energy Supply	Research Scale	[15]
RO-FDP	Red Sea, Egypt	10,000	Wind Turbine and PV	Research Scale and pilot plant	[16,17,18,19]
BY Harald Lampe	*Not designed for a specific location*	90,000	Fossil Fuels	Research Scale	[20]

The review conducted to collect the data presented in Table 1 found that technical and economical approaches are generally adopted to design and/or assess the feasibility and performance of FDPs. The ROFDP is economically assessed in [16] where return on investment and payback period are calculated and compared to land-based plants. Results are positive in favor of FDPs. However, almost none of the proposed nor installed FDPs designers indicates that the design is environmentally driven, and only few platforms are environmentally assessed. Therefore, the aim of this study is to highlight the important role of the Environmental Impact Assessment (EIA) procedures in designing and selecting different components of FDP (see Figure 1). The novelty of this study can be found in the organization of the environmental study and its contribution in the design workflow, to enhance the design process performance, ensure the FDP's sustainability and minimize the associated environmental impacts. In this study, comparing alternatives and analyzing the baseline are the input data used to propose the most sustainable location and design of a FDP in Egypt.

The development of the floating structure in this project went over the following phases chronologically: a) selecting the most suitable site in Egypt by performing a multi-criteria analysis that included a weighting percentage on coastal cities, b) comparing different desalination techniques, c) analyzing each power supply option (conventional and renewable) by its impact on the environment and meeting required demand, d) comparing ten platform design configurations hydrodynamically (experimentally and numerically), while considering the site conditions, and the desalination and power supply technologies adopted, e) providing a baseline that describes the current conditions of this project's site to identify the proper future monitoring and mitigation practices, and finally, f) presenting the environmental impact associated with the operation of the proposed design.



Gap analysis and socioeconomic studies provide the environmental data required for the selection of the criteria to be considered in the optimum site selection task, (freshwater demand, renewable energy data, seawater depth, protected areas...etc.).

Development of multi-criteria decision-making analysis to select the optimum site location considering the involved environmental, social and economic aspects.

Comparison of desalination alternatives suggested the reverse osmosis technology as the most suitable technology for this plant. **Baseline analysis** provided the input parameters required for primary desalination design, (water temp, salinity, chemical composition... etc.)

Development of complete designs and membrane selection of **10000**m^3**/day** RO plant using WAVE; where the arrangement of the plant components is finalized according to the platform final design.

Comparison of power supply alternatives suggested the dependency on renewable energy resources as the sole power source for this plant **Baseline analysis** provided the input parameters required for the performance evaluation of the selected renewable energy devices, (air temperature and humidity; solar intensity and hours; wind speed, density, and directions... etc.).

Selection and performance analysis to estimate the power output of hybrid solar PV/wind power system able to fulfill the desalination and marine systems demand (Approx. **70 MWh/day**) and finally arranged according to the platform final design.

Comparison of platform configuration alternatives excluded tension leg platform from the list of investigated configurations. **Baseline analysis** provided the input parameters required for the design and Performance evaluation of different investigated platform configurations and the selection of the final platform design, (bathymetric data, wind and wave spectrum…etc.).

Development of numerical hydrodynamic assessment using Sesam of different platform configurations considering the desalination and power system contributions (**25000 ton and 60000 ton** of stored freshwater) along with the environmental loads. Experimental investigations the selected cylindrical hull design to develop the final platform design and dimensions.

Environmental impact assessment of the proposed ROFDP during operation.

Development of final designs; including components fittings, specifications and arrangement.

The determination of Egyptian environmental regulations and standards related to the project impact through **Screening and Scoping;** and setting the required monitored parameters, testing intervals and operating ranges of monitoring apparatus to ensure the sustainability.

Development of a full environmental monitoring plan including selection of apparatus.

Complete design of ROFDP
RO plant, wind turbine, PV panels, Platform & monitoring apparatus

Figure 1. Environmental study contributions in the designs.

2. Alternative scenarios

A common feature of EIAs is the need to compare alternative scenarios, and this can be done by using simulation approaches or using the information derived from surveys, literature reviews and records of past designs. The following section presents the comparisons made for decision-making of the preferable site of this study, desalination technology, power supply, and platform configuration.

2.1. Site selection

The selected site would be responsible for the platform mooring and maintenance when the platform is stationary and must ensure the optimum operating conditions (the maximum output and minimum environmental impacts). Egypt has approximately 3,000 km of coastal lines situated on the Mediterranean Sea and the Red Sea [21]. In the study reported herein, 41 coastal cities with different natural potentials are selected after excluding the 30 protectorates all over Egypt that are presented by the Egyptian Environmental Affairs Agency. A list of reasons that restricts the deployment of the FDP in the selected areas is developed to avoid any site that can be an obstacle in the operation of the plant. This list includes but is not restricted to oil and gas extraction sites, military exercise areas, underwater cables, harbors entrances and navigation routes, and areas with environmental restrictions, aquaculture, sand and gravel extraction, marine archaeology sites, landscape and seascape as public heritage, and offshore renewable energy projects already installed. The multi-criteria analysis performed by the research team [16] highlights these locations as ‘Not Suitable’ sites, while the locations that are labeled with “shallow” constraints are the most suitable sites and the highly recommended ones to build a FDP. The criteria involved in the research are considered for many sustainability aspects and given a judicious weighting percentage including: wind potential (20%), water depth (10%), freshwater demand (10%), proximity to coast (10%), social and economic remarks (10%), population density (10%), tourism facilities, distance from roads grid (5%), birds migration (5%), solar potential (5%), distance to power grid (5%) and wave resources (5%).

Based on the analysis, Ras Gharib city is selected. It is located on the coast of the Gulf of Suez and has a total population of about 60,000 people according to the Red Sea Governate website, and has the higher potential weight among other Red Sea Governate cities. Ras Gharib has three major characteristics which are: high solar irradiance throughout the year, optimum water depth nearshore, and high-water demand for civil and industrial reasons. In addition, it is one of the locations that is devoted by the New and Renewable Energy Authority (NREA) in Egypt for development targeting sustainability in the region which makes it the most suitable and recommended site.

2.2. Desalination technology

Seawater desalination processes can be divided into two main technology types: thermal distillation which utilize heat to evaporate seawater and membrane technique which uses membranes as barriers to selectively pass water and retain salts. Membrane technologies are more common as they have taken over 73% of the global installation capacity of desalination plants [17].

The thermal distillation processes can be divided into Vapor Compression Distillation (VC), Multi-stage Flash Distillation (MSF), and Multi-Effect Distillation (MED). The VC process operates with mechanical or electrical energy to evaporate seawater rather than using direct exchange of heat from steam produced in a boiler. Water vapor is drawn from the evaporation chamber by a compressor to be condensed into pure water, and the heat released is used to vaporize additional water. VC distillation process is favored only for small and medium scale plants due to its simplicity and reliability, but no records of such technology exist in Egypt to highlight the performance nor the economics. Meanwhile, MSF and MED use direct heat exchangers to provide thermal energy for water evaporation. MSF consists of 15–28 stages with each one functioning at a lower pressure and temperature than the previous one and consisting of a flash chamber and a heat exchanger/condenser. Before the first stage, the feedwater is heated in the brine heater powered by hot steam to introduce a sudden heated water in the chamber and cause it to boil to form freshwater from the condensation of the water vapor, which is collected at each stage. MED plants are similar to MSF, but in MED plants, the seawater is sprayed over heated pipes in a thin film to further rapid boiling and evaporation of only clean water. The hot water vapor is used to heat the next stage of the evaporation process where the water then cools and condenses and is collected as pure fresh water. This process is done several times at progressively cooler temperatures to generate more clean water. MSF and MED produce freshwater with very low concentrations of salts (10 mg/L or less) from saline water with high Total Dissolved Salts (TDS) of 60,000–70,000 mg/L, and the produced water contains very low levels of harmful substances to health (pathogens) and other pollutants such as boron, bromide and organic matters. They also require skilled operators, precise operational and maintenance plans due to their complexity, and relatively large amount of land, capital and maintenance costs. Out of the three thermal desalination plants, MSF is the most widely used method as it is relatively easy to construct and operate. However, it has extremely high energy consumption and low Gained Output Ratio (GOR) due to operating under very high steam temperatures as the system consumes about 270 MJ/m^3 thermal energy in the form of steam, at an average temperature of 120°C, and about 4 kWh/m^3 of specific pumping energy. Many research studies have proved that MED plants are superior than MSF desalination plants because MED processes are characterized by having higher unit capacity, better quality of distilled water, lower production costs, and higher heat efficiency and by being simpler to be integrated with renewable energy. Reviews and studies on different renewable integrated desalination can be found in [22], concentrated solar power and desalination in [23]; environmental issues related to desalination [24]; energy efficient desalination technologies in [25] and challenges of energy recovery systems in [26].

The membrane desalination (MD) process exists in different types of membranes and can be classified based on the driving force that controls the movement of the media, which are equilibrium-based membrane processes, non-equilibrium-based membrane processes, pressure driven and non-pressure driven processes [27,28]. Pressure driven membrane processes force pure water particles through a semi-permeable membrane to separate salt and freshwater by using hydraulic pressure and generate two streams; brine and freshwater. A comparison provided in [27] between the 4 different types of pressure driven membrane processes shows that Reverse Osmosis (RO) is the most efficient technology in separating small particles like sodium and chloride ions up to 99.5%. Other membrane techniques include MD which features a hydrophobic porous membrane that separates two aqueous solutions at different temperatures and is thermally driven by the partial vapor pressure difference. ED/EDR uses applied electrical potential to separate soluble ions and salts from water or process stream, and this separation occurs through two semi-permeable material, called ion exchange membranes which allow ions to transfer through. Under the influence of electricity, anions travel toward the anode through anionic membranes, while cations travel toward the cathodes through cationic membranes. In Forward Osmosis (FO) desalination process, a semipermeable membrane separates water from dissolved salts using natural energy in the form of osmotic pressure; unlike RO system that requires hydraulic pressure. Of all the membrane separation methods listed, desalination by RO is the most commonly used and the leading application for membrane in water treatment as it produces more than 50% of the world's desalination water [2].

Table 2 presents a detailed comparison between MED and RO as they are the most common thermal and membrane desalination technologies in Egypt [3]. The comparison presented in the above table shows that RO technology has several specific advantages over MED technology in case of FDPs; where, the size of the plant, power supply and infrastructure required are of great importance. Therefore, ocean engineering researchers working on the design of the platform focused on specific parameters such as land use, Specific Energy Consumption (SEC), Recovery Rate (RR), brine temperature and capital cost. Additionally, 90% of the desalination plants installed in Egypt are RO plants which makes the RO preferable over any other desalination technology, due to the availability of experienced skilled operators and precise operational and maintenance companies in the Egyptian market that minimizes construction and operation costs.

Table 2. Comparison between MED and RO technologies modified from [5,31].

Item	MED	RO
Technology	Thermal	Membrane
State of the art	Commercial	Commercial
Land use	Large	Small–Medium
Reliability	High	Moderate
Commissioning period (month)	18–24	18
Common capacity m^3/d	500–35000	0.4–70000
Specific thermal energy (MJ/m^3)	150–390	–
Specific pumping energy (kWh/m^3)	2–4	3–5
SEC (kWh/m^3)	17	3–5
Maximum intake water TDS (mg/L)	20000–100000	50–46000
Required intake water quality	Low–Medium	High
Pretreatment	Simple	Difficult
Produced water TDS (mg/L)	<10	200–500
Recovery rate (%)	23–33	20–50
Brine temperature (C)	55–70	45
CO_2 emissions (kg/m^3)	18	1.8
NO_X (g/m^3)	21	3.9
SO_X (g/m^3)	26	1.1
Capital cost ($\$/m^3/d$)	1600	1200
Maintenance Cost (%)	1	2
Frequency of maintenance per year	1–2	Frequent

2.3. Power supply

The selection of the power supply can be considered as the most influential parameter on the platform design. In general, fossil-fueled power stations compared to renewable resources are cost efficient, compact and can be built almost anywhere; however, their incorporations are usually associated with many economic and environmental complications. On the other hand, the idea of depending completely on renewable energies is much more attractive environmentally but implies reliability and economic challenges.

An electrical generator powered by fossil fueled engines can always be considered as a reliable power supply for marine or any off-grid industrial application. Taking into consideration the SEC presented in Table 2, the possibility of using an auxiliary energy recovery system and operation with annual reliability over 90%, the suitable thermal power supply for such capacity of RO desalination plants would be around 1.75 to 2 MWe. However, some problems can arise due to the use of fossil-fueled electrical generators: a) Fueling the platform will increase the risk of water pollution due to any fuel leakage in supply lines and storage tanks; or oil spills due to accidents. b) The reliability on fuel will limit the accessibility of the platform to some remote areas where the suitable fuel may not be available. c) The fuel storage tanks will also limit the freshwater storage capacity of the platform. d) The high gaseous emissions from fuel burning; as the emissions of carbon dioxide is expected to reach 3300 tons of CO_2/y using simple calculations and benchmark data presented in Table 2.

When considering renewable energies as a power source for this study, two challenges appear. The first, would be to balance the continuous energy demand (almost constant) with the variable energy production. The second challenge is that the power supply would not only be responsible for the desalination plant, but also the demand created due to the accommodation of the operating crew onboard and the marine systems. Preliminary load calculation study is performed to investigate the feasibility of the FDP concept from the power requirement perspective. The breakdown of the power consumption of different systems will be presented in the "Technical description of the proposed ROFDP" section. Reasonable assumptions have been made in order to simulate real conditions based on experiences and surveying the Maritime Labor Convention of the International Labor Organization, the American Society of Heating Refrigeration and Air conditioning Engineers (ASHRAE) handbook of applications 2019, STD 62.1, STD 90.1. and the Society of Naval Architects and Marine Engineers (SNAME) Bulletin [32,33].

On the other hand, it is required to estimate the available renewable energy at the selected site and guarantee that the proposed hybrid renewable energy system is able to fulfill the total demand with acceptable reliability in the Red Sea mainly. For this reason, a survey of the renewable energy resources at Ras Gharib has been performed and will be included in the baseline section of this research. This survey with primary calculations highlighted the possibility of fulfilling the power demand using a hybrid solar/wind power system as the daily power per unit area of incident solar energy is of 7.81–8.3 kWh/m^2/day [34] and the wind power density (power per unit area of a rotor) is 1–1.2 kW/m^2 with zero stillness time according to [35]. More accurate calculations and specifications of the selected renewable energy devices for the FDP discussed herein will be covered in the "Technical description of the proposed ROFDP" section.

2.4. Platform design configuration

FDP supporting offshore wind turbines faces a unique set of design challenges arising from the combined static loads and aerodynamic/hydrodynamic loads which were never faced before by a conventional FDP powered by fossil fuel. Since the design principles of any offshore platform configuration affect the motion characteristics and operation, the dynamic and static performance are evaluated numerically for ten different common platform configurations in order to select the suitable platform shape for the FDP supporting a wind turbine. Tension leg platforms are excluded from this study because of their complexity and stationary mooring system as the proposed platform has a mobility function. The platform displacement is selected to be the main fixed parameter to compare different unit configurations and can be summarized as: a) cube platform, b) cylinder platform, c) cylinder with heave plate, d) hexagonal platform, e) cuboids platform, f) semi-submersible, h) sea angle (V semi-submersible), i) open barge, j) triangle semi-submersible, and k) spar as presented in Figure 2. The platform needs to support a heavy displacement load from the desalination plant as the desalination process has a large volume and a heavy weight from water storage tanks and to hold a wind turbine that requires stability in operation and a large water plan-area to support the dynamic moment loads. The whole system design must also be adapted to the site conditions. Thus, the evaluation of dynamic stability, static stability, platform natural period, and global frequency of overall system must consider the site environmental loads.

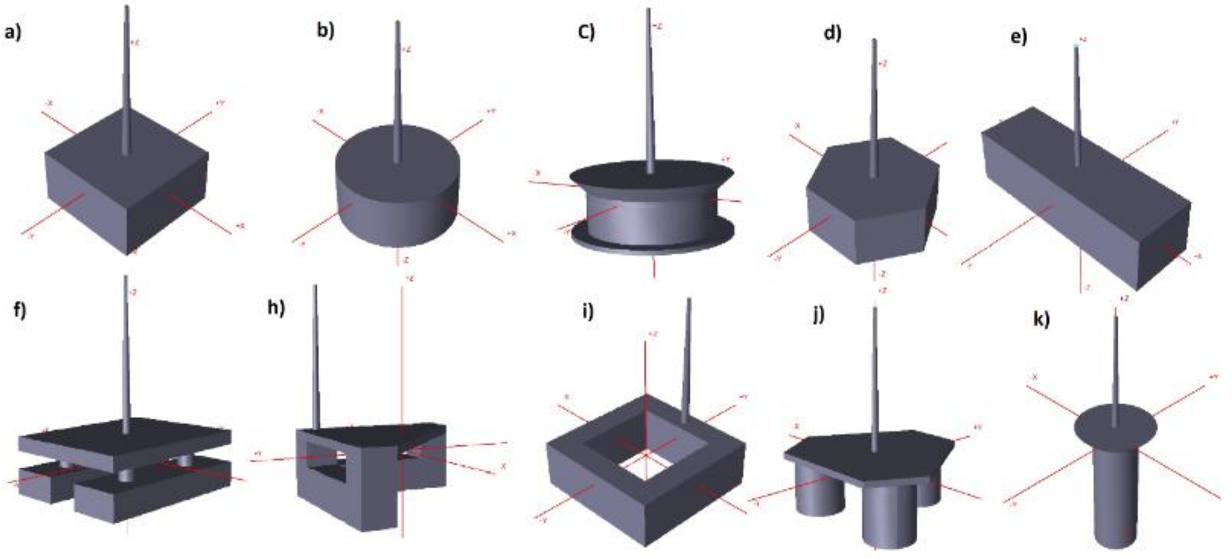


Figure 2. Investigated platform configurations.

Some considerations are set to assure the proper operation of the turbine and the optimum platform behavior. The decline angle should not increase more than 6 degrees to avoid any negative effect on turbine operation and performance [36]. The structure must also have sufficient static stability as the design standard of Det Norske Veritas DNV-OS-J103 states that offshore platforms have to be capable of maintaining stability of the wind turbine at the wind speed producing the largest rotor thrust [37]. DNV-OSJ103 also states that the energy is substantial for waves and wind periods, and the natural period of the platform should be outside of the energy excitation range of waves and winds to avoid resonance and its consequences [37]. Additionally, the global frequency of the overall wind turbine floating system of the selected platform should lie outside the range of frequencies in order to avoid system resonance because platforms supporting offshore wind turbines are dynamically sensitive at different types of low frequencies imposed by environmental and mechanical loads. DNV Guidelines suggest that the natural frequency of the wind turbine- platform system should not come close to the forcing frequencies arising from imposed environmental loads. It is also specified that the global frequency of the system should be at least ±10% away from operational blade passing frequencies (1P) and 2P/3P frequencies which are related to 2 bladed and 3 bladed wind turbines [38].

Detailed results of simulations performed by the research team can be found in [19]. Comparison is performed based on the selection criteria and hydrodynamic performances for the ten different platform configurations. The platform configurations which had a decline angle that exceeds six degrees due to wind force are excluded and marked as (rejected) like Spar, Semi-submersible and Cuboid platforms. The platforms which had their dynamic response out of soft-soft design areas are also excluded for the selection. Some platforms had dynamic response inside the design area but very near to the frequencies of the cyclic dynamic excitation force of wave in Ras Gharib area and those platforms are marked with (critical) like Hexagonal, Cylinder and Cube platforms.

Based on the comparison of the different platform concepts presented in this study, a cylinder hull form with heave plate platform expressed better static and dynamic performance within soft-soft design space to prevent dynamic amplifications in the structure. The global natural frequency of the cylinder with heave plate platform is acceptable in all six degrees of freedom compared to other platforms as semi-submersible and spar platforms do not satisfy stability criteria of floating platforms supporting a wind turbine due to increase in inclination angle more than 6 degrees when thrust moment of turbine is applied. Furthermore, an experimental study was performed by the research team to investigate the performance of the selected cylindrical platform with damping plate [18] and a full description of the platform will be presented in the “Technical description of the proposed ROFDP" section.

3. Ras gharib baseline

Ras Gharib baseline has been described and categorized into 4 main pillars: a) Socio-economic and water resources. b) Physical environment. c) Biodiversity. d) Renewable energy.

3.1. Socio-economic description and water resources

Ras Gharib city, founded in early thirties of the last century, is one of the oldest cities established on the Red Sea Coast in Egypt and is the second largest city in Red Sea Governorate [39]. The city is located in the Egyptian Eastern Desert directly on the Red Sea Coast and lies between latitudes 28°22.170'N to 28°19.560'N and longitudes 33°3.10'N to 33°6.80'N with a total area of 10,464 km^2 [40]. According to the Red Sea Governorate’s official website, Ras Gharib’s population is about 60,000 people, including migrant workers from neighboring governments who mostly work in the oil production sector. The majority of the population lives in the urban center and only a small portion lives in Zaafarana and Wadi Dara villages. The work force in this area can be divided into three basic categories: government/public sector, oil companies’ crews and wage workers. The residents of Ras Gharib are mostly oil companies' crews as the city’s economy relies on oil production which is performed by many national, foreign, joint and private oil production companies that inhabit the city. Considered to be the leading city in petroleum production, Ras Gharib produces now about 70% of the total oil production of the whole country.

Generally, Nile water is transported to the Red Sea’s different cities through two main pipelines. They are Qena-Safaga pipeline and Koraimat pipeline, with diameter 1000 mm until Ras Gharib and 600 mm to Hurghada [41]. The path of both pipelines on the Egyptian map can be found in [40]. The municipal water in Ras Gharib comes from two sources: 5000 m^3/day through the Koraimat pipeline and many small-scale desalination plants owned by the government and private sector.

3.2. Physical environment

Ras Gharib is characterized by two zones: the mountainous zone in the west and the coastal zone in the east. In the west, the area is distinguished by its high elevated hills that reach up to 1600 m high and by its steep slopes [42]. On the other hand, the eastern part of the area consists of relatively flat areas and low land with gentle slopes. Table 3 and Table 4 list the characteristics of seawater and different environmental parameters and in Ras Gharib throughout the year, and several credible resources are used to collect those data. The meteorological data of the research are obtained from El Tor station which is the nearest Egyptian Meteorological Authority (EMA) station to Ras Gharib at a distance of around 60 kilometers [43]. El Tor station is considered to be the most reliable

EMA station for this research compared to the other 22 EMA stations that operate on several ground stations around the country. For a detailed weather report of Ras Gharib, WeatherSpark.com, developed by Cedar Lake Ventures, Inc. is used to collect the statistical analysis of historical hourly weather reports from January 1, 1980 to December 31, 2016 from El Tor station [44]. The company stated that the station records are corrected for the elevation difference between the station and Ras Gharib according to the International Standard Atmosphere and the relative change present in the MERRA-2 satellite-era reanalysis between the two locations. All data related to the Sun's position (e.g., sunrise and sunset) are computed using astronomical formulas from the book, Astronomical Algorithms 2nd Edition , by Jean Meeus [45]. The remaining data collected for this study are from environmental researches and industrial reports developed specifically for Ras Gharib.

Table 3. Chemical composition of gulf of suez seawater [46,47].

pH	K^+	Na^+	Mg^{+2}	Ca^{+2}	Sr	CO_3	Oc^-	Cl^-	SO_4^-	SiO_2^-	Bi^{+3}
7.2	460	12690	1661	391	6.9	0	149.7	23528	23528	10	4.02

3.3. Biodiversity

The Red Sea is very rich in biodiversity, it has the world’s second longest coral reefs and supports high species endemism, as more than 1000 different fish species live among 250 kinds of coral. About 14.7% of those fishes are of endemic species [48]. Examples of marine endangered species in Egypt are marine mammals (17 species), marine turtles (4 species), sharks (more than 20 species), sea cucumbers, some of bivalves, Coral reefs, and mangrove trees [49]. Additionally, the Red Sea Flyway passing through Egypt, is the second most important flyway for migratory soaring birds in the world and is the most important route for Palearctic soaring birds migrating to and from Africa as over one million migratory soaring birds of at least thirty-five species regularly use this flyway, including ten species at risk of extinction [50]. Records show that the Ras Gharib flyway is only busy in the springtime. Detailed records of bird’s migration paths can be found in [21]. Those migratory birds favor flying over mountains, Jabel Gharib, and minimize their time over water to maintain and gain altitude with a minimum expenditure of energy.

3.4. Renewable energy data

Studies have been conducted to determine the potential of renewable energy resources in Ras Gharib. Table 4 shows the average solar irradiance gathered for each month based on data collected from the Global Solar Atlas, and it lists the wind speed data are based on a measurement station on the shore of Ras Gharib which was built in 2000. Wind data available from this station are for two different heights of 10 m and 24.5 m. The data collected ensures that Ras Gharib is an area with a high solar energy potential for both electricity generation and thermal heating application as the monthly average total solar irradiation intensity varies between 537 and 707 W/m^2/month. The solar irradiance intensity varies based on the month of the year and also the time of the day as the time between 10 am to 2 pm is considered to have the highest solar irradiance during the day [34]. Ras Gharib is also capable of providing an abundant wind energy resource as the duration of the stillness is zero, showing that the wind potential at Ras Gharib is reliable throughout the year. The wind speed in the area is in the range from 5 to 10 m/s 54% of the time and in the range from 10 to 17 m/s 19% of the time. The wind blows predominantly from north-northwest (NNW) and west-northwest (WNW) directions for about 77% of the time, and the maximum frequency of occurrence is from the NNW sector (330°), where the wind blows 51% of the time with an average wind speed of 12.6 m/s at 24.5 meters above ground level at the site selected for the onshore wind farm established in Ras Gharib. Further data concerning the wind density and wind rose is available in [35,51,52].

Table 4. Solar, wind and seawater data.

Month	Jan.	Feb.	Ma.	Ap.	May	Jun.	Jul.	Au.	Sep.	Oct.	No.	De.	Ref.
Average Solar Irradiance (W/m^2)	537	582	589	592	604	688	707	695	648	570	552	540	[7]
Sunrise time (am)	6:40	6:25	6:00	5:21	4:57	4:50	5:00	5:17	5:32	5:48	6:10	6:32	[34]
Sunset time (pm)	5:13	5:38	5:56	6:13	6:31	6:45	6:46	6:26	5:51	5:17	4:54	4:53	[34]
Wind Speed at 10 m height (m/s)	6.4	6.6	7.9	8.3	8.8	10.2	9.5	10.0	9.7	8.5	6.6	6.6	[51]
Wind Speed at 100 m height (m/s)	9.7	10	12	12.5	13.3	15.5	14.7	15.1	14.7	12.9	10	9.9	[35]
Mean Daily Max. Temp. (℃)	23	24	28	34	38	41	41	41	39	35	29	24	[46]
Mean Daily Min. Temp. (℃)	6	7	9	13	17	18	20	21	19	16	11	8	[46]
Average rainfall (mm)	2	1	1	0	0	0	0	0	0	3	2	2	[44,52]
Mean Seawater temp. (℃)	20	19	19.5	21	22.5	23.5	26	27	26.2	25	24	21.5	[46]
Seawater salinity (%)	41.54	41.54	41.43	41.43	41.43	42.32	42.32	42.32	42.32	42.32	42.32	41.54	[42,47]

4. Technical description of the FDP

The following section presents the proposed design and specifications of the FDP. The platform design is based on tank experiments [18] and numerical hydrodynamic modelling using Sesam software [19]. The desalination plant is designed using Water Application Value Engine (WAVE Version: 1.64.644) [17]. The hybrid power system specifications will be presented as well in addition to the output power estimations.

4.1. Platform

A cylindrical hull shaped platform with heave damping plate is proposed with the dimensions specified in Table 5. The proposed platform dimensions allow its navigation (towing) through Suez Canal and near shore. The inner center tank is used as the seawater intake tank and pre-treatment tank that can store up to 6000 m^3 feed water and is expected to cause a reduction in Seawater Intake System operational cost compared to land based plants. As shown in Figure3, the platform hull includes 12 tanks. 6 fresh-water tanks with a total capacity of 60000 m^3; in addition to 6 tanks used as ballast tanks. The platform is designed to support a large wind turbine, PV panels covering 6000 m^2 which is the solar deck area of the platform and 10000 m^3 RO desalination plant. The weight of the whole FDP is estimated to be 86,708 tons (approximately 84,593 m^3 volume of displacement). The platform has been experimentally studied in Kelvin Hydrodynamic Laboratory in University of Strathclyde, Glasgow.

Table 5. Platform dimensions.

Platform specification	Dimension (m)
Main hull diameter	70
Deck diameter	87.5
Column height	27
Platform full load draft	20
Total platform height (Deck, hull and heave plates)	32

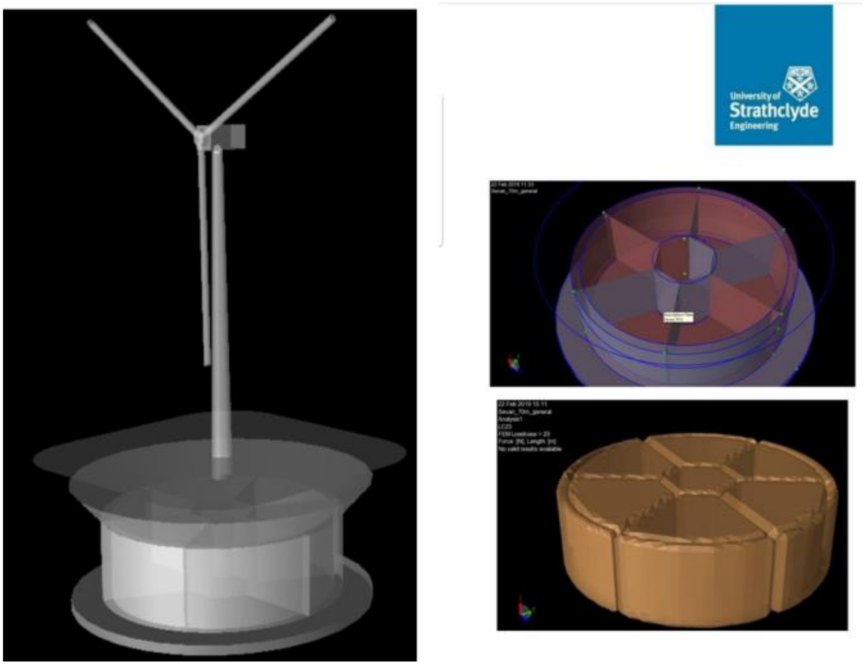
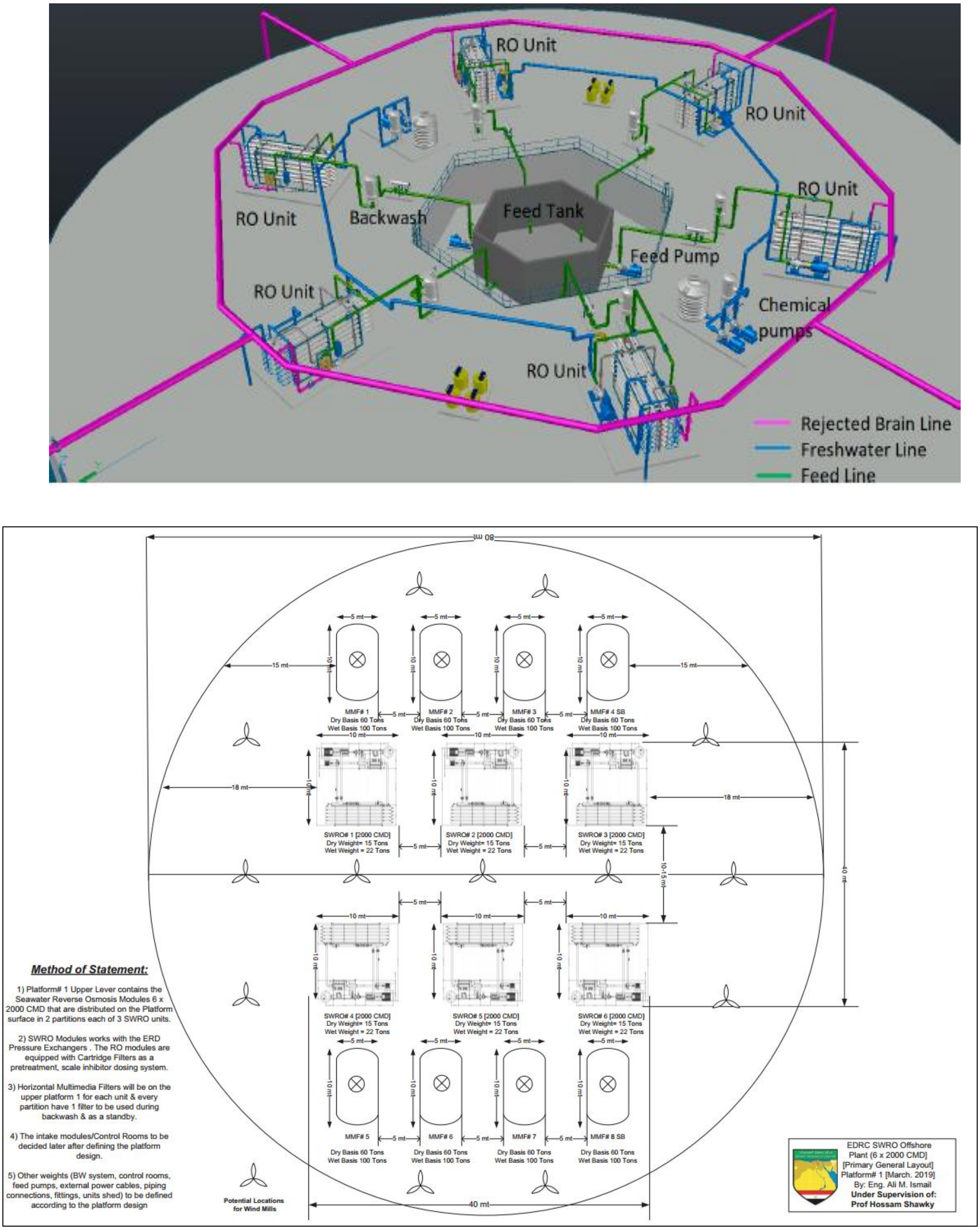


Figure 3. Platform hull and tanks arrangement.

4.2. Desalination plant

The proposed desalination plant has a total capacity of 10,000 m^3/day. The plant consists of six RO units. Each unit produces 2000 m^3/day and has a mass of 133 tons. Among the six units one is for backup. The plant is located below the solar deck in a radial configuration as shown in Figure 4.

Water Application Value Engine (WAVE Program Version: 1.64.644) is used to determine the process of Red Sea desalination and select the suitable configuration. A snapshot of the program results is presented in Figure 5. RO System Analysis (ROSA 6.0.1 software) has been used to determine the power required accurately considering the energy recovery system (ERS). ROSA results pointed that the value of the power ranges from 2.84 to 3.15 kWh/m^3 instead of 5.6 kWh/m^3 calculated without the ERS.



Method of Statement:

1) Platform# 1 Upper Lever contains the Seawater Reverse Osmosis Modules 6 x 2000 CMD that are distributed on the Platform surface in 2 partitions each of 3 SWRO units.

2) SWRO Modules works with the ERD Pressure Exchangers . The RO modules are equipped with Cartridge Filters as a pretreatment, scale inhibitor dosing system.

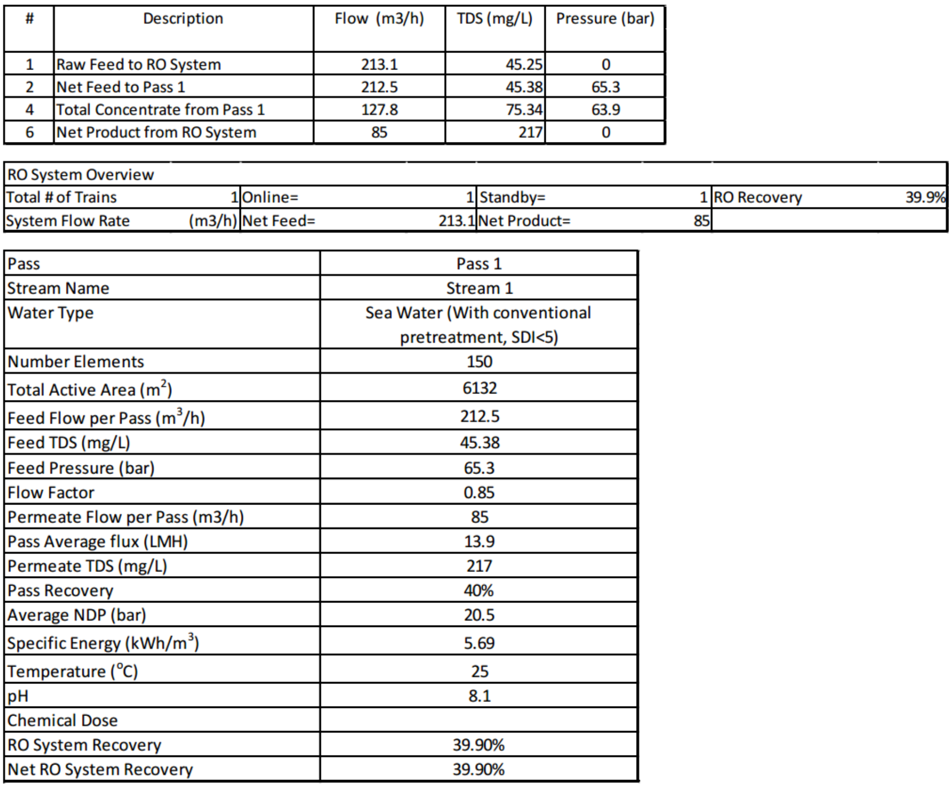
3) Horizontal Multimedia Filters will be on the upper platform 1 for each unit & every partition have 1 filter to be used during backwash & as a standby.

4) The intake modules/Control Rooms to be decided later after defining the platform design.

5) Other weights (BW system, control rooms, feed pumps, external power cables, piping connections, fittings, units shed) to be defined according to the platform design

EDRC SWRO Offshore
Plant (6 x 2000 CMD]
[Primary General Layout]
Platform# 1 [March. 2019]
By: Eng. Ali M. Ismail
Under Supervision of:
Prof Hossam Shawky

Figure 4. Desalination plant design and arrangement.



#	Description	Flow (m3/h)	TDS (mg/L)	Pressure (bar)
1	Raw Feed to RO System	213.1	45.25	0
2	Net Feed to Pass 1	212.5	45.38	65.3
4	Total Concentrate from Pass 1	127.8	75.34	63.9
6	Net Product from RO System	85	217	0

RO System Overview							
Total # of Trains	1	Online=	1	Standby=	1	RO Recovery	39.9%
System Flow Rate	(m3/h)	Net Feed=	213.1	Net Product=	85		

Pass	Pass 1
Stream Name	Stream 1
Water Type	Sea Water (With conventional pretreatment, SDI<5)
Number Elements	150
Total Active Area (m^2)	6132
Feed Flow per Pass (m^3/h)	212.5
Feed TDS (mg/L)	45.38
Feed Pressure (bar)	65.3
Flow Factor	0.85
Permeate Flow per Pass (m3/h)	85
Pass Average flux (LMH)	13.9
Permeate TDS (mg/L)	217
Pass Recovery	40%
Average NDP (bar)	20.5
Specific Energy (kWh/m^3)	5.69
Temperature (°C)	25
pH	8.1
Chemical Dose	
RO System Recovery	39.90%
Net RO System Recovery	39.90%

Figure 5. Snapshot of the RO specifications sheet.

4.3. Hybrid renewable power plant

The breakdown of the power demand of the FDP is presented in Table 6 which shows that the power demand is estimated to range between 2000 and 1200 MWh/month for maximum and normal operating conditions respectively. As shown in Table 6, the maximum power consumption is estimated assuming that all systems of the platform are operating 24/7. Reasonable assumptions of the operating hours are adopted in order to simulate normal conditions based on experiences and surveying the ILO Maritime Labor Convention, ASHRAE (handbook of applications 2019, STD 62.1, STD 90.1) and SNAME Bulletin [32,33].

A hybrid solar/wind power system is proposed to fulfill the platform and desalination plant demands. The selected wind turbine is the V112-3.0 MW equipped with a 112-metre rotor consisting of three blades and a hub. The blades are controlled by the microprocessor pitch control system. Based on the prevailing wind conditions, the blades are continuously positioned to optimize the pitch angle. The blades are made of carbon and fiberglass and consist of two airfoil shells bonded to a supporting beam. The main gear converts the low-speed rotation of the rotor to high-speed generator rotation. It is a four-stage differential gearbox where the first three stages are planetary stages and the fourth stage is a helical stage. The disc brake is mounted on the high-speed shaft. The gearbox lubrication system is a pressure-fed system. Specifications of the wind power system are demonstrated in Table 7. Marine photovoltaic (PV) panels and mounting frame kits must be designed to withstand the harsh conditions at sea and are suitable for all vessels ranging from coastal vessels to ocean-going passenger ferries and cargo ships. 154 Wp Marine Grade Flexible Photovoltaic (PV) Panel acquires all these conditions. The PV panel specifications are presented in Table 8.

Table 6. Daily maximum and normal conditions power demand breakdown.

Systems	Power (kW)	Qty	Qty in normal operation	Total power (kW)	Max. daily operating hours (hr/d)	Max. daily consumption (MWh/d)	Normal daily operating hours (hr/d)	Sharing percentage in max. load condition (%)	Normal Consumption (MWh/d)	Sharing percentage in normal condition (%)
DESALINATION						34.22		50.77	34.22	82.48
Filter feed pump	40	6	5	200	24	4.80	24	7.12	4.80	11.57
HP pump	200	6	5	1000	24	24.00	24	35.60	24.00	57.84
HP booster pump	14	6	5	70	24	1.68	24	2.49	1.68	4.05
Cleaning pump	30	6	5	150	24	3.60	24	5.34	3.60	8.68
Post treatment system	1.2	6	5	6	24	0.14	24	0.21	0.14	0.35
MARINE SYSTEMS						32.64		48.42	7.04	16.97
Ballast tanks pumps	100	6	5	500	24	12.00	4	17.80	2.00	4.82
Discharge pumps	100	6	5	500	24	12.00	4	17.80	2.00	4.82
Firefighting pumps	50	2	2	100	24	2.40	0	3.56	0.00	0.00
Super structure service pumps	30	2	2	60	24	1.44	4	2.14	0.24	0.58
Transportation pumps	100	1	1	100	24	2.40	4	3.56	0.40	0.96
Control and outfitting	100	1	1	100	24	2.40	24	3.56	2.40	5.78
LIGHTING						0.06		0.09	0.04	0.10
Lighting-Rooms	0.01	20	10	0.1	24	0.00	8	0.00	0.00	0.00
Lighting-Lab.	0.02	5	5	0.1	24	0.00	8	0.00	0.00	0.00
Lighting-Restaurant	0.02	5	5	0.1	24	0.00	8	0.00	0.00	0.00
Lighting-Plant	0.02	40	40	0.8	24	0.02	24	0.03	0.02	0.05
Lighting-Deck-light	0.25	6	6	1.5	24	0.04	12	0.05	0.02	0.04
AIR CONDITIONNING						0.43		0.64	0.14	0.35
Air condition-Rooms	2.25	4	4	9	24	0.22	8	0.32	0.07	0.17
Air condition-Lab.	2.25	2	2	4.5	24	0.11	8	0.16	0.04	0.09
Air condition-Restaurant	2.25	2	2	4.5	24	0.11	8	0.16	0.04	0.09
Auxiliaries	2	1	1	2	24	0.05	24	0.07	0.05	0.12
TOTAL						67.41			41.50	

The hybrid system is able to fulfil the FDP’s demand in normal operation. However, when considering the maximum demand condition, a shortage of power can occur which require further studies for electrical storage capacity design. The monthly expected power output in presented in Figure 6.

Table 7. Wind power system specification.

General	Specification
Type	V-112 3.0MW IEC class II A
Nominal output	3 MW
Wind speed rating	12 m/s
Tower	
Tower Weight	190 ton
Tower Height	86 m
Rotor	
Diameter	112 m
Swept Area	9852 m^2
Rotor speed	12.8 rpm
Rotor peed Range	6.2–17.7 rpm
Rotational Direction	Clockwise (front view)
Orientation	Upwind
Tilt	6 °
Blades	
Number of Blades	3
Blade Coning	4 °
Type Description	Airfoil shells bonded to supporting beam
Blade Length	54.65 m
Material	Fiber glass reinforced epoxy and carbon fibers
Hub and blades mass	70 ton
Gearbox	
Type	Differential, three planetary stages + one helical stage
Gear House Material	Cast
Gearbox Ratio	1:113.2
Mechanical Power	3300 kW
Lubrication System	Pressure oil lubrication
Backup Lubrication System	Oil sump filled from external gravity tank. Approximately 1170 l
Nacelle mass	150 ton

Table 8. PV panel specifications.

Properties	Value
P_{max} (+/−5%)	154 W
Efficiency	20%
V_{pm}	18.0 V
I_{pm}	8.1 A
V_{oc}	22 V
I_{sc}	8.7 A
Length	1515 mm
Width	680 mm
Thickness	2 mm
Weight (mass)	2.4 kg
TCFP	−0.34%/C

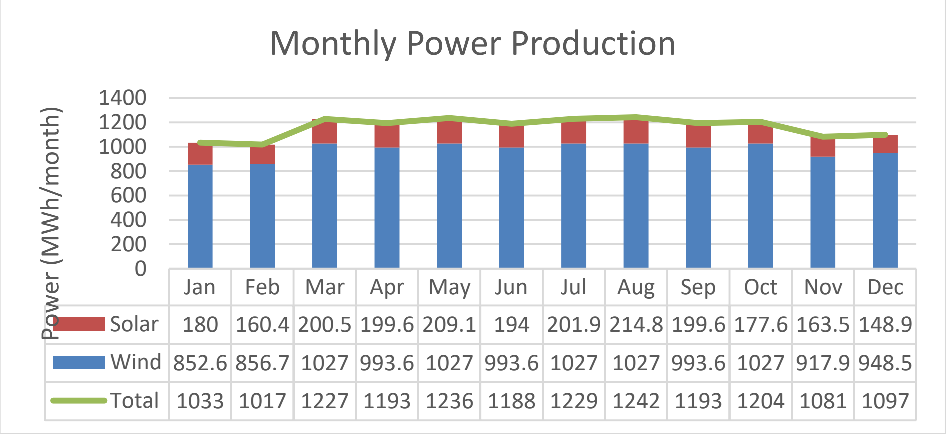


Figure 6. Monthly Power Production.

The average monthly demand in normal operation is estimated to be 1235 MWh/month, among them, only 1020 MWh/month is for desalination and 210 MWh/month is for marine systems. Although the maximum load condition calculations are not realistic but useful for primary power plant design, calculations performed in normal operation are useful in estimating the shortage/excess power generated and designing the back-up or storage system. Energy efficient design and operation reduce the platform demands and permit the platform to serve as a mobile power station as well.

The maximum power production is expected to be in August and reaches 1242 MWh/month, while the minimum is expected to be in 1033 MWh/month in January. A more detailed energy management system using DesignBuilder simulator, as recommended by ASHRAE is required to prevent power shortage due to any environmental or technical reasons. However, any power shortage can cause the stoppage of functions with less priority to safety then operation respectively, which can include the disconnection of one or more RO unit. The energy storage solution in batteries may not be suitable for such capacities and marine environment. Novel studies investigate the storage of energy in thermal storage tanks or pneumatic vessels and the conversion of the stored energy into useful form again; however, both methods are complicated and far from the research's scope. The pilot project expected to operate in 2022 will provide real data of the power production and demand.

5. Potential environmental impacts

According to the proposed design and baseline description; screening and scoping analysis of the environmental impacts characterized those impacts into major and minor impacts (see Table 9). This categorization considered the mobility and small size of the platform which reduced some impacts and the national related environmental standards and regulations.

5.1. Water pollution

During the reverse osmosis process, the membrane allows only water molecules and retains salt particles to a waste stream, known as brine, which is twice as salty as seawater. If the rejected high-density brine is discharged directly back into the sea, an elevated layer of salt concentration will sink and settle on the ocean floor because of the lack of wave energy in the bottom of the sea. The concentrate affects the water quality and causes water pollution due to acquiring elevated salinity, obtaining high temperature, and carrying heavy metals that wore away from the desalination equipment during the operation. Based on a literature review [53] it was found that some species are affected by salinity increases of only 2–3 parts per thousand above ambient, showing that the brine's impact on the water quality can cause widespread changes in the benthic community which would influence the marine life, the sediment quality and the functioning and intactness of coastal ecosystems by causing some fish to migrate while enhancing the presence of others that would kill vital microorganisms [54].

Because the salinity of brine reject is two times higher than the salinity of seawater, the wastewater of the plant has tremendous osmotic energy that could be harvested by suitable energy for power generation like Pressure Retarded Osmosis (PRO) technology intensively reviewed in [55] or microbial desalination cells designed for water purification and power generation [56].

Another form of water-waste is the chemicals reside from the pretreatment and cleaning of the plant that help against biofouling. Installing a water system in seawater creates an organic coding to the surface because the RO membrane only allows water to pass through it and not micro-organisms like bacteria, fungi, or yeasts. Those micro-organisms form unwanted bacterial biofilms on the membrane which become a habitat and food source for larger aquatic. Biofilm is an irreversible process that permanently damages the surface of the RO membrane and forces continuous cleaning to free the membrane. Some of those desalination pretreatments are chlorination, coagulation, anti-scaling and dichlorination which all require the injection of a chemical agent to eliminate microbes. Those chemicals, however, end up being washed in the sea with the concentrate and have the risk to harm the aquatic life. Chemical discharge can also exist by leakage of hydraulic fluid used for turbine and generator lubrications, which result from poor system design, incorrect component selection, poor quality control tolerances during the manufacturing, or incorrect overhaul of rebuilt components [57]. This is in addition to the interactions between platform and the marine environment which make the thing more complex by the fact that the platform would introduce new habitats as it provides attachment surfaces for a variety of algae and invertebrates, so the platform would be colonized by fouling organisms. Moreover, most of the platforms are made of steel, which is a highly corrosive material that affect the quality of water around the platform [58].

Table 9. Major and minor environmental impacts of the ROFDP.

Category	Impact	Cause
Major Impacts	Water Pollution	Brine discharge
		Chemical additives
		Material biofouling
	Seabed Disturbance	Mooring anchors
		Source water intake (impingement and entrainment)
	Noise Pollution	Wind turbine aerodynamics and machinery
		Desalination pumps
		Marine system pumps
Minor Impacts	Bird Fatality	Wind Turbine
	Coastal Erosion and Wave Pattern Disturbance	Nearshore location of the platform
	Visual Impact and Beach Access	Nearshore location of the platform
	Navigation Hazards	Maritime shipping pathway

5.2. Sea-bed disturbance

Anchoring and mooring can cause physical disturbance to the seabed as the Red Sea and Ras Gharib are very rich with coral reefs. The reduction in size and density of reefs can cause a variety of refugees' fish spaces to disappear because fish use the structure of coral reefs as shelter and as nesting sites. The Red Sea Governor created mooring buoys, which are quasi-permanent anchors fixed to the seabed, to prevent dropping anchors to the seabed and damaging the coral reefs [59]. However, those anchors, may be considered as artificial reefs and attract marine creatures which can increase biodiversity and habitat complexity but can also disturb natural habitats and introduce invasive species. Therefore, an understanding of the relative ecological effects of different mooring technologies and of which types of mooring are appropriate or inappropriate in Ras Gharib is important to protect the seabed. The goal is to identify situations in which more environmentally sensitive mooring systems would be preferable. Another concern for seabed disturbance is seawater intakes which can be categorized into impingement and entrainment. Both represents the interaction and removal of marine organisms by the intake screening technology used during the operation of an intake system. The impingement occurs when organisms that are large enough to be retained by the intake screens are trapped against them by the force of the flowing source water, while entrainment exists when marine organisms that are small enough to pass through the particular shape of intake screen enter the desalination plant intake and pass through to the treatment facilities. The seawater intake and brine discharge processes impacts are highly reduced because of the special design of the FDP, where water intake is through the inner tank of the platform and brine is splashed over the water surface.

5.3. Noise pollution

The high-pressure pumps required for desalination are a source of noise pollution and would affect aquatic life because marine creatures have sensitive hearing and use sound for navigation, communication and sonar [53]. The expected noise of the RO system components and different pumps during the operational phase at source is estimated to vary between 80 and 90 dB (A) for each device, and similarly the marine pump system. The wind turbine attached to the FDP also contributes to the noise pollution. A single wind turbine sound pressure is usually between 90 and 100 dB (A), and at 40 m from sea level, the sound pressure level is between 50 and 60 dB (A), which is about the same pressure level as a (continuous) conversational speech [59].

5.4. Minor impacts

An important environmental concern when constructing wind farms is birds colliding with the turbines. The heights, blade lengths, tip speeds and blade appearances to birds are the main factors that determine the collision probability. Most studies have shown that the highest numbers of fatalities occur when wind turbines are built in areas where large numbers of migratory birds pass. In the springtime, Ras Gharib flyway is a very busy and an important route for migratory soaring birds to and from Africa. Special monitoring systems are available to monitor and minimize the bird's fatality rate. System that collects information on how migrating birds behave around the turbines and detects any birds in collision risk with the wind turbine. The systems are usually based upon HD cameras that enable 360 ° surveillance coverage and provides continuous monitoring of the whole day and night by operating with thermal cameras at night. Those cameras are attached to the tower of the turbine and have the ability to survive any extreme weathers. Birds will be detected in real time while a data processing device that is connected with the cameras processes the detected information and generate graphics and automatic reports for any selected period of bird paths records. The online data analysis platform will provide very clear information of bird flights including videos and sounds of birds near the plant. Moreover, it is reported that painting the turbine blades with bright colors reduces the number of bird fatalities by wind turbines.

In general, offshore platforms can have insignificant effects on the wave climate, patterns of vertical mixing, tidal propagation and residual drift currents. The most pronounced effect is likely to be on the wave regime if the structure is extremely large and fixed. In this case, a decrease in incident wave energy could influence the nature of the shore and shallow sub-tidal area and the communities of plants and animals they support. It is not likely that the ROFDP express such impacts because of its dimensions and mobility.

The Red Sea is known for being a rapid touristic area, but the ROFDP can have an effect on some forms of recreation and human coastal activities such as: water skiing, snorkeling, diving, sailing and wind surfing. Additionally, the ROFDP would have a visual impact on the area because the wind turbine will be seen from the coastal line, affecting the view of the site. However, those impacts are considered minor due to the mobility of the platform and the distance between the platform and the shoreline, and desalinated water is extremely needed because areas on the Red Sea are active tourist location.

The Rea Sea at Ras Gharib is known for having an extremely high volume of vessels passing through daily as this waterway is vital for international trading. Therefore, any low freeboard platforms can be potential navigational hazards to trading or fishing ships passing through because a low freeboard could be difficult to detect visually or by radar. A floating desalination can interfere with shipping routes. However, fortunately, collision risk and navigation hazards are not an issue to consider in this study because of the existence of the wind turbine. Moreover, traffic survey for commercial and fishing ships in this area exists along with accurate records of the device location. Finally, the device will include lights and transponders which would minimize the risk of accidents with ships and vessels at night.

Finally, PV systems are clean and sustainable but their operation causes minimal pollution during their lifetime. Such impacts can not be ignored especially during manufacturing and disposal. A detailed EIA of such systems can be found in [60].

6. Relevant national standards and regulations

This section presents the national environmental standards and regulation related to the operation of the ROFDP.

6.1. Wastewater discharge

Law 4/1994 (Section: Wastewater Management) provides guidelines and limitation for wastewater discharge in different local environments. Table 10 presents these limitations in case of discharge in coastal environment.

Table 10. Limits of wastewater discharge composition in marine environment collected from [59,61].

Description	Limit (mg/L) if not mentioned	Description	Limit (mg/L) if not mentioned
Temperature	<10 degrees difference	Petroleum based hydrocarbons	0.5
PH	6–9	Mercury	0.005
Color	Should be absent	Lead	0.5
Turbidity	50 NTU	Aluminum	3
Absorbed Bio-Oxygen	60	Cadmium	0.05
Dichromate	100	Chromium	1
Total Dissolved Solids	2000	Copper	1.5
Total Dissolved Solids ash	1800	Nickel	0.1
Suspended substances	60	Iron	1.5
Phosphate	5	Manganese	1
Nitrates	40	Zinc	5
Fluorides	1	Silver	0.1
Arsenic compounds	0.05	Barium	2
Sulfides	1	Cobalt	2
Oil and Grease	15	Cyanides	0.1
Ammonia	3	Pesticides	0.2
Phenols	1		

6.2. Sea-bed (coral reefs) damage

Mooring systems significantly reduce the damage to the reefs by eliminating the need for anchoring. The Egyptian Environmental Affairs Agency in cooperation with HEPCA program installed over 1000 buoys throughout the Red Sea. HEPCA works in coordination with the EEAA to ensure correct usage of the buoys and to implement EEAA regulations as part of a comprehensive resource protection management strategy [62]. Therefore, the coordination with HEPCA program is highly recommended to the reduce the coral reefs damage caused by the mooting system of the ROFDP.

6.3. Noise pollution

Law No. 4/94 (Section: Noise Pollution and Monitoring) and Law No. 12/2003 on the Protection of Workers and Vocational Health and Safety; provide the basis for regulating noise emissions. maximum permissible noise levels inside the workplace with up to 8 hour shifts and aiming to limit noise hazards on hearing is 90 dB (A) and the maximum permissible Noise in Residential with some workshops or commercial establishments varies between 50 and 60 dB (A). Tables presenting the maximum permissible noise levels inside different types of workplaces; and limits for ambient noise levels, according to the type of area the source is located in can be found in [63].

7. Highlights of The proposed monitoring plan

Although scoping of the impacts reported only minor remarks and that the ROFDP emissions are within the acceptable limits, a monitoring system must be implemented to ensure the propre operation of the systems and quantitively assess the impacts. A proposed monitoring plan is presented in Table 11 highlighting the description, method of monitoring, technical considerations and testing intervals of each parameter.

Table 11. Monitored parameters of the ROFDP.

Monitored Parameters	Description	Method	Considerations	Time Interval
Brine and chemicals discharge	Discharge flowrate and chemical composition	Remote Sensor located at the discharge pipeline	Handles the flowrate produced by the plant and analyzes for pre-defined elements within the apparatus operating range	Continuous real-time monitoring
Platform hull biofouling	Growth of biofilm layers over the platform surface	Manual inspection	Enables DNA-based analysis of biofilms formed on the hull	Periodic inspection
Coral reefs damage	Damage of coral reefs due to mooring anchors	Radar / Piezoceramic transducer	Provides clear bathymetric view to help in selection of mooring locations	Upon mooring
Noise inside the plant	Noise affecting operators	Remote Sensor located inside the plant (Indoor)	Coincides the produced noise bandwidth	Continuous real-time monitoring
Noise around the platform	Noise affecting platform surrounding	Remote Sensor located on the platform deck (Outdoor)	Coincides the produced noise bandwidth and withstands outdoor conditions	Continuous real-time monitoring
Birds' flyways	Flocks' detection	Rada / IR or thermal Camera	Enables early detection and notifications of flocks	Continuous real-time monitoring
Birds' fatalities	Birds' death due to collision	Manual count Sensor located on the platform deck	Reflects the respect of the platform crew to biodiversity	Upon radar notification
Platform location	GPS location of the platform	GPS sensor	Enables online tracking of the platform location	Continuous real-time monitoring

8. Discussion and final remarks

This study highlighted the significant role of the environmental practices to achieve a sustainable design, where most of the Environmental Impact Assessment procedures have been performed prior to the design phase, in order to provide technical help in the task of designing a floating desalination platform.

Throughout the design period of this study, comparison of the alternatives has been considered as a decision-making tool and provided reliable data that help the research team in the selection of the optimum location, best desalination technology, and available power sources. Such decisions directly affected the design of the floating platform. Comparison performed between different cities presented in Figure 1 showed that Ras Gharib is the optimum location to install the platform. The criteria selected in this comparison rely mainly on environmental data such as water depth, solar and wind power abundance, restricted and protected areas besides other socio-economic criteria. Another comparison has been performed between RO and MED after reviewing different desalination technologies. Comparison showed that both technologies are suitable since they can all provide the required capacity, operate with the red sea water TDS and supply good water quality; However, RO plants present: a) The best land use, which is an important factor in case of offshore desalination where platform area is limited. b) The highest water recovery rate and lowest disposed brine temperature minimizing the brine environmental impacts. c) The least SEC and consequently the least CO_2, NO_X and SO_X emissions. d) The minimum construction time and minimum capital cost, mainly governing the cost of desalinated water. The third comparison has been performed between the conventional and renewable power sources available in the selected location. This comparison showed the amount of emissions expected of the conventional (Fossil-fueled) power source and highlighted the possibility of depending on hybrid renewable power system. Finally, a detailed hydrodynamic comparison was performed between platform configurations. Results showed that a cylindrical hull platform with heave damping plate is the best configuration to support a large wind turbine and a desalination plant.

Furthermore, the current baseline of FDP's site, Ras Gharib, has been described and categorized into 4 main pillars: a) Socio-economic and water resources. b) Physical environment. c) Biodiversity. d) Renewable energy. Socio-economic and water resources data highlighted the importance of the project to the Egyptian Red Sea cities in general and Ras Gharib in particular. Physical environment and Renewable energy data served the platform, power system and desalination plant design as the baseline covered the input data required for their designs. Biodiversity pillar highlighted the richness of the Red Sea and the importance of considering the environmental aspects in design to ensure the biodiversity sustainability.

Later on, a technical description of different systems of the study has been presented. Data and designs presented in this section are the final specifications.

Finally, an overview of the environmental impacts associated with the operation of the ROFDP in Ras Gharib has been presented to give guidance on the monitoring and mitigation processes necessary to increase the ROFDP's environmental sustainability. The impacts have been classified as major and minor impacts. This categorization considered the mobility and small size of the platform which reduced some impacts. Major impacts are highly recommended to be considered in the monitoring and mitigation practices, and include a) water pollution mainly due to brine discharge; b) sea-bed disturbance,(coral reefs damage) mainly due to the mooring system, (which is not designed yet) after the impact of feed water intake has been reduced because of the platform design; and finally; c) noise pollution produced from the wind turbine, desalination plant and marine system due to the platform locations nearshore to serve touristic and coastal villages, in addition to its effect on the working personal and marine mammals in region rich in biodiversity.

A detailed monitoring plan has to be developed based on the provided highlights in order to measure the impacts of the ROFDP especially for the wastewater (brine) stream (composition and flowrate), coral damage, noise pollution, and bird fatalities. Moreover, recommendations for impacts mitigation have to be developed before the production of the platform in order to ensure the highest sustainability of the FDP.

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Conflict of interest

The authors declare no conflict of interest.

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