AMERICAN UNIVERSITY OF BEIRUT

FLOATING SOLAR PHOTOVOLTAICS OFFSHORE LEBANON: A PRELIMINARY FEASIBILITY STUDY

by
LORY KANTARGIAN

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Approved by:

Dr. Nesreene Ghaddar, Professor — Advisor
Department of Mechanical Engineering

Dr. Rabih Jabr, Professor — Member of Committee
Department of Electrical and Computer Engineering

Dr. Hiba Khodr, Associate Professor — Member of Committee
Department of Political Studies and Public Administration

Dr. Hassan Harajli, Lecturer — Member of Committee
Department of Economics

Dr. Adnan Mortada — Member of Committee
SMAP Energy Cofounder and Business Development Manager

Date of thesis defense: November 7, 2019

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AN ABSTRACT OF THE THESIS OF

Lory Kantargian for Master of Science in Energy Studies
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Continuous increase in energy demand coupled with limited unconventional energy sources have shifted the global interest towards sustainable energy sources and environmental welfare. This has resulted in the booming of renewable energy markets.

One of the most promising systems within this field is the solar photovoltaics systems as its benefits, amongst others, are energy generation and lack of GHG, gaseous and particulate emissions. Yet, since the solar PV systems require lands to be implemented on, worldwide researchers and investors have been studying and implementing "Floating Solar PV systems" which can be installed on different types of water bodies.

Floating solar PV systems might become an ultimate solution for Lebanon as it is a small country with high competition for land and increasing population and energy demand. Lebanon suffers from a huge energy gap, power shortages, outdated networks and power plants, in addition to the lack of energy sector strategies and policies.

The objective of the thesis paper is to perform a preliminary feasibility study of implementing a floating solar PV system in Lebanon. The study will be carried out by designing a case study of implementing a floating solar system at the offshore area facing the American University of Beirut's (AUB) in Beirut.

The feasibility will be determined from an environmental, financial, and policy perspectives. The paper will discuss Lebanon's current energy policies, the environmental and climatic conditions, and the expected cost of implementing a FPV.

The aim of developing such a system on AUB's offshore area is to create a model which can be replicated and used in different areas of Lebanon's offshore as a viable energy transition option towards bridging the wide energy gap between the demand and supply on one hand, and towards increasing the share of renewable energy in Lebanon's energy mix on the other.

Keywords: Floating solar PV, Renewable Energy, Photovoltaics, Energy Sector, Electricity, Feasibility, Offshore, American University of Beirut (AUB), Lebanon.

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ABBREVIATIONS

ADB: Asian Development Bank

AFD: Agence Française de Développement

ANSI: American National Standards Institute

AUB: American University of Beirut

BDL: Central Bank of Lebanon

BRSS Beirut River Solar Snake (a demonstration PV plant project in Beirut)

CIP: Capital Investment Programme

CNRS: National Council for Scientific Research

CoM: Council of Ministers

EBRD: European Bank for Reconstruction and Development

EE: Energy Efficiency

EEZ: Exclusive Economic Zone

EIB: European Investment Bank

EU: European Union

EUR: Euro Currency

FPV: Floating Photovoltaics

GEFF: Green Economy Financing Facility

GoL: Government of Lebanon

GW: Gigawatts

IEA: International Energy Agency

IEC: International Electrotechnical Commission

IEEE: Institute of Electrical and Electronic Engineers

IRENA: International Renewable Energy Agency

ISO: International Organization of Standardization

kW: Kilowatt

LCOE: Levelized costs of electricity

LPA: Lebanese Petroleum Administration

m: Meter

m: Square meter

mm: Millimeter

MoE: Ministry of Environment

MoEW: Ministry of Energy and Water

MoF: Ministry of Finance

MW: Megawatts

NEEREA: National Energy Efficiency and Renewable Energy Action

OPRL: Offshore Petroleum Resources Law

PID: Potential Induced Degradation

PV: Photovoltaics

RE: Renewable Energy

RPS: Renewable Portfolio Standard

UNDP: United Nations Development Programme

USD ($): United States Dollar

US¢: United States Cents

CHAPTER I

INTRODUCTION

The non-renewable nature of fossil fuel resources and the increasing energy demand have shifted the world's focus towards the deployment of renewable energy (RE). The noticeable rise in the electricity demand, fast depletion of fossil fuels, along with environmental concerns throughout the world have led to the requirement of commissioning solar PV plants in large scale. Solar energy, which has low operation and maintenance costs, and is endowed with an unlimited source of energy, is simultaneously an eco-friendly and sustainable energy resource.

Solar photovoltaics (PV) farms have been experiencing significant growth over the past several years. With a total of more than 97 GW of newly added capacity in 2017, the global generating capacity of solar PV stands at approximately 400 GW (as of end of 2017), registering a 32% increase as opposed to the end of 2016 (BP, 2018a). During the last five years, solar PV capacity has quadrupled. Although its overall contribution to global power generation does not exceed 1.7%, its share has more than doubled in the last three years. Moreover, approximately 20% of the global power growth in 2017 is attributed to the growth of solar power generation (BP, 2018b).

Yet, along with the decrease in solar PV prices and increase in its capacity implementation, the space availability to install the solar PVs is becoming a greater challenge. Installing large solar PV farms requires vast lands which could also be used for various other purposes such as agricultural production or residential units (Choi, 2014). This gave rise to the relatively recent technology of "Floating Solar Systems." The latter, also known as Floating Photovoltaics (FPV), are floating solar PV systems, a relatively simple energy generation method that functions similar to the land-based solar PV farms, but the PV panels are installed on waterbodies and do not require land space.

The adoption of FPV can be very attractive to countries which are densely populated and suffer from limited land availability for large solar energy projects. Countries that lack natural fossil fuel resources, have high dependence on non-renewable energy resources, and aim to achieve energy security can greatly benefit from such called “floatovoltaics”. FPV systems can be either installed on inland water bodies, such as on lakes, dams, and irrigation reservoirs, or on offshore water surfaces.

However, while more than 100 onshore FPVs are operational around the world (Solarplaza, 2019), almost all are on onshore waterbodies since the offshore environment poses more environmental challenges. Yet, developments within the sector has now led to the development of advanced FPV systems which can withstand extreme environmental conditions that range from high water level variations and heavy storms to sub-zero temperatures and water freezing.

Lebanon, a small country which relies on the import of fossil fuels for almost all of its power consumption and has more than 300 sunny days per year, could be well positioned to consider FPVs. Yet, since Lebanon lacks major inland waterbodies, the available option for FPV installation is only offshore, especially that it has a 220 km coastline.

Is offshore FPV feasible for Lebanon? Can it constitute a part of the countries national energy mix? What are the environmental and political barriers which might hinder the application of a FPV offshore Lebanon?

A. Objective of the Study

The objective of this thesis is to carry on a preliminary feasibility study of implementing a FPV system in Lebanon. The aim is to determine the feasibility from a policy, environmental and financial perspectives. The research identifies the environmental, policy and financial feasibility, in addition to the challenges that the FPV might face before its implementation and during its operational phase. It is important to state this is an experimental study.

As a start, a systematic literature review tackles two major topics: FPV systems across the world and Lebanon's electricity sector. First, the review gives insight about the FPV technology and its current status around the world. It also describes the understanding of commercial FPV technology used worldwide, its advantages and challenges. Then, a review focuses on the sustainability challenges of Lebanon concerning its energy sector and its impetus to increase the RE generation. A thorough research and insight is carried out with respect to Lebanese energy laws and policies in order to further comprehend the political context of electricity issues in Lebanon, and identify the missing measures which should be tackled.

A major part of the thesis focuses on a case study of installing a FPV system offshore AUB. Environmental and policy challenges are tackled along with the financial aspect to understand the feasibility of implementing such a system locally. This helps in determining the overall feasibility.

Finally, the outcomes are combined in order the understand the feasibility of applying FPV system in Lebanon, and to fill the gaps on the policy level through recommendations that aim to enhance the electricity sector in Lebanon along with the implementation of FPVs if feasible.

B. Significance of the Study

This thesis studies the feasibility of installing a FPV system offshore Lebanon. To the best of my knowledge, no other research work has tackled the feasibility of FPVs in Lebanon to this date. Hence, this study is the first.

If proven to be feasible, this technology can be implemented in Lebanon and can serve as a clean energy generating technology, providing a new and feasible RE technology besides the land-based solar PVs. Once the first FPV project proves to be an efficient fossil fuel alternative system, FPV systems can be installed on a large scale at the country's offshore simultaneously increasing the share of RE in Lebanon. This further helps the country attain its RE commitments as per the international conventions and treaties, especially that Lebanon already suffers from numerous energy challenges that aggravate the national socioeconomic losses. The energy challenges comprise of legal, political, administrative, technical, financial, and environmental challenges.

These challenges were one of the most significant motivation and driving factor to focus this thesis on such a topic. Maintaining a sustainable and efficient energy sector requires well-established and well-implemented laws and regulations. Among the numerous studies tackling the electricity sector in Lebanon, this thesis aims to assist as a guide for concerned parties and stakeholders towards maintaining a sustainable and efficient electricity sector through a renewable and innovative RE system.

CHAPTER II

FPV SYSTEMS: DESIGN, OPERATION AND COST

The solar energy market is expanding due to the governmental incentives and very attractive Feed-in Tariffs that play as the primary drivers for the adoption of RE alternatives in many countries that aim to attain their RE targets set in international treaties (IRENA, 2019a). FPV systems are an alternative choice against land-based solar PV plants, overcoming the challenge of space availability. They can be installed on inland water bodies, such as lakes, dams and irrigation reservoirs, or offshore on the sea or oceans' surface. In both systems, their installation equipment and components are very similar, likewise their operation and maintenance practices (Sujay et al., 2017).

FPV systems are considered as one of the easiest energy generation systems in terms of installation and operation when compared to other renewable and non-renewable energy generation technologies, such as wind and nuclear (Minamino, 2016).

A. Components and Operation of FPV Systems

The main components of a FPV system are the following:

- *Pontoon/Floating Structure*: The floating body is comprised of the base structure and the pontoon, and allows the installation of the PV module on top. A pontoon is a flotation structure made up of multiple plastic hollow floats which make up a giant pontoon when combined. It has buoyancy enough to float by itself and support a heavy load. The floats are usually made from fiber-reinforced polymer (FRP) or High and Medium density polyethylene (MDPE or HDPE) due to their tensile strength, maintenance free, recyclable, and UV and corrosion resistance characteristics (Choi, 2014).

- *Solar system*: FPV systems include standard PV modules, solar inverter, solar tracker and interconnection wiring (Choi, 2014). Usually, standard crystalline solar PV modules are used, yet due to the salt mist exposure, specifically fabricated modules are needed with alternatives to standard aluminum frames and mounts, such as polymer frames, in order to withstand the salt and mist (Sahu et al., 2016). Solar PV modules are fixed on the pontoon by a metallic structure which is inclined to maximize the solar incidence (Choi, 2014).
- *Mooring System*: The FPV panel structure is held steadily with a permeant structure called mooring. The mooring system is usually made up of mooring line, anchors, and connectors. The type of the mooring line – synthetic fiber rope, wire, chain or a combination of several types – is determined depending on the environmental factors (Sahu et al., 2016). It has to be installed as an anchor relative to a point at the bottom of the water body to fix the floating structure's position in a single direction (Choi, 2014). The mooring system prevents the free movement or turning of the panels on water and holds them in the same position (Sujay et al., 2017). Installing a mooring system can be more challenging as the depth of the water increases. Usually, a relatively less complex anchoring system can be used for inland FPV systems since they are relatively less prone to extreme environmental conditions and are shallower than offshore. On the other hand, more sophisticated mooring system and anchors are needed for offshore FPV plants. Some engineering and harbor equipment suppliers have already cooperated with FPV companies to construct an enough rigid anchoring system that can withstand environmental extremes such as water freezing and hurricane strikes.

- *Cabling*: Cables are pulled from the system to the land to feed the power into the grid or to store it in batteries. Waterproof, robust and high temperature resistance electrical components are utilized to prevent any risk. The cables shall be resistant against UV radiation and shocks (Sahu et al., 2016).

A typical technical diagram of FPV system is shown below in Figure 2-1:

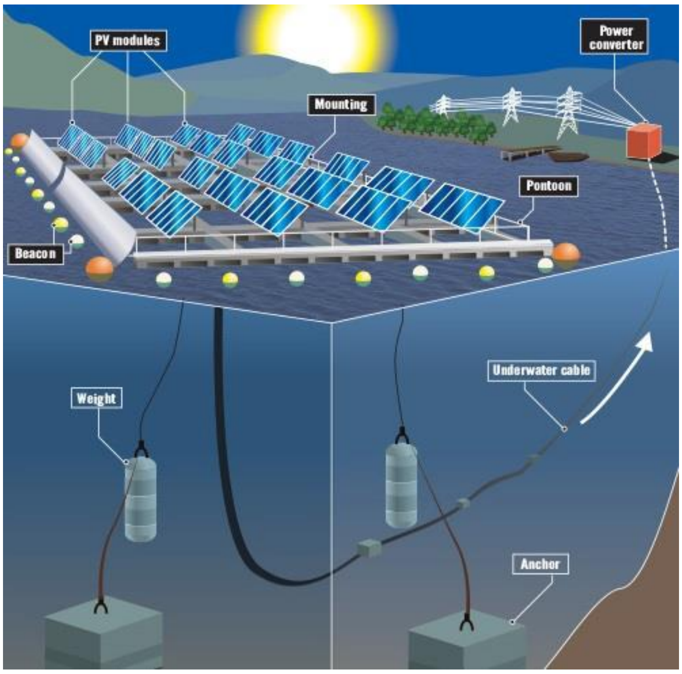


Figure 2-1: Technical details of a floating PV system (Rathi, 2018).

The initial phase of FPV system installment requires site specific planning in order to achieve a well-designed structure with maximum economic and technical efficiency. The water body and environmental challenges have to be thoroughly studied in order for the designed FPV to be adaptable to the natural conditions. Based on the water surface area which will be covered by the FPV, the following must be studied: number of PV modules to be installed, panel orientation, panel tilt angle, and the distance between panel rows to prevent shading effects (Sujay et al., 2017).

As land is and always has been a premium commodity, governments and stakeholders are usually confronted by the issues of space availability, and thus land-based solar PV installations are always coupled with the burden of land availability and acquisition which pose significant financial and social challenges (Sujay et al., 2017). In addition, implementation of land-based solar power plants decreases the economic and aesthetic value of land, thus is sometimes opposed by the public community (Sahu et al., 2016). On the other hand, FPV systems are unobtrusive since they are more “hidden” from the public view, and allow preservation of land for alternative uses. Therefore, countries which have high solar potential, but are simultaneously overpopulated and suffer from land availability and high land costs, might consider FPV implementation more feasible than the installation of land-based solar systems. Japan is a typical example as the presence of large inland waterbodies in Japan further helped to install inland FPVs which are much less challenging than offshore FPVs (Minamino, 2016). For a country who suffers from land availability and also does not own large waterbodies, such as Lebanon, offshore FPV installation is the only available option.

FPV systems, both inland and offshore, have relatively easy installation, operation and maintenance than other types of energy generation technologies. It does not require complex foundational work, unlike wind, fossil fuel, and nuclear power plants which are much more challenging during both, constructional and operational phases. FPV systems require minimal maintenance activities which can be performed easily by adequately equipped and skilled technicians (Minamino, 2016).

The advantages of FPV systems are diverse and numerous. They are eco-friendly, durable and sustainable systems. Unlike land-based solar plants, FPVs do not have the risk of obstacles that block sunlight (Sujay et al., 2017). Moreover, it has been shown that FPV systems have greater generation efficiency than overland PV systems by over 10% due to the cool temperature of the water underneath (Choi, 2014). On the other hand, for overland PVs systems in hot and dry regions, a temperature increase above a certain average heat up the solar modules and thus decrease the energy yield (Sujay et al., 2017). Furthermore, FPVs have proven additional benefits to the aquatic environment by providing shading which limits algae growth (mainly for onshore waterbodies) and prevents water evaporation (Sahu et al., 2016). Corals have seen to grow beneath the FPV structure and fish use it to hide. None of the system components pose a danger to water quality, except if the panels break since solar panels include some substances which might affect water quality. Yet, no such accident happened so far and it is not expected to happen.

The greatest challenge in the installing offshore FPV systems is the designing of the system which has to withstand the surrounding environmental conditions which vary regularly, such as the water depth, wave height, wind speed, and the temperature. Another challenge is the salty environment that poses the risk of corrosion of the FPV components. Yet, according to Sahu et al. (2016) this can be overcome by installing waterproof and anti-corrosion components along with regular maintenance.

As the offshore poses harsher environmental challenges than the onshore, offshore FPV systems have the risk of encountering erratic movements due to heavy winds and waves, especially at high-risk sites with very strong winds, destructive waves, cyclones, and hurricanes (Sahu et al., 2016). The movement of the floating structure has an adverse effect on the power generation efficiency. A study was performed in Hapcheon, South Korea, which studied the amount of sunlight received by the installed FPV solar modules with respect to variations in the wind speed. It was observed that the more is the movement of the FPV structure, the less is the power generated. Thus, the power generated is dependent upon the degree of the FPV structure's movement, and this movement mainly depends on the quality and the design of the anchoring system. Thus, the mooring system specifications must be designed to prevent the extreme movement of the platform, especially in the case of offshore FPVs which require much stronger mooring system than inland FPVs do (Choi, 2014).

Another factor that might affect the power generated is the length of the underwater cable which may increase the cable losses as the distance from the system to the shore increases.

A summary of the advantages and challenge of FPVs are shown in Table 2-1.

Table 2-1: Advantages and challenge of FPV systems.

Aspect	Advantages
Technical	Do not require complex foundational work, have relatively easier installation, operation and maintenance than other types of energy generation technologies.
Technical	Minimal maintenance activities can be easily performed by the equipped and skilled technicians.
Technical	Greater generation efficiency than land-based PV system by over 10% due to the cool temperature of the water underneath and better ventilation.
Technical	Eco-friendly, durable and sustainable systems.
Technical	No risk of obstacles that block sunlight.
Economic and Social	No burden for land availability and acquisition, but rather the preservation of lands for alternative uses.
Economic, Social and Environmental	No risk of decreasing the lands' economic and aesthetic value.
Economic, Social and Environmental	FPV systems are unobtrusive since they are more "hidden" from public view.

Environmental	None of the system components pose a danger to water quality.
Environmental	The aquatic environment benefits from the shading of the FPV which limits algae growth, prevents water evaporation, and corals grow beneath it and fish use it to hide.
Aspect	**Challenges**
Technical	Designing of the system to withstand the surrounding environmental conditions which vary regularly and are beyond the human control such as the water depth, wave height, and wind speed.
Technical	Offshore FPV systems have the risk of encountering erratic movements due to heavy winds and waves, and the movement of the floating structure adversely affects the power generation efficiency.
Technical	Adverse impact due to corrosion, but the use of anti-corrosion materials have overcome this issue.
Technical	The length of the underwater cable may increase the cable losses as the distance from the system to the power grid/station increases.
Financial	Cost uncertainty; cost of a FPV is very site specific, and one of the significant costs is the mooring system cost.
Social and Environmental	Fishing and other transportation activity might be affected based on the selected FPV site.
Financial and Environmental	For countries that do not have large inland waterbodies, offshore FPVs, though more challenging, are the only option.

B. Global Market Potentials and Costs of FPVs

The increase in FPV installations in the coming decades, along with the upsurge of ground-mounted solar PV deployment, will be driven by several factor: Governmental support towards RE for energy generation, national and international obligations to reduce emissions, national strategies that call for energy security, decline of solar PV prices with the increase of competition within the field, and surely the limited land availability which is a barrier for utility-scale PV plant deployment.

Few market researchers have studied the future trends of the FPV market. According to Credence Research (2017), the FPV market in 2016 was valued at 0.16

billion USD while it is expected to achieve 1.6 billion USD by 2022. Its combined annual growth rate (CAGR) from 2016 to 2022 is around 113.9%. On the other hand, Grand View Research (2017) has forecasted that global FPV market is projected to attain 2.5 billion USD by 2025.

Concerning the global potential of FPVs, according to the World Bank, there exists over 400,000 square kilometers of man-made reservoirs globally, pinpointing that from a surface availability perspective the FPV market has a terawatt scale potential onshore alone. A very conservative estimation that assumes only 1 percent of available man-made water areas are used for onshore FPV deployment, indicates a FPV capacity of over 400 GWp. On the other hand, if 10% of the available surface areas of reservoirs is used, the onshore FPV capacity exceeds 4,044 GWp (World Bank, 2018).

The global installed FPV capacity as per the cumulative and annual added capacities from 2007 to September 2018 is shown in the Figure 2-2.

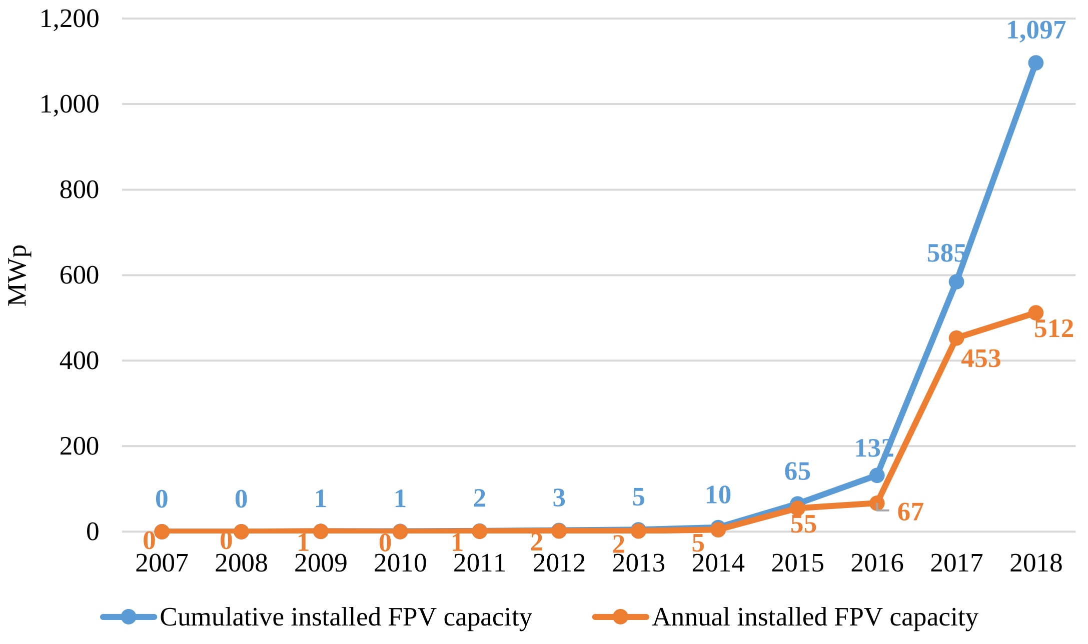


Figure 2-2: Global FPV installations as per the cumulative and annual added capacities (World Bank, 2018).

Wood Mackenzie, a leading firm on market analysis and advisory on the transformation of global electricity industry, released a report which concluded an extremely promising future for FPVs. Although they were non-profitable in its initial years, they are becoming more affordable mainly due to the sharp decrease in solar panels prices. The drop of PV modules prices almost 85% (from \$2.60/W to \$0.40/W) between 2009 and 2017 intensely boosted the solar market (SEAFLEX, 2018).

Due to the projected decrease in FPV prices, Wood Mackenzie's "Rise of the Machines: Solar Module-Washing Robots" expected that Asia will have the largest market growth for FPV. Figure 2-3 below is Mackenzie's projection for the following years (Gallagher, 2018).

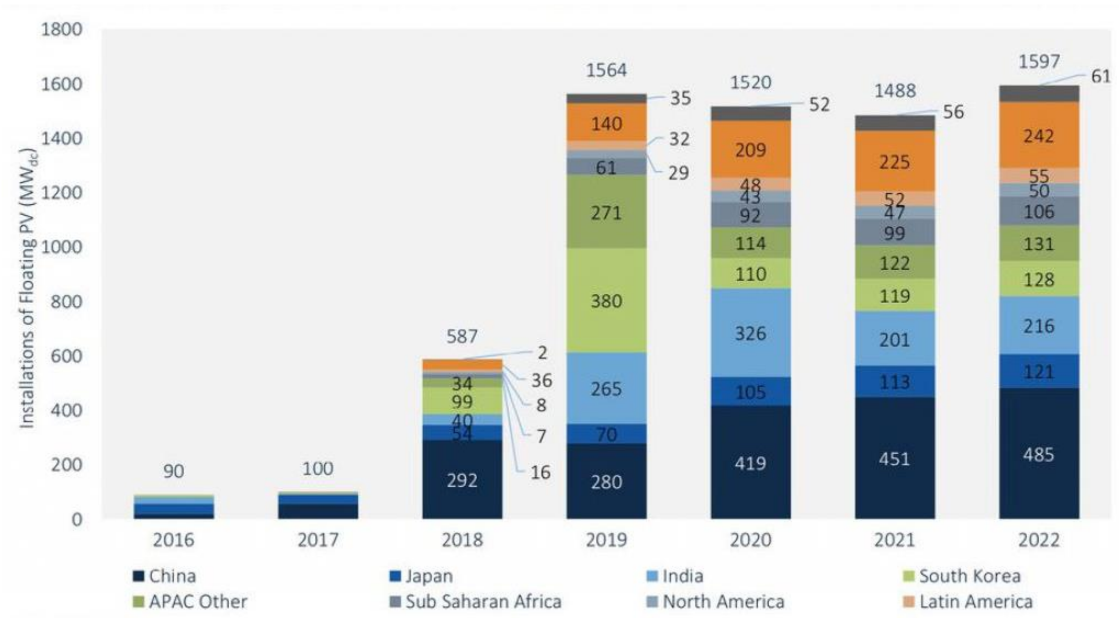


Figure 2-3: Installation and Projections of FPVs by country and region between 2016 and 2022 (Gallagher, 2018).

On the other hand, the World Bank considers offshore FPVs still in earlier stages though it is conceptually similar to onshore FPVs. The main difference is the greater environmental challenges that the offshore setting poses such as rougher water conditions with greater waves and winds, and hence the need for more critical mooring system. Water salinity is also challenge for the system components.

Yet, the stringent requirements imposed by the harsher environment on the system can be overcome by undertaking alternative design and technological solutions based on the wide experience of current offshore and marine industry (World Bank, 2018). This is already being done for FPV deployment in critical environmental conditions. Although inland waterbodies are relatively calmer than the offshore, however, some inland waterbodies are also subjected to challenging natural conditions, such as the case of Canoe Brook and Chungju inland FPVs (to be discussed in Chapter 3.B), where the installations had to withstand the severer waves and winds conditions. However, the use of advanced marine-grade components and the more critical operational and maintenance requirements in harsh environments increase the offshore FPV costs more than those of inland FPVs.

The cost of FPV systems depends on various factors: system size, maximum wave height, maximum wind speed, water depth, distance to shore, and transportation costs. Until this time, the cost of FPV systems is still higher than that of land-based PVs. The slightly higher cost is associated with the additional material expenses regarding the floats, mooring system, and the more resilient electrical components. Yet, the costs are expected to drop with time, especially with better economies of scale.

Unfortunately, not much studies have been performed on the financial aspect of offshore FPVs, since it is a recent technology and the cost mainly depends on various site specific factors. However, based on the installed onshore FPV costs, it is certain that offshore FPVs will cost more, mainly due to higher depth accompanied with harsher environmental conditions that will require a more advanced and complex mooring system. Similar to all electric generating plants, the cost of a FPV system can be considerably reduced if there is a near grid-connection infrastructure.

The total capital expenditures for major FPVs installed within 2014 and 2018 ranged between $0.8/Wp and $2.9/Wp, mainly depending on various factors, including the location, depth of the waterbody, depth variations, and the system size (World Bank, 2018). The World Bank estimates that the total capital expenditures for turnkey floating PV installations in 2018 generally ranged between 0.8 USD/Wp and 1.2 USD/Wp depending on the above mentioned numerous factors.

Figure 2-4 reflects the decline in the investment cost of major FPVs over time.

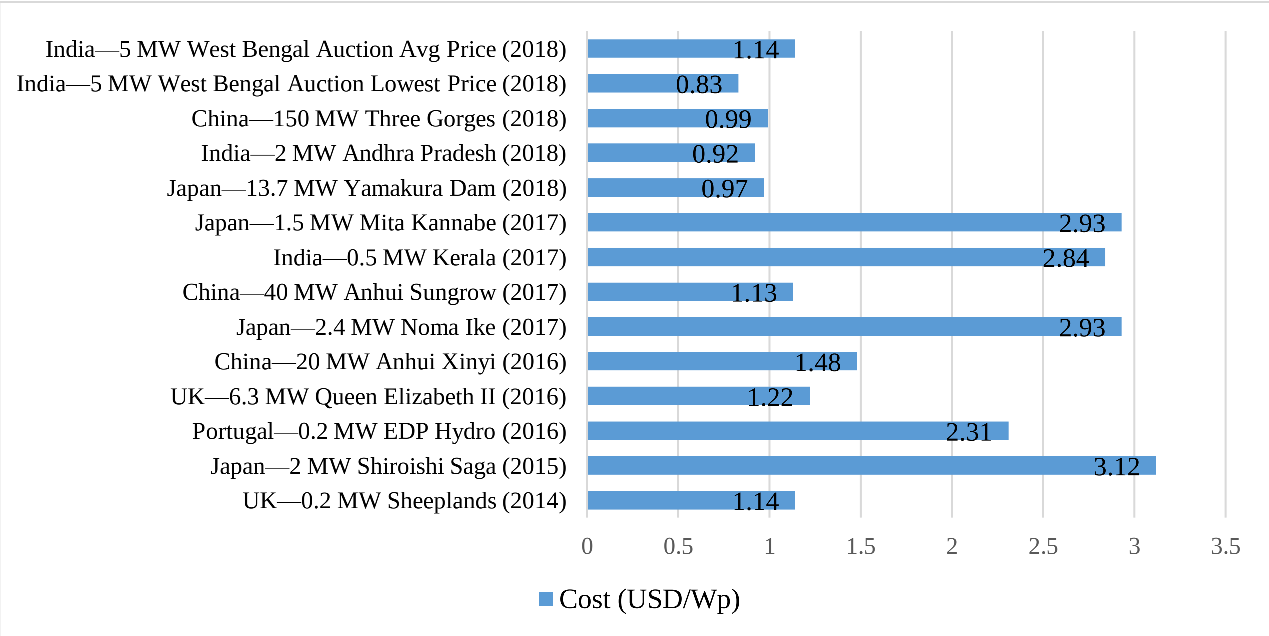


Figure 2-4: Investment cost of major FPV installed from 2014 and 2018

China has the greatest capacity installed with relatively lower prices than Japan. India has also been achieving lower prices than Japan. This pattern is the same for land-based PV system for which the capital costs are also has higher in Japan. While economies of scale has significantly helped China to reduce the costs, the latter for smaller FPV capacities in other regions might vary significantly. According to the World Bank (2018), the LCOE, on a pretax basis, of a 50 MW generic FPV system does not vary significantly from the LCOE of a land-based PV system. However, the higher capital expenditures of FPVs are compensated by a higher energy yield. The latter is very conservatively estimated around 5%, but is potentially at 10-15% in hot climates.

A comparison of LCOEs for a FPV project and a ground-mounted PV project, both having the same theoretical financial assumptions and irradiance, indicate that the major differentiating factors are the following (World Bank, 2018):

- System cost; FPV system is around 18% more experience.
- Insurance cost; 0.4% of the FPV price, while 0.3% of a land-based PV price.
- Performance ratios; 5% higher (very conservatively), but 10-15% higher (potentially) for FPV systems.

At a 10% discount rate, for a generic FPV system with a 10% higher performance ratio than that of a land-based PV project, the LCOE of the FPV can be around 5.3 US¢/kWh which is nearly equivalent to that of the ground-based PV system as per the below Table 2-2 (World Bank, 2018).

Table 2-2: Comparison of the LCOE of a 50 MWp FPV with that of a 50 MWp ground-mounted PV system.

	Ground-mounted PV System	**FPV System**
Electricity Production in GWh (first year)	75.8	79.6
Increase in FPV performance ratio	-	5%
LCOE (UScents/kWh) at 10% discount rate	5.4	6.0

Furthermore, Swimsol, a company that provides solar power systems for tropical coastal regions, states that the cost of its 1 MWp FPV system ranges between 2,000-3,000 USD/kWp. These systems, known as “SolarSea,” are designed for sheltered water areas. Per kWh cost additionally depends on the capital costs and solar output of the specific site. Realistically, per kWh cost ranges between 0.10-0.20 USD/kWh. Operational and maintenance cost is around 1.5 times that of a land-based PV system.

However, if to be implemented on open sea, the cost would be higher. For offshore FPVs, the structural and mooring system might constitute a major part of the total cost of installation. According to SEAFLEX, a leading company in mooring systems, no cost estimation can be provided for FPVs without collecting the needed environmental data which the system will have to withstand. As such, in the case of FPVs, the cost can be studied only on a case-by-case basis.

Concerning the structural cost, Kim, Yoon, and Choi (2017) performed a brief structural cost analysis as part of a study that tackled the design and construction of the structural system of a 1 MW FPV. The cost analysis for the commercial viability of 1 MW FPV system was based on the costs of the different materials which could be used for the fabrication of the structural system. The main three materials studied were steel, aluminum, and FRP, taking into consideration their mechanical properties and allowable stress level. The analysis indicated that aluminum’s unit material cost is higher than that of the FRP, and the latter is higher than that of the steel unit cost. However, in the case of members, the cost of the aluminum members is the highest, followed by that of steel and FRP member cost shown in Table 2-3 below. This is mainly due to the difference of the unit weight of materials.

Table 2-3: Cost difference of different structural materials.

Material	FRP	Steel	Aluminum
Self-weight of structure (kN)	11.48	48.84	17.60
Unit cost of member (US$/N)	0.44	0.16	0.54
Cost of 1 Member (US$/N)	5,051.2	7,814.4	9,504

Moreover, even after adding the cost and number of buoys on the total cost of the members, the total structural cost of the FPV using FRP is around 2.5 times and 1.7 times lower than when steel and aluminum is utilized, respectively. The reason is attributed to the FRP members' light weight. Therefore, when constructing an FPV, FRP is the most cost effective material to be used for the structural system.

It is evident that still more advancements and implementations of FPV systems are needed to estimate an average total cost between onshore and offshore FPVs. Well-designed governmental policies are applied in Eastern Asian countries, such as Japan, Korea, China and India. These policies revolve around setting ambitious RE targets, effective FPV tendering processes, openness and positive receptivity from the waterbodies managing bodies. These countries have also implemented supportive financial incentives, such as higher Feed-in Tariffs for FPVs than for land-based PVs.

However, globally there are no specific regulations for FPVs concerning their licensing procedures. The legal interpretations for FPVs must be different from those of land-based PV plants, mainly due to the need of standards that regulate the waterbodies across the country. Some waterbodies, onshore or offshore, might be potentially protected areas, or the deployment of FPVs on them might be very cost inefficient.

C. Potential Risks of FPV Systems

FPV systems create an environment where water and electricity are present simultaneously, leading to an electrical safety concern. However, FPVs are safe and there has not been any recorded accidents until today. The key for maintaining the safety of FPV systems is to give more consideration to the cabling system and management than it is usually given for land-based PVs. Cables in contact with water need to be fully resistant and impermeable to avoid leakages or performance drop. Connections must be insulated and waterproof in order to safely transfer the power to the onshore (Renewable Energy Corporation, 2018). Similar to other energy generation systems, a FPV system requires maintenance, and sometimes a component might require repair or replacement. Access to and installment of such components shall be carried out along occupational safety practices (Renewable Energy Corporation, 2018).

Safe grounding must be applied for FPVs to protect electric equipment and electric circuits through connecting a conductor to earth. However, grounding of a FPV system slightly differs from the grounding for a ground-mounted PV system, since it is more difficult to install a grounding system outside or at the bottom of a body of water where the floating PV system is located. For such systems, direct underwater grounding has to be adopted. Although underwater grounding methods offer cost benefits, yet it might be difficult to estimate the grounding resistance. The water temperature must be measured in the site where the FPV will be installed to be able to predict the water's temperature-dependent resistivity. After that, the grounding resistance can be calculated through modeling the resistivity based on the electrode position in the water (Ko et al., 2017). As such, the electrical safety of a FPV system can be achieved through the design process of the grounding resistance and its verification.

Currently, specifications for a safe design of a land-based PV system are defined through International Standards; the NEC (National Electrical Code) (National Fire Protection Association, 2017) and the UL (Underwriters Laboratories Inc.) 1741 for Northern American countries (Underwriters Laboratories Inc. UL1741, 2010). Standards for lightning and surge protection is are stated in details in IEC (International Electrotechnical Commission) 62305 (International Electrotechnical Commission, 2006). However, unfortunately, grounding methods for FPV systems are not established yet. Until this time, no national or international safety standards are established for FPVs. For instance, there has been some experimental studies regarding grounding methods and their safety in some FPVs by drawing grounding cables to the surface in cases of a shallow lakes or reservoirs and connecting them in a similar manner as done for ground-mounted PV plants (Choi, 2014). However, as the field is growing, it is recommended to develop a regional or international standards to ensure safe operation of such systems and regulate the feasible site selection of for FPVs across countries.

Furthermore, being installed on water, the FPV system is at high risk of moisture-led degradation, including humidity ingress through the encapsulant and Potential Induced Degradation (PID). Even if the used solar modules are PID-free certified, still being installed in a water environment exposes them to a higher risk. Although the FPV field is growing, yet there are still no certification standards or specific requirements concerning these floating systems other than what already exists for standard ground-mounted PV plants (Renewable Energy Corporation, 2018). However, FPV manufacturers have been working on developing solar modules specialized for FPV with higher capabilities of withstanding the humid environment.

Moreover, due to high humidity levels, the floating installations are recommended to be negatively grounded which permits an extra protection against the moisture-induced drops in the system potential. Another consideration is the isolation faults whereby the insulation resistance (Riso) drops over time for FPV systems. This error is usually because due to low Riso that does not meet the preset threshold, and thus the inverters do not start working until the Riso threshold is passed (Renewable Energy Corporation, 2018). Fortunately, these errors can be prevented or overcome with the proper technical installations and check-ups.

The installment of FPVs have very limited to no risk of contamination. Any floating system, before its deployment, needs to be assessed in order to prevent the risk of impacting the water quality. For instance, Ciel et Terre, a French company and pioneer in FPVs, has succeeded in complying with Great Britain's Water Quality Association's BS 6920:2000 drinking water standards, thus their floating system has been approved to be installed on the drinking water reservoirs. As for other possible harmful materials found in the pontoons, tests on the Ciel et Terre system have shown no risk when using high-density polyethylene (HDPE) plastics. Since HDPE itself is a material utilized for water pipes, there should be no fear or concerns regarding the effects of HDPE on water quality (Renewable Energy Corporation, 2018).

Moreover, an environmental assessment study assessing the possible impact of FPVs on the environment must be prepared. Until today marine biologists have observed no adverse impact on the aquatic life by FPV systems. Still, a site specific environmental assessment is required for FPVs, especially if the site comprises of very sensitive species. The local bird population might be considered, as bird droppings on the panels will decrease the power produced, and will require more frequent cleaning.

CHAPTER III

BEST PRACTICES OF ONSHORE AND OFFSHORE FPV SYSTEMS

A. Onshore FPVs

The first FPV system that has ever been installed on water was hosted in 2007 by Japan on an inland waterbody for research purposes (Sujay et al., 2017).

Currently, FPVs exist around the world, mainly in Japan, China, South Korea, England, Taiwan and others. However, most of the systems installed are located on onshore water bodies and not offshore, mainly because offshore natural conditions pose greater constraints on the FPVs than the onshore natural conditions do since the environmental extremes are harsher and more frequent offshore. These challenges rise from the nature of the surrounding environment comprising of saltwater, water level variations, wave movement, strong winds, and the various meteorological conditions.

Before 2014, only three inland FPV plants were built. Beyond 2014 and until now, over 100 “floatovoltaic” plants have been installed and operational across the world (Mesbahi, & Minamino, 2018).

According to a statistics report by Solar Asset Management, the top 70 FPV plants around the world comprise a cumulative capacity of over 94 MWp. More than half of these plants have a capacity less than 1 MWp, and 17% out of them have a capacity more than 2 MWp as shown in the Figure 3-1 below.

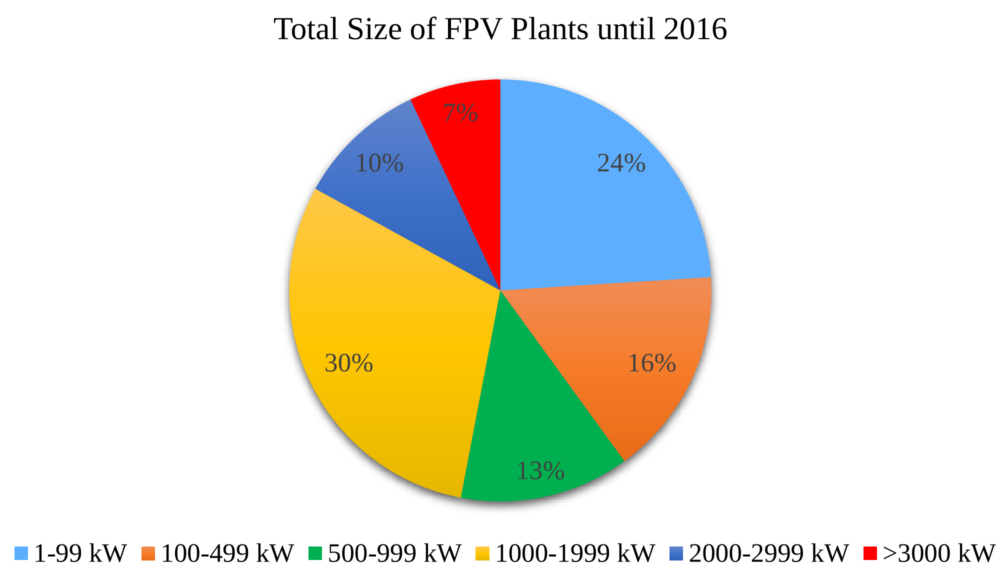


Figure 3-1: Size of Floating Solar PV Plants around the world (Minamino, 2016).

Although the first FPV pioneer country was Japan, recently China has also emerged as a pioneer country by installing FPVs with large capacities (Mesbahi, & Minamino, 2018; Solarplaza, 2018). Currently, the Anhui province in China hosts the largest capacity FPV plant of 20 MWp. However, out of the top 70 FPV systems, Japan hosts 45 plants with combined capacity of 56.5 MW. Japan has been leading this "floating revolution" by hosting around half of the total FPV projects in the world and through its continuous and expanding projects in this field. Japan's dominance in the floating solar sector is mainly attributed to its interest in the development of RE, the availability of good sun radiation, the lack of suitable land, and the generous feed in tariffs (Mesbahi, & Minamino, 2018; Solarplaza, 2018). The number of total onshore FPVs installed worldwide between 2014 and 2016 is shown in the Figure 3-2 below.

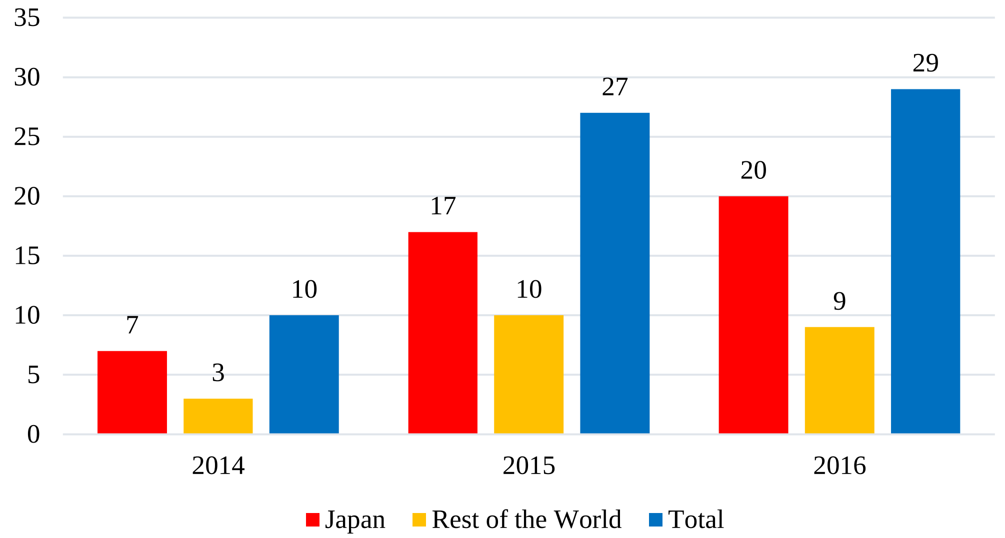


Figure 3-2: Number of total onshore FPV installed between 2014 and 2016 (Minamino, 2016).

B. Offshore FPVs

The first offshore FPV was launched in Maldives in 2014 by Swimsol Company’s SolarSea project. The SolarSea system is specifically designed for sheltered water areas at sea (e.g lagoons) and not for the open sea. It consists of a floating platforms of 196m², with an output of 25kWp, and can be arranged in different systems sizes by using multiple platforms. This SolarSea system is designed to withstand up to 2 m wave height, over 150 km/hour of wind speed, a depth of 1-60 m, and currents up to 8 km/hour. A new SolarSea system prototype is able to withstand up to 4 m waves (Swimsol, 2018).

Figure 03-3: SolarSea’s FPV in Baa Atoll, Maldives.

The company uses corrosion-free materials for the FPV structure, mainly stainless steel, marine-grade aluminum profiles and Styrofoam floating bodies encapsulated with polyethylene. For mooring, metal ropes, screw anchors or concrete blocks are used. Specially designed floating PV panels have been tested for durability and performance. Results have shown two times more durable and long-lasting efficiency than usual PV panels. PV modules are installed on a platform which elevates the surface for the panels by around 1-1.5 m above the water surface. Located above the sea, the panels are kept cooler and subjected to more ventilation. Typically, the panel efficiency is increased by up to 10%. The lack of shading offshore is a great advantage.

The designed systems have a lifetime of around 30 years. According to the company, Solarsea has been providing power to the Maldivian households with up to 50% cheaper energy and without any major issues. Similar to land-based solar panels, floating panels also have an annual degradation of 0.3-0.5%. After 30 years, the panels shall still have at least 83% of their original capacity (Swimsol, 2018).

While Maldives has installed FPVs on its lagoons, Netherlands has planned to build the largest offshore FPV in the North Sea by 2021. The project “Solar-at-Sea” will comprise of around 2,500 m^2 of floating solar panels. The developer is a consortium of six Dutch and non-Dutch companies and institutions. Financial support will be provided by the Dutch Enterprise Agency (RVO) (Bellini, 2018a; Cooke, 2018). Although dealing with the great waves and destructive natural forces is very challenging, however, the joint knowledge and expertise of the consortium regarding the offshore industry ensures the implementation of the project (Oceans of Energy, 2018). The power yield of the offshore FPV solar modules is expected to be 15% greater than that on the land (Cooke, 2018; Oceans of Energy, 2018).

Similar to Netherlands, Sunseap, a project developer in Singapore, has taken on a project to build one of the world’s largest FPV system on seawater. It is expected that the 5 MW FPV system will be operational in 2019 (Hutchins, 2018).

Furthermore, although it is true that offshore conditions offer harsher environmental extremes, however, inland FPV systems are sometimes equally subjected to natural environmental disasters as the offshore floating solar systems. A breakthrough in this field was achieved by New Jersey American Water Company’s FPV plant. The company had set over $1 million project to monitor and construct FPVs on its 735-million gallon reservoir mainly due to the lack of space to install land-mounted solar PVs (New Jersey American Water, 2011). A FPV was installed on the reservoir of the Water Treatment Plant in Canoe Brook, about 25 km away from New York, with a capacity of 135 kW and 538 PV modules (Thurston, 2012). The FPV was specifically built to withstand freeze and thaw environments. It was the first of its kind in the region (SEAFLEX, 2011; Thurston, 2012). The FPV project was initiated by the

American company Eneractive Solutions, who cooperated with the Canadian company Poralu Marine to develop a floating system that takes into account a list of complex specifications and environmental extremes while simultaneously addressing both the financial and practical constraints. The support system was built using Poralu's aluminum pontoons which were made up of Ecostyle polypropylene mesh decking topped with polyethylene floats (Marina World, 2012). The anchoring system was developed by SEAFLEX. The mooring structure was designed to ensure the floating platform's stability during extreme environmental conditions. In order to accommodate to the water level changes, the system was connected to concrete block anchors with an elastic anchoring system which involves several crisscrossing rubberized hawsers. A flexible mooring is needed in such cases to provide the required level of tension which can hold the platform at the optimum orientation for a maximum efficiency (Balcerak, 2012). Such an innovative system design has enabled the platform to withstand environmental extremes[1]. During its first operational year, the Canoe Brook FPV was hit by the strike of Hurricane Irene and was able to withstand it. It was also subjected to full "winterization" and suffered no damage. It is still fully functional (SEAFLEX, 2011). According to the New Jersey American Water (2011), energy cost savings are around $16,000 per year with a return on investment in less than 10 years. Similarly, another onshore FPV, the Chungju Solar Park, located in the Chungju Dam in South Korea, was hit by the typhoon Soulik in August 2018. This 3 MW FPV survived winds of 32 m/s and wind surges of more than 40 m/s (SEAFLEX, 2018).[2]

[1] Seaflex's mooring pontoons for deep water is explained in the following video: https://www.youtube.com/watch?v=isLpnqY4CeI
[2] Typhoon Soulik hit the FPV whose platform was able to stay fixed at its position without major movements. Video link: http://www.seaflex.net/typhoon-tests-seaflex-durability/

CHAPTER IV

METHODOLOGY

In order to have an insight into the field of FPVs, a systematic review of worldwide applications of onshore and offshore FPV systems, their design, capacities, and major manufacturers across the world is studied.

The thesis studies a preliminary feasibility study for implementing a 100 kW FPV system in Lebanon, specifically offshore Beirut, facing the American University of Beirut's (AUB). In order to carry out this feasibility study, the offshore environmental conditions of the site is studied. Data concerning the wind speed, wave heights, seabed characteristics and water depth is also determined.

As for the feasibility from a policy perspective, the current electricity laws and regulations of Lebanon are studied. Since the thesis is studying studying the implementation of a FPV offshore Lebanon, an insight into the Lebanese electricity sector is also provided including the national electricity demand and supply, current institutions and key actors of the electricity sector, and the electricity laws. The political climate and responsiveness is analyzed. An overview of the technical, financial and legal challenges of the electricity sector across Lebanon is also explained. Based on the outcome, recommendations are provided.

The estimate cost of FPV implementation offshore AUB is also identified to indicate the feasibility to implement such a project at this point of time. The thesis also states the status of financial feasibility of the project by providing the overall investment and O&M costs of the FPV system to be implemented. The possibility of different financing mechanisms to finance this project is also provided.

The thesis study relies on several resources. Firstly, thorough online search of scholarly research publications is conducted to collect all the information about FPVs. As for the data concerning Lebanon, websites, reports and publications from governmental (such as MoEW, MEW, EDL, etc…), state-related actors, and international organizations (such as UNDP, World Bank, EU, etc…) is used. Beyond the online research and during the feasibility analysis, contacting companies that have installed FPVs around the world is a crucial component in order to benefit from their experience and estimate the cost of a 100 kW FPV if it is to be installed offshore Beirut.

Furthermore, a basic technical analysis is also provided by using the PVSyst software which is considered the solar simulation software of choice around the globe used extensively by architects, engineers, researchers and experts in the field. PVSyst provides a software package for the study, sizing and data analysis of complete PV systems. The program's forecast outcomes are also significant in financing PV solar projects. It deals with grid-connected, stand-alone, pumping and DC-grid PV systems, and includes extensive meteorological and PV systems components databases, as well as general needed solar energy tools. It offers three levels to study a PV system, almost corresponding to the different developmental stages of a real PV project:

- Preliminary design to size the project.
- Project Design to implement a system design using hourly simulations.
- Databases and Tools to design the project based on given meteorological data and PV components.

CHAPTER V

LEBANESE CONTEXT:
THE CASE OF THE ELECTRICITY SECTOR

Lebanon's energy legislative, institutional and infrastructure frameworks of 21st century date back to the post World War II era. Its energy sector still suffers from deteriorations encountered during the Lebanese Civil War of 1975-1990. The country heavily depends on fossil fuels and manages to supply only a portion of the national electricity demand. Though the electrification rate in Lebanon attains 99%, yet the electricity generation capacity is not enough to supply the actual demand.

Aging infrastructure, outdated grid network, constant delays in electricity generating plants' development, absence of national strategy, and lack of update and implementation of legislations are the main causes for the continued electricity supply failures. Moreover, the announcements of the high possibility of significant natural gas and oil reserves in Lebanon's offshore brought additional challenges to the energy sector of the country since it lacks knowledge and experience in oil and gas sector.

A. Political Climate

Lebanon is comprised of diverse religious, ethnic, sectarian and political groups. As a result, consociationalism, a form of democracy built on power sharing, dominates over the country based on the sectarian identities present. This sectarianism is amplified by the national political plays. Key positions are allocated and divided between the parties in order to ensure a theoretically equal voice (Haines-Young, J., 2018). The chief political parties are associated with the three dominating religious communities I Lebanon: Maronite, Shiite and Sunni (Bou Khater, 2018). As such, the country is in a constant state of political instability. In addition to the national instability, Lebanon is extensively influenced by external forces. Due to its geographic location in the Middle East and the regional insecurities, the country has always been a zone for proxy wars in the region, thus subjected to the influence of greater countries. Any shift in the relations between these countries immediately impacts the Lebanese domestic politics, party alliances and policy-making.

Being based on a consociation democracy, cooperation between different political and elite groups for the purpose of deal-making is required for establishing stability. However, the greatest disadvantage of this systems is corruption and nepotism which has already achieved unprecedented levels across the country in almost all the sectors. The power-sharing system is the core cause of governmental paralysis and corruption. The Lebanese electoral politics is greatly personalized and depends on contacts between the candidates and their respective constituency (Khodr & Hasbani, 2013). Political deadlock is common in Lebanon since its democratic institutions can hardly overcome sectarian divisions in order to adopt or amend a law. Even the most urgent and straightforward decisions are usually delayed for years due to opposite political conflicts and interests. The latter have hindered the establishment of legislations and reforms that have resulted in immense deterioration over all the sectors and public services, including infrastructure, transportation, healthcare, education, water and waste management. The worsening economic, financial, social and environmental situations have significantly reduced investments across the country.

The electricity sector of Lebanon is also a victim of the political conflicts since decades. The sector and its laws are in need of urgent upgrades. Although the daily blackouts have become a routine across the country, no serious measures have been taken to increase the electricity supply (Raphaeli, 2009). Though this issue is always on the agenda of the council ministers, yet political rivalries have prevented reaching a plausible solution. The share of the electricity in the national debt is almost 50%.

Moreover, transparency, which is a mean to hold public officials accountable and fight corruption, is not seen in the sector. In democratic countries, openness and accountability define government transparency. The latter is the government's obligation to share information with the public who have the right to understand how officials conduct the public business and spend taxpayers' money. Such transparency, however, is not observed in Lebanon, and especially in the electricity sector.

Until today, all the proposed electricity measures have either been neglected or delayed in its implementation due to the political interferences and complex procedural requirements. Moreover, introduction of RE in the country's energy mix has recently began and is still in its initial phase. As such, the implementation of a FPV plant across the Lebanon might face some procedural obstacles especially that it would be the first to be installed in the country. The Lebanese political system is characterized as being "not so receptive" towards new energy laws and projects, especially if the latter will require alterations in the current electricity sector's managerial and operational activities.

Fortunately, all the above discussed national obstacles and hindrances are surmountable by setting policy measures that overcomes the stringent sectarian culture. However, this requires a joined political will across the different political levels and groups, and the expansion of their limited receptivity for new laws and regulations.

B. Institutions and Key Actors

In Lebanon, energy issues are under the management and responsibility of the Ministry of Energy and Water (MoEW) with the assistance of the Ministry of Environment (MoE) and the Ministry of Finance (MoF). The role of the ministries and other entities involved in the energy sector are described below.

- Ministry of Energy and Water (MoEW): It is responsible for the all energy policies, tariffs and the sector's regulations concerning setting of the electricity and petroleum prices, along with the agreement of the MoF and the approval of the Council of Ministers. The MoEW consists of three General Directorates - Water and Electricity Resources, Investment, and Petroleum (MoEW, 2018).
- Electricité du Liban (EDL): Established in 1954 as the state-owned institution which has the monopoly for electricity production, transmission and distribution in Lebanon, in addition to the bill collection. Until now it has its monopoly with few exceptions which entail generation, transmission, and distribution concessions in Alley, Bhamdoun, and Zahle (EDL, 2018).
- Ministry of Environment (MoE): The MoE provides support to the MoEW in projects related to energy, particularly in reducing energy usage and promoting RE and EE measures (Khodr & Hasbani, 2013; MoEnv, 2013).
- Ministry of Finance (MoF): Within the energy sector, the MoF, as a body responsible for the state's budget, tackles the yearly governmental transfers to EDL. These transfers impose a significant burden on the state's overall annual budget and constitute almost half of the country's 2017 public debt.

- Lebanese Oil Installations: A governmental body which tackles flexible commercial principles. It is responsible for construction of oil installations and terminals (Lebanese Oil Installations, 2018).
- Lebanese Center for Energy Conservation (LCEC): Established in 2011, it is the national energy agency for Lebanon that acts as an independent governmental organization, affiliated to the MoEW, with an independent financial and administrative functions (LCEC, 2018). LCEC's tackles implementation of RE and EE projects, and preparation of energy strategies and national action plans for a renewable and sustainable energy sector.
- Lebanese Petroleum Administration (LPA): Established in 2012, LPA is an independent public institution, under the auspices of the MoEW, that oversees the upstream offshore petroleum activates. It is responsible for preparing technical studies, supporting decision making, managing all the phases from licensing up to decommissioning, in addition to regulating and supervising the petroleum industry value chain (LPA, 2018a).

In addition to the above entities, Lebanon also has numerous state-related and international institutions, such as the UN, World Bank, and EU, who have significant roles in financing and implementing energy projects. Yet, the private sector's presence in the electricity sector is limited to operation and maintenance roles (Khodr & Hasbani, 2013) due to the incompetent laws and regulations which hinder the entry of the private sector in all the stages of electricity generation, transmission, and distribution.

C. Electricity Sector Challenges: Legal, Technical, Financial

Until today, the electricity sector challenges are numerous and range between legal, political, technical and financial obstacles. The electricity average demand attained 2,900 MW in 2017, with a peak demand that exceeded 3,460 MW. Although the installed capacity of the thermal power plants is 2082 MW, yet the actual capacity is 1,823 MW (CIP, 2018). As such, in 2017, around 40% of the electricity demand was not met by the EDL. The gap is compensated from private generators and the rented electricity barges. With the yearly increase of electricity demand and the decrease in supply, this gap has been annually increasing. Since decades, daily electricity outages range between 3 to more than 8 hours a day.

Due to the weak institutional capacity, Lebanon's energy sector is very weak and suffers from fragmented legislation and lack of updated comprehensive laws (Khodr & Hasbani, 2013). The existing legislation is not fully implemented due to several obstacles, and the provisions of the existing laws are barely implemented even few years after their adoption.

Given Lebanon's emergent need of energy reform for economic, social, and environmental profit, the energy issues are regularly included in the CoM's (Council of Ministers) agenda. The CoM is responsible for adopting strategies, policies, and laws. Yet, no matter of the urgency of the issues, energy remains one of the most significance challenge, if not the most significant, which has been impeding development, and significantly imposing adverse economic, financial, social, and environmental impacts.

The basis of Lebanon's energy sector is the Electricity Law n.16878 (dated 10/07/1964), which established EDL as an autonomous state-owned power utility, under the control of the MoEW. It granted EDL monopoly over the electricity sector, and the responsibility for production, transmission and distribution of power in Lebanon.

In 2002, a new legislation, the Law of Electricity Sector Organization, known as Law 462 (dated 05/09/2002) was set. The objective of this law was to unbundle Lebanon's electricity sector, create an independent regulatory authority for the sector, and establish public-private partnerships and privatization. As such, the law included measures for Lebanon's electricity market liberalization and EDL reform along with its privatization. This law also permits selling 40% of EDL's generation and distribution activities, but preserves the transmission's public ownership with a probable private management. However, neither the latter has been implemented, nor the electricity regulatory authority, which was set to be created according to the updated law. Although before the 2006 July war the government had approved a series of measures to implement the reforms, yet, the July war, coupled with the subsequent political complications, has postponed the complete implementation of the Electricity Law n. 462 (Khodr & Hasbani, 2013).

The main provisions of the Law n.462 are described below:

- **Privatized Companies**

  - The law offers the opportunity to provide one or more joint-stock "Privatized Companies", such that they were initially fully owned by the GoL or public law individuals, a license carry out one, a few, or all of the production and distribution tasks after obtaining.

  - Within a period of maximum two years from the date of establishment of a privatized company, the GoL can sell up to 40% of the shares to private investor and experts throughout an international tender.

- As for the remaining shares owned by GoL, the Council of Ministers is to decide the date will be sold to the private investors.

- **National Electricity Regulatory Authority (NERA)**

  - Organizes and controls all the electricity affairs.

  - Constitutes of 1 president and 4 full-time members of Lebanese nationality. They are appointed by a decree taken in the Council of Ministers, either for a non-renewable or an extendable five years' period.

  - Has legal personality, and technical, financial, administrative independence.

  - Has the right to issue 50 years' licenses throughout public tenders for the aim of electricity production and distribution.

  - Practices transparency and provides the public with access to all the data, records, and documents. It is also obliged to publish a statement of its assets and liabilities, and a summary of its budget not only in the Official Gazetteat, but also in at least two local daily newspapers during the end of each year.

- **Independency Principles for Electricity Production, Transmission and Distribution**

  - Activities of production, transmission and distribution of electricity are functionally, financially, and administratively independent from one another.

  - After being transformed to one or more privatized company, EDL can still have the right to perform more than one of the mentioned three independent activities.

Further Laws − Law 775 (dated November 11, 2006), Law 288 (dated April 30, 2014) and Law 54/2015 − were established as amendments to Law 462/2002. These laws were again not implemented.

The amendments to Law 462/2002 were as follows:

- **Law 775 (dated November 11, 2006)**

  - Until NERA is established, this law empowered the Council of Ministers for only one year to award temporary licenses for electricity production, based on the proposal of Minister of Energy and Water.

- **Law 288 (dated April 30, 2014)**

  - Until NERA is established, this law empowered the Council of Ministers for two years to award temporary licenses for electricity production, based on the proposal of Minister of Energy and Water and the Minister of Finance.

- **Law 54/2015**

  - This law extended Law 288/2014 application until 30/4/2018.

Even after all the above mentioned laws, the electricity sector in Lebanon still remains monopolized by EDL, and no reforms are seen until this time.

Moreover, the private sector’s will to access Lebanon's energy sector is weak due legal hindrances, institutional and process complications, political interferences and lack of government incentives (World Bank, 2010). Though there is a shared realization that actions need to be taken to overcome the sector’s challenges, wide divergences and disagreements persist on the optimum policy solutions that have to be adopted.

Recently, Lebanon has been concerned with a great challenge for the next decade: the establishment of its own oil and gas sector. Once the high probability of having hydrocarbon resources within its borders was discovered, Lebanon set the Offshore Petroleum Resources Law (OPRL) – Law 132 in 2010 that sets the scope of petroleum activities within territorial waters and its Exclusive Economic Zone (EEZ).

The Law outlines the institutional framework of this sector and the exclusive petroleum rights, and regulates the exploration and production agreements (LPA, 2018b).

Moreover, EDL suffers from an aging electricity infrastructure. Both the power plants and the network are old and outdated, and have been lacking the required upgrades since years. The technical and non-technical losses have attained 13% and 18% respectively. The lack of regular maintenance have led to the inefficient operation of the power plants resulting in daily power outages all over the country. In addition, the lack of qualified staff, tariff adjustments and institutional policy decisions have emerged the sector into a crisis (Khodr & Hasbani, 2013). Such issues have amplified over the years and resulted in significant gap between the electricity supply and demand. While the demand kept on rising, the electricity generation capacity remained the same, and further decreased due to the outdated power plants and the old grid network. As a result, currently the annual gap ranges between 1,000 MW to 1,500 MW.

The peak electricity demand in Lebanon attained 3,460 MW in 2017, during the summer season. On the other hand, the maximum power supply peak was only 2,160 MW. The unmet demand attained almost 40% and was covered, as always, by the expensive and polluting diesel generators. The network of such private generators was created since many years and have been operating outside any legal framework (Khodr & Hasbani, 2013). Yet, their presence is very crucial since they are the major compensators for the supply-demand gap which ranges from 35% to 40% each year.

As a remedy, the Government of Lebanon (GoL) has not only been purchasing electricity from Syria, but has also been importing electricity from rented Turkish barges to partly cover the widening supply-demand gap. Around $700 million per year is spent on these barges, and still the reliance on these barges is within the GoL's

Capital Investment Programme (CIP) at least for the upcoming four years (CIP, 2018). As a short-term remedy, these barges have been justified by the government to provide a portion of the electricity demand until the planned new gas-fired power plants are built in the country. The construction phase is expected to take around two years. This implies that if the government decides to initiate construction by the end of 2018, the newly built gas-fired power plants would start operating in 2021. Yet, by also considering the non-technical delays, which are very common and expected in such projects in Lebanon, the newly built power plants would not be operational until 2022. Therefore, reliance on the barges is expected to be extended, increasing the GoL's expenses associated with it (CIP, 2018).

Lebanon's electricity sector is a substantial burden on the government's budget and a major contributor to the public debt (MoF, 2010). According to the GoL's CIP plan, EDL's average cost of electricity production, transmission and distribution is almost 20 USc/kWh, higher than the average electricity tariff which is around 9 USc/kWh. Therefore, all the financial losses are allocated by the government to the EDL as annual subsidies (CIP, 2018). The low tariff prices, coupled with the amplifying technical challenges, are increasing the annual subsidies and imposing a great burden on the GoL's treasury. These annual subsidies usually exceed $2 billion, constituting a substantial drain on public finances. During the period 1992-2017, the overall transfers surpassed $20.6 billion along with an interest that exceeded $15.4 billion.

Consequently, Lebanon's total electricity sector debt reached $36 billion in 2017. As such, out of Lebanon's $79.5 billion gross public debt in 2017, $36 billion is due the total electricity sector debt. This constituted 45% of the gross public debt at end of 2017. Furthermore, with a national GDP of $54 billion, the rate of gross public debt over GDP has attained 147.2%. These figures are alarming and increase the risk of economic crisis in the country.

Even after observing these enormous spending on the electricity sector, over 90% of the power generated in Lebanon is still through the consumption of fossil fuels. Moreover, the purchase for electricity from the barges is for $700 million per year is a heavy expense on the nation's treasury. Reliance on these barges for the upcoming four years as per the GoL's CIP implies a total of $2.8 billion spent on purchased electricity.

On the other hand, on the household level, every month each household pays two different electricity bills; one for EDL and one for the private generator. While the EDL average tariff is 9 USc/kWh, that of the private generators is around 23 USc/kWh, almost 2.5 times that of EDL.

D. RE in Lebanon

The share of RE in Lebanon's national energy mix is very minimal. The electricity is characterized by high dependence on imported fossil fuel resources, and very low dependence on RE technologies. According to the Small Decentralized Renewable Energy Power Generation (DREG) Project's "2017 Solar Photovoltaic (PV) Status Report for Lebanon," the share of RE was only 0.483TWh within the total 15.05 TWh of electricity generated by EDL in 2016. In other words, RE's share was only 3.35% by including Hydro, while this value decrease to 0.35% without Hydro as shown in Figure 5-1 below.

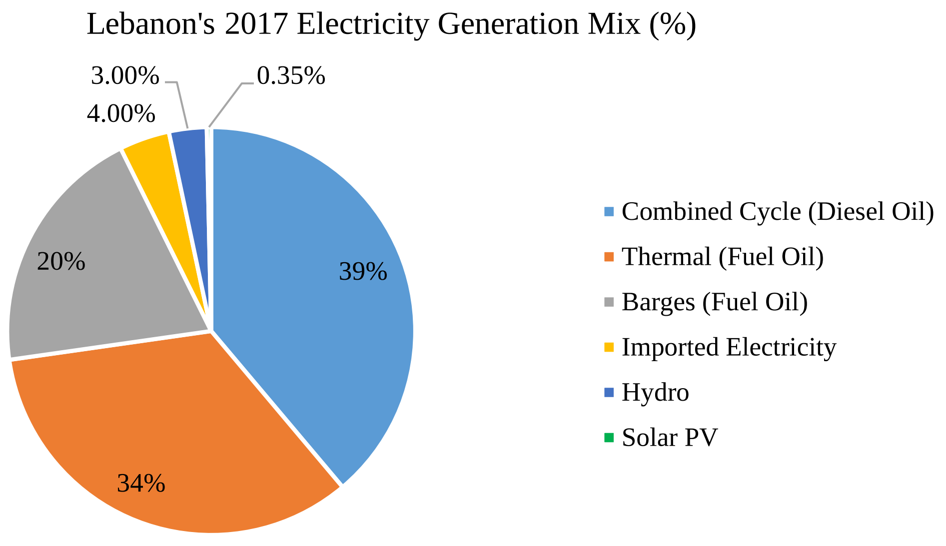


Figure 5-1: Lebanon's 2017 Electricity Generation Mix (%) (UNDP/DREG, 2018).

Consequently, the RE sector in Lebanon is still in its preliminary phase as its share, without Hydro, is almost negligible mainly due to the lack of governmental support through regulations and subsidies. The RE market in Lebanon started developing only recently and through small-scale projects that were backed up through an established financing mechanism called National Energy Efficiency and Renewable Energy Action, and known as “NEEREA”. However, financing mechanisms for large-scale projects, such as PPAs, were not adopted (UNESCWA, 2018). This was a barrier that prevented the expansion of the RE market onto large-scale projects.

In addition to the lack of financing mechanisms, the issue of EDL bankability is another obstacle that hinders the progression a RE market across the country. If EDL is to be the chief customer for all the large-scale projects along its current deficit state, this creates a great risk component for investors who will be taking this higher risk into consideration, hence raising the price. Moreover, the national political instability increases the risk factor and imposes adverse effects on the bankability of projects. While worldwide countries have started subsidizing RE components, the Lebanese tax authorities still considers some of the RE equipment as luxury, thus imposing high customs fees (UNESCWA, 2018).

It is clear that the country is in need of financing mechanism policies for the RE market. Transparent financing models and tackling the issue of EDL bankability could eventually attract investors for large-scale RE projects across Lebanon.

CHAPTER VI

CASE STUDY:
IMPLEMENTATION OF 1OO kW FPV OFFSHORE AUB

A. Case Study: Definition and Purpose

Amongst numerous research methods, case study research is one of the significant research methods used. It is an empirical inquiry that relies on numerous evidences along with data required to be congregated, and benefits from previous theoretical propositions to lead towards analysis. The use of a case study research is mostly applicable when a researcher is interested in studying “how” or “why” something occurs in a contemporary event over which the researcher has almost no control. A case study permits the researcher to focus on a case by retaining a holistic and real-world approach. It serves our diverse knowledge of individual, social and political phenomena. While the results of a case study are not generalizable to populations, yet their aim is to “generalize theories”. A case study is an all-inclusive research method which includes design, data collection, and data analysis. A case study research is a linear but iterative process. The design of a case study research has five major components: study’s questions, propositions, units of analysis, logic linking data to the propositions, and criteria for interpreting the findings (Yin, 2009).

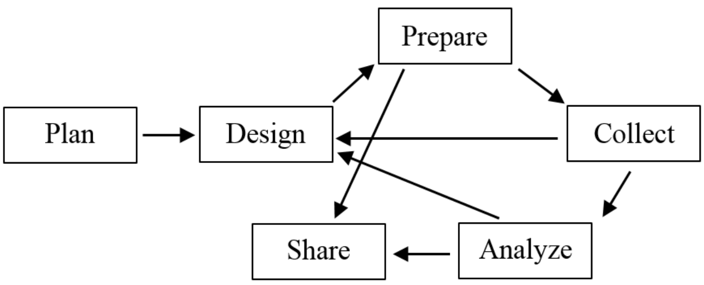


Figure 06-1: Case study process (Yin, 2009).

B. Project Location: Background Information

The case study to be presented in the thesis involves the implementation of 100 kW FPV pilot system offshore Lebanon, specifically in the Beirut area, at the open sea directly facing the AUB University. The generated power will be used to supply part of the University's total power demand.

Lebanon is located on the eastern shores of the Mediterranean Sea, between Latitudes 33˚ 03' 20" N and 34˚ 41' 35" N and Longitudes 35˚ 06' 15" E and 36˚ 37' 21"E. The total area of the country is around 10,452 km^2.

The total length of the Lebanese shoreline is 225 km. In Lebanon's northern, between Batroun and the Syrian borders, the continental shelf is the widest, attaining a width of 18 km. In these regions, the coast has mainly widespread sandy beaches and only few rocky promontories. The shelf starts to narrow to less than 3 km between Batroun and Ras Beirut. The coast becomes rocky, with cliffs, and has very few sandy beaches and bays. As from Ras Beirut towards Tyre and the southern regions, the continental shelf widens once again attaining a width 6 to 7 km. The coast in this area is characterized by its numerous bays and expanses of sandy beaches separated by only a few rocky headlands (Kabbara, 2005).

Figure 6-2 below shows the offshore location of the case study site. The FPV platform will be implemented at around 30 m distance from the shore.

Figure 6-2: AUB Offshore (picture captured from AUB).

As observed, the sea is very near to AUB, and the generated power of the FPV can easily provide part AUB's total electricity needs. AUB consumes electricity from its subscription to EDL and its private diesel generators, along its small-scale solar PV plant. Moreover, AUB has 8 substations. Data concerning AUB's electricity consumption and cost are provided in the Table 6-1 below.

Table 6-1: AUB's data on electricity consumption.

Parameter	**Value**		
Subscription to EDL	Almost 10,000 KVA		
Total installed capacity of AUB power plant	16 MW (without solar)		
Total installed capacity of AUB solar PVs	130 KW		
Total annual energy consumption by AUB Campus	*From Diesel oil*	*29,710,000 kWh*	≈ 30,000,000 kWh
	From Solar PV	*290,000 kWh*	
Cost of total annual energy consumption by AUB Campus	4,500,000 USD		

Figure 6-3 below represents AUB's total monthly power consumption in kWh. This shows the consumption of the University campus only and does not include the AUBMC medical center. The monthly values presented are the average monthly values for the years 2015, 2016, 2017 and 2018.

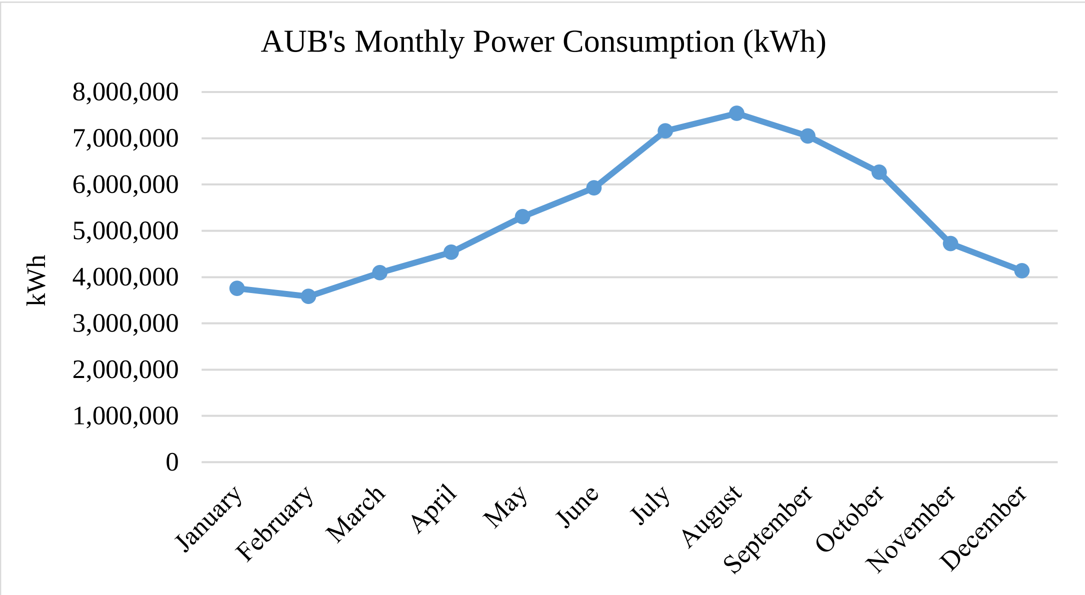


Figure 6-3: AUB's monthly average power consumption from 2015 till 2018.

Even when EDL electricity is available, AUB always has 2 "Safe line" generators of around 1.8 MW operating, mainly to provide the required sites at AUB and AUBMC with 24 hours electricity without any outages.

Since the beach in Lebanon is considered a public commodity, AUB has leased the land from the GoL in order to establish the AUB Beach at the shore. The lease was set for 99 years, and ends around 2050. This lease, at around 240,000$ per year, permits AUB to use the assigned shore area only during the summer season. The legal procedures to take the lease requires contacting the Ministry of Public Works and Transport that hosts the Directorate General of Land and Maritime Transport. An application shall be submitted to the Department of Investment and Control of Marine Property if a project is to be implemented on a public property area. Once approval is received, the Ministry of Interior and Municipalities should also sign its approval. Similar to the above procedure, most probably a lease will also be needed in order to implement a FPV offshore Lebanon.

C. Project Location: Environmental Data

The main environmental challenge for installing a FPV offshore is the wind speed, wave heights and the extreme temperatures that the system will have to withstand, in addition to the water depth, and the characteristics of the seabed. Figure 6-4 below shows Lebanon's major coastal cities and their activities, in addition to the different type of the coastlines (Badreddine et al., 2017).

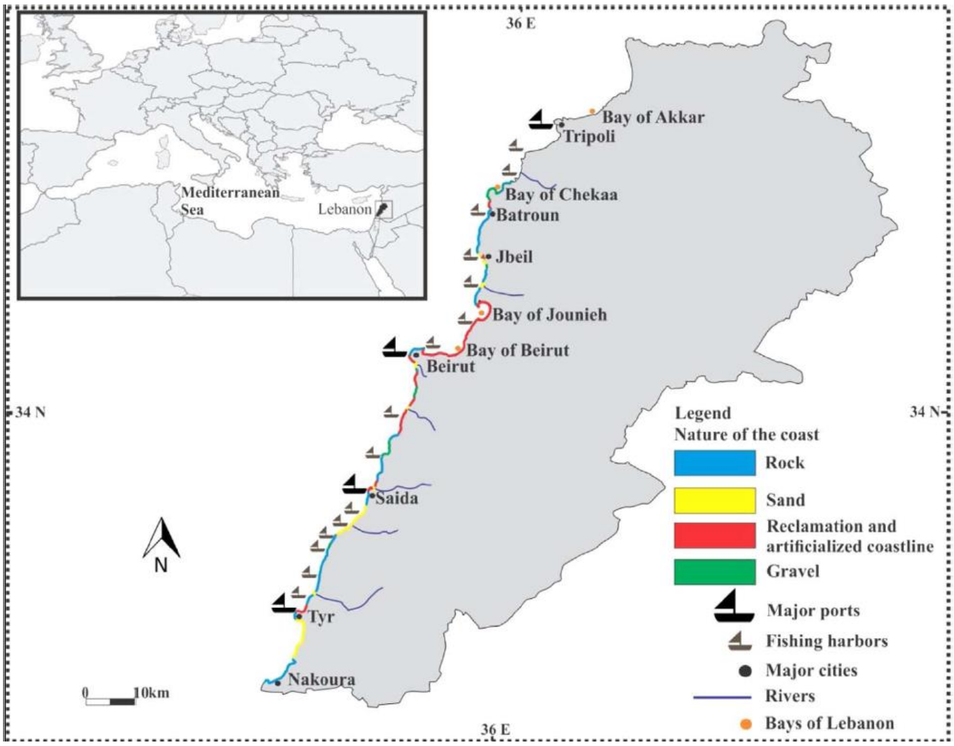


Figure 6-4: Lebanon's major coastal cities (Badreddine et al., 2017).

In Lebanon, merely few studies have been conducted regarding the wave height and the coastal sediments dynamics across the country's offshore. The studies conducted were solely based on limited time-series datasets and cover only some regions (Beydoun, 1976; Kabbara, 2005). However, all the findings show a minimal variation in the waves and tides, along with low stream sediment loads throughout the year, primarily because all the coastal areas are belong to the partially closed Mediterranean Sea (Beydoun, 1976; Ghoussein et al., 2018; Kabbara, 2005).

The Lebanese continental shelf is characterized with frequent rock outcrops most of which are Pleistocene eolianite, also known as kurkar ridges. They occur along the shore, particularly in the Beirut area. Beachrocks usually include cemented pottery fragments and pebbles indicating active lithification and cementation (Beydoun, 1976). In Beirut, kurkar is present on the shore and at offshore at distances reaching around 200 m from the shoreline. Our study site offshore AUB at a distance of around 30 m from the shoreline, is also characterized by kurkar ridges. Kurkar is referred to aeolian quartz sandstone with carbonate cement, known as a calcarenite. In Lebanon, kurkar is also referred to as "Ramleh" (Marriner et al., 2014). Younger kurkar formations are also present along the coast forming small islets. The origin of kurkar are windblown quartzitic sands which create dunes that eventually become cemented by carbonates, compacted under pressure, and transformed to sandstone forming solid rock ridges; this is process is called lithification process. Kurkar is abundant not only on the shore, but also under the sea level on the continental shelf.

Bathymetry studies (Refer to Appendix A) show that the sea level depth from the shoreline at a distance of around 250 m range from 0 to 6.667 m. Unfortunately, there are no specific bathymetry studies that determine the exact depth of the sea level at a distance of 30-50 m. Thus, an estimate number will be used for the purpose of this study, considering that the sea level depth at the FPV site does not exceed 5 or 6 m.

As a Mediterranean country, Lebanon's coastal region is characterized by a Mediterranean climate of hot, dry and humid summer season, and mild, rainy winter season. Although rainfall levels vary from one year to another, yet the main period of precipitation is in winter, usually in December and January. In the winter season, the northern regions of Lebanon are affected by the cold winds from Europe. Therefore, the northern coastal regions are generally cooler and wetter whereas the southern regions are have drier and warmer climates. The average maximum temperature during summer is around 30°C, while it decreases to around 11-13°C in winter. Since no extreme temperatures are observed, Lebanon's coastal are not subjected to snow or water freezing situations. On average, the wind speed is higher during the day than at night. The difference between the wind speeds observed during daytime and at night is decreased in the winter season (UNDP/CEDRO, 2011). Lebanon's coast is also characterized with a relatively high average rainfall of 700 to 1000 mm (Bariche, 2010).

The offshore surface salinity ranges between 37.6 % and 38.2 %. The surface currents have an anticyclonic regime parallel to the coastline from west to east with maximum velocities of around 0.9 knots (0.46 m/s) (Ghaith, Ciavola & Fakhri, 2019).

The Wind Atlas of Lebanon by UNDP/CEDRO applied mesoscale and microscale wind flow modelling in order to determine the variation of wind speed at heights of 50 m Lebanon. A similar study was carried out for the wind speed variation at the same height for the offshore region lying within 20 km of the Lebanese coastline. For our case study site, the offshore wind speed at 50 m above ground level height does not surpass 3.5 m/s (UNDP/CEDRO, 2011). Kabbara (2005) has conducted a statistical analysis of wind measurement data at the Beirut-Golf (south of Beirut) area for a two-year period 2000-2003. The study had indicated that the most intense period regarding the wind conditions in the Beirut coastal area extends from January to April. During winter, especially during storms which last 2 to 3 days, the wind speed can attain to 5-6 m/s. The direction of the wind depends on the regional wind patterns, varying from south, southeast, southwest, and sometimes form the north, northeast, and northwest.

Due to the wind, the water in the upper 50 m is usually very well mixed in winter while it is stratified during the other seasons (Bariche, 2010). Kabbara (2005) states January and February as the period with the most intense wave conditions in the Beirut coastal area. The maximum wave height recorded during this period was 1 m and occurred in Beirut-Golf (south of Beirut) (Kabbara, 2005). On the other hand, a recent study by Aoun et al. (2012) also determined the average monthly significant wave heights at offshore Beirut. The results of both studies are shown in Figure 6-5. Kabbara's study and Aoun et al.'s study are referred to as "Study A" and "Study B", respectively.

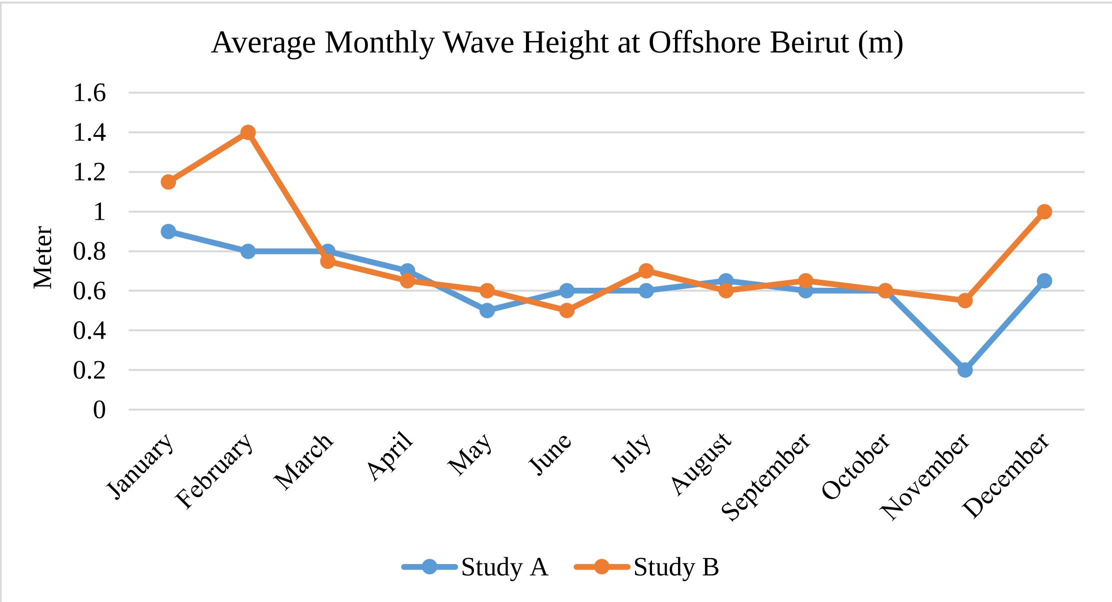


Figure 6-5: Average monthly wave height at offshore Beirut (m) based on two studies.

For our case study, study B will be considered with an average maximum wave heights of 1.4 m and an average minimum of 0.5 m. However, it is important to mention that Lebanon is subjected to rare cases of storm surges during its winter season. These surges can last for up to 2 to 3 days during when the waves at offshore Beirut can surpass 2 m height. Such events have low recurrence period, occurring during 3% of the year, during which maximum wave heights might exceed 2 m or more with periods of around 6s. The waves may reach the onshore and splash over the sidewalks of the corniche facing AUB. According to Kabbara (2005), the periods vary from 5s to 11s, depending on the weather conditions and storm surges.

Furthermore, since the project entails installation of solar PV, it is important to determine the solar irradiance of the study area. According to the World Bank's Solar Resource Map, the average daily global horizontal irradiation exceeds a yearly average of 1,972 kWh/m^2, and the average daily direct normal irradiation also exceeds yearly average of 2,120 kWh/m^2. Ali et al. (2017) indicated that the global horizontal insolation values for Beirut range between 2,388 Wh/m^2/day in January and 7,192 Wh/m^2/day in June. The World Bank's Solar Resource Map states a yearly average PV output of around 1,680 kWh/kWp in Beirut. The Photovoltaic Electricity Potential map shows that the yearly average PV output specifically at our case study site offshore Beirut exceeds 1,683 kWh/kWp (Refer to Appendix B).

D. Project Description

1. FPV System and Technology

Swimsol Company was contacted for the purpose of this study. After joint input and effort, two different options were proposed for the case study as shown in Table 6-2 and Table 6-3 below.

Table 6-2: The proposed two FPV options: SolarSea 1500 and SolarSea 4000.

	Option 1: SolarSea 1500	**Option 2: SolarSea 4000**
Technology	Swimsol's commercial SolarSea 1500 technology	Swimsol's Solarsea 4000
Size	14 x 14 x 3 meters	24 x 24 x 12 meters
Maximum wave height	1.5 m	4 m
Recommended minimum water depth	3 m	6 m
Substructure weight	2.9 tons	7 tons
Number of panels	96 panels (60 cell)	324 panels (60 cell)
Approximate output	30 kWp	100 kWp
Notes	Requires installing a breakwater system to reduce the maximum wave height. The damping requirement for the breakwater system is around 65% for the highest waves with short length.	The first prototype with a scale of 1:2 was tested successfully. Implementation of this system will require an additional 6-12 months of R&D.

Table 6-3: Components used for both SolarSea technologies (SolarSea, 2019).

Components	**Material Used**
Profiles	Marine Grade Aluminum
Joints	A4 marine grade stainless steel
Floating bodies	EPS (Expanded Polystyrene), HDPE with UV stabilizers
Mounting system	Altec 75 x 45 mm

The structural and design component of the system is greatly optimized through its low-volume and truss-like floating platform and with a patent-pending float distribution. Not only it offers very low wind contact surface, but it also remains stable during the presence of waves. The design of the structure minimizes the mechanical stress on the PV panels and the other components. To minimize the risk of bio-fouling and wave impact damage, the floating platform offers an elevated surface area for the solar panels. Certainly, the system platform only uses corrosion-proof materials, such as plastic, aluminum and stainless steel that lengthen the system's lifetime up to 30 years.

Both of the SolarSea FPV technologies are designed in such a way that allow wind and short waves, which do not exceed the maximum wave tolerance limit of each technology, to flow through the floating substructure with no impacts on the modules. As in the case of longer waves and tidal variations, the flexible mooring system aids the platform to adapt to the situation.

Swimsol uses specialized heavy duty solar panels in order to prevent the risk of corrosion in salty and humid environments. These panels' sealing inhibits the entry of water vapor into the panels. Also, the efficiency of the FPV system will be higher than those of ground-mounted solar PV systems by 10% due to the cooling effect of the water beneath. It is important to state that the panels are not inclined. For aerodynamic reasons, only a dual tilt is possible with a very small angle that does not lead to a significant output increase. A dual-tilt inclination with around 5° on the platforms posed an additional investment cost of approximately 50-100 USD/kWp without providing a measurable increased output. Hence, the panels are mounted completely flat.

Until this day, there has been no observed adverse impacts imposed by the floating system on the surrounding environment. The impact of these floating platforms on the marine ecosystem have been previously studied by marine biologists. The FPV system is not expected to impose adverse impacts on the surrounding environment.

2. Mooring, Anchoring and Cabling Systems

The multiple platforms are connected through mooring grids which is designed to maintain the platforms in place, keep the required distance between the platforms, and stabilize them during strong wind and wave conditions. It does so without the need to anchor each single platform individually to the seabed. The mooring systems allows only a limited movement of the platforms only to permit energy expenditure and thus minimize any sudden shock loading.

A grid of steel ropes that connect the platforms (referred to as grid lines) lie near the water surface and are supported by heavy duty Polyform buoys to which they are connected. The Polyform buoys are found in between the platforms and also surround the area of the multiple platforms. The platforms are attached via their corners to the grid through Polyamide bridle lines. The grid lines, bridle lines and the buoys are all connected at the grid intersection points through steel plates. The overall grid is supported by a larger Polyform pre-tension buoys which are attached to the sea floor by either screw anchors or concrete blocks. The distance between the platforms in the mooring grid is 5 m for SolarSea 1500 and 8 to 10 m for SolarSea 4000 platforms.

When large waves are present, the Polyform pre-tension buoys are either partially or completely submerged into the water in order to add tension to the system and thus to further constrain movement during high wave conditions. This avoids collision of the platforms by limiting their lateral movement all the while permitting enough looseness in the system to lessen large internal loads generation. In a single mooring grid, it is possible to connect up to 16 platforms.

The preferable anchoring method is screw anchoring. Screw anchors have high holding capacity, impose very limited impact on the ecosystem, and are cost-efficient. The required size of the anchoring system for this project can only be determined after a closer analysis. If the on-site assessment shows that screw anchors cannot be used due to seabed composition, then the alternative is the use of deadweight anchors for which the weight and dimension can be determined only after an on-site analysis.

As for the cabling works, since the FPV platform is located only around 30 m away from the shore, Swimsol suggests using submarine DC cables to connect the platform to land. Since the platform is composed of aluminum and floats in the sea, additional earthing is not needed. The cabling works are expected to be smooth, especially with the presence of close substation in AUB, next to the AUB power plant, which facilitates FPV's connection to the power system. Through underground cabling, the FPV can be directly connected to AUB's substation. Consequently, AUB can use the FPV's generated power to provide a portion of its electricity demand which reaches an annual average of 30,000 MWh. Moreover, as there is a constant electricity demand at AUB there is no need to install expensive batteries for power storage. The generated power will be directly consumed by the University at all times.

3. Layout

a. <u>Option 1: SolarSea 1500 + Breakwater System</u>

For option 1, Figure 6-6 and Table 6-4 below show the potential layouts for the proposed four different system sizes.

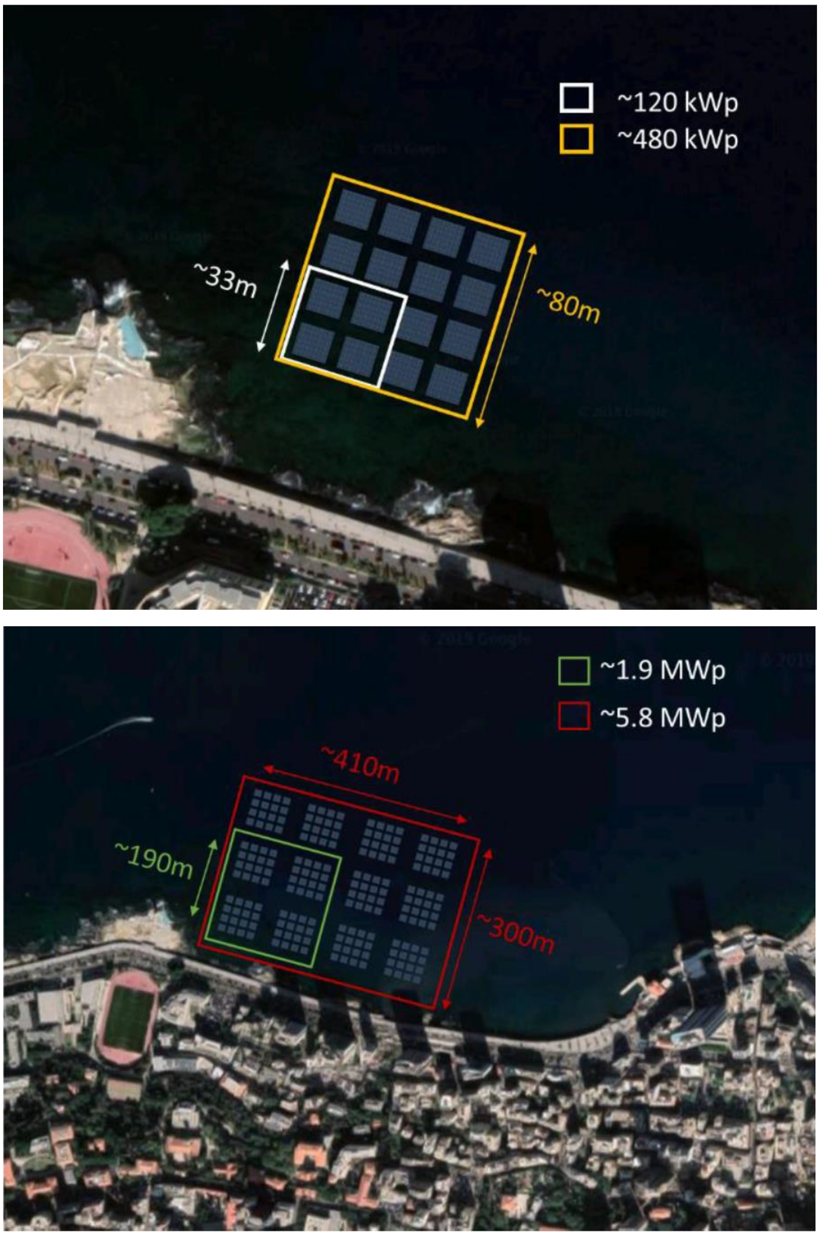


Figure 6-6: Potential layouts for SolarSea 1500 for the proposed four different system sizes (Swimsol, 2019).

Table 6-4: The dimensions and area for the proposed SolarSea 1500 system sizes.

System Size	Dimensions	Area
120 kWp	33 x 33 m	1,089 m^2
480 kWp	80 x 80 m	6,400 m^2
1.9 MWp	190 x 190 m	36,100 m^2
5.8 MWp	410 x 300 m	123,000 m^2

Research shows waves throughout the year come from the West with a degree direction of 240-300° and a height reaching 1.5 to 2 meters. If an on-site study confirms this, then a breakwater system would be needed on this side as per Figure 6-7 below.

Figure 6-7: The layout of SolarSea 1500 with the proposed breakwater system on one side (Swimsol, 2019).

b. <u>Option 2: SolarSea 4000</u>

For option 2, Figure 6-8 and Table 6-5 below show the potential layout of SolarSea 4000 for the proposed two different system sizes.

Figure 6-8: Potential layouts for SolarSea 4000 for the proposed two different system sizes (Swimsol, 2019).

Table 6-5: The dimensions and area for the proposed SolarSea 4000 system sizes.

System Size	Dimensions	Area
100 kWp	24 x 24 m	576 m^2
400 kWp	60 x 60 m	3,600 m^2
2 MWp	170 x 130 m	22,100 m^2
6 MWp	200 x 340 m	68,000 m^2

4. Cost, Pricing and Warranty

The prices provided below will not only depend on the 100 kWp FPV price, but also for larger capacities that can provide the benefit of economies of scale.

a. <u>Pricing for Option 1: SolarSea 1500</u>

Table 6-6 shows the per kWp estimate price for different system sizes SolarSea 1500, in addition to the percentage of each component form the overall cost.

Table 6-6: Pricing of proposed different capacities of SolarSea 1500 (SolarSea, 2019).

	Pricing in USD for Option 1: SolarSea 1500 (pricing does not include breakwater system)*							
	100 kWp	% Share	480 kWp	% Share	1.9 MWp	% Share	5.8 MWp	% Share
PV components	680	25	595	27	500	26	530	29
Floating platform	800	29	800	37	800	41	730	40
Underwater cable	200	7	195	9	130	7	110	6
Mooring	150	5	100	5	100	5	100	5
Services	900	33	500	23	400	21	350	19
TOTAL	**2,730**	**100**	**2,190**	**100**	**1,930**	**100**	**1,820**	**100**

** This pricing is preliminary and an estimation.*

The project can also include an operation and maintenance (O&M) contract with Swimsol. As per Swimsol, the annual O&M costs depend on the system size and lie between 2.5% (for small system) and 1.75% (for large system) of the initial investment. Starting at a system size of 480 kWp, the following model can be applied:

- Swimsol makes the entire investment and the University has zero CAPEX.
- Swimsol bears the cost of O&M (monitoring, repairs & insurance).
- University buys the solar electricity from Swimsol at a fixed price.
- After the contract duration of 20 years, the FPV ownership is transferred, free of charge, to the University.

For each system size, approximate tariffs are shown in Table 6-7 below.

Table 6-7: Proposed estimate tariffs for SolarSea 1500's capacities (SolarSea, 2019).

	480 kWp	**1.9 MWp**	**5.8 MWp**
Tariff	0.165 USD/kWh	0.148 USD/kWh	0.138 USD/kWh

An investment sharing option can also be implemented between the University and the Company as both can invest either 50/50 or 75/25 and as such the tariff and/or contract period can be respectively reduced.

b. Pricing for Option 2: SolarSea 4000

Table 6-8 shows the per kWp estimate price for different system sizes SolarSea 4000, in addition to the percentage of each component form the overall cost.

Table 6-8: Pricing of proposed different capacities of SolarSea 4000 (SolarSea, 2019).

	Pricing in USD for Option 2: SolarSea 4000*							
	100 kWp	% Share	400 kWp	% Share	2 MWp	% Share	6 MWp	% Share
PV components	650	17	570	17	540	18	520	18
Floating platform	1650	43	1610	47	1,570	51	1,540	52

Underwater cable	210	5	180	5	140	5	120	4
Mooring	310	8	280	8	260	8	260	9
Services	1010	26	800	23	570	19	530	18
TOTAL	**3,830**	**100**	**3,440**	**100**	**3,080**	**100**	**2,970**	**100**

** This pricing is preliminary and an estimation.*

As per the manufacturer conditions, the solar panel power output warranty for a minimum of 80% of power retained is for 30 years for both Option 1 and Option 2. Table 6-9 below shows the warranty of the different components.

Table 6-9: Warranty duration of the system's different components (SolarSea, 2019).

Components	Warranty period
Solar panels	12 years
Inverters	5 years
Floating platform	10 years
All other components	2 years

5. Timeline

According to Swimsol, the implementation can start after 6 to 9 months once the agreement is set. The installation periods vary depending on the options and the size. For instance, the installation of 100 kWp SolarSea 1500 takes around 2-3 weeks, while that of the 480 kWp takes around 4-6 weeks.

E. Project Financing and Management

In addition to the proposed FPV's investment sharing option between AUB and Swimsol, different types of project financing mechanisms can be possible ooptions for such a project (Refer to Appendix C).

1. International Financing Mechanisms

There are several financing mechanisms that the developer of this project can resort to. A great advantage is that this is a new project being implemented for the first time in Lebanon and this can attract the attention of funders who usually like to be contributors in bringing new projects into Lebanon, mainly for the purpose of their reputation. However, the downside to this is that FPVs are rarely heard about or discussed in Lebanon, and most people who are not knowledgeable about it might need time to be convinced of the technology and its performance.

There are several chief funding sources that can be targeted if the first ever FPV is to be implemented offshore Lebanon. As an expanding RE technology, it has a grabbed the attention of major multilateral international organizations and development finance institutions, such as the World Bank, UNDP, EBRD, AFD, ADB, etc. For example, the World Bank is funding two 10 MW FPV projects in India, so far the largest across the country. Each 10 MW plant will be located in two different regions in southern India, and each project will cost around 9,800,000 USD (The Economic Times, 2017). Furthermore, Ivory Coast has been granted a fund of €80 million from the French Development Agency (AFD), part of which will be allocated for the development of country's first onshore FPV (Bellini, 2018b). The Asian Development Bank (ADB) is considering to finance a 47.5 MW FPV on the reservoir of a hydropower production plant in Vietnam (Bellini, 2018c). Also, Mauritius is opting to install a 2 MW FPV on a reservoir, and as such UNDP is in the process of hiring consultants for a feasibility study for the project (Bellini, 2018d).

Such examples indicate how land constraints in RE development has shifted the attention of international organizations and funders towards floating solar systems.

Moreover, witnessing such a wide diversity of international organizations and banks financing FPV systems in different regions of the world reassures the fact that the FPV technology is yielding promising results from one year to another.

Consequently, as a developing country, Lebanon can also attract such organizations that are active across the country, like the World Bank, EBRD, and AFD, to get funds to implement the first FPV in the country.

2. National Financing Mechanisms

a. Banque du Liban (BDL)

BDL which is Lebanon's Central Bank has invested its time and effort to bridge the gap between the energy sector and the financial sector in the country through encouraging investments in clean energy technologies rather than those in unconventional energy methods. Since 2010, BDL started launching financial initiatives to promote the development of RE and EE in the Lebanese energy sectors. BDL closely collaborated with MoEW and international institutions to create the suitable atmosphere in order to attract investments and financial sustainability in the local energy sector.

b. National Energy Efficiency and Renewable Energy Action (NEEREA)

NEEREA is a national platform to finance green energy projects in Lebanon. It was introduced by BDL with the support of EU to promote clean energy in the country.

Established as a green financing mechanism in 2010, NEEREA provided long-term, interest-free loans to residential, commercial and industrial sectors for their RE and EE projects. The loan had an upper limit of 20 million USD offered at a 0.6% interest rate. It provided up to 14 years of maturity and 4 years of grace period. Its interest and commissions did not attain 1%. Currently, however, the new NEEREA loans have increased interest rates attaining 2.25%. Projects greater than 60 kW can benefit from this loan. Most commercial banks are accepting these loans that are subsidized by BDL which is one of the stakeholders besides EU, MoEW, and LCEC. Yet, the increase of interest rate adversely affected the local RE market and investments as the number of projects was significantly decreased in 2018. These green loans are offered through the Lebanese commercial banks can be one of the options to finance a FPV system in Lebanon (LCEC, 2018).

c. Lebanon Energy Efficiency and Renewable Energy Financing Facility (LEEREF)

LEEREFF was developed by BDL, European Investment Bank (EIB), and the French Development Agency (AFD) to support private companies' investments in RE and EE projects in Lebanon.

The Facility's credit line of a total of 80 million EUR is funded by the EIB (50 million EUR) and AFD (30 million EUR). The interest rates is provided by BDL which will make the proceeds of this loan available to partner banks to lend it to the private sector. LCEC is the project implementation unit responsible for LEEREFF's implementation, while the EU is responsible for funding the free technical assistance.

The loans are denominated in USD. The interest rate can reach up to 2% maximum based on BDL's decision. It is fixed throughout the loan duration. The loan can last up to 15 years, and the grace period can be up to 4 years. If possible, LEEREFF can also be joined with other subsidized green funds.

There are two types of investment loans within LEEREF:

- Standard investment Loans for project loans that range from 40,000 EUR to 250,000 EUR. Projects comprising of the eligible technologies by LEEREF undergo a fast-track assessment procedure. Among these eligible technologies are solar PV modules.

- Non-standard investments which include larger scale projects with investment beyond 250,000 EUR and up to 15 million EUR. Such project require more comprehensive assessment and procedures.

The investment limits are 40,000 EUR to 100,000 EUR for investments in a single technology, and up to 250,000 EUR for investments in more than one technologies. LEEREFF loans a maximum of 80% of an investment, thus the actual loan amounts ranges from 32,000 EUR up to 200,000 EUR.

d. Green Economy Financing Facility (GEFF)

The European Bank for Reconstruction and Development (EBRD) signed the first GEFF in Lebanon with Bank Audi, a Lebanese commercial bank. Under this agreement, EBRD will be providing a loan of 90 million USD, complimented with by a 10 million USD from Taiwan ICDF, Taiwan’s foreign aid program. Bank Audi will also provide an additional 100 million USD, increasing the green financing to 200 million USD (Bank Audi, 2018; Reuters, 2018).

The fund will be provided to individuals and businesses who will be investing in green projects that aid Lebanon’s transition to a green economy (Reuters, 2018). The Facility has a list of pre-approved technologies which will automatically be eligible for projects up to 300,000 USD. Solar modules are within this technologies. As for projects that comprise of technologies beyond this list, technical experts will intervene to assess their eligibility. Facility's consultancy is also a must for projects exceeding 300,000 USD and up to 15,000,000 USD. The Facility consultants will provide assistance, free of charge, during all the stages of the project. They will also facilitate capacity building to attain successful green projects that provide maximum profitability.

The loan to the private sector has competitive rates. Moreover, in some cases, projects might also be eligible to benefit from much lower interest rates subsidized by NEEREA. The loan period will be decided on a per project basis based on the project's expected cash flow, repayments, and the need for a grace period which implies to an interest only period.

3. Private Investor

AUB, as an academic institution, can itself invest in this pilot project. It would be the first entity to invest in a FPV project in Lebanon and as a higher educational institution, it can also provide further required technical and financial studies. It can also engage its students in this project and further carry on the required research and feasibility studies to study the possibility expansion of FPV projects in Lebanon.

As AUB always has a minimum amount of electricity being consumed 24 hours a day during the week, the power generated by the FPV will directly be consumed by the institution in addition to the EDL electricity and AUB's private diesel generators. AUB can also show it's the financial gains that the FPV can result as it helps to decrease the consumption of diesel generators especially that the average kWh consumption for a diesel generator costs around 23 US¢/kWh.

Another possible route for AUB to realize this pilot FPV is to get a funding specifically for this project. The financing, either partially or fully, can be obtained from either one or more of the different organizations or financing mechanisms as discussed above. As a reliable and renowned academic institution, and one of the best universities in the region, it would be relatively easy to attract a funding to invest in new technologies. AUB is an independent institution with no political affiliations, there would be no political interferences in project. Moreover, from a bankers' and investors' perspective, they are usually very satisfied to provide even huge funds to such an educational and financially solid bankable institution.

Within this framework of FPV project, even though the GoL is not a stakeholder, yet its role is important since it must lease the area which will be occupied by the FPV platform. Similar to the lease that AUB has from the government for its AUB Beach area, the GoL can also provide a 30-year lease to the University for the platform area for a certain price, or it can give a permission for no cost especially that the system is a floating platform similar to any ship that floats with no needed lease contract. Also, an agreement shall be given to extend the underground cable from the platform on the sea towards the shore, so that it will directly be connected to the AUB substation. In other words, the GoL's coordination is very important especially in the beginning phases during the legal and administrative procedures. It shall arrange the necessary clearances to provide the project permit.

Moreover, besides AUB, the implementation of this FPV project can also surely be done by a private investor who wishes to invest in a creative energy generating green technology. Such an investor would invest in the project and sign an agreement with AUB who can buy the produced power from the FPV at the same kWh price as EDL's which is around 0.09 USD/kWh. The EDL tariff is set to increase, most probably attaining around 0.14 USD/kWh. Then, the kWh cost from the FPV shall also increase to remain equal to EDL's tariffs. AUB's 24 hour power consumption will ensure that all the generated electricity will be consumed directly, and thus no need to invest in a power storage system.

F. Political Receptivity

The implementation for RE projects, especially in developing countries is highly reliant on the sociopolitical acceptance. It is insufficient to only have community support since the development of such innovative projects will require the support of policy actors who will have to develop effective policy measures. In other words, there should be "window" on the policy making level within the energy sector so that FPVs, a new RE technology, can be implemented in Lebanon. However, receiving support from the policy level might be very challenging in Lebanon since the government does not have a clear guiding vision on reforming the electricity sector and introducing RE within the energy mix. Lebanon still owns a monopolized electricity sector.

Internationally, governmental policies promoting RE rely on RPS (Renewable Portfolio Standards), Feed-in Tariff schemes, Net-metering, and other market incentives. However, such policies do not exist or are not implemented in Lebanon. Therefore, the implementation of a FPV offshore Beirut might face legal and administrative challenges. The lack of national strategy for the development of RE sector in the country and the different energy agendas of the different political parties are already key challenges which impede the inclusion of both, RE technologies and the private sector in the energy value chain.

G. Social Acceptability and Public Participation

Located in between Hamra, Ain Mreisseh, and Ras Beirut, AUB and its surroundings are considered as very busy areas. The region is a hub comprised of large number of businesses, educational institutions, hotels, apartments, shopping centers and small shops. As such, the region suffers from daily traffic due to the large number of inhabitants and the larger number of people who access it daily. Moreover, as a coastal region and an important link between different areas around and beyond Beirut, it is frequently accessed by a significant number people and commuters on daily basis.

Facing AUB, wide pavements are spread all along the corniche. As a public area, people access the corniche daily starting from the very early hours during the day and carry on different activities, including walking, running, and sometimes swimming. Some people access the corniche for fishing by standing on the pavements, while some fishermen use their small boats to go fishing. These activities are observed daily during all seasons, although less during winter. On a daily bases, crowdedness on the corniche is at its peak during the morning and tends to decrease during noon and afternoon. During summer, the area gets crowded with visitors and tourists in the evening.

Thus, it can be concluded that the seashore near the site of FPV installation is busy with daily activities. Although the FPV is to be installed on the sea at around 30 m away from the shoreline, however the public has the right to be informed of the project before its implementation. With the aim to be implemented successfully and sustainably, this RE project, similar to any other project, requires the social acceptance (Sauter & Watson, 2007). Public participation, also known as community consultation, is an essential component in a project's environmental and social impact assessment study. Project developers use consultations as tools in order to inform the public about a proposed project before making the final decisions (Yuan et al., 2011). The public includes all those who might be affected by the project, whether positively or negatively. For any negative impact, the people affected shall be compensated. Public consultations also sheds light on certain social impacts that project developers would not have determined without communicating with the public. Developers should also be disclosing the relevant information pertaining to the project's different phases as this is the public' right. As such, involving the local community in the decision making process helps project stakeholders to avoid possible future social conflicts.

As for the aesthetic impact imposed by the FPV installation offshore, no significant negative impact is expected to occur. Until today, no records of adverse impacts on water quality or fish diversity have been documented at implemented FPVs worldwide. Although the literature has not mentioned any minimum buffer zone which must be considered around the FPV, yet, as a precaution, a buffer zone of 20% might be recommended to restrict the access of boats near the platform. During the installation period, a wide buffer zone can be implemented and the general public's access to the site can be restricted due to safety concerns. It is important to note, that this project will neither affect the activities on the corniche, nor will it hinder the ships' routes. Furthermore, since the site is not deep offshore, it is not a common route for huge transportation ships. Therefore, no social rejection is expected to occur if this project is to be implemented by carrying out public consultations during the process.

However, according to Yuan et al. (2011), social acceptance of a RE project is greatly influenced by the success of previously implemented RE projects, in addition to the public' trust towards the developer. Unfortunately, power generation projects, including RE projects, are rarely implemented in Lebanon; until this time the government has not been able to construct feasible electricity generating plants and delays in such projects are very common across country. Over the years, this has broken the public's trust in the government, and thus if the government is to implement such a project, it is expected that the public would refuse due to their lack of trust. On the other hand, however, if the private sector is to implement the project, the public's engagement would be somehow more positive. For instance, if AUB as a renowned, independent and private educational establishment pioneers this project or takes the management as discussed above, then there would be a higher probability to earn public acceptance.

H. Limitations

This thesis presented a case study which provided a preliminary feasibility study of installing a FPV system offshore Beirut at a designated site facing AUB. As previously mentioned, to my knowledge, this is the first study being done one a FPV project in Lebanon. Surely if it is to be implemented, a more thorough study and on-field analyses is required for a further detailed site assessment. This will precisely allow to estimate the exact cost of the overall system and will determine if any other measures shall be taken. An environmental assessment must be carried out by experts. Simultaneously, a detailed financial feasibility study is recommended to be performed by a financial expert. In the meantime, the required processes on a policy level must be handled by the concerned personnel. Collaboration between the University, stakeholders and the GoL might ease the process of implementing this first FPV project in Lebanon.

CHAPTER VII

ANALYSIS

On a global level, FPVs are still a technology that pose somewhat “vague” perspectives and ongoing questions concerning their technical or financial feasibility.

From an economic perspective, experts say that the main advantage of solar farms is that they can generate huge amounts of electricity without using valuable real estate (Bennington-Castro, 2019). Some experts have also mentioned that if the cost of land clearing and soil treatment is added on the cost of a land-based solar plants installation, then the total cost of a land-based solar PV system can be higher than that of a FPV system. In addition, recent studies have shown that the cool temperature of the water can boost the solar modules’ efficiency by more than 15% and up to 22% (Bennington-Castro, 2019). As such, even if FPVs are still considered as a costly electricity generation technology, the increase efficiency and the lack of real estate costs can offset the high costs of the FPV systems.

On the other hand, an overview of the FPV industry indicates that this is relatively a new industry, and as such FPVs can be considered as one of the latest power generation systems. Although its flourishment throughout the different continent was very quick, however, it has only been a decade since the first ever installed operational FPV system in the world. In other words, the world still has very limited experience with FPVs, thus it is hard to predict how the operational FPVs will perform on the long term. Similarly, their environmental effects on the local wildlife is still somehow vague considering the long-term lifetime of the plants. The environmental impacts studied by different institutions has only been based on theoretical studies and currently operational FPVs, all of which have been operational for less than a decade.

However, the promising technical potential of large-scale FPVs is a driving force itself which will drive scientists and companies to dig deeper into this industry and develop FPVs which can overcome the different potential barriers. With the current technological pace, FPVs can even become a commonplace in the coming few years. As the price of ground-mounted PV systems are dropping quickly on a yearly basis, a similar trend is being observed for FPV systems although the drop of the latter can be relatively more slowly, mainly due to the mooring systems.

Concerning this study, the results show that the wind speed at the study site causes no risks on the FPV system. Yet, the wave heights differ and although they usually do not reach 2 meters, in rare cases they might exceed that during rare stormy occasions that occur only during 3% of a year.

Direct observations of the different prices show that the SolarSea 1500 technology is obviously much cheaper than the SolarSea 4000 technology. This can be explained by the fact that the Swimsol 1500 technology is already the commercial type installed by SolarSea, while SolarSea 4000 is still in its pre-commercial phase and its installation requires further research and development. However, as per the environmental circumstances at the studied site, SolarSea 1500 cannot withstand waves higher than 2 meters. As the area is subjected storm surges around 3% time of the year, there is the probability that the waves might exceed 2 meters height and thus installing SolarSea 1500 requires a breakwater system that can dampen the waves.

From a financial perspective, the cost of one kWp for SolarSea 1500 for the given four capacities range between around $1,800 and $2,730. Owing to the economies of scale, the lowest price of around $1,820 per kWh is attributed to the largest given capacity which is 5.8 MWp. As such, the price of per kWp rises to around $1,930,

$2,190 and $2,730 for the system sizes of 1.9 MWp, 480 kWp and 100 kWp, respectively. In 2018, LAZARD indicated a capital cost range of $1,850/kW to $3,000/kW for community-level solar PV projects. All of the four proposed different capacities of SolarSea 1500 technology are within this range. The $1,820 per kWp price for the 5.8 MWp is even less than LAZARD's lowest cost of $1,850/kW. On the other hand, providing $2,730 for only a 100 kW might not seem economically feasible especially for such a small capacity. Installing 5.8 MW will require a total investment of around $10,556,000, while this value decreases significantly to around $3,667,000 for an FPV of 1.9 MW. The total investment for a 480 kW and 100 kW of SolarSea 1500 technology attains, respectively, around $1,051,200 and $273,000. As the first FPV project even that could be installed in Lebanon, investing a $10,556,000 would seem economically unattractive. Similarly, a price of $2,730 for only a 100 kW might seem economically unfeasible. As for the in-between two capacities, while the 480 kW system costs $1,051,200, quadrupling the capacity to around 1.9 MW increases the prices by around 3.5 times attaining $3,667,000. Surely, investing in the 1.9 MW FPV will yield much more power as opposed to 480 kW system, resulting in more financial gains for the developer with less investment cost for per kW. However, the installation of SolarSea 1500 systems will require the installation of breakwater system to dampen waves that are over 2 meters. As such, the total investment cost for this project would be increased by the cost of the breakwater system which must be implemented on one side of the platform.

A company expert in breakwater systems was contacted for this purpose. According to them, given the project site characteristics and environmental conditions, a U-Block shaped breakwater system is needed. The extensions of the walls under the water increase the draft and activate a larger body of water to act as a damper than the pontoon part would on its own. Moreover, the breakwater should be longer as waves turn around the breakwater. In general, it can be assumed that breakwater length should be around 1.5 times the platform length. The system is able to dampen significant waves that exceed 2 m height and also have periods reaching 6 seconds.

A breakwater system will cost around $8,380 to $11,000 per meter. This includes the cost of concrete pontoons, connections and anchorage. Materials used are chosen such that they do not impact the environment unlike constant breakwaters that comprise of other components such as rocks. Its lifetime is 70 to 100 years. It requires inspection every year and connection repairs after 20-30 years. The structure is fully guaranteed with 2 year warranty that can be extended up to 30 years at a cost.

On the other hand, SolarSea 4000 systems do not need breakwater system. The cost of one kWp for SolarSea 4000 for the given four capacities range between around $2,970 and $3,830. Owing to the economies of scale, the lowest price of around $2,970 per kWh is achieved with the largest given capacity of 6 MWp. The price of per kWp rises to around $3,080, $3,440 and $3,830 for the system sizes of 2 MWp, 400 kWp and 100 kWp, respectively. While LAZARD’s (2018) stated capital cost range of $1,850/kW to $3,000/kW for community-level solar PV projects, three out of the four proposed different capacities of SolarSea 4000 technology are higher than this range. Only the 6 MWp capacity of SolarSea 4000 has a kWp price of slightly less than $3,000. Therefore, comparing these costs with the usual land-mounted PV projects indicates that the SolarSea 4000 is still expensive. The total investment needed for each of the 6 MWp, 2 MWp, 400 kWp and 100 kWp capacities are around $17,820,000, $6,160,000, $1,376,000, and $384,000, respectively. Investing around $17,820,000 for a

6 MWp FPV would seem economically unattractive. Similar is the case of $6,160,000 for 2 MWp. As a project which will be the first one ever to be implemented in Lebanon, investors would opt to pay as less as possible, especially that the country does not have any previous experience with this specific technology. As for the least two capacities, while the 100 kW system costs $384,000, quadrupling the capacity to 400 MW increases the prices by around 3.6 times attaining $1,376,000. If one of these two systems is to be implemented, the choice highly depends on the interest of the investor and the financing mechanism used. Surely the 400 kWp system will allow more yield, yet the overall project cost can still be considered high.

The greatest advantage of SolarSea 4000 technology is that it can withstand waves higher than 2 meters and thus no need to install a breakwater system. This means that the total investment cost is only attributed to the cost of the FPV without the need for other installations and breakwater barriers. Yet, this technology still needs some months of R&D before its installment.

Table 7-1 shows the total investment cost for each of SolarSea 1500 and SolarSea 4000 capacities.

Table 7-1: Total investment cost for each of the capacities of SolarSea 1500 and SolarSea 4000 technologies.

SolarSea 1500			**SolarSea 4000**		
Capacity	Price/kW	Total Investment	Capacity	Price/kW	Total Investment
100 kWp	$2,730	$273,000	100 kW	$3,830	$384,000
480 kWp	$2,190	$1,051,200	400 kW	$3,440	$1,376,000
1.9 MWp	$1,930	$3,667,000	2 MWp	$3,080	$6,160,000
5.8 MWp	$1,820	$10,556,000	6 MWp	$2,970	$17,820,000

An O&M contract can also be signed with Swimsol with an annual cost that depends on the system size and ranges between 2.5% (for small systems) and 1.75% (for large systems) of the initial investment.

For a system size of 480 kWp and beyond for the SolarSea 1500 technology, Swimsol itself can become the chief and only investor of the project. While the Company itself makes the entire investment and bears the O&M costs, the University signs a deal to buy the electricity from Swimsol at a certain fixed price. This offer saves AUB from the burden of the initial investment and the O&M while it allows it to benefit from the power produced at a fixed tariff. This will increase AUB's power consumption from RE systems, will decrease its consumption of fossil fuels, and will boost its reputation as the first institution in Lebanon to use FPV power. Asper Swimsol, after a contract of 20 years, the FPV ownership is transferred free of charge to the University who starts operating the system. An estimation of the tariffs depending on the capacity of the SolarSea 1500 system can be around \$0.16/kWh, \$0.15/kWh and \$0.14/kWh for the capacities of 480 kWp, 1.9 kWp and 5.8 kWp, respectively. The tariffs are considered as financially feasible since they can offset the University's consumption of diesel from its private generators. On average, operating a private generator costs around \$0.23/kWh. Although the EDL provides power with an average of \$0.09/kWh, yet this tariff is to be almost doubled as per the governmental decision released recently. An increase in the EDL tariff would encourage engaging in such an IPP contract. On the other hand, if AUB itself also wants to be an investor in this project, investment sharing options can also be implemented between the University and the Company as both can invest either 50/50 or 75/25 or so. Surely, in such a case the tariff and/or contract period can be reduced respectively.

As for the power output of the floating systems, the following formula was used to calculate the output:

E = Number of panels X nominal panel capacity X average annual solar output

= Number of panels based on system size X 0.351 kW X 1,683 kWh/kWp

The energy yield was calculated by multiplying the number of panels by the nominal panel capacity and the average annual solar output in kWh/kWp in Beirut. Note that only 315 Wp monocrystalline panels are used for the FPV platforms. According to the Global Solar Atlas, the average annual solar output in Beirut is around 1,683 kWh/kWp. However, some losses of around 5 to 10 percent shall be considered since the solar output value considers an optimal inclination in Beirut which is between 20 to 30 percent. Yet, this losses can be compensated by the 5 to 10 percent increased efficiency of the solar panels due to the cooling affect by the water and the better ventilation over the ocean. Hence, it will be considered that the increased efficiency will cancel out the losses resulting from the lack of inclination of the solar platforms. Consequently, as the single platform of SolarSea 1500 has 96 panels, the energy output would be E = 96 x 0.315 kWp x 1,683 kWh/kWp = 50,893 kWh. Table 7-2 below shows the annual power output of SolarSea 1500 and SolarSea 4000 systems.

Table 7-2: The annual power output of each technology based on system size along with investment costs.

SolarSea 1500			
Capacity	Number of Panels	Energy (kWh/year)	Total Investment (US $)
100 kWp	320	169,646	273,000
480 kWp	1,536	814,303	1,051,200
1.9 MWp	6,144	3,257,211	3,667,000
5.8 MWp	18,432	9,771,633	10,556,000
SolarSea 4000			

Capacity	Number of Panels	Energy (kWh/year)	Total Investment (US $)
100 kWp	324	171,767	384,000
400 kWp	1,296	687,068	1,376,000
2 MWp	6,480	3,435,340	6,160,000
6 MWp	19,440	10,306,019	17,820,000

Yet, since the panels' have around 0.3% of yearly depreciation, Table 7-3 and Table 7-4 below show the yearly energy outputs over a system lifetime of 25 years.

Table 7-3: The yearly energy output of different system sizes of SolarSea 1500 technology during its lifetime.

		Energy Output by SolarSea 1500 (kWh/year)			
Years	**kWp/Panel**	**100 kWp**	**480 kWp**	**1.9 MW**	**5.8 MW**
1	0.3150	169,646	814,303	3,257,211	9,771,633
2	0.3141	169,137	811,860	3,247,439	9,742,318
3	0.3131	168,630	809,424	3,237,697	9,713,091
4	0.3122	168,124	806,996	3,227,984	9,683,952
5	0.3112	167,620	804,575	3,218,300	9,654,900
6	0.3103	167,117	802,161	3,208,645	9,625,935
7	0.3094	166,616	799,755	3,199,019	9,597,057
8	0.3084	166,116	797,355	3,189,422	9,568,266
9	0.3075	165,617	794,963	3,179,854	9,539,561
10	0.3066	165,121	792,579	3,170,314	9,510,943
11	0.3057	164,625	790,201	3,160,803	9,482,410
12	0.3048	164,131	787,830	3,151,321	9,453,962
13	0.3038	163,639	785,467	3,141,867	9,425,601
14	0.3029	163,148	783,110	3,132,441	9,397,324
15	0.3020	162,659	780,761	3,123,044	9,369,132
16	0.3011	162,171	778,419	3,113,675	9,341,024
17	0.3002	161,684	776,083	3,104,334	9,313,001
18	0.2993	161,199	773,755	3,095,021	9,285,062
19	0.2984	160,715	771,434	3,085,736	9,257,207
20	0.2975	160,233	769,120	3,076,479	9,229,436
21	0.2966	159,753	766,812	3,067,249	9,201,747
22	0.2957	159,273	764,512	3,058,047	9,174,142
23	0.2949	158,795	762,218	3,048,873	9,146,620
24	0.2940	158,319	759,932	3,039,727	9,119,180
25	0.2931	157,844	757,652	3,030,607	9,091,822

Table 7-4: The yearly energy output of different system sizes of SolarSea 4000 technology during its lifetime.

		Energy Output by SolarSea 4000 (kWh/year)			
Years	**kWp/Panel**	**100 kWp**	**400 kWp**	**2 MW**	**6 MW**
1	0.3150	171,767	687,068	3,435,340	10,306,019
2	0.3141	171,252	685,007	3,425,034	10,275,101
3	0.3131	170,738	682,952	3,414,758	10,244,275
4	0.3122	170,226	680,903	3,404,514	10,213,543
5	0.3112	169,715	678,860	3,394,301	10,182,902
6	0.3103	169,206	676,824	3,384,118	10,152,353
7	0.3094	168,698	674,793	3,373,965	10,121,896
8	0.3084	168,192	672,769	3,363,844	10,091,531
9	0.3075	167,688	670,750	3,353,752	10,061,256
10	0.3066	167,185	668,738	3,343,691	10,031,072
11	0.3057	166,683	666,732	3,333,660	10,000,979
12	0.3048	166,183	664,732	3,323,659	9,970,976
13	0.3038	165,684	662,738	3,313,688	9,941,063
14	0.3029	165,187	660,749	3,303,747	9,911,240
15	0.3020	164,692	658,767	3,293,835	9,881,506
16	0.3011	164,198	656,791	3,283,954	9,851,862
17	0.3002	163,705	654,820	3,274,102	9,822,306
18	0.2993	163,214	652,856	3,264,280	9,792,839
19	0.2984	162,724	650,897	3,254,487	9,763,461
20	0.2975	162,236	648,945	3,244,723	9,734,170
21	0.2966	161,749	646,998	3,234,989	9,704,968
22	0.2957	161,264	645,057	3,225,284	9,675,853
23	0.2949	160,780	643,122	3,215,608	9,646,825
24	0.2940	160,298	641,192	3,205,962	9,617,885
25	0.2931	159,817	639,269	3,196,344	9,589,031

CHAPTER VIII

DISCUSSION

After completing the case study, the most recommendable system and size that seems feasible at this point of time is SolarSea 1500's 480 kWp capacity floating system. This outcome is based on several factors the most important of which are total system cost, financing mechanism, system area and size, and power output.

From the cost perspective, it is of no doubt that the larger is the capacity, the more is the benefit of economies of scale. Yet, acknowledging that this floating system is the first ever to be implemented in Lebanon and knowing that the country has no previous experience with this technology, investing several millions of dollars is not desirable. The option of implementing a SolarSea 4000 technology seems infeasible since it is still in its initial phase, is very expensive, and also its capital cost exceeds LAZARD's (2018) stated capital cost range of $1,850/kW to $3,000/kW for community-level solar PV projects. This is unattractive for investors. This implies that the option that can be implemented is one of the four capacities of the SolarSea 1500 floating platform. The two largest capacities of this technology with a 1.9 MWp and 5.8 MWp offer greater economies of scale for sure, but their investment cost exceeds $3,000,000, another unattractive investment for a project which will be implemented for the first time in the country. Moreover, it is also very important to note that for both, a 1.9 MWp and 5.8 MWp system sizes, the Swimsol Company has offered to itself make the entire investment and bear all the O&M costs. The University will have a zero CAPEX and will only have to buy the power from the project for fixed tariff of $0.15/kWp and $0.14/kWp for the capacities of 1.9 kWp and 5.8 kWp, respectively. After a contract of 20 years or so, the FPV ownership is transferred free of charge to the

University who can operate the system itself. With such low tariffs, these might seem a very attractive option which enables AUB to lower its private generators' diesel costs. Yet, they are faced with the issue of the systems' platform area. The 1.9 MWp and 5.8 MWp systems take up a very large surface area of 36,100 m^2 and 123,000 m^2, respectively. Implementing such a project on such a large space on the sea might pose greater environmental risks, and can disrupt the ship passing by. The governmental approval to build such a project with a huge area at the offshore might even be considered as impossible, in the present time at least.

As such, the most feasible option is either the 100 kWp or 480 kWp capacity of SolarSea 1500 capacities:. The total investment cost of a 100 kWp and 480 kWp system is $273,000 and $1,051,200, respectively. These costs seem attractive and reasonable for such a project. Yet, the main disadvantage of a 100 kWp system is that it has a per kW investment cost of $2,730, greater that of the 480 kWp system's which is $2,190. While both values are within the LAZARD's (2018) capital cost range of $1,850/kW to $3,000/kW for community-level solar PV projects, per kW cost of a 100 kWp system is nearer to the higher end of the range. Still the per kW cost of the 480 kWp FPV is higher than the global weighted average of total installed cost of ground-mounted solar PV which attained around $1,210/kW in 2018 (IRENA, 2019b).

As for the total system area, that of a 100 kWp platform is 1,089 m^2 and that of a 480 kWp is 6,400 m^2. In both cases, the surface area is not expected to cause obstacles as the space that they will take up at the offshore is not expected to cause major changes in the ships' routes. Moreover, the risk of environmental impacts is to be much less.

The greatest advantage of a 480 kWp system over the 100 kWp system is that Swimsol has also offered an IPP contract, similar to the one stated above for the system sizes of 1.9 MWp and 5.8 MWp, only in the case of a 480 kWp system and not for a 100 kWp system size. Similarly, the Company is ready to fully invest in the SolarSea 1500 FPV of 480 kWp in addition to taking on its behalf all the O&M. With a zero CAPEX and OPEX, AUB will only have to buy the power from the FPV at a fixed price which is to be around $0.16/kWh for 20 years. After this period, the ownership of the floating system is transformed to the University at no cost. This implies that there would be no need to find an investor if the IPP is to be adopted. Hence, the 480 kWp system of SolarSea 1500 can offer financial gains to the University as the fixed tariff is less than the cost of operating its diesel generators. Yet, a 20 year long contract might seem as a very long period during which the system shall be checked on a regular basis to look for any errors or issues. As a precaution for such circumstances and possible conflict between the parties, AUB would not be ready to engage in a strict 20 years contract, but rather another better option would be to set a contract that shall be revisited every 5 years or so, as agreed upon by the parties, to solve any issues that have arisen.

Moreover, we wanted to determine whether taking the IPP offered at a tariff of around $0.16/kWh is financially more feasible for AUB rather than if AUB finances it itself by taking soft loans. Hence, at first, a general research was done to determine the average LCOEs of FPVs. It was observed that there is a diverse range of average LCOEs for FPV plants since the LCOE highly depends on the capacity. For large system sizes, the LCOE can range anywhere between $0.05/kWh to $0.1/kWh. On the other hand, for small capacity FPVs, the LCOE can be even reach to more than $0.17/kWh. EL-Shimy and Vasilenko (2019) indicated that the LCOE of FPV is around $0.14/kWh to $0.15/kWh. Barbusica (2018) carried out a sensitivity analysis of the LCOE variation depending on FPV system size, and indicated that a system of around

480 kW capacity was analyzed to have a LCOE of around $0.15/kWh to $0.17/kWh. However, in order specifically estimate the LCOE of SolarSea 1500's 480 kW FPV, calculations were carried out using SolarSea 1500's 480 kW FPV's total investment and O&M cost. If AUB is to invest in this project (By using its own money from the bank and earning interest on), then LCOE turned out to be $0.146/kWh, which is less than the IPP offer with a tariff of around $0.16/kWh. Moreover, if AUB could get a soft loan with a 2.5% rate of interest, then the LCOE is reduced to $0.105/kWh. Thus, for implementing SolarSea 1500's 480 kW FPV, financially the most feasible option is for AUB to finance it itself by getting a soft loan.

Furthermore, in order to further determine the accuracy of the calculated 807,941 kWh annual power output of SolarSea 1500's 480 kW system, the PVSyst software was used to identify the monthly power generated from the SolarSea 1500's 480 kW system (Refer to Appendix D). The results are shown in Figure 8-1 below.

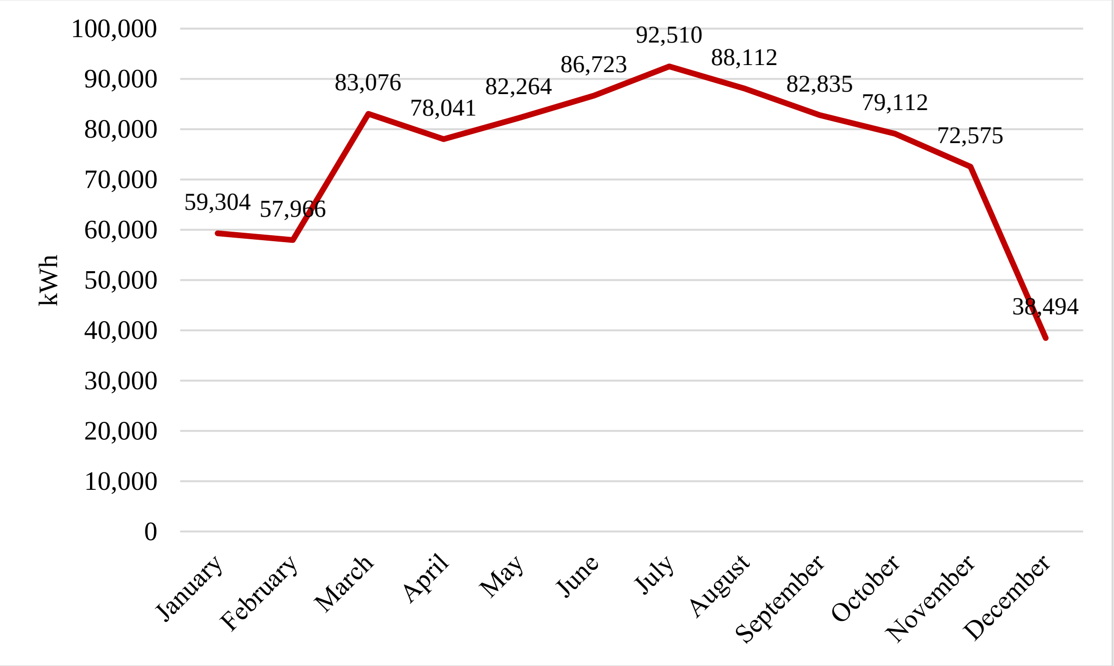


Figure 8-1: The monthly power generated from the 480 kW SolarSea 1500 FPV.

The software identifies the system's annual output of around 901,013 kWh. When this value is compared with the power output result obtained previously by using the power output formula – E = Number of panels X nominal panel capacity X average annual solar output – as advised by Swimsol, it is seen that there is a difference of around 86,700 kWh/year. The formula yielded a result of around 814,303 kWh/year for SolarSea 1500's 480 kWp system size, while the PVSyst software, for the same system, yielded a power output of around 901,013 kWh/year. This difference is expected and acceptable as per the usual slight alterations in the assumptions that the formula considers on one hand, and the PVSyst software does on the other.

When the 480 kWp FPV's monthly power generation is compared to AUB's average monthly power consumption as in Figure 8-2 below, it is clearly observed that the power generated by the FPV will be directly consumed by AUB due to the latter's constant and high power demand. The curve showing the energy generated from the FPV (in red) shown in the Figure 8-1 is seen as a mere line in the Figure 8-2 below once the FPV's total generated power is compared with the curve showing AUB's power demand (in blue). The reason is because AUB has a minimum specific power consumption at all times during the day due to its several amenities. This is further proof that there is absolutely no need for power storage batteries.

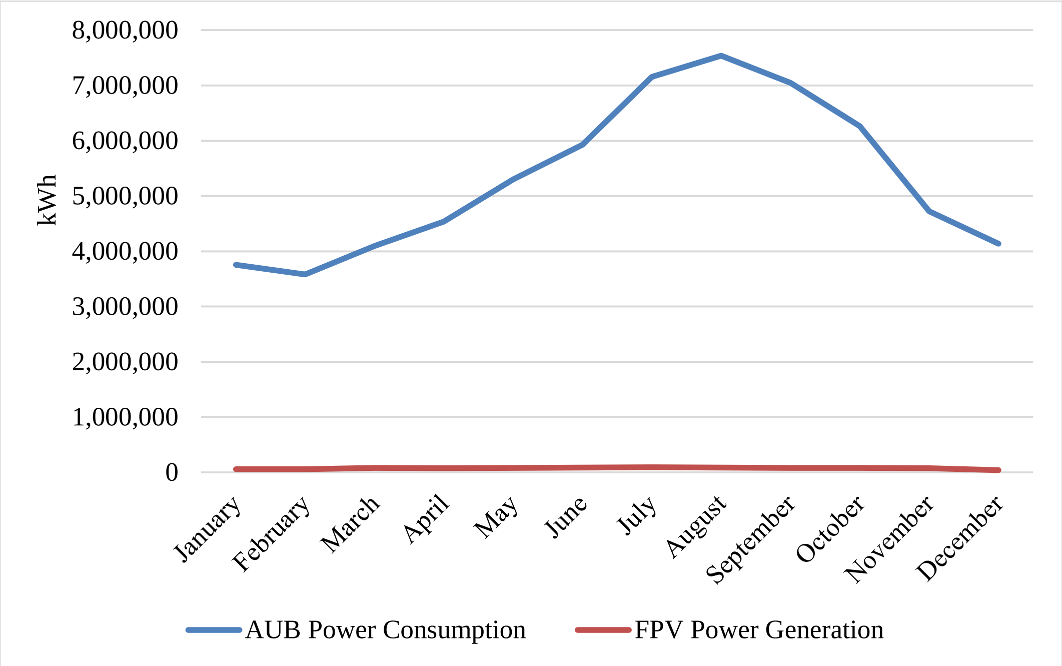


Figure 8-2: AUB's average monthly power consumption compared to 480 kW SolarSea 1500 FPV's monthly power generation (kWh).

Moreover, although the implementation of a FPV offshore Beirut might face administrative challenges mainly while dealing with obtaining the permission for the offshore area where the FPV will be situated, yet, no administrative issues for Net-metering is to be faced since as AUB will be immediately consuming all the power generated from the FPV on the spot, and there will not be any unconsumed power left to be fed into the national grid.

The only obstacle which can inhibit the fast implementation of a 480 kWp SolarSea 1500 system is the fact that it needs a breakwater system which is costly. As discussed in the above section, the required breakwater system is expected to cost between $8,380 and $11,000 per meter, thus estimating a per meter average cost of $9,690. Also, since breakwater length should be around 1.5 times the platform length, the 480 kWp system with a side length of 80 m requires a breakwater system length of 120 m. This can roughly cost around $1,162,800. This cost has to be paid either by the

University or an investor. This a direct expense on the overall project. However, establishing tenders and bidding for the breakwater system among national and international companies can certainly lower the cost. Yet, surely it is also important and possible to look into other types of breakwater systems which are made up of other materials and have alternative designs. Such other options might be proven to be financially more feasible.

On the other hand, irrespective of the financial factors, as one of the top universities in the region, being the promoter of the first ever implemented floating solar system across Lebanon would greatly boost its social and educational status not only locally, but also regionally. Also, it can significantly benefit from this opportunity to develop its own expertise in the field of FPVs, and to carry on its own R&D within its labs. Not only this will offer numerous research projects and funding for AUB, but it will also allow students to engage in the development of such a new technology which is expanding its presence worldwide.

Consequently, this thesis concluded that for the tackled case study and given the current circumstances the optimum and most feasible FPV option is SolarSea 1500 system’s 480 kWp FPV capacity. A summary of the case study is shown below in Table 8-1.

Table 8-1: Summary of the case study and the outcomes.

Project Description		
Platform Specifications	**“SolarSea 1500” FPV System**	
	Size	14 x 14 x 3 meters
	Maximum wave height it withstands	1.5 m
	Substructure weight	2.9 tons
	Number of panels	96 panels (60 cell)
	Approximate output	30 kWp
	Lifetime	25-30 years

<table>
<tr><td rowspan="6">System Components</td><td>Components</td><td>Material Used</td></tr>
<tr><td>Profiles</td><td>Marine Grade Aluminum</td></tr>
<tr><td>Joints</td><td>A4 marine grade stainless steel</td></tr>
<tr><td>Floating bodies</td><td>EPS (Expanded Polystyrene),
HDPE with UV stabilizers</td></tr>
<tr><td>Mounting system</td><td>Altec 75 x 45 mm</td></tr>
<tr><td colspan="2"></td></tr>
<tr><td>Efficiency</td><td colspan="2">The panels are mounted completely flat, yet they have 10% higher efficiency due to the cooling and ventilation effect.</td></tr>
<tr><td>Mooring</td><td colspan="2">Platforms are connected through mooring grids.</td></tr>
<tr><td>Anchoring</td><td colspan="2">Screw anchors.</td></tr>
<tr><td>Cabling</td><td colspan="2">Underground cabling connects FPV to AUB’s substation.</td></tr>
<tr><td>Layout</td><td colspan="2">Dimensions: 80 x 80 m
Area: 6,400 m^2

Breakwater system is needed from the West side to dampen 2 m waves.</td></tr>
<tr><td>Installation Timeline</td><td colspan="2">Around 4-6 weeks.</td></tr>
<tr><td rowspan="5">Warranty</td><td>Components</td><td>Warranty period</td></tr>
<tr><td>Solar panels</td><td>12 years</td></tr>
<tr><td>Inverters</td><td>5 years</td></tr>
<tr><td>Floating platform</td><td>10 years</td></tr>
<tr><td>Other components</td><td>2 years</td></tr>
<tr><td rowspan="8">Preliminary Pricing of 480 kWp of SolarSea 1500 (pricing does not include breakwater system).</td><td>Components</td><td>Cost (USD)</td></tr>
<tr><td>PV components</td><td>595</td></tr>
<tr><td>Floating platform</td><td>800</td></tr>
<tr><td>Underwater cable</td><td>195</td></tr>
<tr><td>Mooring</td><td>100</td></tr>
<tr><td>Services</td><td>500</td></tr>
<tr><td>Total/kW</td><td>2,190</td></tr>
<tr><td>Total Investment</td><td>1,051,200</td></tr>
<tr><td>Breakwater System</td><td colspan="2">A 120 m of U-Block shaped breakwater system is needed to dampen waves that exceed 2 m height.
- Per meter cost is around $8,380 to $11,000.
- It requires inspection every year and connection repairs after 20-30 years, and has a lifetime of 70 to 100 years.
- The structure is fully guaranteed with 2 year warranty that can be extended up to 30 years at a cost.
- Open bidding for national and international companies can certainly reduce the price.
- Surely, it is also important and possible to look into other types of breakwater systems</td></tr>
<tr><td colspan="3">Project Financing and Management Options</td></tr>
<tr><td>IPP Contract</td><td colspan="2">The Company’s proposed IPP is as follows:</td></tr>
</table>

<table>
<tr><td></td><td colspan="3">- Swimsol makes the entire investment and bears the cost of O&M (monitoring, repairs & insurance).
- AUB has zero CAPEX, and is only required to purchase the FPV's power from Swimsol at a fixed price or around 0.16 USD/kWh. Surely, this price can be negotiated.
- After a 20 years contract, as per Swimsol, the FPV ownership is transferred, free of charge, to the University. Surely, it can be negotiated for a shorter term contract subject to review and renewal every 5 years.</td></tr>
<tr><td>AUB Financing it Itself</td><td colspan="3">If AUB is to invest in this project, then LCOE turned out to be $0.145/kWh, which is less than the IPP offer with a tariff of around $0.16/kWh.
If AUB could get a soft loan with a 2.5% rate of interest, then the LCOE is reduced to $0.105/kWh.
Thus, for implementing SolarSea 1500's 480 kW FPV, financially the most feasible option is for AUB to finance it itself by getting a soft loan.</td></tr>
<tr><td colspan="4">Power Generation and Consumption</td></tr>
<tr><td>Annual Output (Calculation Method 1)</td><td colspan="3">Around 807,941 kWh/year with 0.3% yearly depreciation during system's lifetime (Per formula: E = Number of panels X nominal panel capacity X average annual solar output).</td></tr>
<tr><td>Annual Output (Calculation Method 2)</td><td colspan="3">Around 901,013 kWh/year (As per the PVSyst software).</td></tr>
<tr><td rowspan="13">AUB's Average Monthly Power Consumption (kWh)

Versus

FPV's Monthly Power Generation (kWh)</td><td>Month</td><td>AUB Power Consumption</td><td>FPV Power Generation</td></tr>
<tr><td>January</td><td>3,757,609</td><td>59,304</td></tr>
<tr><td>February</td><td>3,581,001</td><td>57,966</td></tr>
<tr><td>March</td><td>4,095,096</td><td>83,076</td></tr>
<tr><td>April</td><td>4,534,757</td><td>78,041</td></tr>
<tr><td>May</td><td>5,303,360</td><td>82,264</td></tr>
<tr><td>June</td><td>5,928,058</td><td>86,723</td></tr>
<tr><td>July</td><td>7,155,894</td><td>92,510</td></tr>
<tr><td>August</td><td>7,538,047</td><td>88,112</td></tr>
<tr><td>September</td><td>7,046,500</td><td>82,835</td></tr>
<tr><td>October</td><td>6,264,898</td><td>79,112</td></tr>
<tr><td>November</td><td>4,722,850</td><td>72,575</td></tr>
<tr><td>December</td><td>4,135,249</td><td>38,494</td></tr>
<tr><td>Storage</td><td colspan="3">As shown above, with constant high electricity demand at AUB, there is no need to install storage batteries.</td></tr>
</table>

CHAPTER IX

RECOMMENDATIONS

The analyzed results within this thesis gave rise to several and diverse recommendations. They shed light on the significance of numerous high level decisions which seriously lack in the country. This study was capable, to a certain extent, to understand the political challenges and the inhibitory factors which have been obstructing the development of a reliant and secure electricity across the country. Moreover, this thesis was able to run a quick overview of the feasibility of the FPV implementation offshore Beirut. Also, as previously mentioned in the beginning of the study, until this date this is the first research, to my knowledge, which studies the feasibility of a FPV system in Lebanon. Impediments brought about by a wide scope of stakeholders, including the government, concerned ministries, electricity-related authorities, governmental bodies, public opinion and social acceptance, were studied throughout the study, in addition to the widespread factors that are greatly impacting the reform programs towards a sustainable power sector in Lebanon.

A. General Recommendations for the Electricity Sector

The UNDP report of "Lebanon: Derisking Renewable Energy Investment" indicates that cost of equity for solar PV in the country is around 16% and the cost of debt at 9% (UNDP, 2017). These confirm that the financing costs of solar PV in the country are currently high due to the lack of favorable investment environment evidently displayed by the power market risk, grid and transmission risk, counterparty risk, and political risk. By categorizing different derisking measures concerning policy and financial instruments to target the investment risk categories, the report was able to lower the solar PV generation cost from 10.0 US¢/kWh to 8.2 US¢/kWh while aiming to attract more RE investments. In the business as usual scenario, the report estimates a premium price of 140 million USD needed over the next 2 decades to achieve the envisioned national RE target. However, if 46 million USD is invested in derisking measures, then solar PV will become 18% cheaper and the premium price is reduced to 43 million USD, hence saving 97 million USD in generation costs during the upcoming 20 years. Hence, prioritizing the implementation of the derisking instruments will indirectly create a favorable environment that will attract investments for all types of RE technologies on the longer term. Some of this derisking instruments will be mentioned within other recommendations in below sections (UNDP, 2017).

Recommendations stated below were recognized as crucial recommendations that have to be applied as soon as possible to avoid all the major issues stated in this report and that Lebanon is suffering from. The electricity sector is bound to indebt the country more than it has already has and this trend shall be halted. The energy reform policies have to save the Lebanese electricity sector from its deficient state and near bankruptcy position. Consequently, below are important general policy measures that tackles the changes required at the policy level, irrespective of any potential plans for FPV installation offshore Beirut. These policy recommendations are on a country level.

It is of no doubt that the first step is to implement the law 462/2002 in accordance with the provisions of law 54/2015. Policies for the deployment of RE shall also be established. Some of the most important reform measures are the following:

- Permitting private entities to enter the electricity sector and generate power by removing the monopoly in the sector.

- Diversifying the country’s energy mix from different energy resources by implementing RE projects.
- Setting enhanced efficiency guidelines through the Energy Efficiency law.
- Setting ambitious national RE targets by carrying out RE feasibility studies across the country. Yet, it is important to limit the ambitious targets based on the country’s financial, technical and human capital impediments.
- Encouraging the production of RE through establishing policy incentive measures, such as Feed-in Tariff.
- Reducing or exempting taxes for RE equipment through new laws and regulations.
- Adopting a transparent custom fee through setting new regulations for transparency.
- Setting a transparent financing model to be applied for utility-scale RE projects by consulting with experts and stakeholders.
- Updating and implementing the established Net-metering scheme as a major incentive for residential and large-scale businesses to install RE.
- Resolving the EDL bankability issue by assigning an agency related to the MoEW to operate as a buffer customer for all RE projects.
- Establishing a licensing scheme, by consulting experts, for RE suppliers to control the quality of equipment introduced into the local market. Several diverse guidelines and standards already established abroad can be abided by nationally, including the International Organization of Standardization (ISO), International Electrotechnical Commission (IEC), American National

Standards Institute (ANSI), Institute of Electrical and Electronic Engineers (IEEE).

- Implementation of large-scale projects by governmental support will provide incentive for companies to invest in local manufacturing of products and create market competition.
- Maintaining a stable national market is a key factors that increases investments. This requires economic and political stability.
- Rebuild the trust of people in the current political system. This can be achieved through policymakers who adopt serious actions towards the implementation of well-designed locally-feasible energy policies. Especially in the electricity sector, this trust has been lacking for over decades.

Furthermore, an extensive update is needed for the electricity grid across the country. The recommendations are the following:

- Establish a grid code for Lebanon as the country still does not any. A grid code is essential to allow RE's successful integration into the grid. This requires consultations between the MoEW and international experts.
- Upgrade the grid by carrying out a grid integration and impact assessment for the targeted utility-scale RE projects expected to be built in the short and long term. This helps to identify the impact of current and future power generation technologies' integration into the network.
- Control the system to maintain an optimum operation level by installing smart grids for the fluctuating generation levels from the RE plants.

For the policy reforms to be implemented and efficiently abided by, cooperation is indispensable among all levels of the public and private sector. Yet, there would be three main entities who would regulate and control the sector: MoEW as the key governmental institution, the private sector as the entity which will share the electricity sector and its activities, and the regulatory body to be established as an independent body to monitor and control the whole sector.

The success of the reforms and the sector is highly dependent on the how each entity plays its role and keeps away unwarranted interferences from non-concerned entities. Success can be defined as enhanced availability and reliability of the power network. Once reforms are implemented, the sector should be continuously monitored. Setting regulation on a sector-by-sector basis is an advanced level of energy policymaking which should certainly be part of the Lebanese energy laws once the primitive reform is accomplished. Sector-based policies shall establish EE standards and audit requirements.

All the above stated policies are important to develop the RE sector in Lebanon. In addition to the general policies, RE deployment shall be have its own set of guidelines and regulations depending on the technologies' technical, financial, environmental and social considerations. Since this report focuses on FPV application, policies specifically for FPV application will be stated below.

B. Specific Recommendations for FPV Implementation

Since FPV is a new technology in Lebanon, financial incentives are a must for its deployment. Initial projects might require higher form of support to overcome the barriers of cost and lack of previous experience. Similarly, supportive governmental and regulatory policies should be set to locally to implement FPVs. The required financial incentives and governmental short and long-term policies are the following:

- Extra bonuses and compensation rates for FPV projects by setting laws and regulations.
- Ease of the long administrative procedures by providing clear guidelines for the administrative processes.
- Unique policies that permit and ease the licensing of water-lease contracts by the entities and authorities managing the water bodies.
- The permission of FPV implementation shall require an environmental impact assessment to be carried out by a trusted third party.
- Provide access to existing infrastructure and network by setting the required regulations.
- Once proven feasible to be implemented on a large-scale, tendering processes for FPV implementations can be prepared by the MoEW.
- Use qualified components to ensure operation safety by setting specific criteria regarding the FPV system.
- FPV application requires higher Feed-in tariffs than land-based PV. This requires setting a Feed-in tariff law.
- Tariff setting for FPVs could be done using similar mechanisms as used for land-based PVs. While Feed-in Tariffs could be implemented for small-scale FPVs, auction and bidding processes, prepared by the MoEW, can be applied for large-scale ones.
- For any IPP contracts in FPV projects, the contract set shall be revisited every few years in order to ensure that the system is operating as it should and that both parties are receiving their rights as was previously agreed.

- For the breakwater system in the case of our case study, establishing tenders and bidding for national and international companies can certainly lower the cost. Yet, surely it is also important and possible to look into other types of breakwater systems as they might be proven to be more financially feasible.

In conclusion, the key factors that boost the FPV application, or any other new energy generation technology, are the governmental incentives, the reduction of FPV system prices, and surely the increase of PV panels' efficiency. The governmental incentives play a major role in this. This is clearly seen in Japan, where a high Feed-In Tariff of US$53.4 cent/kWh transformed Japan into one of the pioneers in FPV market.

1. FPV Application with Hydrocarbon Industry

As Lebanon is on the verge of its first oil and gas exploration phase in its offshore, it might become a hydrocarbon exporting country with several rigs in its offshore. Knowing that each rig will consume electricity itself in the far offshore, FPVs might be installed beside each rig to produce the energy required on the rig. This can represent a perfect example of how RE can even serve in the polluting sector of hydrocarbons. Surely, a feasibility study is needed for such a potential project.

2. Future of FPVs

FPV applications are expected to increase as the technology matures and the price declines. This will open a new frontier in the RE field especially in areas with limited land and large water surfaces. The global potential of floating solar is 400 GW under very conservative assumptions. With such a potential, FPVs can double the existing installed solar PV capacity with no land acquisition (World Bank, 2018). Even though the market is still in its growing phases, the number of experienced suppliers is increasing, while the cost of FPVs is rapidly decreasing.

The priority during the present stage is to carry out strategic assessment of sites where the deployment of FPVs is economic. The sites shall be of two categories, onshore and offshore. These economic sites shall then be labeled with precautionary principles in the presence of any possible social or environmental impacts. Such limitations shall state the maximum portion of a water surface that can be covered, and the protection of littoral zones if the FPV is to be installed near the shore or in any site with abundant animal and plant life.

In addition, constant monitoring of the installed FPV systems will surely provide “Lessons Learned” that convey the positive and negative impacts generated by a FPV system. This can serve to avoid possible issues in upcoming FPV projects. Although costly, yet developing countries can use climate financing funds in order to invest in such a new technology. Success and even failures in this technology will surely aid in enhancing the technology.

FPV applications still face challenges despite the fact that several commercial projects have already been implemented. The main challenges are lack of a robust track record, uncertainty of costs as they are highly dependent on on-site factors, and uncertainty of long-term environmental impacts as the technology has been operating since recently.

Beyond the challenges, the development of the FPV market on national level in each and every country will require an active dialogue not only among all public and private stakeholders, but also cooperation with the industry on a global level. This can certainly help the countries to benefit from the experience of the industry and to further understand the applicability of FPV within its borders throughout the lessons learned from previously implemented worldwide projects. The World Bank Group has been working thoroughly on the FPV market developments and is looking forward to further flourish it while cooperating with governments, investors, research centers and the industry value chain (World Bank, 2018). Lebanon, as a developing country, can certainly join this force and study the feasibility of FPVs nationally.

C. Future Research

As the industry is flourishing, more rigorous and advanced research and regulations are opt to be established. Further outcome to be achieved in this field are:

- Handbook for FPV practitioners.
- Global mapping of FPV potential sites that takes into consideration the solar potential and also the environmental factors.
- Safety standards and guidelines for FPV applications as until this time there is no specific national or international safety standards for FPV systems. As the industry in growing, it is recommended to regulate the FPV systems across different countries, set criteria for qualified components, and ensure operation safety and system dismantling after its lifetime.

CHAPTER X

CONCLUSION

This thesis studied the feasibility of implementing a FPV offshore Beirut, Lebanon. The study was based on an in-depth analysis of existing policies on one hand, and the status of energy sector on the other. Therefore, existing laws and policies concerning the energy sector, and specifically electricity generation, in addition to laws and policies dealing with the Lebanese offshore are analyzed. In addition, a brief technical and cost analysis was performed for the case study concerning the implementation of a FPV offshore Beirut. Based on the case study analysis, the required recommendations were stated. The recommendations tackled not only the FPV implementation of also the Lebanese electricity sector in general.

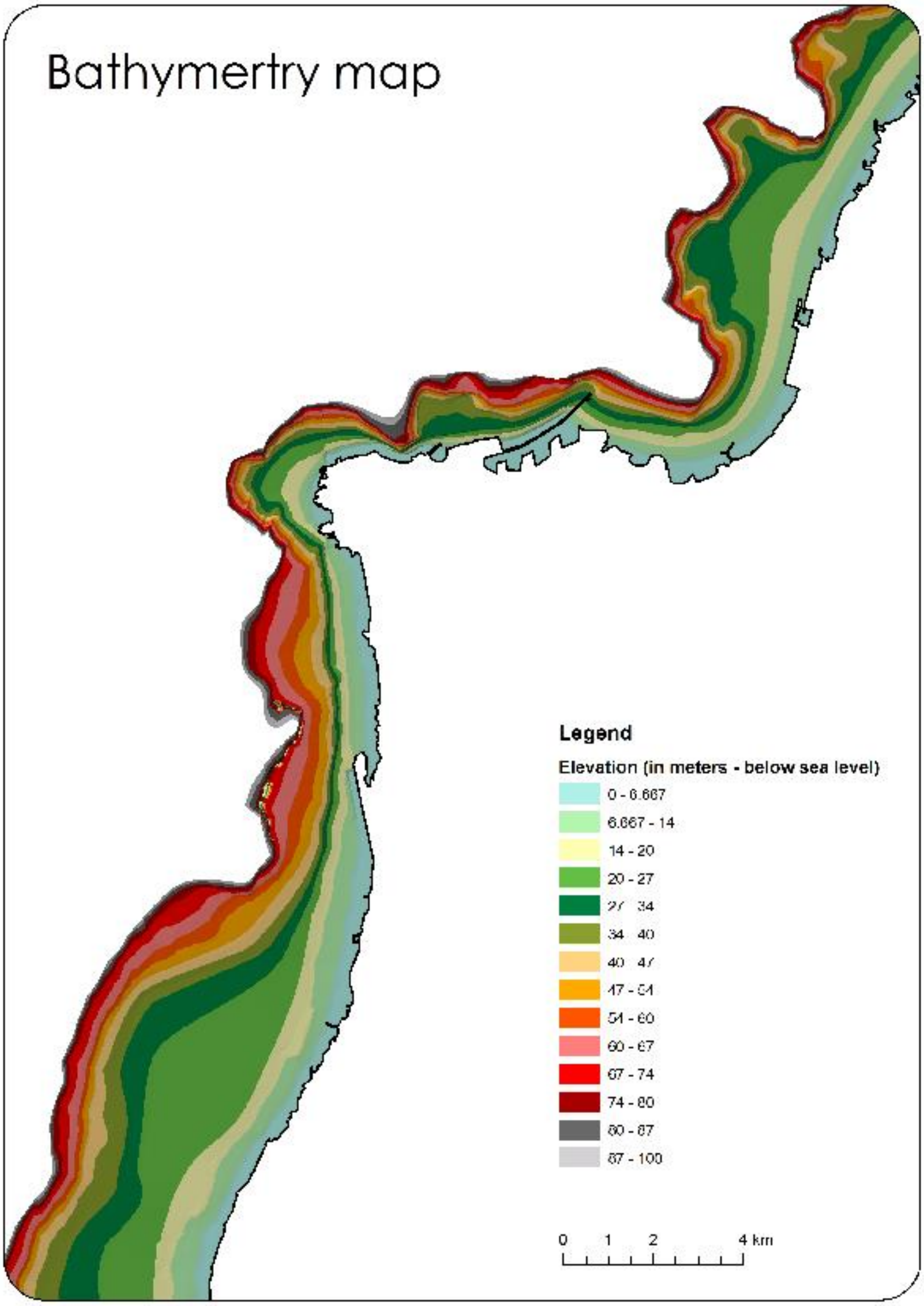
In conclusion, the FPV implementation offshore Beirut can be considered as financially infeasible and environmentally very challenging, especially when comparing it with ground-mounted solar PV systems. Yet, the case study also indicated that it is still possible to implement such an FPV project while benefitting from the expertise of international companies, in addition to also benefitting from the various international donors and national financial mechanisms that can significantly reduce the financial burden. As for this specific study conducted, it was concluded that during this period of time and given the current circumstances, a FPV of around 480 kWp capacity, financed by AUB itself through getting a soft loan, seems the most feasible. Surely if this project is to be realized, an on-site study is required to gather exact weather data and seabed characteristics, and to study the marine ecosystem. As required by the law, an environmental assessment is also a must before the project implementation. As for the financing of the breakwater system, establishing tenders and bidding for national and international companies can certainly lower the cost. Simultaneously, a possible option is to set a deal with Swimsol if they can finance also the breakwater system, while slightly adjusting the tariff that AUB has to pay for Swimsol for the 480 kW FPV. Yet, surely it is also important and possible to look into other types of breakwater systems that can be designed and constructed with other types of materials. Such breakwater systems might be proven to be financially more feasible.

Although an overview of the FPV project offshore Beirut might seem slightly infeasible when compared to other projects, yet the fact that the FPV is a recent technology which is growing worldwide with decreasing prices should initiate a state of interest in the country to implement such a project. Moreover, especially that implementing a FPV offshore Lebanon will be the country's first FPV project, the technical and financial outcomes of this case study cannot be considered as completely infeasible or impossible. Every technology once newly adopted requires funding and then once proven feasible, it becomes feasible especially with the rapid decrease in costs. Whatever type of project, once it is the first time to be implemented across a country, will surely have a relatively higher cost than the other already implemented technologies. The outcome of this study aims to encourage Lebanon to have a serious insight into realizing its first FPV project on its offshore. A feasibility study across the near offshore along Lebanon's coastline might further indicate some other offshore areas that may be more feasible for a FPV with less environmental and financial challenges.

Finally, the fact that Lebanese electricity sector needs major reforms was one of the drivers behind the "October revolution" which began on October 17 2019, when protests stated to rise all over the country's different regions. Protestors carried out protests for weeks and demanded the resignation of the government. The driver behind this “revolution” was the ongoing fear of an impending currency crisis and the Lebanese political system, which based on its sectarian identity, has failed to provide the most basic of services within all the sectors, including the electricity sector which has been in a crises since decades. These protests highlighted the alarming situation in Lebanon urging the country to start reforming all its sectors as soon as possible, including its electricity sector.

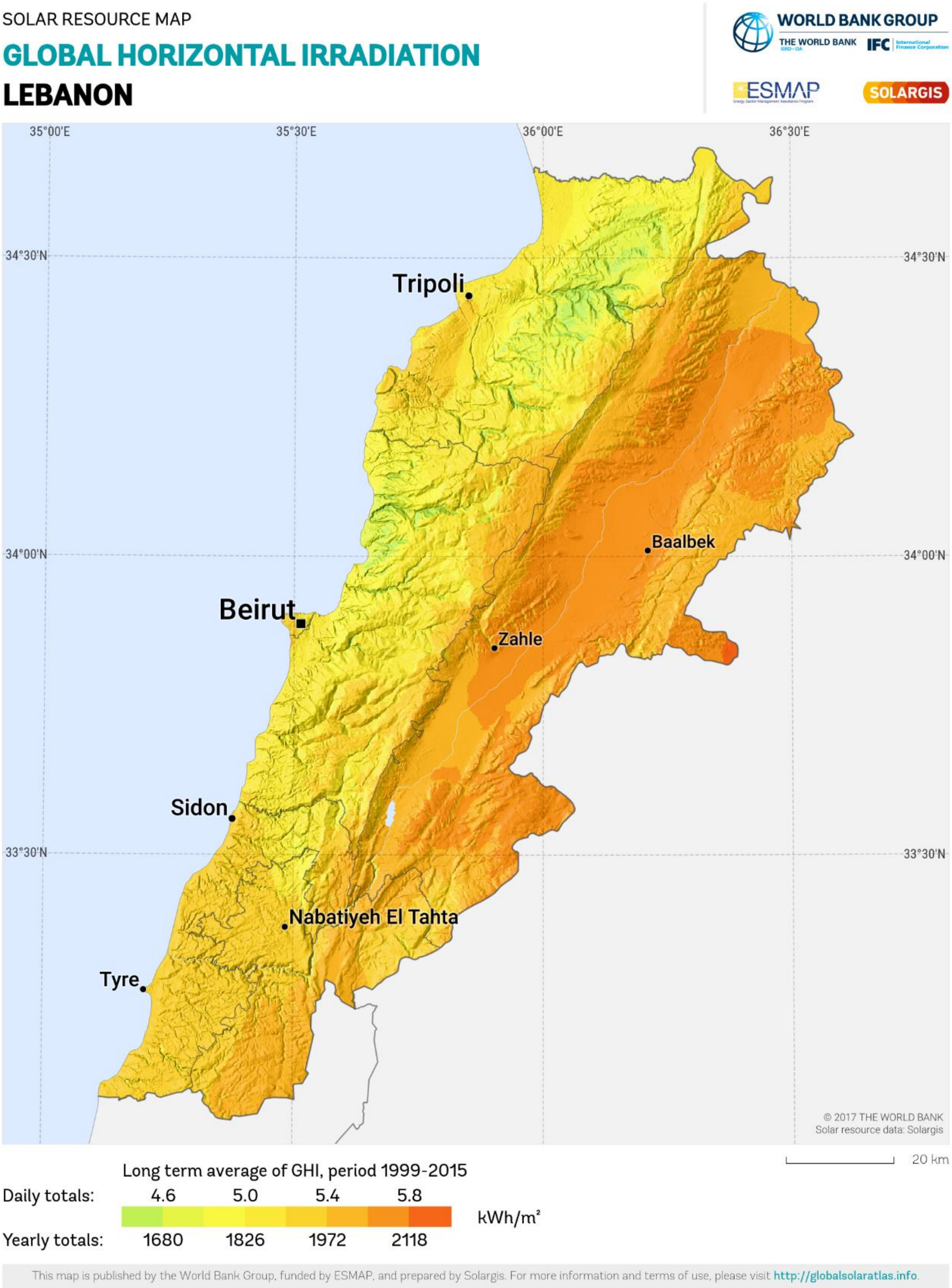
APPENDIX

A. Appendix A: Bathymetry Map

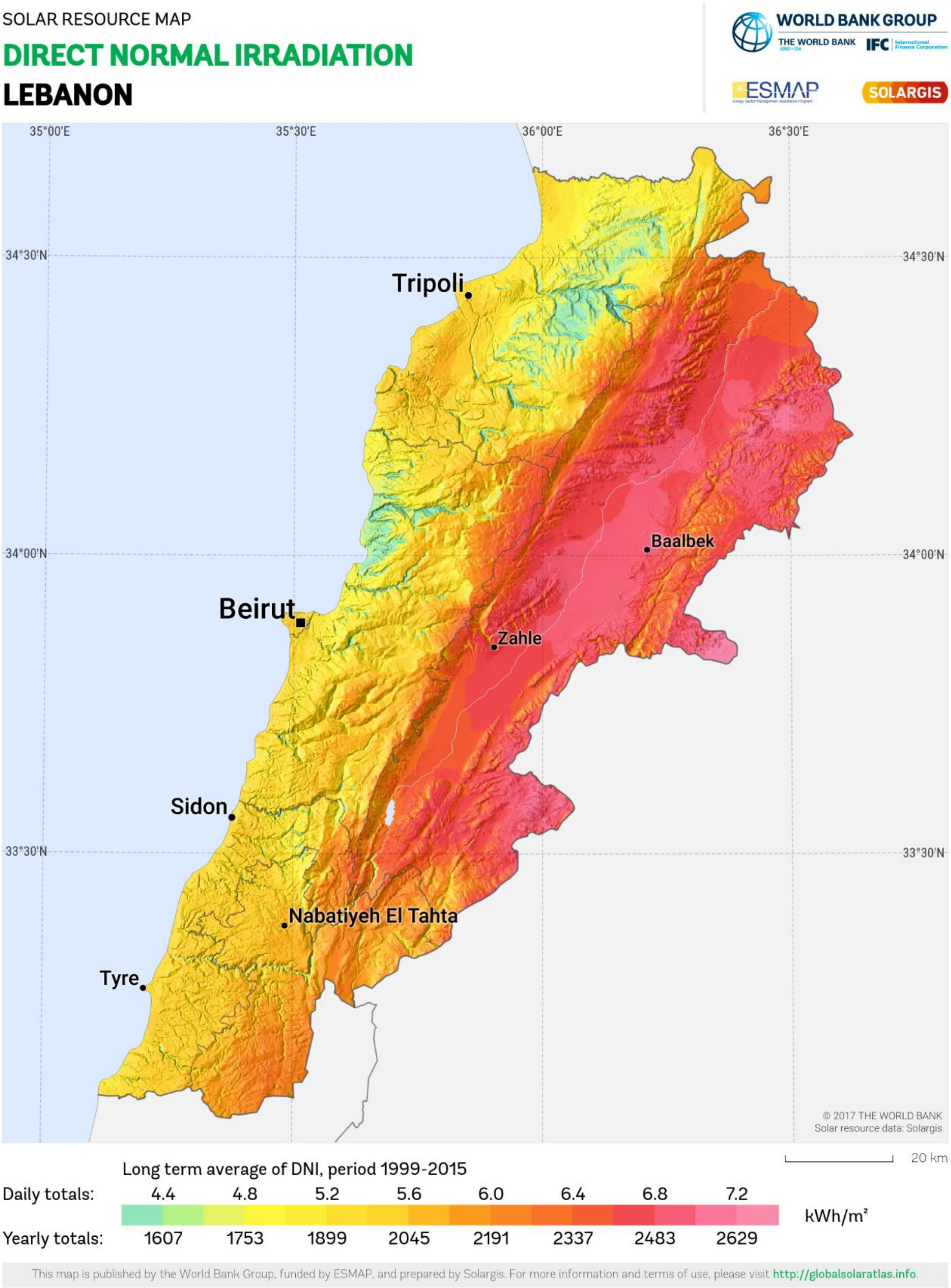


The Bathymetry Map of Lebanon's Shoreline
(The World Bank, Solar resource data: Solargis, 2017).

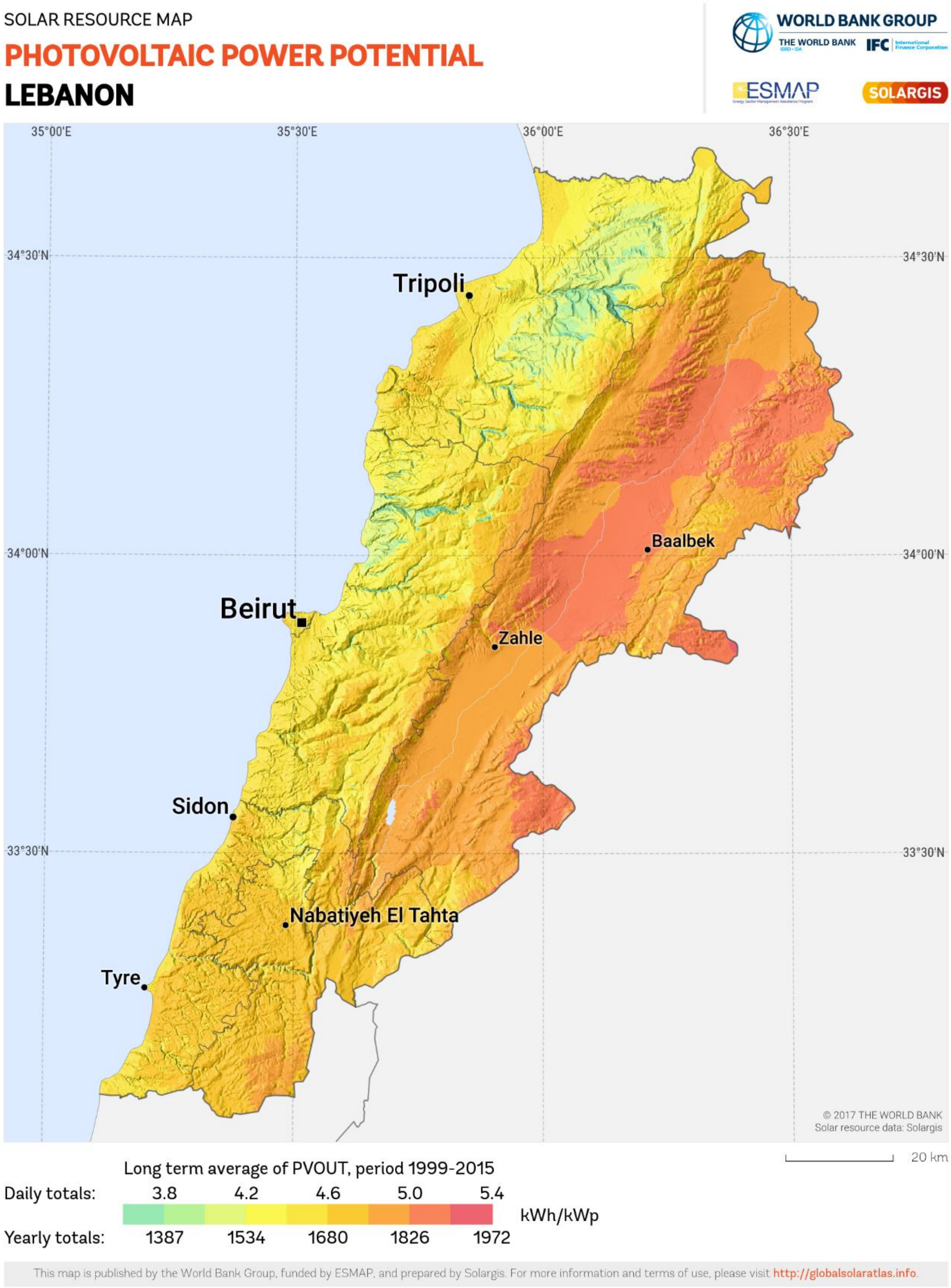
B. Appendix B: Solar Resource Maps



The Global Horizontal Irradiation in Lebanon
(The World Bank, Solar resource data: Solargis, 2017).



The Direct Normal Irradiation in Lebanon
(The World Bank, Solar resource data: Solargis, 2017).



The Photovoltaic Power Potential in Lebanon
(The World Bank, Solar resource data: Solargis, 2017).

C. Appendix C: Project Financing Mechanisms

1. Public private partnership –PPP

A Public-Private Partnership, also known as PPP, is set when a private investor or a consortium builds or operates an asset in exchange for the right to collect user fees and other revenues associated with the asset. The asset can be an existing or a newly built asset. Usually governments resort to PPPs in order to generate investment capital to build a new infrastructure for which the government itself does not have the required capital or fund (International Bank for Reconstruction and Development/World Bank, 2017).

Such PPP agreements have usually long contracts durations that typically last between 30 to 99 years. The disadvantage is that private companies, governmental entities, and the public alters through time, and what seems the society's best interest at the beginning of the contract might not be the case anymore after decades. Moreover, especially with energy projects, the technological advancement is causing huge price variations for different electricity generation technologies. The fees, which seem to be cheap and thus settled in the PPP agreement at the start of the contract, might become one of the most expensive generation costs after a couple of decades.

PPPs can be established through several models, such as the below (International Bank for Reconstruction and Development/World Bank, 2017):

- BOT (build–operate–transfer)
- BOOT (build–own–operate–transfer)
- BOO (build–own–operate)
- BLT (build–lease–transfer)
- DBFO (design–build–finance–operate)

- DBOT (design–build–operate–transfer)
- DCMF (design–construct–manage–finance)

The difference between them is the role of the private entity who can be responsible for one or more of the following: financing, designing, building, operating and managing of assets. Private party's investment is compensated by its right to collect revenues associated with assets.

For instance, in Build-Operate-Transfer (BOT) partnership, the governmental entity allows the private party to build and operate the facility for the concession period during which it recovers the costs of investment from the revenues generated by the project. The facility is then transferred to the public entity at the end of the agreement. A Design-Build-Operate-Transfer (DBOT) model is similar to the BOT in addition to granting the private party the responsibility of designing the facility. Build–Own–Operate–Transfer (BOOT) differs from a BOT such that during the concession period the private entity not only operates, but also owns the facility and aims for higher margin on the project (International Bank for Reconstruction and Development/World Bank, 2017).

2. Independent Power production

An independent power producer, also known as IPP, is a private sector entity which owns electric power facilities to generate electricity and sell it to end users. IPPs are privately owned and self-financed.

IPPs are very common in Europe and the US due to their advanced and wide energy sector market. However, because of EDL's monopoly, there is no advanced energy market in Lebanon, and hence IPPs have not been significantly present introduced in Lebanon's electricity sector.

3. <u>Power Purchase Agreement (PPA)</u>

The procurement process of a PPP or IPP is usually done through bids. Once the government decides what type of PPP it wants to grant for the project, it initiates a competitive bidding following a transparent tender process. Bidders are required to submit their offer and qualifications documentation. The winner of the bid is awarded the contract, known as a Power Purchase Agreement (PPA) (World Bank, 2017).

A PPA is a key instrument of project finance. It is a legal contract between two parties: the entity who generates the electricity (often a privately owned power producer) and the entity who is purchases the electricity (often a state-owned electricity utility). A PPA defines all the commercial terms between the parties, including the tariff adjustment, payment stream, and the obligations of the parties.

The clauses tackle a variety of topics, such as the date that the project will begin its commercial operation, the schedule electricity delivery, invoices and payment terms, termination, and penalties, and can also state, depending on the type of the PPA, the required design, output, operation and maintenance specifications of the facility (World Bank, 2017). The electricity rates are agreed per the PPA, and can be flat, escalate with time, or be of any other form as long as both parties have agreed. The seller shall guarantee that the project will meet the required performance standards and the contractual energy demand requested by buyer.

Power purchase agreements are of benefit to both, the supplier and the purchaser. It provides protection to the supplier and the buyer concerning their rights within the agreements. The seller ensures that it will get paid for the quantity produced, and the purchaser secures that the quantity that will be supplied.

A PPA is also a significant tool to raise financing from a bank or other financing counterparty. There are several forms of PPA as they vary according to the needs of the parties involved, usually the seller, buyer and the financing counterparties (World Bank, 2017). Since one of the parties is always the private sector, the PPA is considered as the chief document in the development of an independent electricity generating sector.

D. Appendix D: PVSyst: System Assumptions and Design

PVSYST V6.81		25/06/19	Page 1/1

Grid system presizing

Geographical Site	**'Ayn al Muraysá**		Country	**Lebanon**
Situation	Latitude	33.90° N	Longitude	35.48° E
Time defined as	Legal Time	Time zone UT+2	Altitude	5 m
Collector Plane Orientation	Tilt	30°	Azimuth	0°

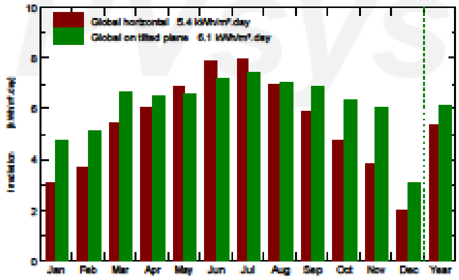
PV-field installation main features

Module type	Standard
Technology	Monocrystalline cells
Mounting method	Flat roof
Back ventilation properties	Ventilated

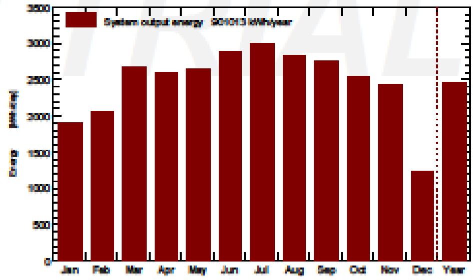
System characteristics and pre-sizing evaluation

PV-field nominal power (STC)	Pnom	480 kWp		
Collector area	Acoll	3000 m²		
Annual energy yield	Eyear	901 MWh	Specific yield	1877 kWh/kWp
Economic gross evaluation	Investment	'64066 USD	Energy price	0.09 USD/kWh

Meteo and incident energy



System output



	Gl. horiz. kWh/m².day	Coll. Plane kWh/m².day	System output kWh/day	System output kWh
Jan.	3.02	4.74	1913	59304
Feb.	3.69	5.13	2070	57966
Mar.	5.42	6.64	2680	83076
Apr.	6.05	6.45	2601	78041
May	6.85	6.58	2654	82264
June	7.87	7.17	2891	86723
July	7.98	7.40	2984	92510
Aug.	6.95	7.05	2842	88112
Sep.	5.91	6.84	2761	82835
Oct.	4.73	6.33	2552	79112
Nov.	3.86	6.00	2419	72575
Dec.	2.01	3.08	1242	38494
Year	5.37	6.12	2469	901013

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