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Conducting a feasibility study for generating power from renewable energy resources and utilizing High Voltage Direct Current for interconnection in the Middle East and North Africa

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Abstract

Electricity consumption is on the rise as the global population is increasing. The need of energy has been discussed in length over the years. Oil and gas have been the primary resource for generators fuel. As oil and gas are a finite resource, an alternative resource that does not harm the environment is needed to generate energy. The Middle East and North Africa have a huge potential for using solar and wind energy to generate electricity as MENA region has one of the highest levels on solar irradiation. A new system of transferring the power through the MENA region is proposed. HVDC can be utilized to transfer energy over large distance with minimal losses where it is used for an interconnection grid between the MENA countries. Moreover, factors affecting future project, in the MENA region, such as the political atmosphere of the MENA countries, and how it affects the decision of constructing a project are analyzed. Secondly, the infrastructure and readiness of the MENA countries toward building Renewable energy and HVDC substation. Thirdly, risks and constrains of implementing these projects. Fourthly, the financial cost of the RE and HVDC projects. Fifthly, how social media and news orient the people thinking and decision making. Sixthly, existing rules and regulations in the energy sector are investigated. Finally, recommendations were given to each factor to ensure the smooth transition to produce green energy by utilizing renewable energy.

Keywords: Renewable Energy, MENA, HVDC, Sustainability, Risk Assessment, Grid Analysis, Energy Sector

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Introduction

In recent years the demand for electricity has been on the rise. Cities and governments have noticed expansion in the development of infrastructure, buildings and homes. As a result, the usage and the future demand of electricity has been a subject in the scientific field to develop a way to secure electrical energy. For the past 100-years, fossil fuel has been the primary source of energy to supply the electrical generators with fuel [81]. Advances on the technology and consumption have been made to ensure maximum energy output from the fuel used in the generation process. Oil and gas have primary resource of fuel for the electrical generation in the MENA region. Experts in the energy and electricity field have approximated that fossil fuel will be depleted; oil in 2050 and gas in 2060, if no new fossil fuel reserves to be found in the following years [18]. Moreover, climate change has been the hot topic in scientific expos. UN committees have been conducting meetings on the regular to discuss the climate change [24]. Many countries have taken the matter on their hands and started putting rules and regulations to reduce CO2 and greenhouse gas emissions in their countries. Furthermore, the Paris agreement signed by 189 countries; USA withdrawing in 2019, to decrease global warming by putting a structure or missions in order to reduce emissions produced by the countries [45,81]. Some criticism has been made regarding the Paris climate agreement towards the lack of an enforcement mechanism, but it is considered as a first step made toward actions being taken by counties to reduce their overall CO2 and greenhouse emissions [45]. Additionally, new methods of producing electrical power have been discussed in length. So which method of producing electricity will have the least negative affect on the environment? Renewable energy like solar, wind, hydro, biomass, geothermal and many others have been on the agendas of many countries. For example, these recourses will be taken into consideration when planning of any new electricity generation station. Many European countries have included renewable energy in their rules and future agendas [67]. For example, the European emission standards has started in 1993 with EURO 1 till EURO 6 in 2014 and in the future with EURO 7 [67].

Stage	Date	CO	HC	HC+NOx	NOx	PM	PN
		g/km					#/km
Positive Ignition (Gasoline)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-	-
Euro 2	1996.01	2.2	-	0.5	-	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-	-
Euro 4	2005.01	1.0	0.10	-	0.08	-	-
Euro 5	2009.09[b]	1.0	0.10[d]	-	0.06	0.005[e,f]	-
Euro 6	2014.09	1.0	0.10[d]	-	0.06	0.005[e,f]	6.0×10^{11} [e,g]
Compression Ignition (Diesel)							
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)	-
Euro 2, IDI	1996.01	1.0	-	0.7	-	0.08	-
Euro 2, DI	1996.01[a]	1.0	-	0.9	-	0.10	-
Euro 3	2000.01	0.64	-	0.56	0.50	0.05	-
Euro 4	2005.01	0.50	-	0.30	0.25	0.025	-
Euro 5a	2009.09[b]	0.50	-	0.23	0.18	0.005[f]	-
Euro 5b	2011.09[c]	0.50	-	0.23	0.18	0.005[f]	6.0×10^{11}
Euro 6	2014.09	0.50	-	0.17	0.08	0.005[f]	6.0×10^{11}

* At the Euro 1..4 stages, passenger vehicles > 2,500 kg were type approved as Category N_1 vehicles
† Values in brackets are conformity of production (COP) limits
a. until 1999.09.30 (after that date DI engines must meet the IDI limits)
b. 2011.01 for all models
c. 2013.01 for all models
d. and NMHC = 0.068 g/km
e. applicable only to vehicles using DI engines
f. 0.0045 g/km using the PMP measurement procedure
g. 6.0×10^{12} 1/km within first three years from Euro 6 effective dates

The goal of European emission standards is to put rules and regulations for new cars manufactured and sold in their territories. The rules govern the emissions of nitrogen oxides, total hydrocarbon, non-methane hydrocarbons, carbon monoxide and particulate matter for most of vehicle types [67]. Renewable energy is considered the life line after oil. A form of transferring the power supply from remote locations where renewable energy is found to the city outskirts where then electricity can be distributed to industrials, commercial and residential areas. High Voltage Direct current (HVDC) will come into place, with its strong suit of transferring electricity for long rages with minimum losses, so HVDC is an excellent form of transferring energy from remote locations [63]. HVDC can be used for wind and solar farms to transfer electricity to the distribution centers. In our feasibility study we will look at using HVDC system to interconnect the countries' electrical systems and to utilize renewable energy in the MENA region [63].

Literature Review

MENA Region

The Middle East and North Africa region (MENA) are divided into three distinguished regions. North African countries, Levant countries and GCC countries. In the African region, the countries from west to east in a geographical map are Morocco, Algeria, Tunisia, Libya and Egypt. In Levant region, the countries are Jordan, Syria, Lebanon and Palestine. In the GCC region, the list of countries are Saudi Arabia, Yemen, Oman, United Arab Emirates, Qatar, Bahrain, Kuwait, Iraq and Iran. It is important to consider the MENA region as a power; divided into countries, but still a power that the world put into consideration. Moreover, the location of the MENA countries put them nearly at the center of the geographical and economical world. They are the connection point or path between Europe and the emerging countries of east Asia. As the MENA region is growing in the economy, population is also increasing with migrant workers from east Asia and Africa

Nationality / Gender	مجلس التعاون Total GCC	الكويت Kuwait	قطر Qatar	عمان Oman	السعودية KSA	البحرين Bahrain	الإمارات UAE	الجنسية / النوع
Total	53,446,862	4,082,704	2,617,634	4,414,051	31,787,580	1,423,726	9,121,167	جملة
Males	32,763,445	2,455,424	1,975,536	2,886,083	18,259,719	888,389	6,298,294	ذكور
Females	20,683,417	1,627,280	642,098	1,527,968	13,527,861	535,337	2,822,873	إناث
Males (%)	...	60.1	75.5	65.4	57.4	62.4	...	ذكور (%)
Females (%)	...	39.9	24.5	34.6	42.6	37.6	...	إناث (%)
Citizens	...	1,222,837	...	2,344,946	19,863,975	647,835	...	مواطنون
Males	...	608,818	...	1,184,430	10,121,867	328,887	...	ذكور
Females	...	531,944	...	1,160,516	9,742,108	318,948	...	إناث
Males (%)	...	49.8	...	50.5	51.0	50.8	...	ذكور (%)
Females (%)	...	43.5	...	49.5	49.0	49.2	...	إناث (%)
Non-Citizens	...	2,812,503	...	1,986,226	11,705,998	759,019	...	غير مواطنين
Males	...	1,822,961	...	1,660,693	8,028,355	551,555	...	ذكور
Females	...	989,542	...	325,533	3,677,643	207,464	...	إناث
Males (%)	...	64.8	...	83.6	68.6	72.7	...	ذكور (%)
Females (%)	...	35.2	...	16.4	31.4	27.3	...	إناث (%)

A trend that can be noticed in in the GCC region is that expats are much more than nationals. This is because of the economic boom that the GCC is having for the past few years. Consequently, the populations of these countries are on the rise. As a result, the consumption of energy has been on a rise.

Political

The MENA region is influenced by multiple global and internal political factors. On the global side, all the superpower countries affect the MENA region. Countries such as USA, Russia, China and Europe are influencing the political decisions that are taken in the MENA countries [93, 27]. With these superpowers wanted to take resources or sell their production to the MENA region. Moreover, USA, Russia and Europe are selling armaments and providing military training to MENA armies [27, 41]. The Superpower would benefit destabilizing the MENA countries and creating wars of false report and threats. For example, the Iraq second war where USA and UK declared war on Iraq with weak intelligences of mass weapons of destruction with the Iraqi government [27, 41]. As a result, Iraq has been in chaos since 2003, with its national recourses oil and gas being stolen or sold for cheaper prices. Additionally, Russia and china are influencing the political parts in Iran and Syria [27]. Lastly, with Europe influencing the North African region. France buying gas and oil from Algeria for cheapest prices and having no problem with dealing and signing agreements with corrupt politicians in Algeria [98]. It can be seen how international influences can affect and benefit from destabilized MENA region. On the other hand, there are regional factors influencing MENA region. Neighboring countries affecting the political situation. Their goals might be self-preservation, economical, and land expansion. For example, Saudi Arabia and Iran are having a political war and proxy war in the GCC countries [57]. Iraq and Yemen are one of these countries that are in a proxy war. Furthermore, Libya is on a civil war for the past few years, with global and regional influences supporting both sides of the armies. Also, the internal influences can affect the country within. For example, the political parts, Shia and Sunni and dictatorships [57]. Finally, all of these intervenes in the MENA are affecting the people, depleting the national resources and destroying the economy and development [57].

National Resources

The MENA region is filled with national resources that can be used to generate electricity to power the world [11, 74, 118]. The MENA region has an abundance supply of oil, gas and national resources. GCC is taking the lion share of oil and gas reserve. Also, the GCC region is supplying more than 30% of the global oil demand [74]. Renewable energy can also be found in the MENA region. The two most abundant resources are solar and wind, with solar being biggest slice of the cake. Hydro can also be found in Egypt, Syria, Iraq and Iran. Solar can be found in almost all of the MENA countries [118]. Also, wind power can be found in multiple areas of the MENA region. As result, MENA region has multiple resources of energy that can be used to produce energy and sustain it [11, 38].

Country	Onshore Wind	Offshore Wind	Wave	Geothermal	Hydro	Tidal	Solar (Residential Rooftop)	Solar (Government Rooftop)	Solar (Utility)	Solar (CSP)
Algeria	1.3%	0.0%	0.0%	0.0%	0.2%	0.0%	10.9%	12.1%	60.5%	15.0%
Egypt	20.0%	0.3%	0.2%	0.0%	1.3%	0.0%	13.7%	9.5%	40.0%	15.0%
Libya	26.5%	3.5%	1.0%	0.0%	0.0%	0.0%	6.7%	9.3%	38.0%	15.0%
Morocco	22.5%	5.0%	0.6%	0.0%	2.7%	0.0%	9.9%	8.8%	45.5%	5.0%
Tunisia	23.0%	4.0%	0.6%	0.0%	0.2%	0.0%	6.0%	6.6%	54.5%	5.0%
Bahrain	1.0%	8.0%	0.2%	0.0%	0.0%	0.0%	3.8%	6.3%	60.7%	20.0%
Kuwait	5.0%	6.8%	0.2%	0.0%	0.0%	0.0%	1.6%	3.7%	54.7%	28.0%
Oman	18.0%	3.8%	0.5%	0.0%	0.0%	0.0%	1.8%	2.3%	58.6%	15.0%
Qatar	3.5%	7.9%	0.2%	0.0%	0.0%	0.0%	1.4%	3.2%	77.3%	6.5%
Saudi Arabia	11.0%	0.0%	0.2%	0.0%	0.0%	0.0%	3.8%	5.1%	45.0%	35.0%
United Arab Emirates	4.0%	4.0%	0.1%	0.0%	0.0%	0.0%	0.9%	1.5%	79.4%	10.0%
Israel	6.0%	1.0%	0.1%	0.0%	0.0%	0.0%	17.1%	16.2%	39.5%	20.0%
Jordan	30.0%	0.0%	0.0%	0.0%	0.1%	0.0%	11.1%	10.8%	33.0%	15.0%
Lebanon	10.0%	8.0%	0.3%	0.0%	2.1%	0.0%	5.2%	10.2%	59.2%	5.0%
Syria	35.0%	1.5%	0.0%	0.0%	5.9%	0.0%	13.9%	6.8%	29.9%	7.0%
Iran	11.0%	2.5%	0.1%	0.0%	2.2%	0.0%	2.9%	2.7%	60.6%	18.0%
Iraq	25.0%	0.0%	0.0%	0.0%	4.5%	0.0%	12.9%	7.7%	39.0%	10.9%
Yemen	4.0%	5.0%	2.0%	1.2%	0.0%	0.1%	27.3%	8.3%	39.1%	13.0%

For each MENA country, the share of proposed renewable energy technology is shown. The highest technology shares are shown in green and the lowest shares in red.

Environment

The world is now facing a major problem with pollution and global warming as they are in the rise [108]. Global warming is affecting the MENA region heavily with high temperatures and less rainfall in winter. Moreover, there is much pollution that is being produced in the MENA region [53, 15]. For example: greenhouse emissions from cars and factories. Moreover, the rules are very relaxed and lenient toward pollution and emissions. However, MENA countries are starting to enforce emission laws, but they are still far away from what the Europe has achieved in the past few decades. As a result, MENA region affect and get affected by the Global warming and pollution. Some of MENA countries are on the Tropic of Cancer, which result on the highest sun exposure through the year while the North African have lower temperature compared to the GCC countries [79, 124]. These is a double-edged sword, with high sun exposure. The

MENA region will have the best place to install solar panel with high effective rate and minimal loss throughout the year, but the region will suffer from difficult living environment.

Economy

Economy is the drive for future development in any country especially in the MENA region where it is considered as developing nations [106, 34, 1]. MENA countries' economy is on the rise with expats migrating towards the MENA nations; seeking better living conditions and higher salary and some seeking fortune. As the countries in the MENA region have national recourses and a booming economy, the living conditions are extremely good: with few of them being in the highest income per person in the world [34, 112]. Continuing with economy, the MENA region having the lowest electricity tariffs in the world with some countries having the government co-paying their bills [112, 86]. Moreover, some countries are allocating annual budgets to reduce the tariffs per KWH. Furthermore, MENA countries can benefit from the economical booming and lenient rules to develop the nation sectors. For example, governments can spend the revenue from selling oil and gas to build hospitals, government buildings and improve the infrastructure. Finally, MENA countries are benefiting of selling energy to boost their economy and further their development.

Rules and Regulations

As the economy of the country is flourishing, rules and regulations must adapt and expand to suit the economic environment. One of the most important rules and regulations in a country is the rules toward energy production and consumption. Additionally, rules regarding the environment are getting stricter, as global warming is becoming a noticeable issue. Rules regarding electrical installation and power factors are being put into consideration with newer buildings. For example, LED are becoming mandatory is some public buildings. Also, air conditioning with lower than 90% power factors is not allowed to be installed [23]. Moreover, in Dubai (United Arab Emirates) solar water heater is compulsory for new houses. Rules regarding the carbon emissions are put into action with yearly test on vehicles CO2 emissions [65]. Similarly, retro fitting old buildings with new energy saving devices are being made on a large scale [65]. Appliance standards are required to the appliance to enter the market. For example, fridges and dishwashers must follow certain rules because some of them operate on a 24/7 basis [49]. Public sector is also taking some actions with energy efficient streetlight, motion sensor in buildings to turn the lights on and off. In the end, these rules and regulation as far from being the best compared to other developed countries.

Technical

HVDC

High Voltage Direct Current (HVDC) is a system used to transfer large amounts of power for large distances [69, 34, 90]. Also, HVDC can be used to link to different alternating current (AC) networks with different frequencies [90]. The HVDC system consists of two parts, conversion and transmission. In the conversion side, the two main and wildly used HVDC systems are current source convertors (CSC) and Voltage source convertors (VSC) [48]. The CSC is considered the older system that uses thyristors and VSC is the newer system model that uses IGBT technology [48]. The main components of a HVDC system are converters, inverters, breakers and cables [104, 48]. One of the advantages of HVDC system is that cables are not affected by the skin affect [104]. Nowadays, VSC systems are getting more attention, and being used in future installments. HVDC is being used because of its advantages. On the other hand, there is a large disadvantage that is protecting the HVDC system is very hard and still being researched [88]. The only available option for some systems is to take the whole HVDC system out by the AC beaker at both ends of the system [33]. Researchers are on the look for a suitable breaker for the system; they have come up with multiple types [48]. Moreover, the latest finding in HVDC system is Voltage source converter- based multi terminal HVDC (VSC-MTDC) [67]. This system is showing great advantages and expands the potential usage of HVDC system. Finally, researchers have noticed a dominance of three companies in the HVDC field, which are ABB, Siemens and Alstom.

Interconnection System

For the second part of HVDC system the transmission, there are also two main components: towers and cable [82]. First, HVDC towers are different from the normal AC towers than can be easily seen in the city outskirts. HVDC towers require fewer branches, but need a stronger structure. Secondly, there are two types of cables used in the HVDC system: MI cable and XLPE cables. MI cables were used in the beginning of HVDC system in the 70s, with XLPE coming later in the 90s [25].

Smart Grid

Smart grid is the future of the HVDC system. Moreover, the integration of AI is enviable with human advances in science and automation. Having an AI system installed will lead to better response to interruption and fast changing of line to reduce the overall shutdown period. Example for a smart system is having smart equipment and monitoring.

Research Question

In this research study we are conducting a feasibility study of utilizing renewable energy in a high voltage direct current interconnection grid in the MENA region.

What is a feasibility study and its types?

A feasibility study is the analytical process, which a project manager can determine the project success rate [32]. Also, through a feasibility study a project manager is able to see the usefulness of the project and the completion time. There are many types of feasibility studies. The ones we have been concentrating on this research paper is a hybrid Feasibility Study, that combine the following studies:

1. Technical Feasibility Study is the engineering feasibility of the project in viewed in the technical feasibility. Certain important engineering aspects are covered which are necessary for the designing of the project like civil, structural and other relevant aspects. The technical capability of the projected technologies and the capabilities of the personnel to be employed in the project are considered [32].

   In certain examples especially when projects are in third world countries, knowledge transfer between cultures and geographical areas should be analyzed. By doing so, productivity gain (or loss) and other implications are understood due to the differences in fuel availability, geography, topography, infrastructure support and other problems [32].

2. Managerial feasibility study is ascertained by certain key elements like employee involvement, demonstrated management availability & capability and commitment. The managerial and organizational structure of the project is addressed by this feasibility which ensures that the proponent's structure mentioned in the submittal is feasible to the kind of operation undertaken [32].
3. Economic feasibility study refers to the feasibility of the considered project to produce economic benefits. A benefit-cost analysis is needed. Furthermore, the economic feasibility of a project can also be evaluated by breakeven analysis. In order to facilitate the consistent basis for the evaluation, the tangible and intangible facet of a project must be translated into the economic terms. Economic feasibility is critical even when the project is non-profit in nature [32].
4. Political Feasibility Study that directions for the proposed project are mostly dictated by political considerations. This is certainly correct for large projects with potential visibility that may have important political implications and government inputs. For example, regardless of the merit of the project, the political necessity may be a source of assistance for a project [32]. On the other hand, because of political factors, projects may face uncontrollable opposition. An evaluation of the objectives of the project with the current objectives of the political system is required in the political feasibility analysis [32].
5. Environmental Feasibility Study is very crucial in making any potential project successful or failed. In the very early stages of the project this aspect should be considered. All the environmental concerns raised or forecasted should be addressed in an environmental feasibility study so that proper actions can be taken to cover relevant issues of the environment. The ability of the project to timely acquire the required permits, licenses and approvals at a reasonable cost should also be included in this area [32].
6. Market Feasibility Study must not be mixed up with economic feasibility. The potential influence of market demand, competitive activities and available market share should be considered in the market feasibility analysis. During the start-up, ramp-up and commercial start-up phases of the project, possible competitive activities (local, regional, national and international) should be analyzed for early contingency funding and impacts on the operating costs [32]. These combined studies create

the best atmosphere for our project to flourish, as our project is complicated and has many different aspects to be taken into consideration in the implementation of a HVDC system that utilize renewable energy [32].

Methodology

What are we trying to accomplish?

We are studying the feasibility of building an interconnection grid between the MENA countries by using the renewable energy found those areas.

Why are we trying?

We are conducting the study to find a method of transferring the electrical energy for large distances with minimum losses. Moreover, the traditional methods of producing electricity oil and coal are depleting in an alarming way, so a new source of energy must be researched and devolved [96]. Since the highest solar index is in the MENA region [84]. We are recommending using the renewable energy in that region with solar energy taking the lion share.

How are we going to accomplish?

To accomplish energy independence for each country in the MENA region, an interconnection grid system between the MENA countries with using high voltage direct current (HVDC). This system is a new technology that has been in development for the past few decades. It shows high potential in transferring electrical energy for long distances.

Information collection method

The information collected for the study was from academic journals and utility companies that were building a HVDC system in the grid. For example, data from the Chinese electricity company were used for technical part. Moreover, India electricity company data were used for methods of constructing HVDC towers and transferring energy from remote power generation station to the cities, were the energy will be inverted and used. Finally, European company's data used for history and development of the HVDC systems.

Statistical tests used

There will be few statistics used in the feasibility study, as the study is a Managerial study. As a result, we will show the formulas without calculations.

How the study was conducted?

Study was conducted in a theoretical form with no physical visits and work. The study used previous data and information from research and work done in different parts of the world, to simulate the project in the MENA region. The location of the HVDC stations and lines will be recommended be us based on a multiple of factors, that will be discussed in details in the follow sections.

Barriers

The difficulties we are facing in conducting the study are site visiting or a working model. There is no HVDC system in the UAE that we can go to analyze the working processes. Also, due to the COVID-19 pandemic we were not able to get a hold of a specialized engineer in the HVDC systems.

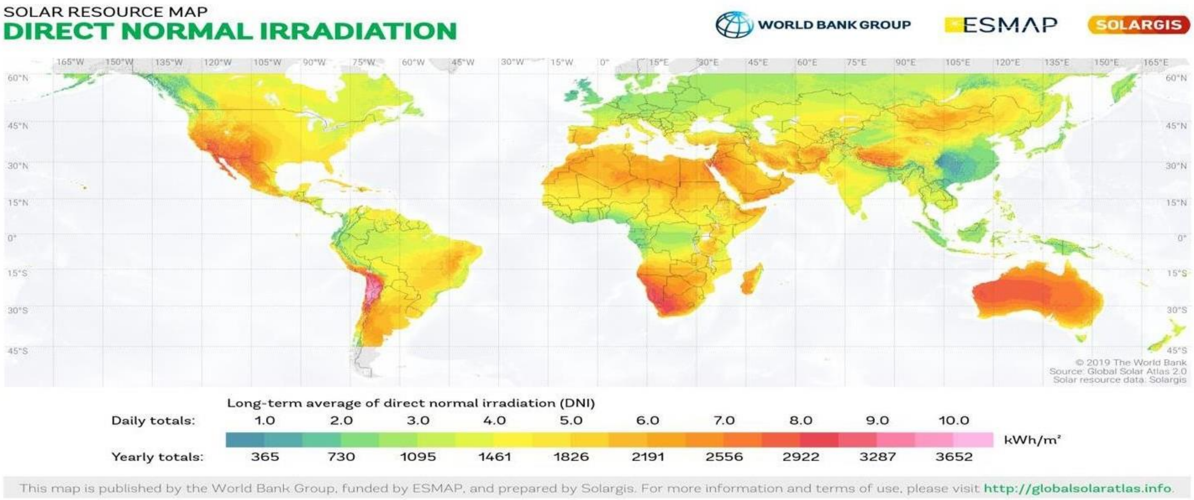
Analysis part 1: Renewable Energy

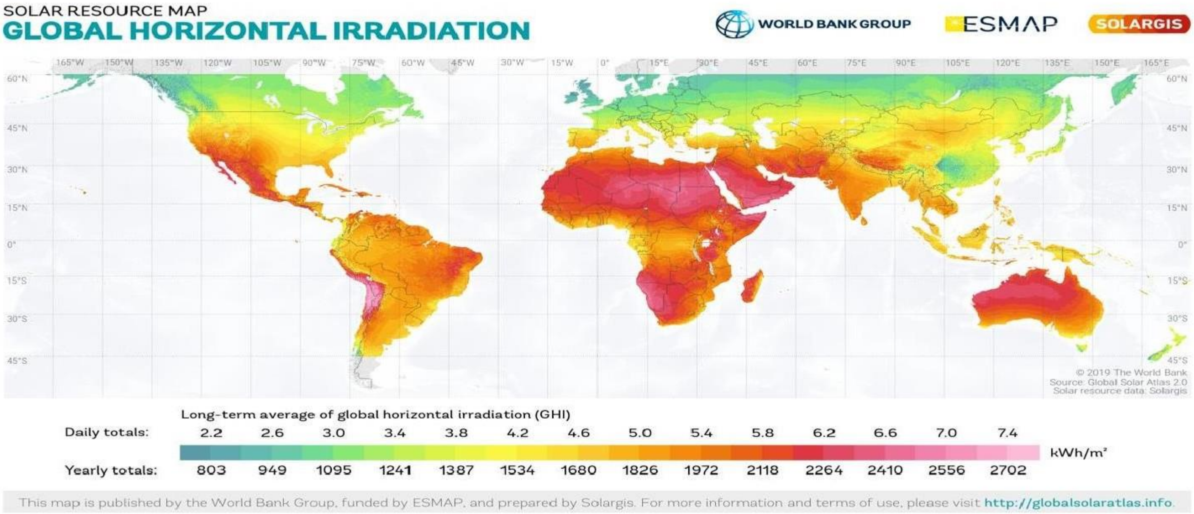
In the analysis part of the research paper, we will divide the part into two. The first will be about the renewable energy (RE), and the second part will be about the High Voltage Direct Current (HVDC). We are going to analyze the previous projects made on RE and HVDC. Also, we are going to analyze the future plans. The most important aspect of the research paper is the feasibility of a RE with HVDC system in the MENA region as a future energy scheme to sell the energy to countries with fewer RE resources or capabilities. This is a result of the exhausting oil resources over the years in the world and especially in the MENA region. RE is promising alterative to oil in producing energy. As discussed in the literature section of the paper, there are two prominent RE in the MENA region. First being the solar energy, which can be found in high potential in the MENA. Second being wind energy, which is fewer and in specific areas and with less speed in these potential areas.

Site selection

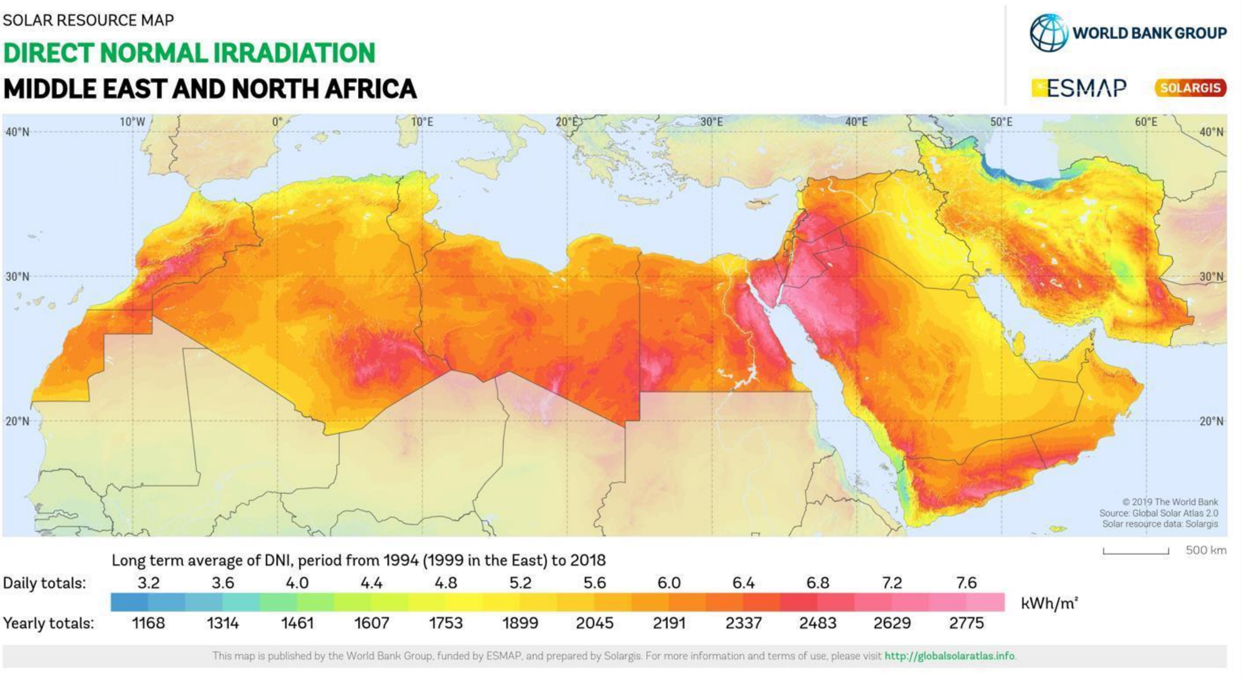
Solar Energy

In the solar energy there are four main factors to be considered with calculation the production capability and site selection. First is the Global Horizontal Irradiation (GHI). It is the solar radiation a horizontal surface receives during the day [101, 22, 7]. GHI is used to calculate and assess the performance of PV modules. Second is the Direct Normal Irradiation (DNI). It is the solar radiation a surface facing the sun receives during the day [101, 22, 7]. DNI is used to calculate the solar energy concentration in order to build a solar farm in a specific location. DNI is also used to maximize the output during the day [101, 22, 7]. For example, when passing through solar energy farms, the observer will notice some farms and PV modules are not side by side, that is because of the DNI. Third is the Air temperature. It is the forgotten factor when taking or discussing about solar energy. Air temperature is used to calculate the factor of locating the solar farms [7, 123]. Even though a site or location might have great DNI and GHI levels, but the air temperature is too high for PV cells to function at its optimal range. Air temperature being too high is also bad for the PV cells to generate electricity [7, 123]. On the other hand, concentrated solar power suffers fewer losses, as CSP fundamental concept of generating electricity depends on melting salt. Last is the Seasonality index [7, 123]. Usually when calculating for solar irradiance, we neglect the seasonality factor in the calculations for the energy yield. Seasonality are the four seasons of the year; summer, winter, autumn and spring. Typically, with winter and autumn having cloudy days, we get lower DNI and GHI than summer and spring [7]. This might be true in northern parts of Africa, where they have the fully four seasons. In the Middle East and especially GCC countries. The seasonality has mush lower effect on the DNI and GHI levels [122]. Hence having better over than year energy yield. On the other hand, North Africa benefits from the seasonality in winter and autumn, the wind speed would be faster compared to the hotter seasons. Overall, seasonality has some benefits and drawbacks to solar and wind energy generation [122]. In the next section we are going to discuss about the DNI and GHI levels in the MENA region. As can be seen in the figures obtained from the World Bank indicators. We can say that the levels for DNI and GHI in the MENA region are one of the highest in the world. Also, the gathering and accumulation of high DHI and GHI areas give an advantage to large capacity solar energy farms that can be as an interconnection in a HVDC system.

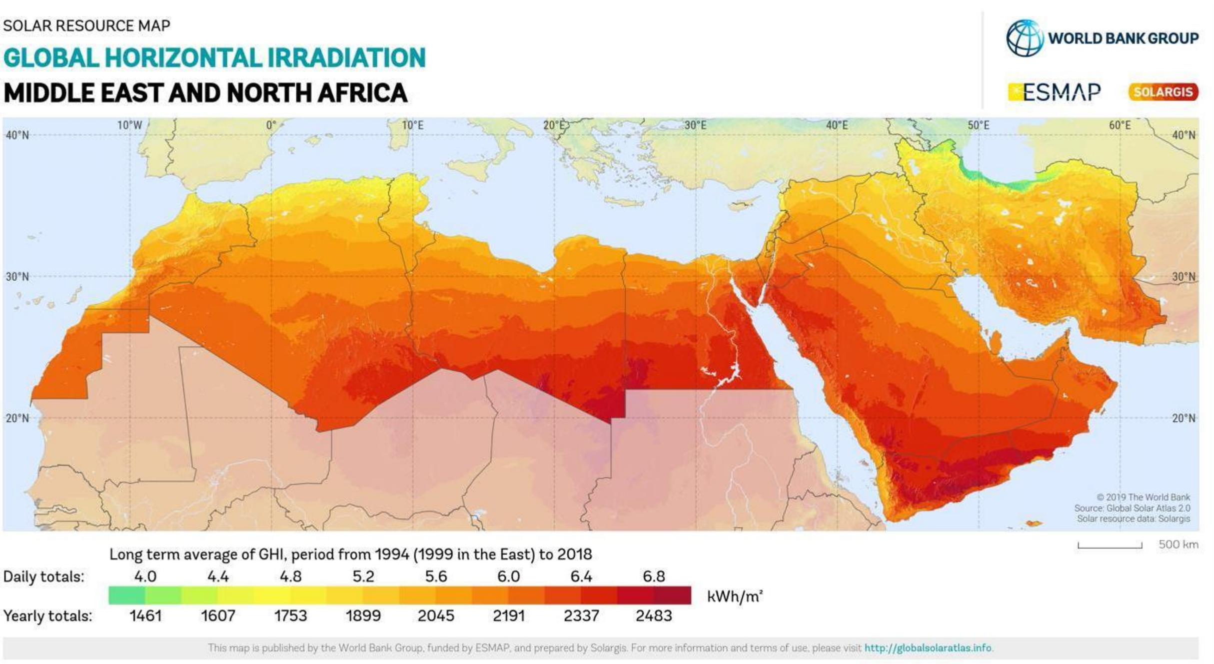




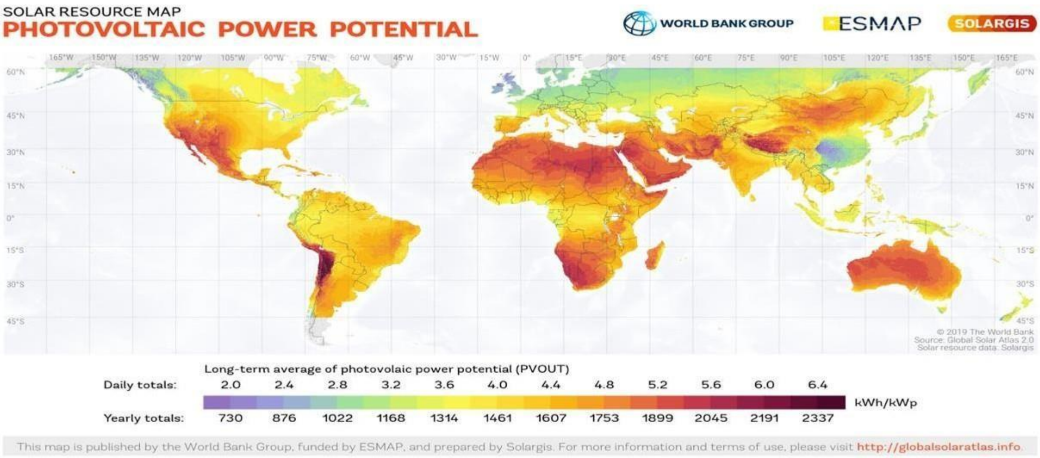
Furthermore, in the figures we can see a detailed image to the DNI in the MENA region. We can realize that the average number is between 4.8 to 7.6 kWh per Meter Square. Hence, that the availability of large areas that can be utilized for solar energy, there is miles upon miles of unused land to waiting for reclamation.

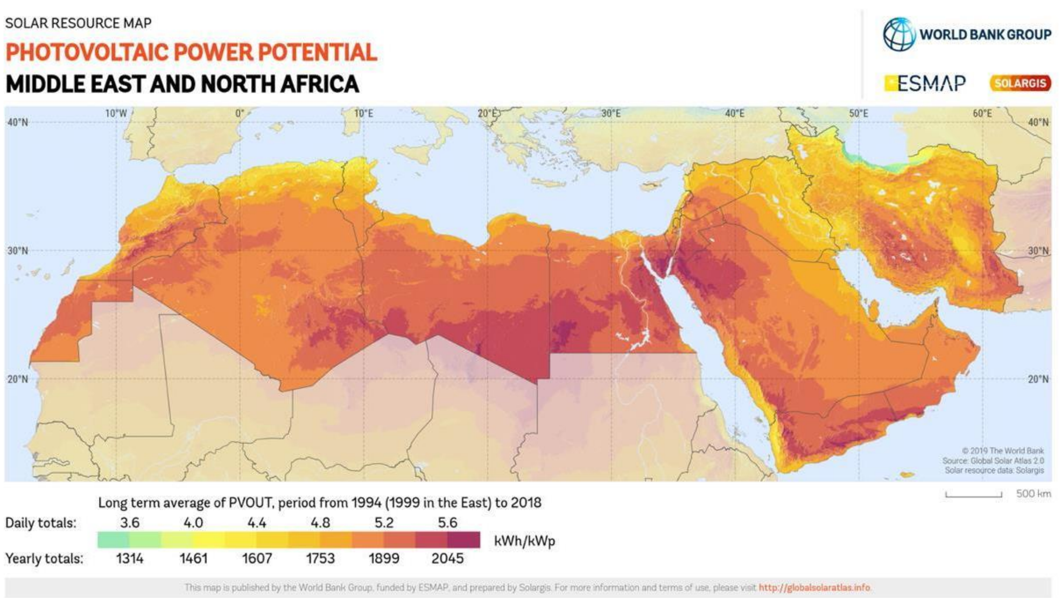


Furthermore, in the figures when can see a detailed image to the GHI in the MENA region. We can realize that the average number is between 4.8 to 6.8 kWh per Meter Square. As a result, the high number of DNI and GHI is suitable for solar energy farms.



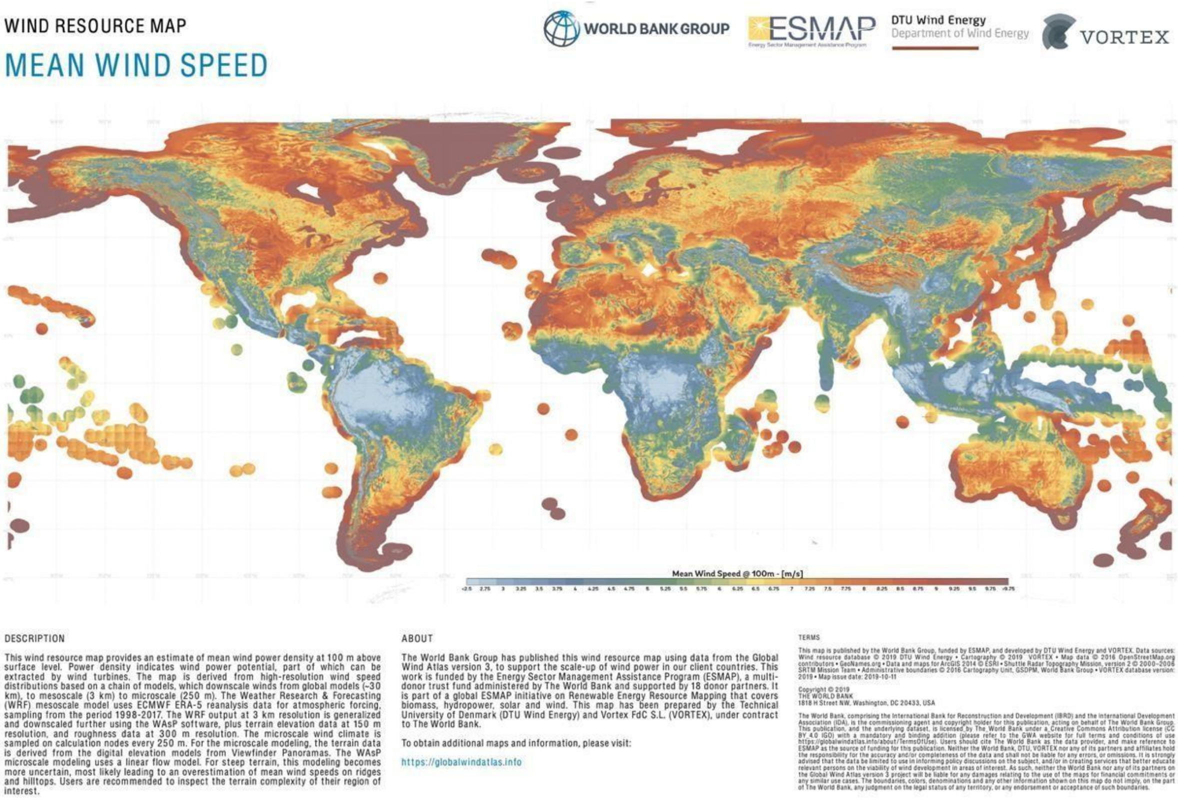
Additionally, we can grasp the large potential power that can be used for PV technology, and the density of the solar rays, which can be used to power the PV cells.

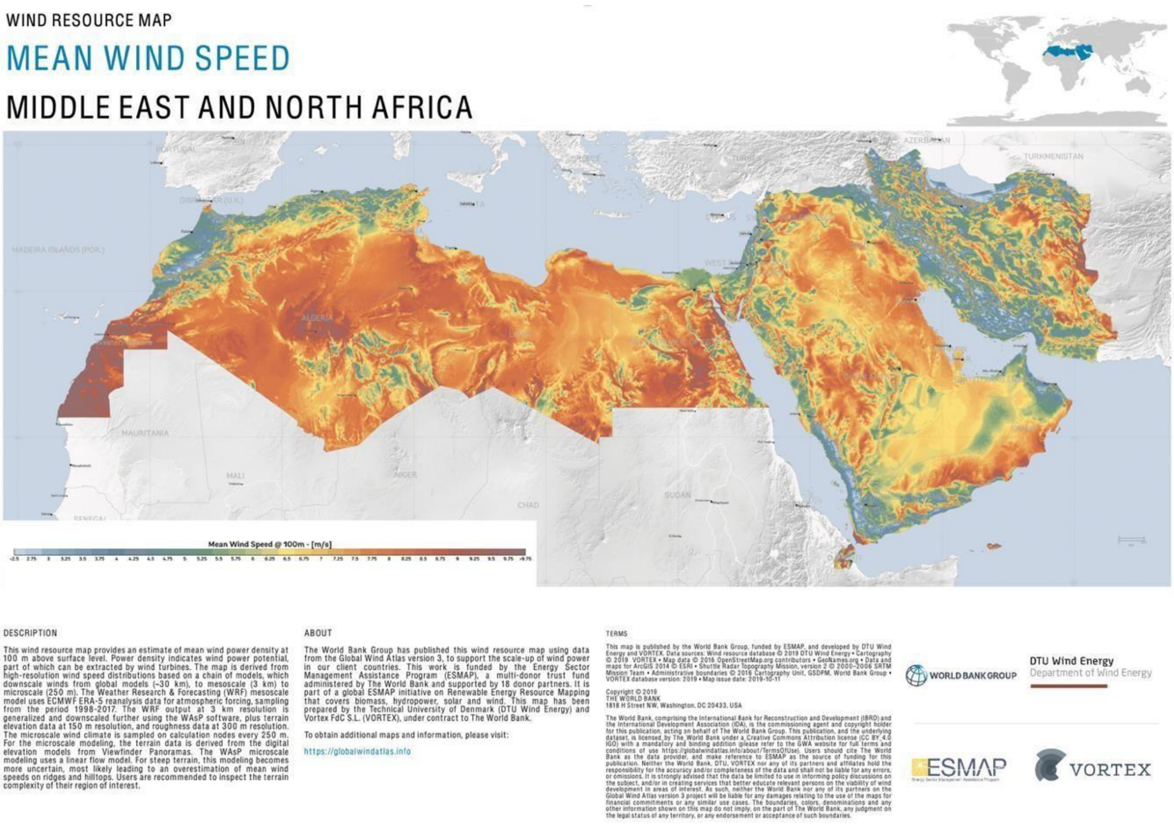




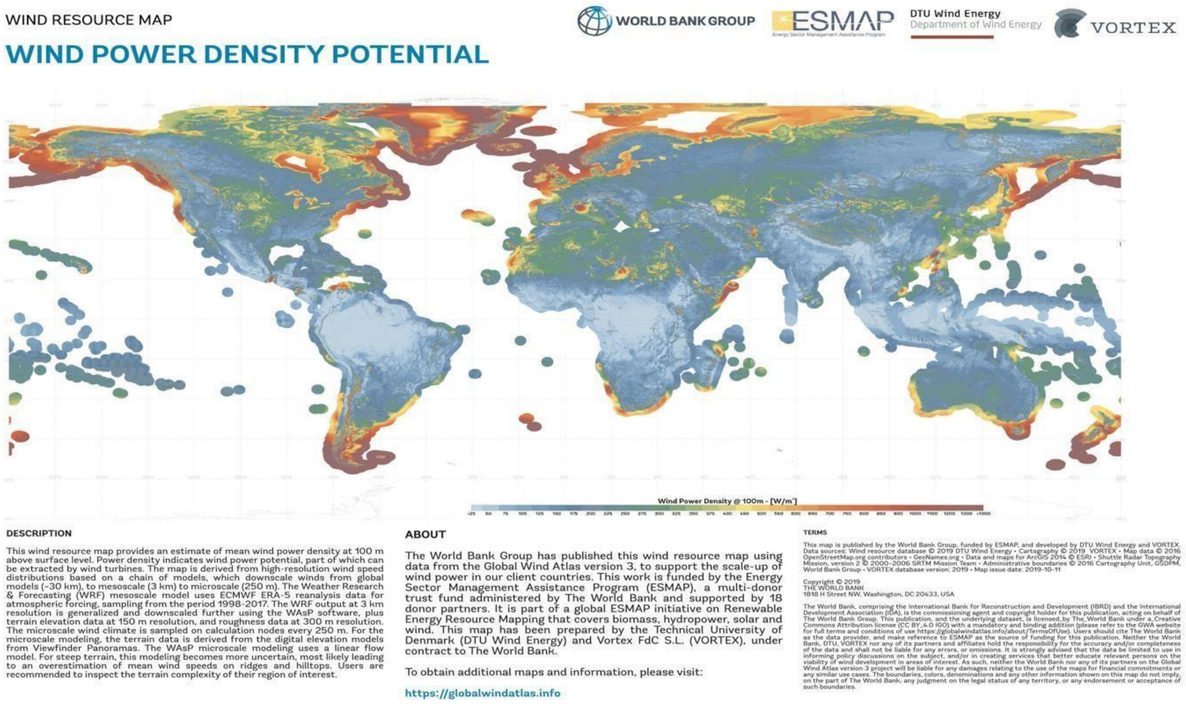
Wind Energy

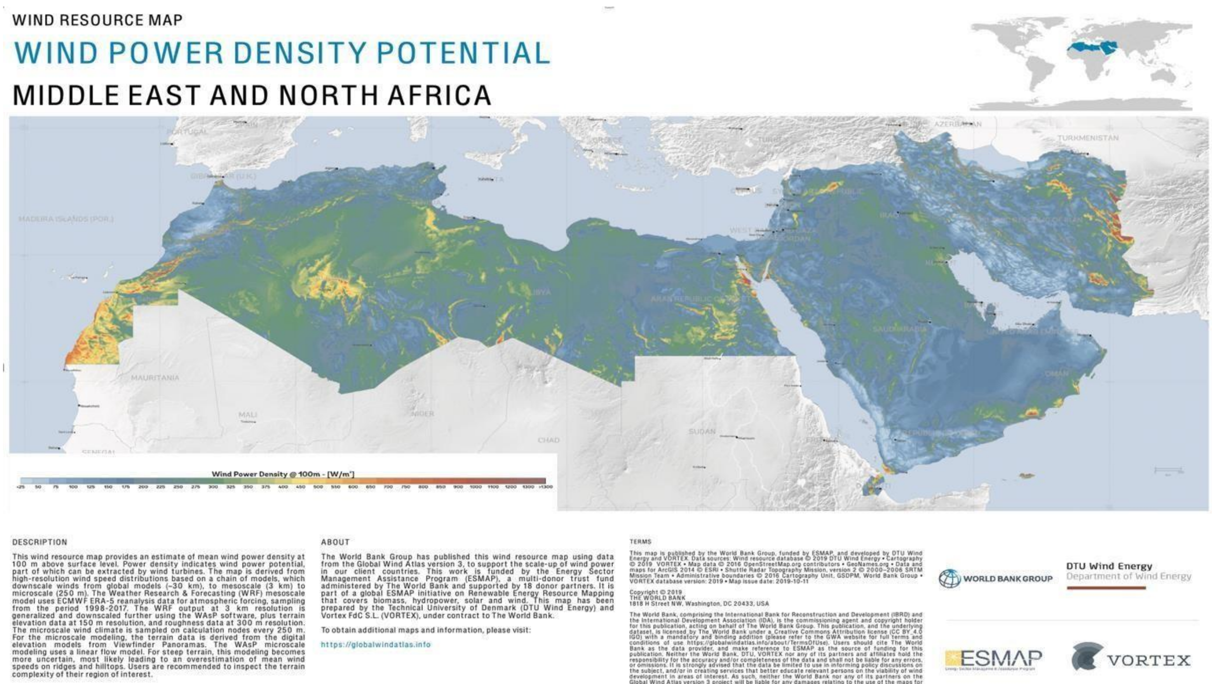
Continuing with RE energy resources in the MENA region, the second most available energy resource is wind power. There are two main factors to be considered when planning for a wind energy farm [7, world bank]. The first factor to be taken into consideration is the Mean Wind Speed (MWS). It is the average wind speed through the year. As can be seen in the figure, the calculation of MWS is done at 100 m above the surface of the sea. The average speeds in the MENA region is between 2.5 up to 9.75 m per second. While compared to the rest of the world, MWS is above average.



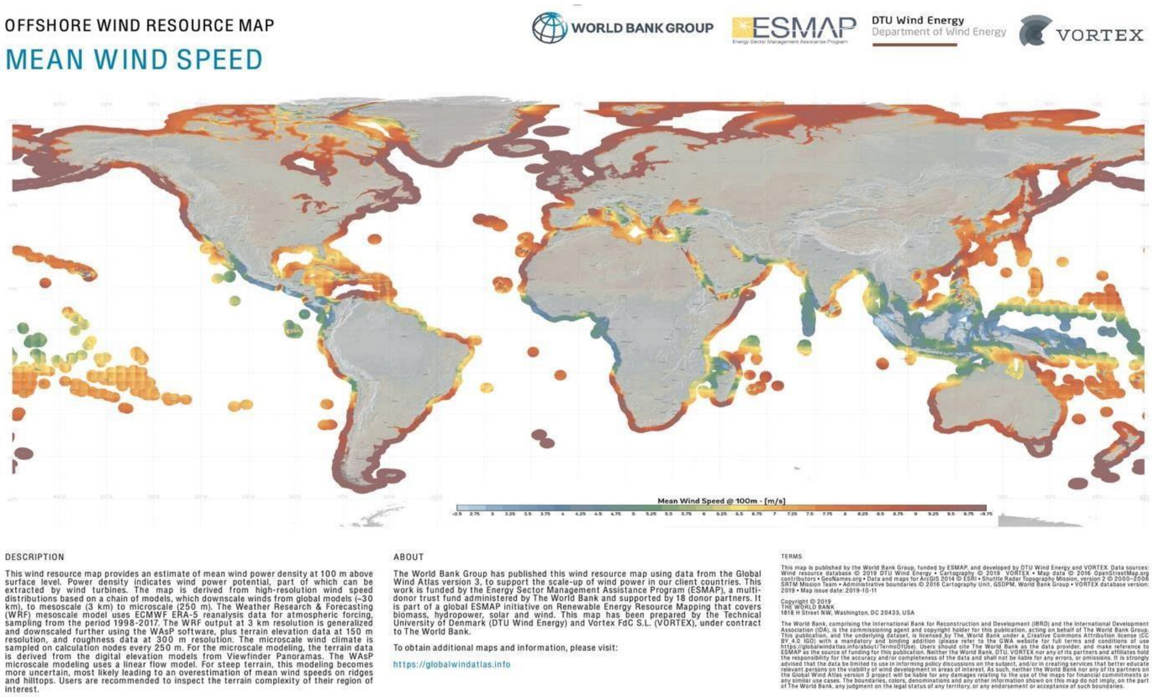


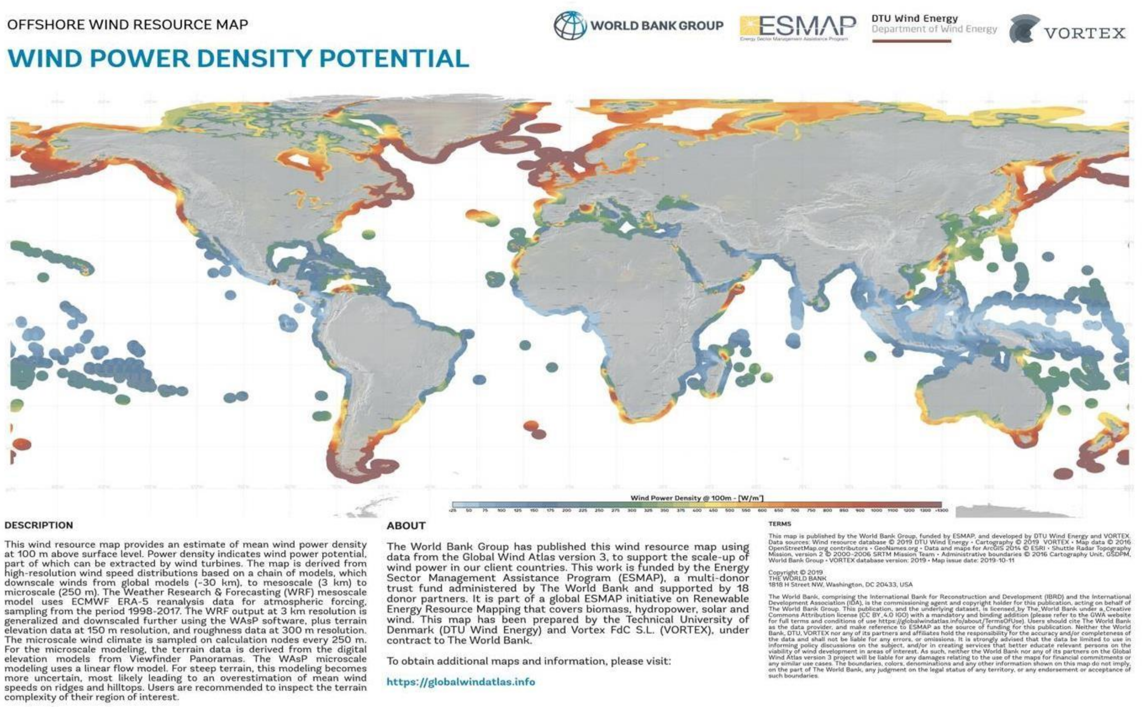
The second factor to be taken into consideration is the Wind Power Density Potential (WPDP). WPDP is the energy potential that a wind turbine can use or harvest. WPDP is measured in Watt per Meter Square. Moreover, it is the measurable potential energy available at a specific area at a specific height. As we can see in the figures, the mean region has an average power potential for wind turbines, but MENA region benefits from large areas for the installation of wind energy farms [122].





Lastly in the power index is the offshore energy potential. The MENA region can have some usability of offshore wind farms. But unfortunately, the available areas are small and mostly used for ships routes. With the small availability for offshore wind farms, only few countries in the MENA can utilize the offshore energy potential. For example, Morocco and Oman are the two best countries suited to install offshore wind farms.





Generation

Solar

energy PV

and CSP

There are two most commonly used technologies to generate energy from sun light, photovoltaic (PV) and Concentrating Solar Power (CSP) [13,30,96,].

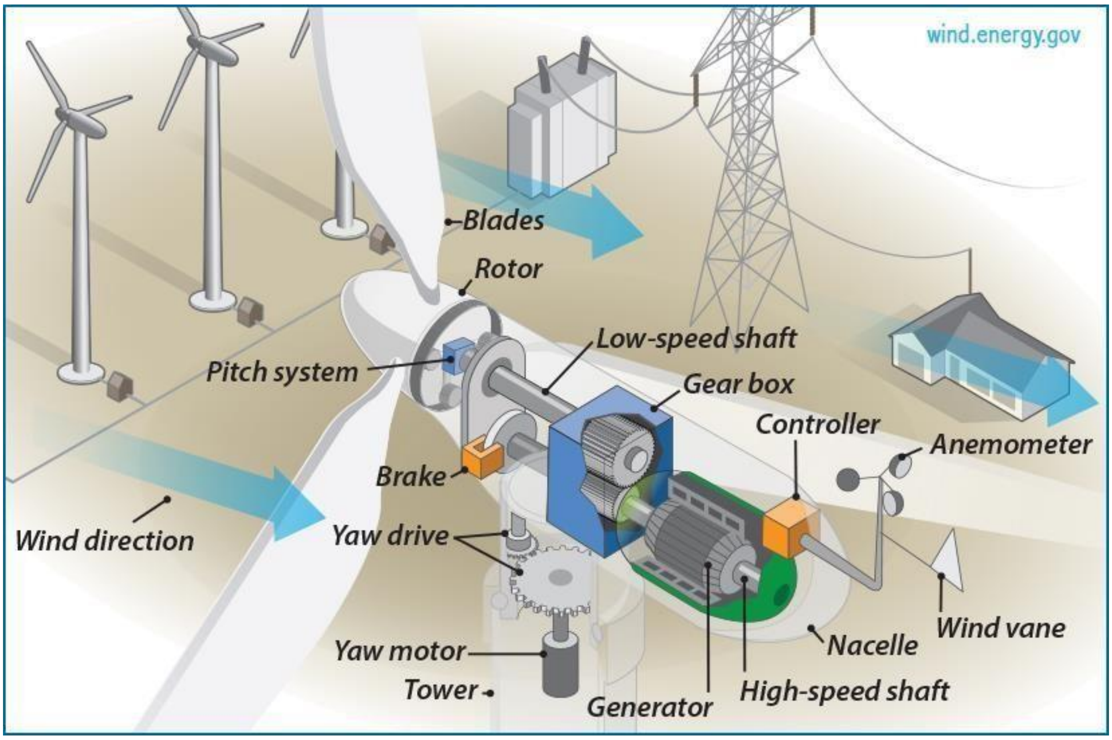
Photovoltaic is the process from converting sun light to electricity, which can be accomplished by using the photovoltaic effect. Scientists working in Bell laboratories discovered PV effect in 1954 [30]. PV is made of silicon that generate electricity when espoused to sunlight [13]. As a result, PV was used for a variety of applications. For example, in calculators, watches and most importantly in the space missions by the USA. Nowadays, PV is competing in the electricity generation market, as its cost is becoming less and energy yield is getting higher [54].

Concentrating Solar Power is the process of using mirrors to reflect the sunlight falling on the mirrors, so it can be redirected to a central thermal heating tower which then can be used to generate electricity.

Wind energy

As for wind energy there is only one form of technology to capture the wind to generate electricity, which is by using wind turbines. Wind turbines are set of equipment that comes together.

In the wind turbine there are the following parts to produce electricity.



1. **Anemometer:** Measures the wind speed and transmits wind speed data to the controller.
2. **Blades:** Lifts and rotates when wind is blown over them, causing the rotor to spin. Most turbines have either two or three blades.
3. **Brake:** Stops the rotor mechanically, electrically, or hydraulically, in emergencies.

4. **Controller:** Starts up the machine at wind speeds of about 8 to 16 miles per hour (mph) and shuts off the machine at about 55 mph. Turbines do not operate at wind speeds above about 55 mph because they may be damaged by the high winds.
5. **Gear box:** Connects the low-speed shaft to the high-speed shaft and increases the rotational speeds from about 30-60 rotations per minute (rpm), to about 1,000-1,800 rpm; this is the rotational speed required by most generators to produce electricity. The gear box is a costly (and heavy) part of the wind turbine and engineers are exploring "direct-drive" generators that operate at lower rotational speeds and don't need gear boxes.
6. **Generator:** Produces 60-cycle AC electricity; it is usually an off-the-shelf induction generator.
7. **High-speed shaft:** Drives the generator.
8. **Low-speed shaft:** Turns the low-speed shaft at about 30-60 rpm.
9. **Nacelle:** Sits atop the tower and contains the gear box, low- and high-speed shafts, generator, controller, and brake. Some nacelles are large enough for a helicopter to land on.
10. **Pitch:** Turns (or pitches) blades out of the wind to control the rotor speed, and to keep the rotor from turning in winds that are too high or too low to produce electricity.
11. **Rotor:** Blades and hub together form the rotor.
12. **Tower:** Made from tubular steel (shown here), concrete, or steel lattice. Supports the structure of the turbine. Because wind speed increases with height, taller towers enable turbines to capture more energy and generate more electricity.
13. **Wind direction:** Determines the design of the turbine. Upwind turbines—like the one shown here—face into the wind while downwind turbines face away.
14. **Wind vane:** Measures wind direction and communicates with the yaw drive to orient the turbine properly with respect to the wind.
15. **Yaw drive:** Orients upwind turbines to keep them facing the wind when the direction changes. Downwind turbines don't require a yaw drive because the wind manually blows the rotor away from it.
16. **Yaw motor:** Powers the yaw drive

[wind.energy.gov]

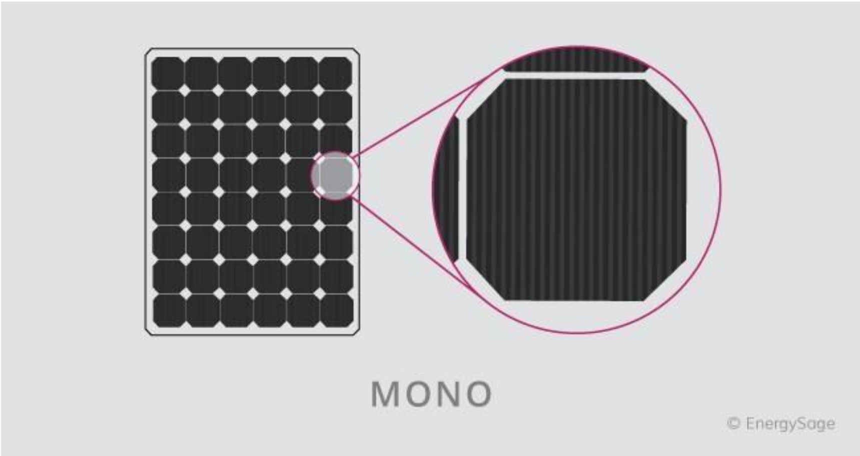
Technology

Solar energy

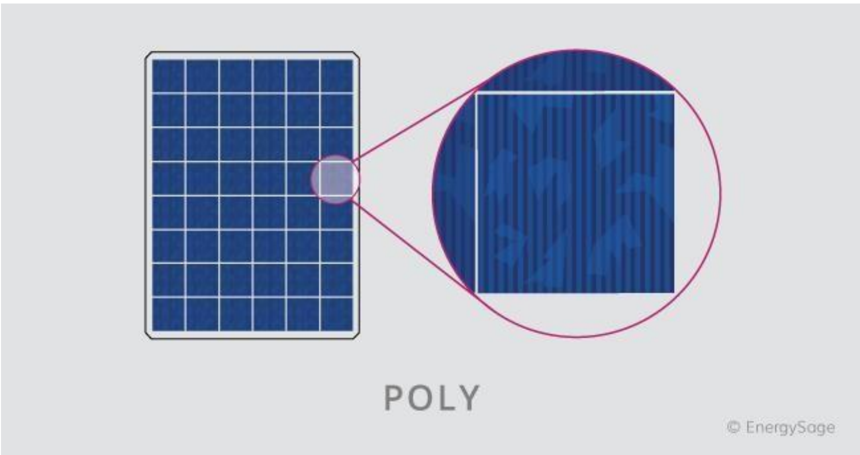
There are many types of PV and CSP which are sold in the market and each one of them have advantages and disadvantages.

PV

1. Monocrystalline Silicon Cell: was the first PV cell type to be introduced commercially to the public, it was made from high content of purity. To manufacture cell, silicon is melted and seed crystal are pulled to form an ingot. Then the ingot is cut into thin wafers and Dropped; it is the process to introducing foreign atoms, to create the P-N junction. An anti- reflective coat is applied to the wafers, and the wafers are wired to each other to form a cell then a full solar panel is made [46, 107].

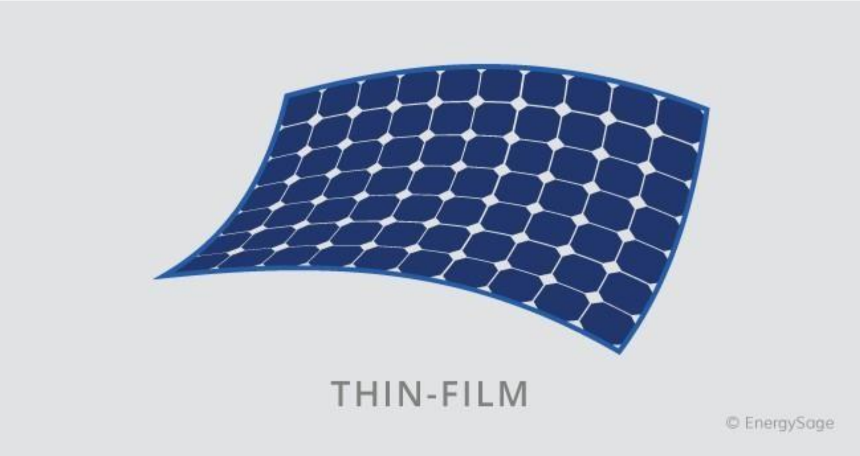


2. Polycrystalline Silicon Cell: unlike Monocrystalline, Polycrystalline are made out of multiple small crystals. The manufacture process that follows are similar to Monocrystalline process. Another method of manufacturing Polycrystalline Silicon Cell is by edge-defined film-fed growth. Cells are made by pulling a thin ribbon out from a molten silicon mass [46, 107].



3. Thin Film Cells: is a thin and flexible type of PV cells, which make the cell durable for installation. Amorphous silicon is one type of thin film cell, which is made by depositing thin layers of silicon into a glass sheet. As a result, thin film cells use less silicon and cost less to manufacture. On the

other hand, the thin silicon cells have a lower efficiency compared to the PV cells [46, 107].

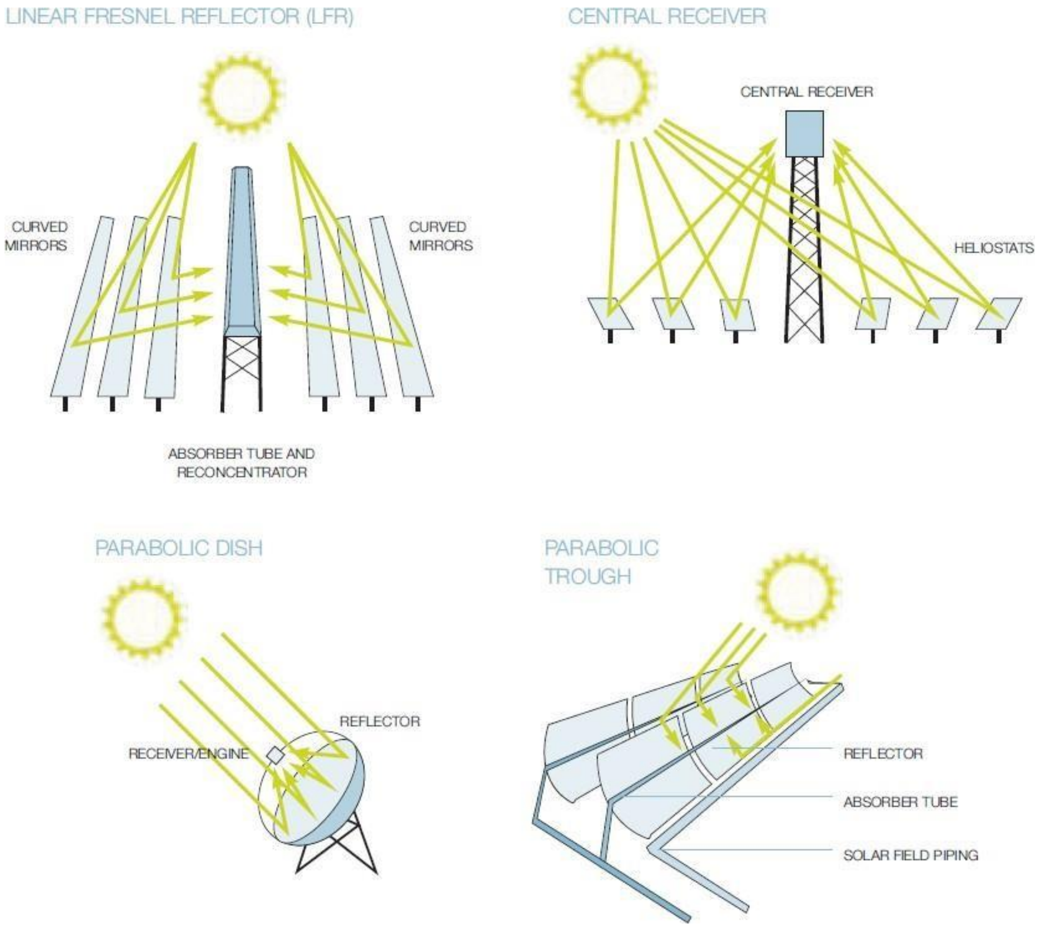


CS
P

1. Linear Concentrator Systems: collect sun light using rectangular, curved mirrors. The mirrors are positioned to face the sun. The sunrays are collected and reflected to a tube running the full length of the mirror. The heated fluid running in the tube is sent to a heat exchanger with water which then can be used to power up steam turbines to generate electricity [66,12,91]

2. Dish/Engine Systems: is an array of small mirror attached together to form a dish shape (satellite dish), which then can be used to reflect sunlight to a thermal receiver. The heat can be used to generate electricity [66,12,91].

3. Power Tower Systems: is a large filed of mirrors know as heliostats that follows the sun through the day. Mirrors concentrate the sunlight to a thermal receiver. A heat-transfer in the tower in then sent to an electricity generating system. Moreover, some towers use water and steam to generate electricity, but some advanced designs use molten nitrate salt. The molten salt is used because it can hold thermal energy even after the sunset. As a result, the system will continue to produce electricity even if the weather is not optimal or cloudy [66,12,91].



PV types

Solar panel types	Advantages	Disadvantages
Monocrystalline	• High efficiency/performance • Aesthetics	• Higher costs
Polycrystalline	• Low cost	• Lower efficiency/performance
Thin-film	• Portable and flexible • Lightweight • Aesthetics	• Lowest efficiency/performance

[66,12,91]

Monocrystalline VS Polycrystalline

	Monocrystalline	Polycrystalline
Cost	More expensive	Less expensive
Efficiency	More efficient	Less efficient
Aesthetics	Solar cells are a black hue	Solar cells have a bluish hue
Longevity	25+ years	25+ years
Major manufactures	Canadian Solar Sunpower LG Hyundai SolarWorld	Hanwha Kyocera Hyundai SolarWorld Trina

[66,12,91]

PV VS CSP

	PV	CSP
Output	DC	AC
Storage	Only with batteries	Yes, molten salt
Power dispatch	Only during the day or with batteries	Any time
Price	Cheap	High
Risks	High	High
Build	Easy	Hard
Time to build	Fast	Moderate

[66,12,91]

As a conclusion, both PV and CSP can be used in the MENA region. CSP can be used as a base line of electricity generated through the day. Because of CSP technology, energy production can be produced on a 24/7 basis while PV can be used for peak power consumption. Moreover, any additional energy can be sold to the neighboring countries or regions connected through a transmission grid.

Wind energy

Advancements

1. Longer and lighter rotor blades – with some reaching 95 meters long
2. Blades with curved tips that are designed to take maximum advantage of all wind speeds
3. Blades that are better able to withstand the stresses of high-altitude wind and taller towers
4. Performance-optimizing control systems
5. More reliable gearboxes
6. Digitalization of processes

Advantages of Wind Power

1. **Wind power is cost-effective.** Land-based utility-scale wind is one of the lowest-priced energy sources available today, costing 1–2 cents per kilowatt-hour.
2. **Wind creates jobs.** wind energy sector will create more than 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050 in the US.
3. **Wind enables industry growth in the country**
4. **It's a clean fuel source.**
5. **Wind is a domestic source of energy.**
6. **Wind energy is sustainable.**
7. **Wind turbines can be built on existing farms or ranches.**
8. **Wind farm companies will pay the farms rent for their land, which will provide an additional income.**

CHALLENGES OF WIND POWER

1. **Wind power must still compete with conventional generation sources on a cost basis.** .
2. **Good land-based wind sites are often located in remote locations.**

3. **Transmission lines must be built to bring the electricity from the wind farm to the city.**
4. **Wind resource development might not be the most profitable use of the land.**
5. **Turbines might cause noise and aesthetic pollution.**
6. **Wind plants can impact local wildlife.** Turbine blades can kill birds.

Rules and Regulation

In every country or region there is a set of rules and regulation that they must follow. These rules can be for factors, houses and any commercial business. Also, there are rules and regulation for renewable energy production, transmission and distribution. Furthermore, government or regulatory authorities should write a set of rules and regulation for renewable energy. Therefore, rules are important for RE so it can enter the market.

Solar energy

1. Start or beginning of building a RE project

We were only able to get information about RE project that are only for residential or commercial buildings. As for both of them there is only one option and it is by installing PV cells or the roof or any suitable location. Also, some countries do not allow for negative feedback which is supplying the grid with power and reducing the electricity bill [75].

2. Maintain or operate a RE site

As for maintaining a RE project, there was not clear rules.

3. Decommission

The MENA region is still new to RE technology, as oil has been their main supply of electricity generators. Most of the RE project did not reach their end of life or service, so there is no clear guides to how equipment are going to be decommissioned.

4. Green houses

We can find many green houses with zero emissions worldwide, but in the MENA region emissions are hardly enforced or pushed in the market [37]. One of these small pushes can be found in Dubai in the UAE, where solar water heaters are compulsory by the regulatory authority. Also, we only see green houses in expos or as a model, but nobody is going to live in it.

5. Pollution

As for MENA region there is few rules for pollution and gas emissions, and minimal fines for large polluters. For example, paint companies, sea vassals and vehicles [117]. Additionally, till now we can see car garages and A/C repairmen releasing refrigerant gas into the atmosphere [117].

6. Codebook

We can find rules and regulation for RE installations in the US (NEC) book and EU (IEEE and BS), but there are minimal rules if any in the code books in the MENA region [16].

7. Framework

The table show the current frameworks, that Japan, New Zealand, US and EU are follow for new RE projects:

Strengths

Japan	New Zealand	EU	Us
Public and local involvement	Extremely short processing time No involvement of EPA	Increased public input	Federal process only for projects with federal projects
Many stages for revisions and subsequent input	Cost limits and fixed maximum timeframes for PNSs	Creation of harmonized guidelines and increased screening process clarifications	Some states without any environmental laws
Implementation of restructuring plans	Cost support for surveys and pre-EIA steps in some instances	Increased public accountability, monitoring and expert involvement	High level of public involvement and mandatory timeframes under (NEPA)
High degree of accountability, pre and post-monitoring provisions	Integrated one-stop shop approach	Creation of one-stop shop requirement	

For national EIAs, expertise is shared	Limited legal obstruction possibilities		

Weaknesses

Japan	New Zealand	EU	US
Vague screening process	Short time limits for public involvement	No mandatory scoping	Project across state lines finds absence of an EIA body
Numerous legal obstruction	Limited legal recourse facilities	No mandatory timeframes in the Directive	Rules to determine what projects fall under federal jurisdiction are not clear
Solar PV not subject to the EIA Law	Small project requires authority approval.	No one-stop shop obligation	Federal process takes long for approval
Absence of one-stop approach or dedicated authority	Does not automatically apply to all RE projects	Application of EIA guidelines only voluntary	Some state processes very lengthy in absence of uniform rules
Competence take multiple authorities to get approved		Opting for a Directive Regulation leads to legal fracturing	Absence of one-stop shop approach in most states and on the federal level
Long procedural timeframes		TEN-E Regulation not applied to RE generation projects	
		Risk of increased costs	

[120]

Lastly, all of the RE projects are government initiatives or were mainly funded by the government. As a result, companies or personals will face huge difficulties to start or establish a profitable business from RE production.

Future Plans in MENA

In this section we are going to view and analyze the future RE project in the MENA rejoin. The information will be presented in a table for clear view and ease of follow up.

Country	RE target	Year
Algeria	27% of electricity generation by 2030; 22 GW of installed capacity Technology-specific targets: • Solar photovoltaic (PV): 3 GW by 2020, 13.6 GW by 2030 • Wind: 1 GW by 2020, 5 GW by 2030 • Concentrating solar thermal power (CSP): 2 GW by 2020, 2 GW by 2030 • Biomass: 0.4 GW by 2020, 2 GW by 2030 • Geothermal: 15 MW by 2030	2020 & 2030
Bahrain	5% and 10% of electricity generation by 2025 and 2035, respectively Technology-specific targets: • Solar PV: 0.3 GW by 2025 • RE mix: 0.7 GW by 2030	2025 & 2035
Egypt	20% of electricity generation by 2022 and 42% by 2035 Technology-specific targets:	2022 & 2035

	• Solar PV: 0.2 GW by 2020, 0.7 GW by 2027 • Wind: 7.2 GW by 2020 • CSP: 1.1 GW by 2020, 2.8 GW by 2030 • Hydropower: 2.8 GW by 2020	
Iran	10% of electricity generation by 2025; 10 GW of installed capacity Technology-specific targets: • Solar and wind energy are prevalent: the capacity is not specified.	2025
Iraq	10% of electricity generation by 2030 Technology-specific targets: • RE mix: the capacity is not specified.	2030
Israel	Initial target goals were 10% of electricity generation by 2020 and 17% of electricity generation by 2030 Technology-specific targets: • Solar PV and CSP: 63.4% of total generation by 2020 • Wind: 29% of total generation by 2020 • Biomass (including biogas): 7.6% of total generation by 2020	2020 & 2030
Jordan	The target goal was 1.8 GW of installed capacity by 2020, but it has been modified to 2 GW by 2020; 10% of energy supply Technology-specific targets:	2020

	• Solar PV: 0.6–1 GW by 2020 • Wind: 0.6–1 GW by 2020 • Waste-to-energy: 30–50 MW by 2020	
Kuwait	5% of electricity generation by 2020 and 15% of domestic energy demand by 2030; 4.5 GW of installed capacity Technology-specific targets: • Solar and wind energy: the capacity is not specified.	2020 & 2030
Lebanon	12% (9 TWh) of the total electricity and heating demand by 2020 Technology-specific targets: • Solar PV, CSP and solar water heaters: 4.2% of total RE by 2020 • Wind: 2.1% of the total RE by 2020 • Hydropower: 3.2% of the total RE by 2020 • Biomass: 2.5% of the total RE by 2020	2020
Libya	10% of electricity generation by 2020 and 30% of electricity generation by 2030 Technology-specific targets: • Solar PV: 0.15 GW by 2020; 0.5 GW by 2025 • Wind: 1.5 GW by 2020; 2 GW by 2025 • CSP: 0.8 GW by 2020; 1.2 GW by 2025 • Biomass: 0.3 GW by 2020; 0.6 GW by 2025	2020 & 2030
Morocco	42% of electricity installed	2020 &

	capacity and 52% by 2030 Technology-specific targets: • Solar energy (PV and CSP): 2 GW by 2020 • Wind: 2 GW by 2020 • Hydropower: 2 GW by 2020	2030
Oman	10% of generation mix by 2025; 3 GW of installed capacity Technology-specific targets: • Solar and wind energy: the capacity is not specified.	2025
Qatar	Increasing RE share by 2030 Technology-specific targets: • Solar energy: 1.8 GW by 2020 (16% of total electricity generation) and 10 GW by 2030	2030
Saudi Arabia	9.5 GW of installed capacity by 2023. A 200 GW PV capacity is planned to be implemented in cooperation with SoftBank Group by the year 2030. In addition, a more practical strategy to enhance RE is stated to be announced in late 2018. Technology-specific targets: • Solar PV is the dominant technology, with look at the other sources such as CSP and waste to energy	2023 & 2030
State of Palestine	10% of domestic electricity generation by 2020; 130 MW of installed capacity	2020

	Technology-specific targets: • Solar PV: 34.6% of the total RE by 2020 • Wind: 33.8% of the total RE by 2020 • CSP: 15.4% of the total RE by 2020	
Syria	4.3% of primary energy demand by 2030 Technology-specific targets: • Solar PV: 0.25 GW by 2030 • Wind: 1–1.5 GW by 2030 • Biomass: 0.25 GW by 2030 • Solar thermal energy: 11.6 TWh/annum by 2030	2030
Tunisia	30% of electricity generation Technology-specific targets: • Solar PV: 1.5 GW by 2030 • Wind: 1.7 GW by 2030 • CSP: 0.5 GW by 2030 • Biomass: 0.3 GW by 2030	2030
United Arab Emirates (UAE)	7% of electricity generation by 2020 and 30% of electricity generation by 2030. 7% of installed capacity in Abu Dhabi and 5 GW of solar PV capacity in Dubai by 2030. Technology-specific targets: • Solar energy (PV and CSP) is the dominant technology, followed by wind energy and waste	2020 & 2030

	to energy	
Yemen	15% of installed capacity by 2025 Technology-specific targets: • Solar PV: 0.6% of the total RE by 2025 • Wind: 56.3% of the total RE by 2025 • Geothermal: 28.2% of the total RE by 2025 • CSP: 14% of the total RE by 2025 • Biomass: 0.8% of the total RE by 2025	2025

[42]

Infrastructure

In the section for the research paper, we are going to discuss about the infrastructure in the MENA region for renewable energy.

1. Laws

The current laws in some of MENA countries are vague and not clear to how should a company apply for RE project [61,114]. Some approval might take weeks and months to get approved. Moreover, these laws are not following up with the new RE technology, everyday there is advancement in the RE world [61,114]. Systems and equipment are being sold and used, while these laws will not cover them [61,114].

2. Technology

Unfortunately, there are no companies in the MENA region that design RE equipment for a large-scale site, but there are few companies in the MENA region produce some RE equipment [3]. There are small companies which only install solar panel on homes, but they do not manufacture the cell or the converter. As a result, MENA counties and personal consumers are under the mercy of nation companies [3].

3. Telecommunications

Overall, the MENA counties are well established with high-speed Internet connection while some other MENA countries are still lacking behind [71]. Unfortunately, some counties offer these Internet services but with high cost. For example, UAE has a fast and reliable Internet for use, but the prices are high [71]. The Internet is important for RE companies to move the business to the MENA region.

4. Grid

The current situation in the MENA region is heading toward the best. There is RE site that produce electricity in some countries. Also, all of the MENA countries have plans for RE in the future.

5. Workforce

In the MENA counties there are the abundance of engineers and workforce that can be used for building and operating RE sites [102]. The issue is that most of the contractors and consultant are from Europe or US because they have experience. Also, companies which are tendering the RE site do not have trust in their own people or the local workforce [103].

6. Agencies for RE

For any RE project to start, an RE concerned authority must sign off on the paper so contractors can start the work. In the MENA counties, the national electricity providers are the client and the lawmaker in the same place, so it’s hard to deal with them [6]. As a result, they will always win no matter the issue because they are the law and a government entity. There are some agencies that have offices in the MENA like International Energy Agency (IEA) and the renewable energy agency (IRENA), but they are more of an advisory position rather than a governor [6,50]. Each MENA country has its own rules, so companies must adjust their work to suite each country.

7. House RE system

In some of the countries in the MENA region, RE can be found at homes and commercial buildings. RE can be solar panel or wind turbines. For example, Dubai is pushing homeowners to install solar panel on their existing or new houses [7]. Especial approval and equipment are required for the RE to be installed. One initiative of Dubai is the 5000 houses that are retro fitted with solar panels [7].

Political

In this section of the research paper, we are having a look to how politics have influence on renewable energy, and how it impacts RE projects and future decisions.

1. Political risks are related to political events which negatively impact the value of investment including war, civil disturbance, sabotage, expropriation and non-honoring of contracts. As a result, investors running away from the countries, and many sectors will be affected by the closure of businesses.
2. Recognize that some government systems might influence the RE project, as the government path or orientation is not suitable with RE project. For example, some MENA countries have plans for RE projects, but if it is counted to the percentage of the total resources expended on generating electricity [97]. The percentage is low compared to the EU countries.
3. Impact of governance on RE investment in the MENA region and to examine how trade open-ness may affect this relationship. While some MENA counties are willing to invest in the RE project, others will not have the same enthusiasm [73, 109]. As a result, RE project will suffer from delays and incompletion or abundance of the whole RE project.
4. Several studies designate corruption as one of the major causes of environmental degradation. One of the worst things to have in any government system is corruption [7, 47]. Some MENA countries have corruption in the core of the government and in the daily lives of the people. Corruption is a deadly blow to any RE project, and investors will run away [47].
5. Personal gain from high position in government is as problematic as corruption. It might look the same, but there is a difference in between. Personal gain is about raising the price of any project or taking bribes to complete or pass a RE project [47]. The project will be completed but with a higher cost, if the project was compared to a similar project in another country.

In conclusion, political risks are hidden risks that many companies fail to count for in their future expansions and projects.

Risks and Constrains

In this section of the research paper, we are evaluating the risks and constrain that a RE project will have to go through in the process of completing the project.

1. Most of power sectors are owned by the state or a government entity [31,62,103]. As a result, companies do not have a change to break into the market of producing electricity even if the company wants to sell the power to the distribution companies. The only option for a RE project in the MENA region is if a government entity releases a tender for a RE project, and companies can only build or supply the RE site.
2. Power sectors are dominated by oil, as in most of the MENA countries. Oil industry is the biggest supplier for fuel to run the electricity generators [44,99]. As a result, the oil industry will push back any RE project or progress to be done, in the name of risking the oil industry and many personal will lose their jobs. Also, oil fields are the main income for some countries in the MENA region. For example, more than 90% of the GDP in Kuwait is provided by the oil industry [99, 33].
3. Lack of transparency and predictability in support of RE, in case of any new project. We will see some advertisement of a RE project being built in TV, but in real life the project is something else. Moreover, some MENA government will have RE in their agendas, but they soon will forget about or move to something the world is busier about [94]. Also, specific people control some governments, and projects are made depending on their mood of the day. As a result, investors will not be confidants in the government to invest in RE projects
4. Environment or public view is important, have the public behind a RE project is crucial. Some wild activists will argue about the harm a RE site might affect the wild life in a particular area [95,125]. For example, wind turbine blades will kill birds, and solar farm will destroy the habitat of a certain animal [31, 78]. Moreover, people who are located near the wind turbines will complain of loud noises generated by the blades [78]. Lastly, some government and public will protest the large areas a RE project will require to build on. For example, wind farms might take tens of KMs to fix the wind turbines to be efficient [31, 56].

5. There are many risks when it come to the deployment of RE in MENA countries and the export of electricity:
    a. Inappropriate regulatory framework
    b. Lack of political support
    c. Undefined tariff
    d. Low regional cooperation
    e. High investments required
    f. Lack of financial support
    g. High investment risks
    h. Lack of awareness

[85]

Finance and Cost

In this section of the research paper, we are going to discuss about the finance and cost in the MENA region for renewable energy.

1. Government support for RE project is important; this can be as a funding to the project. In the MENA region the governments fund most of RE projects. As a result, the scale of the projects is huge and the ambitions are big for these projects to succeed.
2. Investors are the second driver to the RE project. Nowadays, governments in the MENA are allowing investors to fund the project to some extent, but the government will take the lion share in the project and in the administration [64,105]. Nevertheless, it is a welcome sign and a promising aspect to investors.
3. Benefits to the local market a RE project will bring is immense. As the workforce will be needed, new job opportunities will be available. Moreover, factors will turn its wheel to supply the RE project with its needs. Some of the MENA countries are producing solar panels in their factories. For example, Saudi Arabia are producing si-PV cells [111].
4. Initial costs of a RE project can be higher than a conventional oil-based power generating station because RE technology is still new and advancements are still being made. Moreover, the cost of PV

cells is reducing in a positive rate, so the cost of constructing a RE project is reduced [36, 84]. Also, the personals salaries and needs during the construction. MENA governments are usually the funders of RE project [84].

5. Production cost of the equipment must also be taken into consideration, as the parts are either bought or manufactured.
    a. Solar cells
    b. Wind turbine
    c. Convertors
    d. Salaries
6. Operation and maintenance cost of running the RE site and ensure 24/7 through the year electricity production. Some cities in the MENA region are keen on an uninterruptible power supply [36]. These costs will be paid either by the consumers or co-payment in some of the MENA countries.
7. Tax and insurances are a great help to fund RE projects. In some of the MENA countries taxes are applied, so these tax moneys can help with funding the RE projects [56]. On the other hand, insurance is required to guarantee the safety and investment of the project in case of a catastrophic failure or human mistakes [56].
8. The land that a RE project will be built on must also be added to the RE project investment, as of these lands are owned by private people [62]. In some MENA countries, if the government owns the land and the project serves the people, then the land is given for free. Which is a huge cost removed from the investment [62].
9. Economic life of investment, as for any project the lifecycle is important to assess the investment. Experts in the RE business field will provide the forecast of the return profits. The revenue might not be as money only, but for multiple sectors.
10. Inflation must be calculated in, as in the RE project lifecycle. To see if the project is worth building.
11. Distribution and transmission cost for RE projects, as the site are usually in a remote area [25]. As a result, transmission lines must be contracted to deliver the power from the site to the cities needed.

12. Pricing of electricity is needed to maintain the operation of the electricity producing. These costs are divided into two parts:

    a. Initial price of connection is the cost a person or company has to pay for the power company to connect the premises to the electricity grid [104]. These prices can be in thousands or even millions depending on the project. For example, we will take the Dubai water and electricity authority for the pricing.

Bands of TCL (Total Connected Loads) and rate															
Slab		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Load Range (KW)	From	1	171	401	1,001	2,001	3,001	4,001	5,001	6,001	7,001	8,001	9,001	10,001	Above 11,000
	To	170	400	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000	11,000	
Unit Rate (Dhs.)		250	290	300	310	317	481	1,053	1,863	2,152	2,442	2,683	3,026	3,368	1,656

    b. Tariffs are the monthly payments that the consumers have to pay to the electricity provider.

	Retail tariffs[a] (US Cents/kWh)		
	Residential	Industrial	Commercial
Saudi Arabia	1.3	3.2	4.1
Iran	0.4–9.6	0.6–4.3	2.6–10.7
Kuwait	0.7	0.7	0.4
UAE (Abu Dhabi)	5.6–8.7	4.2	4.2–8.0
UAE (Dubai)	7.8–12.1	7.8–12.1	7.8–12.1
Qatar	2.2–6.0	2.5–4.9	2.2
Bahrain	0.8	0.8	3.8
Oman	2.6	5.2	4.2

[63]

Social

In this section of the research paper, we are going to discuss the effect of society on RE.

1. Society as a whole will have a huge impact on the acceptance of RE project. RE awareness is a big push forward for RE project to be built in the country. The people sayings are the final saying [4].

2. Media affects the delivery and opinions of people on RE. Media can boost the reputation and necessity of RE or show it as a buggy man. Regular TV or social media can be of help or disruption to any RE project [4].

Formulas

In the last section of the RE part, we are going to show and discus about the formulas used in RE. Formulas that will be used in the MENA RE project. Moreover, the formulas are in the general form, and can be modified to suit each project. There will not be any calculation done, as the research paper is a managerial feasibility study. Also, due to the current COVID-19 pandemic, getting information from experts are hard.

1. Function for RE for generation planning [71]

$$F_1 = \min\Big\{(C_{\text{wind}} S_{\text{wind}} + C_{\text{PV}} S_{\text{PV}} + C_{\text{CSP}} S_{\text{CSP}}) / Y_{\text{inv}} + \sum_{i=t}^{T} [E_{\text{wind\_loss}}(t) Pri_{\text{wind}} + E_{\text{PV\_loss}}(t) Pri_{\text{PV}} + E_{\text{CSP\_loss}}(t) Pri_{\text{CSP}}]\Big\}$$

2. Function for RE for minimizing system cost [35]

$$\sum System\ cost\ [k€] \rightarrow min$$

$$f_{annuity} = \frac{i \cdot (1+i)^{t_y}}{(1+i)^{t_y} - 1} \quad (2)$$

$$\boldsymbol{C}_{capital} = (\boldsymbol{P}_{addedCap} + P_{existCap}) \cdot c_{specInv} \cdot f_{annuity} \quad (3)$$

$$\boldsymbol{C}_{operation} = (\boldsymbol{P}_{addedCap} + P_{existCap}) \cdot c_{specInv} \cdot c_{O\&MFix} + \sum_t \boldsymbol{P}_{gen}(t) \cdot (c_{O\&MVariable} + c_{Fuel} + c_{Emission}) \quad (4)$$

$$System\ cost\ [k€] = \boldsymbol{C}_{capital} + \boldsymbol{C}_{operation} = Capital\ Cost + Fix\ O\&M\ Cost + Variable\ O\&M\ Cost + Fuel\ Cost + Emission\ Cost \quad (5)$$

3. Function for RE for risk factor [103]

$$ORF = \frac{RI}{RDI} \times \frac{RP}{RDP}$$

where *ORF* is the overall risk factor function, *RI* is risk impact, *RP* is risk probability, *RDI* is risk discrimination impact, and *RDP* is risk discrimination probability in the project life cycle.

4. Function for RE for PV output [76]

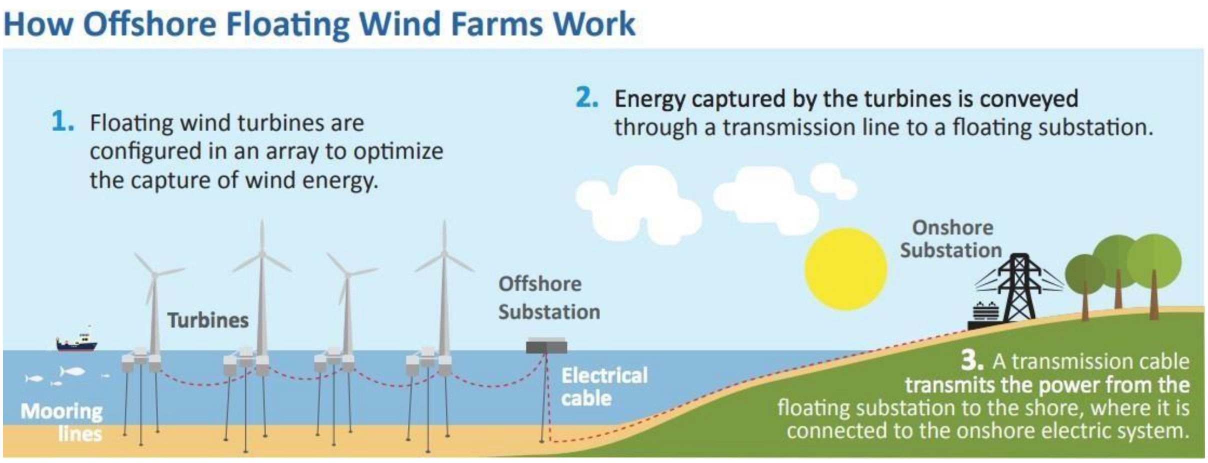
Calculating annual PV solar system output is a function of the equation **E = A * r * H * PR**, in which:

- A = Total solar panel Area (m^2)
- r = Solar panel efficiency (%)
- H = Annual average solar radiation on tilted panels (shadings not included)
- PR = Performance ratio, coefficient for losses (range between 0.5 and 0.9)
- E = Energy (kWh)

Part 2 Analysis: HVDC

Site selection

The location of a HVDC station is usually near the generation station or both of them are integrated into each other to form a single substation. As for any transmission system the other side will be near the place where electricity is needed. A city or an industrial complex is the location a substation will be located it. As for real application these cities will be connected a RING or multiple RING to ensure no blackouts [74]. Moreover, for offshore wind farms the HVDC substation is either located on land or places on a platform [13, 117]. These platforms are already being used in the North Sea. SylWin alpha built by Siemens is a HVDC substation operating on a platform [117]. In the MENA there is few HVDC systems, and all of them are land located substations.



Conversion and Transmission

There are two main components for any HDVC system. First is the AC/DC power converters. AC power comes to a HVDC substation and enters the conversion system to be converted to HVDC to be transmitted for long distances [50, 89]. The converters work on a basic principle of full bridge rectifier, and depending on the manufacture of the system smoothing capacitor and thyristors will be used. The system will operate on a three phase with 12 pulses to reduce the losses during the conversion and improve the satiability of the HVDC system [28,50]. The second component of the HVDC system is the transmissions lines. The transmission system will consist of two part, the towers and the cables [48, 107]. The HVDC lines are similar in construction as regular AC lines, but with less lines and smaller diameter cables running through the transmission towers [28, 50].

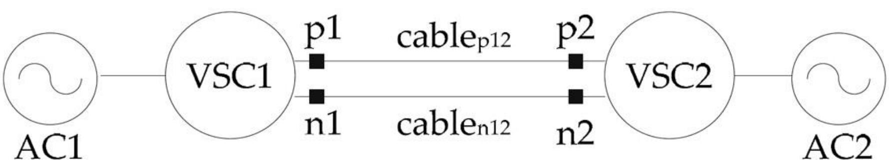
Technology

General

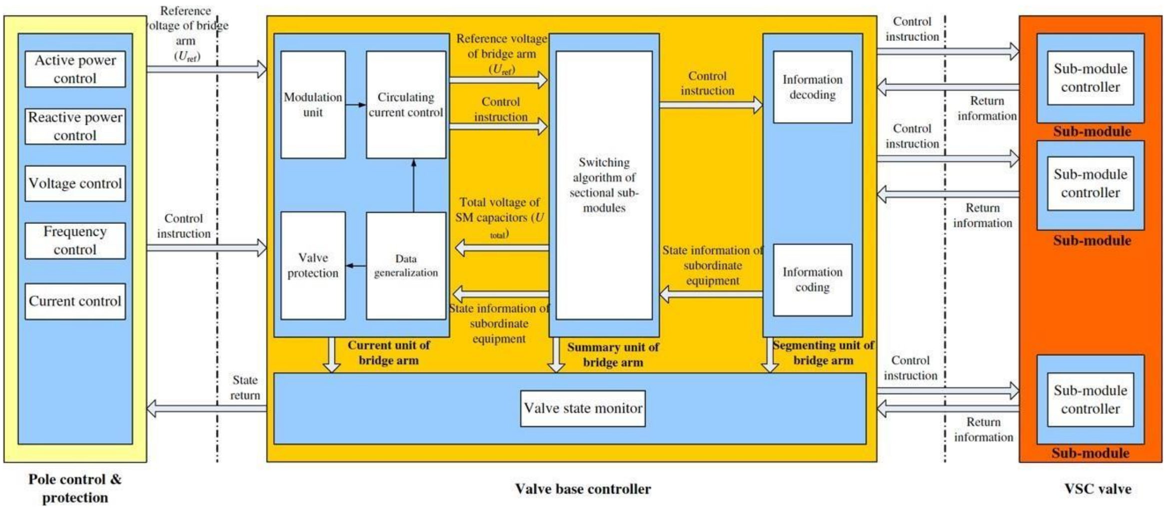
There are two main HVDC configurations, Voltage-source converter (VSC) and current-source converter (CSC) or better known in the industry as line-commutated converters (LCC) [60, 87]. The advantages of HVDC system over HVAC system are fewer transmission conducting wires and towers, asynchronous interconnections, reduced visual impact and right-of-way area, reduced corona effect, higher stability and reliability, absence of skin effects that avoids localized surface heating, fewer environmental concerns, higher power-carrying capacity for very long distances, freedom from inductance compensation requirements, freedom from reactive power compensation [50, 73, 114]. However, the HVDC system has a high capital cost [114].

Technical comparison summary between HVAC and HVDC transmission.

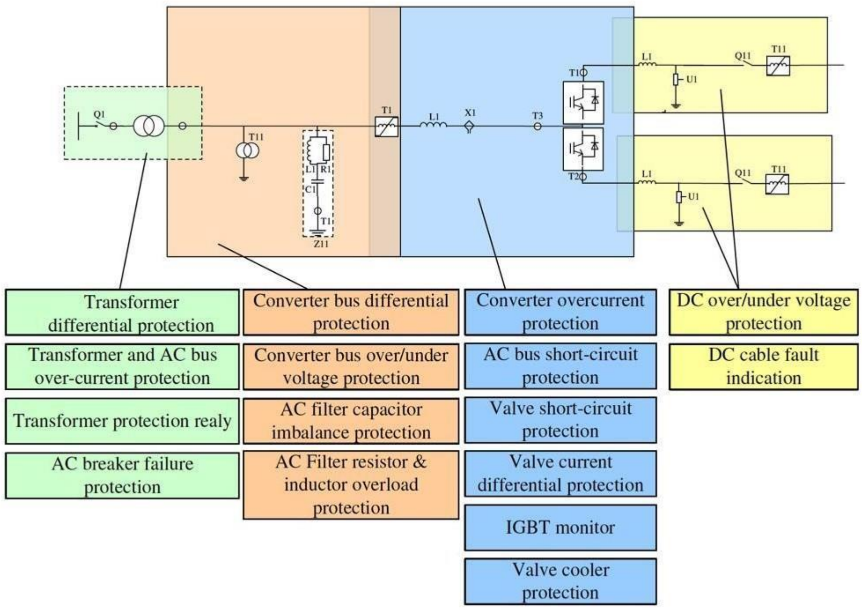
Transmission Type		HVAC	HVDC
Cables/Lines	Number of Conductors	Higher (3-phase conductors, lower individual ratings, cumulatively more expensive)	Lower
	Utilization	Limited by skin-effect (although bundled conductors are used to limit it)	Full up to thermal limits
	Losses	Higher (mainly resistive and reactive, requiring expensive line-capacitance compensators)	Lower (mainly resistive and corona losses)
	ROW	Higher (could exceed ×3 times of HVDC) [20]	Lower
Maximum Implemented 2018 Distance	Lower (1049 km: Yuheng-Weifang link in China [17,18])	Higher (3324 km: Changji-Guquan link in China [16])	
Meshed Grids	Availability	Widespread on a global scale	Currently limited with significant predicted growth
	Protective Equipment	Well-Developed UHV Circuit Breakers	Extensive R&D effort to develop HVDC Breakers and/or converters fault blocking capability
Substations	Cost	Significantly Lower	Higher (converter stations)
	Losses [21]	Low transformer and HV equipment losses (0.3% in AC double circuit)	Higher station losses (could exceed 1% for VSC)
Economic Viability		UG Cables < 50–100 km Overhead Line < 300–800 km	(Point-to-Point Links)



VSC simplified system [67]



Station and converter control system [43]



Typical protection zoning of flexible HVDC system [40]

LCC

Line-commutated converters (LCC) have problems with week AC system, which will lead to limitations in the maximum available power, susceptibility to commutation failure and voltage regulation [26, 55, 121]. Using the dynamic reactive power supply apparatus such as synchronous compensators or static synchronous compensators can solve some of these problems.

VSC

VSC benefits from being a bi-directional power flow, which limits the need for a secondary tower system running along [39, 92]. Most of the VSC systems consist of three-level neutral-point clamped (NPC) converters, or MMCs with half-bridge inverter cells [39, 92].. The issue is in case of short circuit fault; the converters lose the current control capability [39, 92].. VSC is a practical solution for optimal allocation implementation, flexible for large remote renewable energy and wide-area reciprocity [39, 92].. Some of the advantages of using VSC are good controllability, does not need for reactive power supply at the converter, reduced harmonics and can operate into very weak ac networks [39, 92]..

For control and power sharing technologies such as margin control, coordinated control, slave control and droop control have been proposed [2, 17]. The master–slave of the control and power sharing methods requires fast communication, and the system is unstable when transforming from one converter station to another [2, 17].. On the other hand, droop control allows multiple converter station, which keeps the power balances [2, 17]..

PROS AND CONS FOR BUILDING A MULTITERMINAL HVDC BASED ON CSC OR VSC

	Advantage	Disadvantage
CSC-based	high voltage and power rating	risk of commutation failures, collapse of DC line voltage
	low losses	strong AC-side requirement, consumes reactive power
	low rate of rise of short-circuit current	vulnerable to AC-side faults
VSC-based	stiff voltage on DC side	lower power rating
	power reversal w/o voltage reversal	higher losses
	more suitable for cables	vulnerable to DC-side faults

KEY DIFFERENCES BETWEEN THE CSC- AND VSC-BASED HVDC SYSTEMS

	CSC based	VSC based
basic element	thyristor	IGBT
harmonics related issues	intense low-order harmonics	weak high-frequency components
reactive / active power	consumes large amount of reactive power	reactive and active power can be fully controlled on both ends
losses	$\sim 0.7\%$	$\sim 1.6\%$
maximum power rating (bipolar)	up to 6400MW (800kV, 4kA)	$>$ 400–800MW (300kV)
connection to AC-grid	converter transformer	series reactor & transformer
reversal of power flow direction	change of pole voltage	adjust PWM sequence but keep voltage
control during DC fault	adjust phase angle control	control lost (due to diodes)
DC side inductors	large	small
DC side capacitors	small (larger with cables)	large
rate of rise of DC short-circuit current	small and controllable	large

[30]

Comparison between HVDC transmission technology options.

HVDC Converter Types		LCC	VSC
Switching Device		Mercury Arc (1950s–1970s) Thyristor (1970s – Present)	IGBT (1990s – Present)
Commutation (Frequency Range)		Line Dependent (50–60 Hz)	Self-Commutated (up to few kHz)
Station Power Loss [15,54,117]		0.6%–0.8%	~1%
Power-Flow Reversal Mechanism		Voltage Polarity Reversal (slow, causes more current stress)	Current Direction Reversal (Fast, adds more reliability)
Network Strength Dependency		Dependent (expensive added equipment in weak grids) [58]	Largely Independent
Converter Station Footprint		Larger	Smaller (40–50%) [75]
Inherent VAR Consumption		50–60% of rated MW	None, and can support reactive power to AC grid
Reactive/Filtering Equipment Requirements		High (Expensive)	Low
Inherent VAR control and Grid Support		No	Yes
Inherent AC Grid Black-Start Capability		No	Yes
Fault Handling Capability	AC Side	Lower (Line-Frequency Dependent)	Higher (MVAR Support/Black Start)
	DC Side	Higher (DC Reactor/SC failure)	Lower (High di/dt rate)
AC & DC Side Harmonics Level		Higher	Lower
Market Share (# of Projects) [27]	(1954–2018)	81%	19%
	(2010–2018)	70%	30%
Available Rating Combinations[a]	Max	12,000 MW/ ± 1100 KV	2000 MW [118]/ ± 500 kV [15] (525 kV [119][a])
	Average	2000 MW/ ± 400 kV	580 MW/ ± 220 kV
Common Applications		High-Power, Long Distance	Offshore/Cable-based Projects
Multi-Terminal HVDC Suitability		Limited	Highly Suitable
Stations Cost (at High Ratings)		Lower	Higher

[a] Current maximum VSC voltage is ± 500 kV at Skagerrak 4 project [15], which will be taken over by NordLink in 2020 with ± 525 KV [119].

[117]

MTDC

Multiterminal DC (MTDC) System (MTDC) is another advancement in the HVDC system. There are two types of the system, series MTDC and parallel MTDC systems. MTDC has the benefits of flexibility of power dispatch control, nil commutation failure, independent reactive power, independent control active and large capacity of power transmission [14, 83, 110]. Also, MTDC can send and receive power from multiple terminals, which solves the problem of widely dispersed renewable energy resources. Wind power output continuously fluctuates with wind conditions. As a result, DC voltage must be properly controlled. Power dispatch control is required to ensure balanced power received at each terminal [61].

Protection:

To find the fault location in HVDC system a traveling wave theory is mostly used [116]. Moreover, the S transform is used, with the frequency of f=0. As the we increase the frequency, the resolution of S transform gets better [5, 116]. For testing a new protection system, three types of fault will be simulated [20, 77]. The faults are pole-to-pole fault, positive pole-to-ground fault, and negative pole-to-ground fault [20, 77]. For fault direction two sensors are placed on the line, if both detect fault from the same direction a trip signal is sent to the breakers [20, 77]. To test the AC system connected to HVDC, the short circuit ratio (SCR) and the effective short circuit ratio (ESCR) are used [29].

Construction:

China is leading the ultra-high voltage direct current (UHVDC) power technology and already establishing world's first ±1100 kV transmission line from Zhundong to Wannan [9]. For the construction of HVDC to be beneficial these properties must be found, flexible configuration, long distance, safe and reliable, high capacity and withstand harsh conditions [68, 102, 119].

Substation:

The HVDC substation will usually consist of:

- Converter Station
- Converter Unit
- Converter Valves
- Converter Transformers
- Filters
- AC filter
- DC filter
- High-frequency filter
- Reactive Power Source
- Smoothing Reactor

[68, 102, 119].

For a long time mechanical DC circuit breakers (CB) have been used, which consist of normal AC CB operating at 30-100 ms. As result, the whole HVDC system will be down in case of a fault, and a new DC breaker has the capability of interrupting short-circuit currents very quickly and needs to dissipate the large amount of energy which is stored in the inductances in the system [10, 77]. For circuit breaker, a Surge-less Solid-State DC Circuit Breaker is used for VSC-HVDC. Solid-state dc circuit breakers have been considered because it does not have moving parts and arc discharge. Another hybrid dc circuit breaker consists of a number of IGBT modules connected in series using RCD snubber circuits [19, 87].

DC reactors are installed at both terminals of the line in VSC-HVDC systems. DC reactors are used to reduce the damaging harmonics on the power lines, and smooth the current pules in the DC circuits [120].

Transmission lines:

Conduction:

Transmission system consists of two components, the cables and the towers.

Protection:

1. VSC-HVDC will greatly suffer from a fault occurring on the lines.
2. Unpredictable and harsh environments will increase the probability of a fault.
3. Two directional comparison sensors are placed in the lines to protect from faults
4. To install the Current and voltage sensors on the cables, Rogowski coil will be used.
5. Rogowski coil is used as a partial discharge measurement device.
6. Capacitive voltage sensor is used to measurement purposes.
7. HVDC lines have lower loss than AC because the lines do not have the capacitive/reactive charging effects.
8. MI cables advantages are:
    a. Low weight and design flexibility, leading to easier transportation and site installation.
    b. More mechanical robustness.
    c. Faster manufacturing process
    d. Environmentally friendly with no oil leaks and use of recyclable materials.
9. Aluminum Conductor Steel Reinforced" (ACSR)
10. These problems in ACSR have not been fully solved
11. All Aluminum Alloy Conductor" (AAAC)

12. DC cables do not have the skin effect and proximity effect like the AC conductors. Moreover, the segmentation of cables is not required even if the transmitted current is large.
13. During the cable selection and requirement these parameters should be taken into consideration:
    a. Maximum load allowed by the DC cables should not make the electric field intensity on the insulation surface exceed its permissible value.
    b. Not only the maximum working temperature of the cables shall be considered but also the temperature distribution of the insulating layer.

[21,59]

Summary of the medium term horizon for main HVDC transmission system components.

System Component		Medium-Term Technology Outlook	Likely Impact
HVDC Converters	LCC	Maintaining its position as the main OH UHVDC power transfer technology	Pushing the maximum power transmission limit in Asia beyond 12,000 MW at ± 1200 kV [220]
	VSC	Available at higher ratings beyond 650 kV at lower normalized costs and station losses [105]	Playing vital role in MTDC development, increasing interconnected markets share and RES utilization (expected 65% of new HVDC projects by 2020 [75])
HVDC Cables	MI	Higher rating availability (750 kV at 3000 MW per bipole by 2030 [105])	Pushing the maximum rating limits for projects with UG/submarine cable sections, yet with overall diminishing market share compared to XLPE
	XLPE	Higher rating availability (650 kV at 2600 MW per bipole by 2030 [105])	Expanding its market share dominance, parallel to VSC technology progress and fuelled by the need to construct new MTDC links connected to offshore wind farms
DC Grid Protection	DCCB	Moving from MV prototyping stage to HV implementation around 2030 [220]	Accelerating DC grids implementation. Leading to increased MTDC networks share, increased security of supply and enhanced RES utilization
	VSC Based MMC	Enhanced control algorithms for DC fault-blocking at higher ratings [87]	

Comparison between XLPE and MI DC cables technology.

Cable Type	Mass Impregnated (MI)	Extruded (XLPE)
Insulation Type	Paper insulated/Oil filled	Polymer (cross-lined polyethylene)
First Use for HVDC	1954	1999
HVDC Applications	LCC & VSC	Mainly VSC (limited suitability for LCC due to voltage reversal)[a]
Mechanical Weight/Installation	Higher/Harder	Lower/Easier
Maximum Rating (Project-Based)	2200 MW/ ± 600 kV (Western Link) [137]	2000 MW/ ± 320 kV[b] (INELFE) [118]
Longest Distance	580 km (NorNed) [127]	400 km (NordBalt) [147]

[a] Special types of XLPE cables are rarely used in LCC projects (e.g. the ± 250 kV Hokkaido-Honshu link in Japan) [146,148].
[b] NEMO Interconnector commissioned in 2019 uses 400 kV XLPE cables manufactured by JPS of Japan [151]. ABB has also recently manufactured 525 kV XLPE cables that should be soon in service [39].

[59, 100]

Rules and Regulations

The rules and regulations codebook for HVDC in the MENA countries are non-existence. We were not able to find a codebook for HVDC system. As result, there only way to understand HVDC system is to look at the US, European codes. Moreover, the European Network of Transmission System Operators for Electricity (ENTSO-E), which is under the European Transmission System Operators (TSO) cooperation are developing a codebook for HVDC [20]. Nevertheless, grid codes are often similar to other countries, as the equipment used is similar. Examples of requirements that are needed for wind farms interconnection standards are:

a. Voltage range for continuous operation.

b. Frequency range for continuous operation.

c. Low voltage ride through.

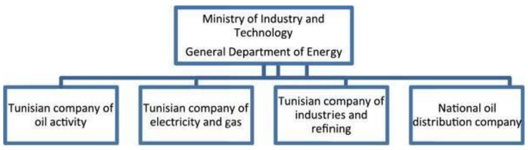
d. Active power set point and ramp rate control.

e. Reactive power control and voltage regulation.

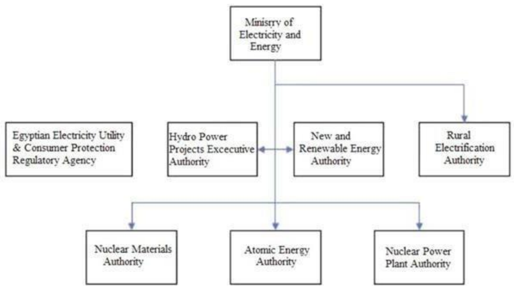
f. Power quality such as flicker, harmonics and voltage fluctuation.

[62]

Furthermore, climate change policies affect the decision made regarding power transmission. Also, energy security is critical to the MENA countries, as the situation is unstable. Finally, the GCC has formally established the GCC Interconnection Authority (GCCIA) in May of 2001, with the plan to provide power trading between the GCC countries [51, 116].



Tunisia Energy sector



Egypt Energy sector

Current national market structure, institutions and regulations.

	Algeria	Egypt	Tunisia	Libya
Reform	Under way with new law passed	Limited	Limited	None
Market structure	Single buyer with unbundling	Vertically integrated under the Egyptian Electricity Holding Company	Limited	Vertically integrated
Separate regulator	Yes	Yes, but without responsibility for tariffs	No	No
Open access	No	No	No	No
Grid code/distribution code	Yes/yes	Yes/no	No/No	No/no
Private sector participation	Yes, in generation and distribution	Yes, in generation	Yes, in generation	No
Tariffs	Subsidized	Subsidized	Subsidized	Subsidized

[52]

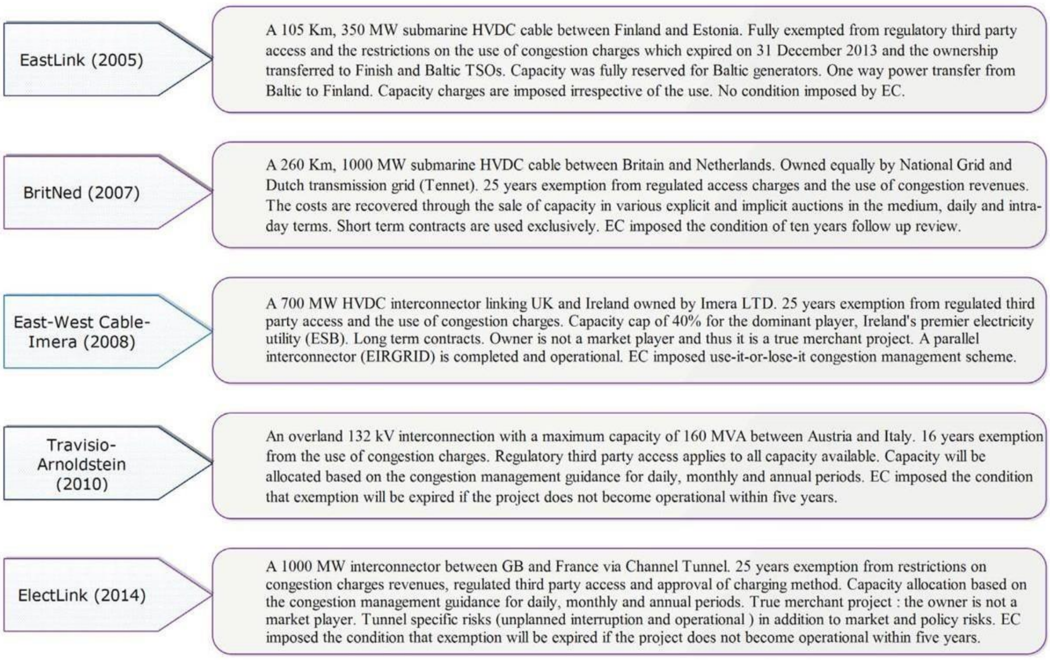
Political

The MENA region has a long history of interaction with each other, by friends or enemies. Nowadays, the MENA region is a fragmented region, facing political, economical and social issues. As the MENA region is divided into big parts, large continental project will face difficulties [80]. These difficulties happen because each country has a different political view from another country. Moreover, even inside the country there will be an opposition part that will hold back the construction of a HVDC system [80, 117]. They will come with multiple reasons to stop the project from coming to life. Also, personal gains and corruption of people in charge will definitely destroy the HVDC project [117]. The corruption rank or rate in the MENA region is the astonishing. Furthermore, the location of the controlling centers will be fought on. Finally, The 2030 sustainable development agenda was proposed by the United Nations [57, 92].

Existing and Future Network

The existing HVDC network between EU and MENA are:

1. The North West Maghreb countries via the Spain-Morocco cable
2. The North East Maghreb block connected with the Mashreq countries
3. The system including Palestine and Israel
4. Limited interconnection between Turkey and Bulgaria as well as Turkey and Greece.



EU interconnection projects [17]

Table 1 Electricity exports and imports of Maghreb countries in 2014

Maghreb country	Electricity export (GWh)	Electricity import (GWh)
Morocco	128	6138
Algeria	877	686
Tunisia	625	536

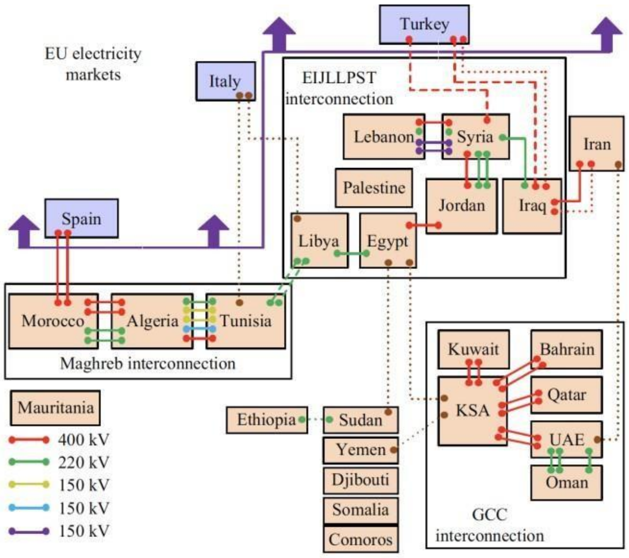
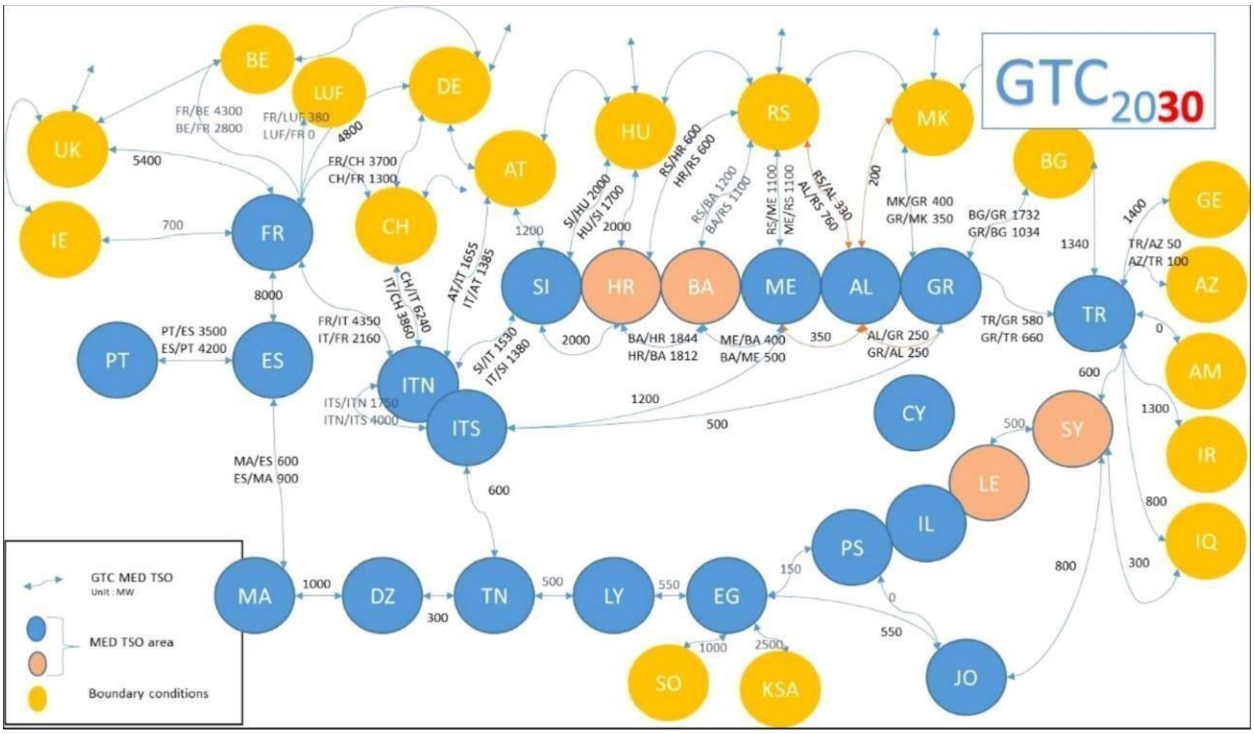


Fig. 6 Existing and planned grid interconnection in Middle East (the solid line represents "existing"; the dash line represents "not operational/island operation"; the dotted line represents "under-consideration, -study, -construction")

Electricity exports and imports [36]   existing and planned gird interconnection [87]

Interconnection will initially developed to export excess electricity capacity from Europe to North Africa

Future

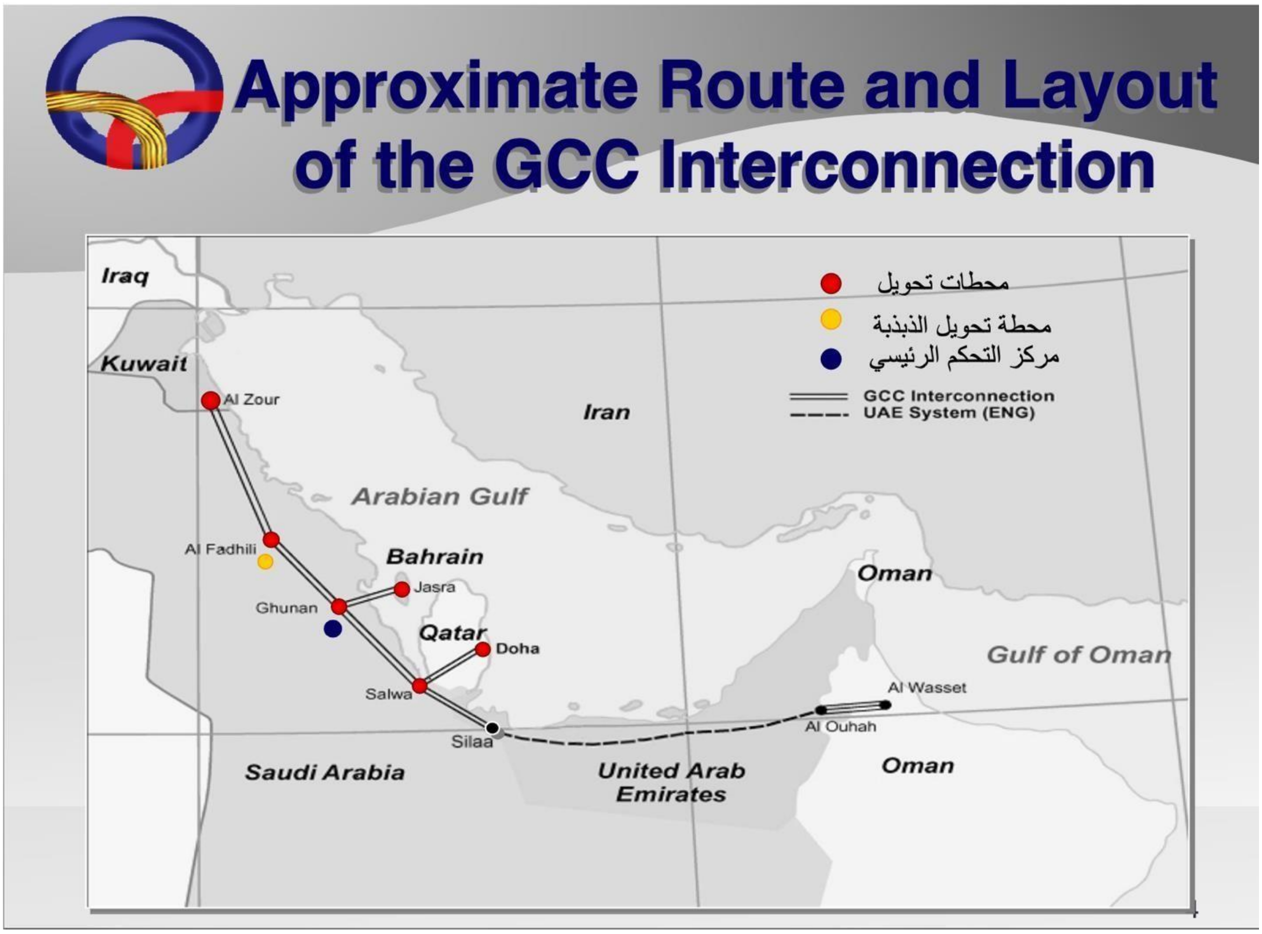


[100]

Details of the HVDC infrastructure for CSP imports from MENA to Europe. All HVDC lines have a nominal voltage of ±600 kV.

Import country	Start point	End point	Overhead line length (km)	Underground cable length (km)	Sea cable length (km)	Start year (a)	Full load production (h/a)	Net import capacity (MW)	Net import electricity (TWh/a)	Total investment (M€)	Import electricity cost (€/kWh)	Solar multiple	Total length (km)
Germany/ Denmark	Morocco #1	Karlsruhe, Germany	2506	278	132	2020	6679	3440	23.0	32,005	0.116	3.5	2917
	Morocco #2	Jülich, Germany	2075	231	149	2030	6943	3522	24.5	25,355	0.086	3.5	2455
	Tunisia #1	Mainz, Germany	1634	182	344	2040	6584	3587	23.6	23,048	0.081	3.5	2160
	Algeria #1	Hannover, Germany	2384	265	202	2045	6967	3456	24.1	22,370	0.077	3.5	2851
	Algeria #2	Munich, Germany	1427	159	413	2050	6883	3620	24.9	21,813	0.073	3.5	1998
France	Morocco #1	Paris, France	1957	217	132	2020	5284	3547	18.7	23,055	0.102	2.5	2306
	Morocco #2	Paris, France	1611	179	149	2030	5492	3613	19.8	18,560	0.078	2.5	1939
	Tunisia #1	Paris, France	1666	185	344	2040	5962	3581	21.3	20,221	0.079	3.0	2195
	Algeria #1	Lion, France	1480	164	202	2045	6967	3633	25.3	21,655	0.071	3.5	1847
	Algeria #2	Lion, France	1805	201	202	2050	6883	3569	24.6	21,416	0.073	3.5	2208
United Kingdom	Morocco #1	London, UK	2125	236	282	2030	5284	3498	18.5	19,481	0.088	2.5	2643
	Morocco #2	London, UK	1835	204	265	2040	6287	3557	22.4	20,089	0.075	3.0	2304
	Algeria #1	Newcastle, UK	2196	244	308	2050	6967	3481	24.3	22,075	0.068	3.5	2748
Spain	Morocco #2	Madrid, Spain	853	95	16	2040	5492	3775	20.7	15,698	0.063	2.5	964
	Algeria #1	Zaragoza, Spain	879	98	202	2050	6451	3750	24.2	18,545	0.064	3.1	1178
Italy	Algeria #2	Milano, Italy	1057	117	413	2030	5454	3693	20.1	19,034	0.079	2.5	1587
	Tunisia #1	Firence, Italy	980	109	344	2040	5208	3715	19.3	16,935	0.073	2.5	1432
	Libya #1	Roma, Italy	1305	145	312	2050	5626	3655	20.6	17,189	0.070	2.7	1761
Poland	Egypt #1	Warszaw	2574	286	665	2030	5625	3369	18.9	21,246	0.093	2.5	3525
	Jordan #1	Warszaw	3053	339	108	2040	5435	3335	18.1	17,833	0.082	2.5	3500
	Egypt #2	Warszaw	2837	315	665	2045	6655	3317	22.1	21,589	0.081	3.0	3817
	Saudi Arabia #1	Warszaw	3130	348	108	2050	7158	3320	23.8	22,154	0.078	3.5	3586
Turkey	Jordan #1	Ankara, Turkey	2050	205	0	2030	5435	3546	19.3	18,332	0.079	2.5	2255
	Saudi Arabia #1	Ankara, Turkey	2100	210	0	2040	5663	3537	20.0	16,604	0.069	2.5	2310
	Saudi Arabia #1	Ankara, Turkey	2100	210	0	2050	5838	3537	20.6	16,221	0.065	2.6	2310
Czech Republic	Algeria #2	Prague, Czech Republic	1635	182	413	2040	5445	3580	19.5	17,714	0.076	2.5	2230
	Libya #1	Prague, Czech Republic	1629	181	344	2050	5303	3588	19.0	16,552	0.072	2.5	2154

[19]



[121]

Developments in UHV and smart grid domains became inevitable because global energy interconnection (GEI) will be built up to link clean energy bases such as wind farms in the arctic and solar farms in the equatorial regions where the potential are relatively higher than other places in the world.

Financial Cost

1. Capital cost

The initial cost is the cost that a company or a government has to pay in the beginning of a project. For HVDC, the cost is going to be in billions to make the project profitable. Moreover, the LCC-HVDC technology is older but cheaper, as the equipment used is well established and available in the market by multiple companies [70]. Three suppliers, ABB, Siemens and Alstom, dominate the HVDC market [58, 102].

2. Production costs

The HVDC company will have the opportunity to generate electricity in remote areas and resources, and not lose power over the transmission.

3. Tax and insurance

As in the MENA region the HVDC system owners are mostly going to be the government taxes will not be applicable for them, but they will have to cover the HVDC system and personal in case of a failure with insurances [68].

4. Cost of land use

Similarly, the land that the HVDC systems are going to be built on is mostly owned by the government [116]. As a result, there will be a small amount of money paid toward the land as reclamation.

5. Economic life of investment

The lifecycle of the HVDC depends on the maintenance of the equipment and quality of built. The HVDC system is built for power losses and transmission for long distance.

6. Opportunity cost of investment

Unfortunately. There is no opportunity for companies in the MENA region to enter the HVDC businesses because of the capital costs. Also, politics are a main factor on the idea of HVDC interconnection.

7. Inflation

As a business proposal the HVDC investment might be affected by inflation, because of the currencies of the MENA countries. Some of them suffer from a week economy [26, 95].

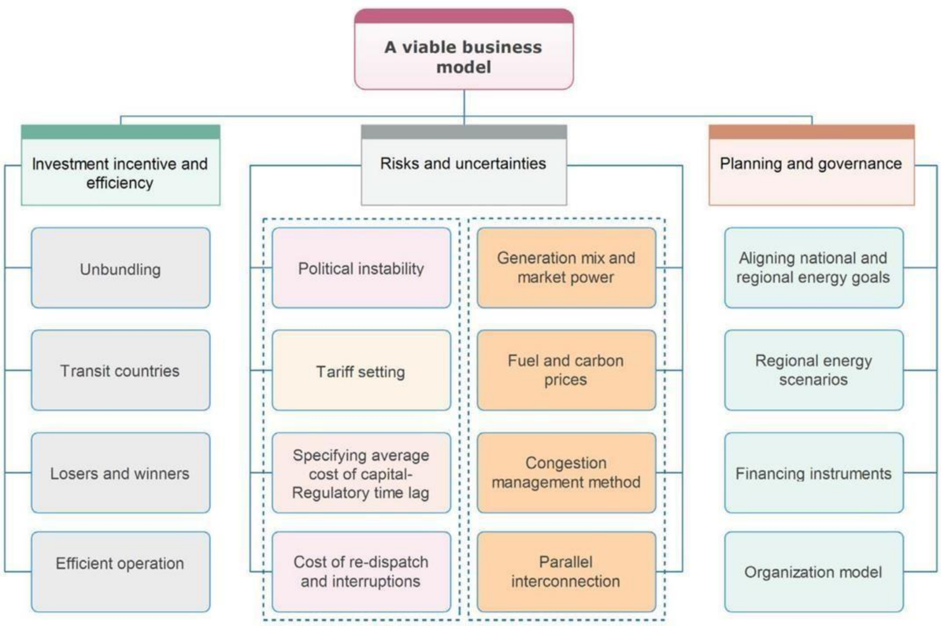
8. Distribution and transmission costs

The costs for transmission are reduced because of the HVDC technology and the AC power distribution will remain at the same rate.

9. Local funds

One of the biggest factors for projects to be built in the MENA region is the local demand. Moreover, some countries ask the help of their people to fund projects.

Finally, interconnected grids will enable the users to utilize 80% of the forecasted clean energy generation by 2050 [37].



Main elements of a viable business model for interconnection investment [92].

Risks

There many risks and constrains HVDC system will face during the construction and in operation. First, the only customer in the MENA countries, are governmental agencies, which sometimes may face difficulties dealing with them [9, 42, 96]. Also, The AC industries will push back any HVDC project, even though the market for AC will remain operating with the introduction of HVDC system [9, 42, 96]. Moreover, transparency and predictability of the market is tough because the MENA region is in a political unrest [9, 42, 96].

Infrastructure

In the section of this research paper, we are going to discuss about the infrastructure in the MENA region for HVDC.

1. Laws

The current law in some of MENA countries are vague and not clear to how should a company apply for HVDC project, as there are only few projects operating. Also, in the GCC the HVDC system is still under construction [23, 65, 114]. Plans might take weeks and months to get approved. Moreover, these laws are not following up with the new HVDC technology, as HVDC is a new technology.

2. Technology

Unfortunately, there are no companies in the MENA region that design or build HVDC equipment. The construction company will face the issue of ordering and waiting for items to come from overseas [53]. As a result, MENA HVDC project are under the mercy of nation companies.

3. Telecommunications

Overall, the MENA counties are well established with high-speed Internet connection, while some other MENA countries are still lacking behind [83, 102, 123]. Nevertheless, all the MENA countries are upgrading their Internet Infrastructure because Internet is needed for new companies to move their business to the MENA region. Moreover, the communication system for HVDC is private and isolated from the rest of the Internet [83, 102, 123].

4. Grid

The MENA countries have some experience with HVDC system that is operating in North Africa [40]. Unfortunately, there is no grid available or capable of handling HVDC currently.

5. Workforce

In the MENA counties there are abundance of engineers and workforce that can be used for building and operating HVDC sites. The issue is that HVDC system are not well taught in universities [61]. There might be a subject or two about HVDC, but there is no specific major for HVDC. As for construction worker, there is enough people to cover all the aspects of the build.

6. Agencies for RE

The Gulf Cooperation Council Interconnection Authority is the agency responsible for the electricity interconnection between the GCC countries. Their HQ and control center is located in Saudi Arabia. The agency control both AC and DC system. The AC system is in operation and HVDC under construction. As for North Africa, the local agencies are responsible for the interconnection system.

Formulas

The mean DC output voltage of a six-pulse converter is given by:[13]

$$V_{\mathrm{dc}} = V_{\mathrm{av}} = \frac{3V_{\mathrm{LLpeak}}}{\pi}\cos(\alpha) - 6fL_{\mathrm{c}}I_{\mathrm{d}}$$

Where:

V_{LLpeak} - the peak value of the line to line input voltage (on the converter side of the converter transformer),

α - the firing angle of the thyristor

L_{c} - the commutating inductance per phase

I_{d} - the direct current

The converter operating overlap angle is a function of the operating current and the converter transformer leakage reactance:

$$\mu = \cos^{-1}\left[\cos(\delta) - \frac{Id}{Id_o} \times \chi_p\right] - \delta$$

μ = the converter overlap angle (rad),

Id = converter DC operating current (pu),

Id_o = rated converter DC operating current (pu),

χ_p = converter transformer leakage reactance (pu),

δ = converter control angle,

= alpha (α) for rectifier operation (rad),

= gamma (γ) for inverter operation (rad).

I_n = harmonic currents from the converter

I_{fn} = harmonic currents in the filter

I_{sn} = harmonic currents entering the supply system

Z_{fn} = harmonic impedance of the filter

Z_{sn} = harmonic impedance of the AC system

The current and voltage distortion can be calculated from the following expressions:

4)

$$I_{sn} = \frac{Z_{fn}}{Z_{fn} + Z_{sn}} \times I_n$$

5)

$$V_n = \frac{Z_{fn} \times Z_{sn}}{Z_{fn} + Z_{sn}} \times I_n$$

[7, 72,114]

Recommendations

1. Laws

One of the most important aspects for RE to become a reality is the support of a strong well-established laws. These laws can be for the material at the borders that need especial approval to enter, and a fast path for RE equipment to pass through the customs [3]. Moreover, laws can help with the buying and selling agreements and taxes [3, 115]. Especial channels and offices would make a huge difference. Furthermore, more lenient laws for RE equipment manufacture. Additionally, there should be a regional regulatory framework, that all of the MENA countries can agree upon.

2. Technology and advancements

Research centers and testing sites are extremely important requirements for RE to have a chance in the MENA market. These test sites will be for testing new technology that can be installed in a hot, dry environment such as deserts [51, 76]. Research centers will analyze the equipment durability and efficacy in MENA hot climate and will give recommendations based on the tests.

3. Telecommunications

Internet and monitoring systems are an essential part of the RE system. Engineers and researchers can use the data provided through the network to make adjustment and forecast the output for the next few days. Moreover, network connectivity will take advantages for fast response in case of a fault occurring at site or unit without the need for the personal to be at site [8]. This is useful in case of remote locations that might take days for personal to reach to.

4. Grid

Connection to the Grid has to be seamless and with no fluctuation. The foundation for any grid is the power lines and substations. These stations are used for converting the power or for rerouting the power, as the need requires. Grids must be of the highest technology and advancement available in the market and with a monitoring system for the transmission lines [28]. Moreover, governments should strengthen their existing interconnection so future projects will be able to adapt with ease [28, 63]. Also, they should extend the interconnection to countries still unconnected. Furthermore, standardization between the MENA countries must be made, to ensure harmony in constructing projects [42, 82,115].

5. Workforce

A skilled workforce is needed for the building and maintaining the RE site and transmission system. As a result, MENA countries must introduce RE subjects to schools and majors in the universities so MENA countries will have skilled engineers and technicians for the RE sites [51].

6. Dedicated agencies

RE agencies are necessary for RE to be built and maintained. These agencies are there to write the laws and installation guidelines [72, 103]. Also, they monitor the overall of the systems placed in the country. A local and nation agency will be prefect for the MENA region. For example, the EU has a European commission where they take control of legislating the RE project [33]. Moreover, governments should establish an agency so they can negotiate with EU for power trading.

7. Public

Governments and companies should increase the public awareness toward renewable energy and efficient means of power transmission so students will enter these fields [60].

8. Financial

Governments should encourage private investors to enter the electricity sector. Also, governments should provide an efficient cost allocation system that will co-pay with private investor to build any project [76]. Additionally, financing mechanisms should be written so investors will have the confidence to enter the projects. Furthermore, competitive tenders will urge companies to enter new markets. Banks can provide loans with low or no interest rates for public projects [76]. Likewise, private public ownership will increase the people to invest in project. For example, Sukuk scheme is one financial support for new project to get funds and the public will benefit from a yearly return. Similarly, taxes cuts will help with starting new renewable energy projects. Finally, Lower tariffs for properties with renewable energy technology installed at site [11].

Conclusion

In conclusion, a feasibility study was made to analyze the potential of renewable energy in the MENA region, and use High Voltage Direct current (HVDC) as a method of transmission power through the region. As solar and wind energy are the most available renewable energy in the MENA region. The research study covered the site selection of solar panels and wind turbines, and how generation of power is made. Secondly, the site selection of HVDC, and the process of converting AC to DC. Thirdly, the technology used in both RE and HVDC, and the advantages and disadvantages. Fourthly, the rules and regulation that are in practice for electricity in the MENA region. Fifthly, the political influences on RE and HVDC construction and operation. Sixthly, the existing and future project plans for RE and HVDC. Seventhly, the financial cost of building and maintaining RE and HVDC system. Eighthly, the risks and constrains that RE and HVDC have to overcome. Ninthly, the infrastructure needed to realize the projects of RE and HVDC. Tenthly, the social impact of the ongoing and future RE and HVDC projects. Eleventhly, the formulas used in RE and HVDC. Lastly, recommendations for all aspects of RE and HVDC were given.

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