Techno-Economic and Environmental Evaluation of Introducing Renewable Energy Systems in a Reverse Osmosis Desalination Plant

التقييم التقني الاقتصادي والبيئي لإدخال نظم الطاقة المتجددة في محطات التحلية بالتناضح العكسي

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ABSTRACT

It is quite conspicuous that the population tends to increase in the coming decades which would evidently increase the global demand for fresh water. In Middle Eastern regions, the source of fresh water is usually a desalination plant which provides water for agricultural and drinking purposes. This research project concentrates on a Reverse Osmosis (RO) desalination plant located in UAE. RO plants come under the membrane technology and have high electricity consumption (which leads to high associated CO2 emissions considering the use of fossil fuels). Considering the location, this research probes into the introduction of solar photovoltaic energy systems, wind energy systems and hybrid PV-WT systems into the existing RO desalination plant and evaluates its technical, economic and environmental feasibility under varied conditions and combination of systems. With simulations as the core research methodology, HOMER Energy and IES VE are used for the technical, economical, and environmental analysis of the systems. The simulations in HOMER Energy is done in a step by step series from 25%, 50%, 75%, 100% renewable fraction connected to the grid to a standalone system with 100% renewable fraction.

The results observed from the various configurations are that the hybrid PV-WT systems and PV systems have a viable technical and economic feasibility whereas WT systems fare poorly in the region. In these systems, the primary loads are met in most case configurations in an optimal way. It is seen that in the 25% renewable fraction case configurations all configurations fare well especially the PV system and hybrid case configuration with 0% unmet load , 0% excess electricity and 0% capacity shortage. In the 50% case configurations, 15% excess electricity is produced by the hybrid system whereas the other case configurations concerning the PV systems and Wind turbine system produce no excess electricity. No capacity shortage or unmet electric load is observed in any of the systems in the 50% case configuration. However, from the simulations concerning the 75%, 100% and standalone case configurations, excess electricity is produced in the PV and Hybrid system. The system components tend to increase exponentially from the 50% case configurations onwards with the high annual electrical load demand of 8,341.26 kWh/day. There is also a reduction in the PV panel requirement for the hybrid configuration from 50% case configuration onwards. These parameters make the hybrid case configurations a more technically viable option.

However, from the economic analysis it is seen that the renewable electricity cost is not viable considering the current costs levied on the desalination unit .The net present cost is used to identify the economic feasibility of the systems used in the study which show that the least cost incurring system is when the unit is connected to the grid with the NPC of $1,195,957.98. This is followed closely by configurations where 25% renewable fraction is integrated with PV systems and hybrid systems with NPC $3,683,774.00 and $3,964,293.00 and respectively. However, through many propositions which may not be always technical, a change to renewable energy can be introduced in this region such as; introduction of net metering, feed in tariffs, government incentives, improving the desalination process, more efficient and cheaper renewable system components through new noble technologies. Finally, it is observed from the study that carbon emissions are reduced when the renewable system is connected to the grid. In the case of PV system which has just 25% renewable fraction and the rest connected to the grid shows a carbon dioxide reduction from 2563674 kg/year when only connected to the grid to 1879703 kg/year. The case where the renewable fraction is more, the carbon dioxide produced is also seen to be lesser. Though these renewable case configurations may give a higher cost for electricity, it is seen clearly from the emissions reduced how this transition from fossil fuel to renewable will help save the world from a point of never coming back.

ملخص:

من الواضح تماماً أن عدد السكان يتجه إلي الزيادة في العقود المقبلة بما من شأنه أن يزيد الطلب العالمي علي المياه العذبة. في مناطق الشرق الأوسط، تعتبر محطات تحلية المياه هي عادة مصدر المياه العذبة التي توفر المياه للأغراض الزراعية والشرب. يركز هذا المشروع البحثي على محطة تحلية المياه بالتناضح العكسي الموجودة في دولة الإمارات العربية المتحدة. تدخل محطات التناضح العكسي في باب تكنولوجيا الأغشية وتستهلك الكهرباء بصورة عالية (الأمر الذي يؤدي إلي ارتفاع انبعاثات غاز ثاني أكسيد الكربون المتعلقة باستخدام الوقود الأحفوري). وفيما يتعلق بالموقع، يتحقق هذا البحث من إدخال الطاقة الشمسية الضوئية ونظم طاقة الرياح ونظم توربينات الرياح – الهجين في محطة التحلية بالتناضح الحالية وتقييم جدواها الفنية والاقتصادية والبيئية في PV-WTالفولتية الضوئية ظل ظروف متنوعة ومجموعة من الأنظمة. مع المحاكاة حسب منهجية البحث الأساسية، وقد استخدمت طاقة هومر (التصميم الأمثل لنظام توليد طاقة هجين) والحلول البيئية المتكاملة للبيئة الافتراضية في التحليل الفني والاقتصادي والبيئي للأنظمة. وقد أجريت المحاكاة في طاقة هومر في سلسلة تدريجية من نسبة متجددة 25%، 50%، 75%، 100% متصلة بالشبكة إلي نظام مستقل مع جزء متجدد بنسبة 100%.

الهجين PV- WTتتمثل النتائج الملاحظة من التشكيلات المختلفة هي أن نظم توربينات الرياح – الفولتية الضوئية والأنظمة الفولتية الضوئية تتمتع بجدوي فنية واقتصادية قابلة للتطبيق، في حين أن أنظمة توربينات الرياح تجري بشكل سيئ في المنطقة. في هذه الأنظمة تستوفي الأحمال الأساسية في معظم تكوينات الحالة بطريقة مثلي. ومن المُشاهد أن تكوينات الحالة المتجددة بنسبة 25% تجري كافة التكوينات بشكل جيد خاصة الأنظمة الفولتية الضوئية وتكوين الحالة الهجين مع نسبة 0% حمل غير مستوفي، 0% كهرباء زائدة و 0% نقص القدرة. وفي تكوينات حالة 50% تنتج 15% من الكهرباء الزائدة عن طريق النظام الهجين حيث أن تكوينات الحالة الأخرى المتعلقة بالأنظمة الفولتية الضوئية ونظام توربينات الرياح لا تنتج كهرباء زائدة. ولم يلاحظ أي نقص في القدرة أو الحمل الكهربائي الغير مستوفي في أي من الأنظمة في تكوينات حالة 50%. ومع ذلك، من المحاكاة المتعلقة بتكوينات الحالة القائمة بذاتها بنسبة 75% و 100%، أنتجت الكهرباء الزائدة في النظم الفولتية الضوئية والهجين. وتميل مكونات النظام إلي الزيادة أضعافاً مضاعفة من تكوينات الحالة بنسبة 50% فصاعداً مع ارتفاع طلب الحمل الكهربائي السنوي الذي يبلغ 8,341,26 كيلوا وات / يوم، كما يوجد أيضاً إنخفاض في مطلب اللوحة الفولتية الضوئية للتكوين الهجين من تكونات الحالة 50% فصاعداً. هذه المعايير تجعل تكوينات الحالة الهجين أكثر قابلية للتطبيق من الناحية الفنية.
ومع ذلك، يتضح من التحليل الاقتصادي أن تكلفة الكهرباء المتجددة ليست قابلة للتطبيق نظراً للتكاليف الحالية المفروضة علي وحدة التحلية. يستخدم صافي التكلفة الحالية أكثر من 20 عاماً من العمر لتحديد الجدوي الاقتصادية للأنظمة المستخدمة في الدراسة التي تبين أن أقل تكلفة يتكبدها النظام هي عند ربط الوحدة بالشبكة مع صافي التكلفة الحالية التي تبلغ 1,195,957.98 دولار وتلتها التكوينات حيث تم دمج نسبة 25% من الجزء المتجدد مع الأنظمة الفولتية الضوئية والأنظمة الهجين بصافي تكلفة حالية تبلغ 3,386,774.00 دولار و 3,964,293.00 دولار علي التوالي. ومع ذلك، من خلال العديد من المقترحات التي قد لا تكون جميعها تقنية، يمكن إدخال التغيير إلي الطاقة المتجددة في هذه المنطقة مثل إدخال صافي القياس وتعريفات التغذية والحوافز الحكومية بما يحسن من عملية التحلية مكونات نظم متجددة أرخص وأكثر كفاءة من خلال التقنيات الممتازة الجديدة.
وأخيرا، لوحظ من الدراسة انخفاض إنبعاثات الكربون عند توصيل النظام المتجدد بالشبكة. وتظهر في حالة الأنظمة الفولتية الضوئية ذات الجزء المتجدد بنسبة 25% فقط والباقي متصل بالشبكة انخفاض ثاني أكسيد الكربون من 2563674 كجم/ العام عند اتصالها فقط بالشبكة إلي 1879703 كجم/ العام. وقد أشارت الحالات إلي أنه كلما زاد

الجزء المتجدد كلما كان ثاني أكسيد الكربون المنتج الملاحظ أقل. علي الرغم من أن تكوينات الحالة المتجددة هذه قد تمنح تكلفة أعلي للكهرباء، ومن الواضح من الإنبعاثات المخفضة كيف سيساعد هذا الانتقال من الوقود الأحفوري إلي الطاقة المتجددة في إنقاذ العالم من نقطة عدم العودة مرة أخرى.

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1 CHAPTER I - INTRODUCTION

GLOBAL SCENARIO

Human beings have existed on earth for quite some time being in harmony with nature. Like all life on earth, they need water as it a vital to sustain life. Around 70 percent of the earth's crust consist of water, thus one tends to feel that water is plentiful to all, which is exactly opposite to the scenario we are facing. It should be understood that as little as 3 percent is only available as potable water on the planet, out of which around 65 percent is trapped in ice glaciers (WWF, 2015). Water scarcity can be either economical or physical as illustrated in figure (1.1). The typical way to access water scarcity is by looking at the water- population statistics in a region (UN. Org, 2015).

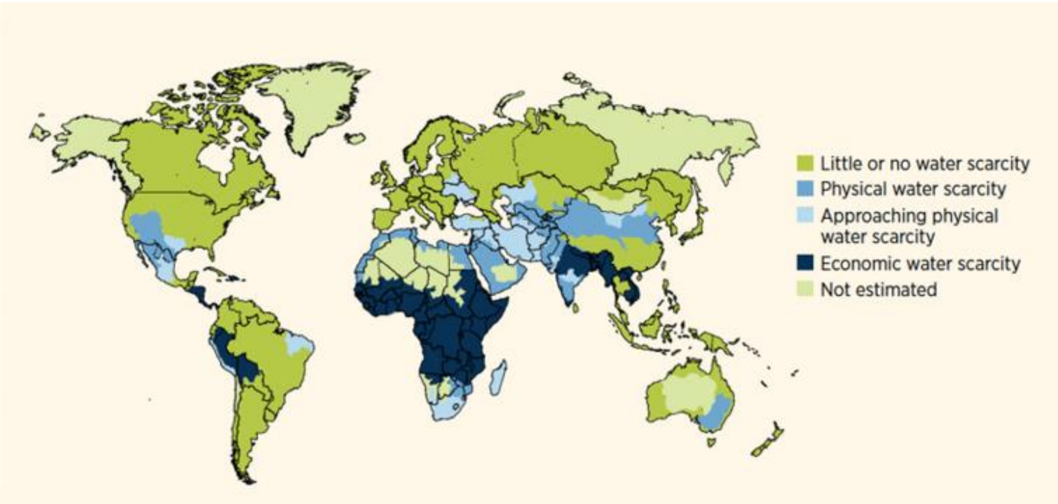


Figure 1.1: Global water scarcity (WWAP, 2012)

Recent studies have shown that the current geometrical increase of the human population and their excessive use of natural resources for comfort and industrialization have started affecting the planet and causing it to become into an unbalanced state. It is quite conspicuous that the population tends to increase in the coming decades which would evidently increase the global demand for water, energy and other natural resources. This rapid increase in the need for resources to sustain life on this planet is leading to devastating results which would in the end affect all life on earth. The main causes of water scarcity can be vaguely indicated as pollution, agriculture, and population, which together have given rise to climate change.

Climate change is the phenomenon occurring due to the excessive greenhouse gases (carbon dioxide, methane, nitrogen dioxide, etc.) being injected into the earth's atmosphere. Figure (1.2) illustrates the alarming high concentration of carbon dioxide in the earth's atmosphere .This would lead to diverse weather patterns and water scarcity or abundance in many parts of the world. Some regions would have floods while the other may be infested by droughts, glaciers may melt resulting in chaotic fresh water supplies on communities downstream, thus disrupting all ecosystems on earth (WWF, 2015).

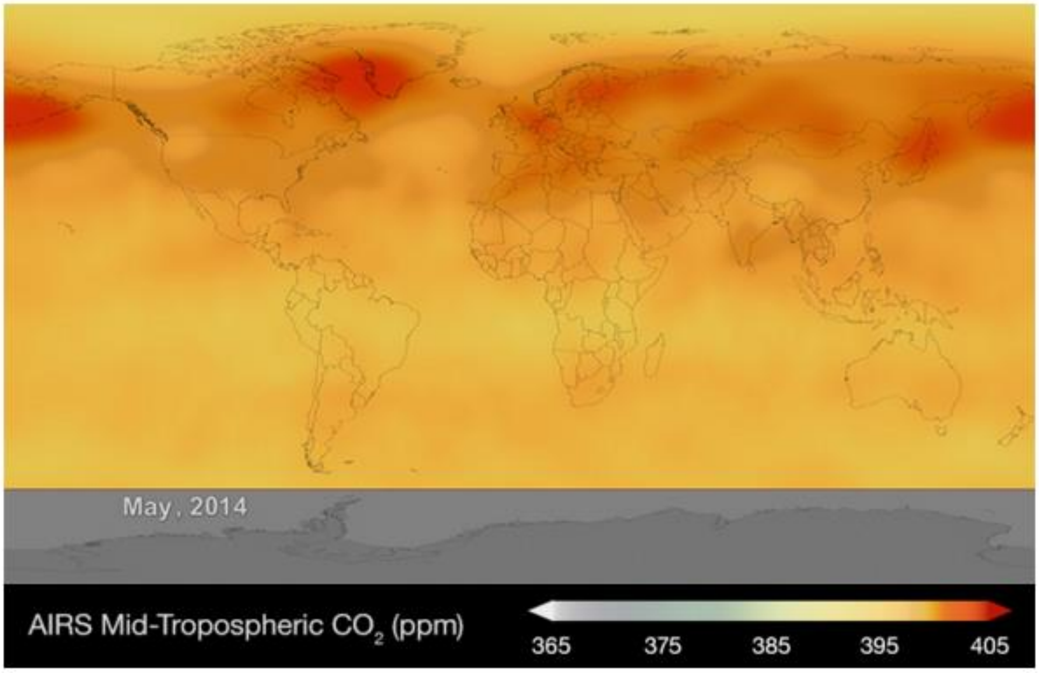


Figure 1.2: Carbon Dioxide concentration in the atmosphere (NASA, 2014)

Global warming and climate change, the main outputs of the fossil driven economy which has called for agreements like the Kyoto Protocol, Copenhagen Accord and the global climate summit in Paris. These agreements should be considered as the stepping stone into public awareness on how the earth is affected by the surge in greenhouse gasses and what all can be done to keep it in check for a better future for all the occupants in planet. Figure (1.3) depicts how irrationally the amount of carbon dioxie has incresed in the earths atmosphere after the industrial revolution.Thr current (October 2015) measurement of carbon dioxide in the atmosphere is calculated to be 401.58 ppm which is an alarming rate of concentration (NASA, 2015).

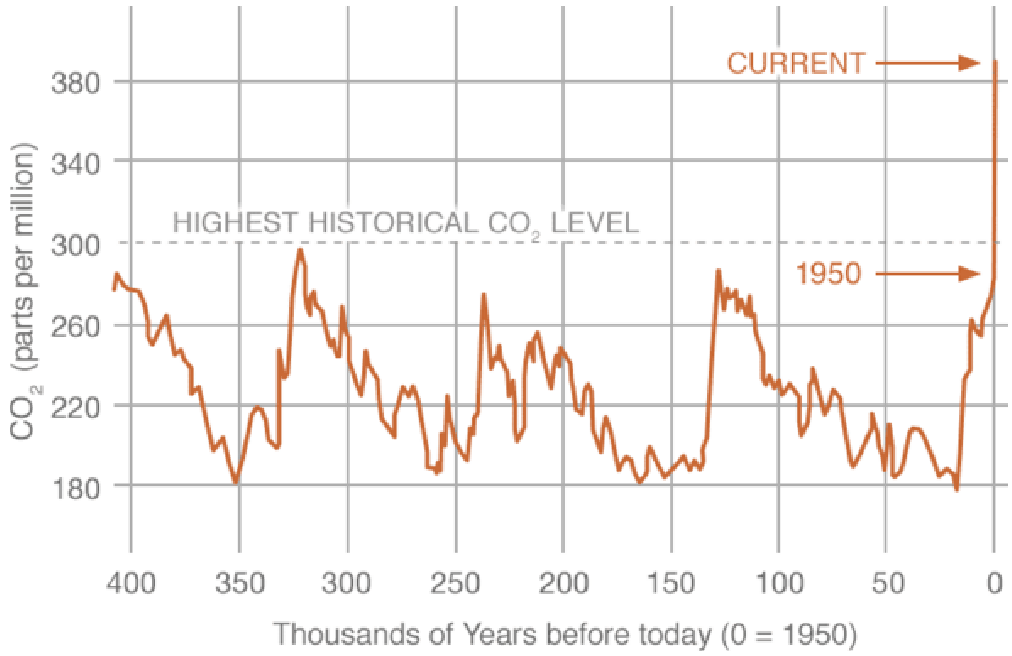


Figure 1.3: evidence that CO2 has increased drastically from the industrial revolution. (NOAA, 2015)

According to the World Energy Outlook Report by IEA (2015), energy seems to be the most intensive variable in producing high amounts of carbon dioxide as shown in figure (1.4) .Thus; the current scenarios have led to the need for producing sustainable and renewable sources of energy to tend to the growing needs of the population. However, it can be analyzed that all the discussed topics are interlinked to one another, which leads to a clear understanding that to produce sufficient water resources to the population; it should be assumed that the process of obtaining it (potable water) should be energy efficient, preferably from renewable resources and least polluting to the environment.

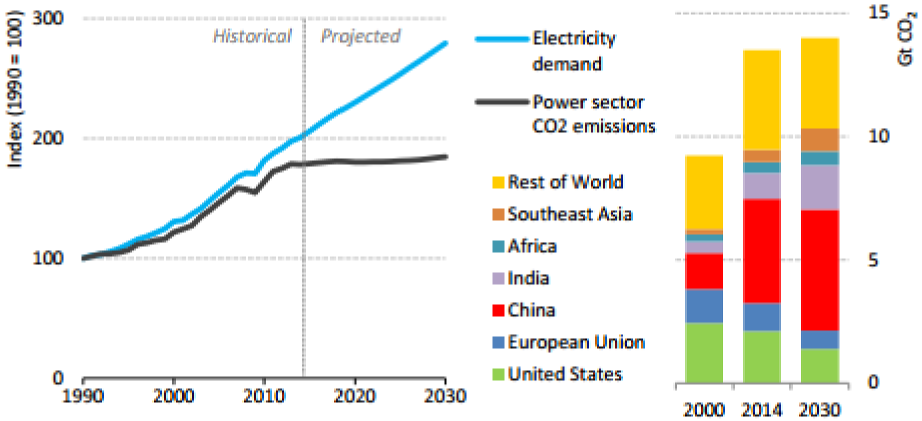


Figure 1.4: World electricity demand and related CO2 emissions (IEA, 2015)

In most areas of physical water scarcity, sea water desalination is the most opted method for obtaining potable water. But unfortunately, it can be noted that these processes are very much energy intensive, thus leading to increased carbon emissions. As desalination seems to be the only option in many of these areas, more research and development is suggestive to improve the energy efficiency of the desalination plants and as well as integration of renewable energy generation systems into these plants for sustainable development.

1.1 DESALINATION – WATER ENERGY NEXUS

Hameeteman (2013) points out that the United Nations predict 2-7 billion would face the problems regarding water scarcity in the coming years, thus most of the potable water industries are relying upon desalination of brackish water supplies. Desalination plays a very important part in arid, semi-aid, and coastal areas as the water scarcity is due to physical reasons. In such areas, desalination of seawater or brackish water can supplement the ever growing need for potable water which is understood by the increasing capacity of desalination depicted in figure (1.5).

Although desalination can curb the shortage of fresh water, it should be noted that desalination is a very energy intensive process. The energy supply is usually by use of fossil fuels which have lower market prices compared to renewable energy resources thus not making it very sustainable in the long run (IRENA tech brief). It is eminent that major desalination plants are located in areas where energy is relatively cheaper thus; only 1 percent of desalinated water seems to be from renewable resources (IRENA tech). However, due to increased awareness of the need to shift to renewable energy sources have led to decrease in prices of such technologies, making renewable energy an accomplishable alternative to fossil fuels.

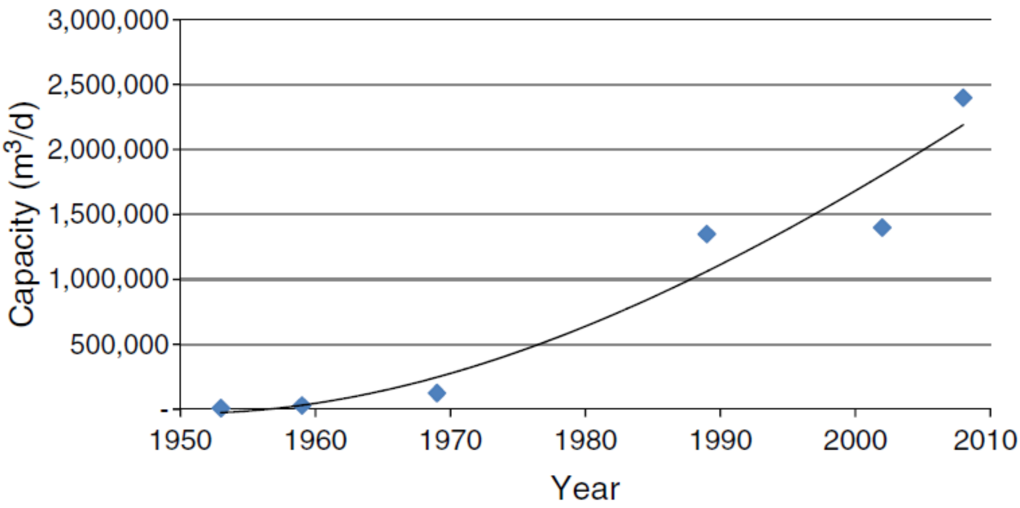


Figure 1.5: Growth of desalination capacity (ESCWA, 2009)

The desalination process is mainly governed by two technologies, thermal desalination, and membrane desalination (Greenlee et al., 2009). The former technology derives fresh water by intensive heating whereas the latter uses high pressure pumps and membranes to separate fresh water from brackish water. Thermal technologies include Multi Stage Flash (MSF), Multi Effect Distillation (MED), Vapour Compression (VC) whereas Membrane technologies include mainly Reverse Osmosis (RO) and Electro dialysis (ED) (IRENA, 2012).Table (1.1) depicts the major desalination technologies and their characteristics such as the environmental impact, technology growth, energy requirement, and cost of water. Subramani et al. (2011) argues that the predominant factor associated with desalination is cost due to the substantial use of energy, thus this also means that the immense use of energy releases considerable amounts of greenhouse gasses into the earth's atmosphere. While introducing renewable energy to these processes the local availability of the renewable resources place a very important role, such as in the middle east region, concentrated solar power can help in thermal desalination and solar photovoltaic energy can be used for membrane technologies as these regions have a vast solar resource potential.

In the middle eastern regions, Reverse Osmosis method of desalination is gaining high popularity even though thermal desalination is the dominant technology used (Greenlee et al., 2009). In a typical reverse osmosis plant, the feed water is pumped into pre-treatment tanks to filter the water and make it suitable for processing in the membranes. Then the water is pumped into the membrane configuration using high pressure pumps thus separating the fresh water from the brackish feed water .This water then undergoes post treatment which includes ph adjustment, removal of dissolved gasses etc. The high pressure pumps take up most of the energy needed to desalinate the water, which can be about 30 percent of the total cost of the desalinated water (Subramani and Jacangelo, 2015). In many reverse osmosis desalination plants an energy recovery device is usually used with a booster pump to recover the pressure and reduce the size of the high pressure pumps (Drake and Adato, 2014).

Table 1.1: Major types of desalination technologies and their characteristics
(Mezher et al., 2011)

	MSF	MED	RO
Energy requirement (kWh/m^3)	Electrical (SA or CG)[1]: 3.5–5.0 kWh/m^3 SA: Thermal: 69.44–83.33 kWh/m^3 CG: Thermal: 44.44–47.22 kWh/m^3	SA: Electrical: 1.5–0.5 kWh/m^3 CG: Electrical: 1.5–2.5 kWh/m^3 SA: Thermal: 41.67–61.11 kWh/m^3 CG: Thermal: 27.78 kWh/m^3	Seawater (SW): 4–8 kWh/m^3 Brackish water (BW): 2–3 kWh/m^3
Cost of water ($\$/m^3$)	0.9–1.5 $\$/m^3$; the cost reduces with cogeneration and unit capacity	Around 1 $\$/m^3$; 0.827 $\$/m^3$ for Jubail II plant; the cost reduces with cogeneration use of thermal VC (TVC) and unit capacity	0.99 $\$/m^3$ for seawater RO; 0.53 $\$/m^3$ for Ashkelon 0.2–0.7 $\$/m^3$ for brackish water
Technology growth trend	Moderate Is a mature technology	High Is a mature technology	High, with membrane technology growth RO will become more and more economical
Environmental impact	Discharge is 10–15 °C hotter than ambient, TDS increase of 15–20%	Brine discharge and temperature rise are similar to MSF	Brine discharge at ambient temperature TDS increase of 50–80%

[1] SA stands for Stand alone; CG stands for co-generation.

Multi –Effect Distillation (MED) desalination plants have their process details varied according to plant design and the feed water input. The MED process basically has many stages, also known as effects where the feed water is heated up by steam in tubes .The tubes may be placed in two ways; it can be submerged into the feed water or the feed water can be spared onto a bank on top of horizontally placed tubes. In each stage, some of the water evaporates and the rest of the steam flows into the tubes to the next stage. Thus in a continual process, each effect or stage uses a bit of the energy from the previous stage and finally, the last stage would yield the pure water condensed in a final condenser (Buros, 2000). MED uses electrical and thermal energy but the consumption tends to be lower than MSF but higher than RO plants.

In the case of Multi Stage Flash (MSF) desalination plants, portable water is produced by boiling the feed water and then condensing it. The feed water is first pre-heated in tubes and a brine heater and then it is made to enter a vessel whose pressure is kept lower than the pressure of the brine heater, thus making the water boil spontaneously(flashing). Stage flashing typically means that at each stage or vessel, the water is made to boil suddenly due to low ambient pressure. The water is made to go through a lot of stages; usually plants have 4 to 40 stages, depending upon the size and quality of feed water (Cooley et al., 2006). This process consumes both electrical and thermal energy making it very energy intensive compared to both RO and MSD desalination processes.

Thus when we look at the main desalination processes, we can clearly see how energy intensive they are with MSF desalination process needing around 3.5 – 5 kWh/m3 electrical energy and 44.44 – 83.33 kWh/m3 thermal energy, MED desalination process using around 1.5-2.5 kWh/m3 electrical energy and 27.78-61.11 kWh/m3 thermal energy and finally RO plants require around 2-8 kWh/m3 electrical energy, making it the least energy intensive of the lot(ESCWA,2009).Table (1.2) depicts the statistics concerning energy demand by IRENA tech Brief (2012) and are almost similar with the ones depicted by ESCWA (2009).

Table 1.2: Energy for desalination (IRENA, 2012)

	MSF	MED	SWRO[1]	ED
Operation temp., °C	90–110	70	Ambient	Ambient
Electricity demand, kWh/m³	2.5–3.5	1.5–2.5	3.5–5.0	1.5–4.0 feed water with 1500–3500 ppm solids
Thermal energy demand, kWh/ m³	80.6 (290 kJ/kg)	80.6 (290 kJ/kg)	0	0

SWRO: Spiral wound reverse osmosis

1.2 DESALINATION AND RENEWABLE ENERGY POTENTIAL – THE UAE SCENARIO

1.2.1 DESALINATION

As mentioned before, the main drivers of desalination is physical water scarcity and population growth. In GCC countries, it has been noted that the population increase is expected only at a lower rate according to the statistics shown in Table (1.3) by ESCWA (2007).

Table 1.3: Trends in population growth rate in GCC countries (ESCWA, 2007)

Country	Growth rate (%)					
	1995–2000	2000–2005	2005–2010	2010–2015	2015–2020	2020–2025
Bahrain	2.80	1.56	1.79	1.56	1.35	1.18
Kuwait	5.48	3.73	2.44	2.04	1.77	1.55
Oman	2.30	1.00	1.97	1.95	1.81	1.58
Qatar	2.85	5.86	2.11	1.76	1.49	1.16
KSA	2.80	2.69	2.24	2.05	1.84	1.62
UAE	5.76	6.51	2.85	2.13	1.85	1.64

However, the per capita rate of use of domestic water is almost doubled in most of these countries. While looking at the figure (1.6), between the domestic water consumption in GCC countries it can be clearly noted that UAE has one of the highest domestic water use per capital. The projected domestic water use for 2025 is around 1500.2 million m3, which is an alarming number; this also indicates the heavy dependence on desalination in the coming years (ESCWA, 2009).

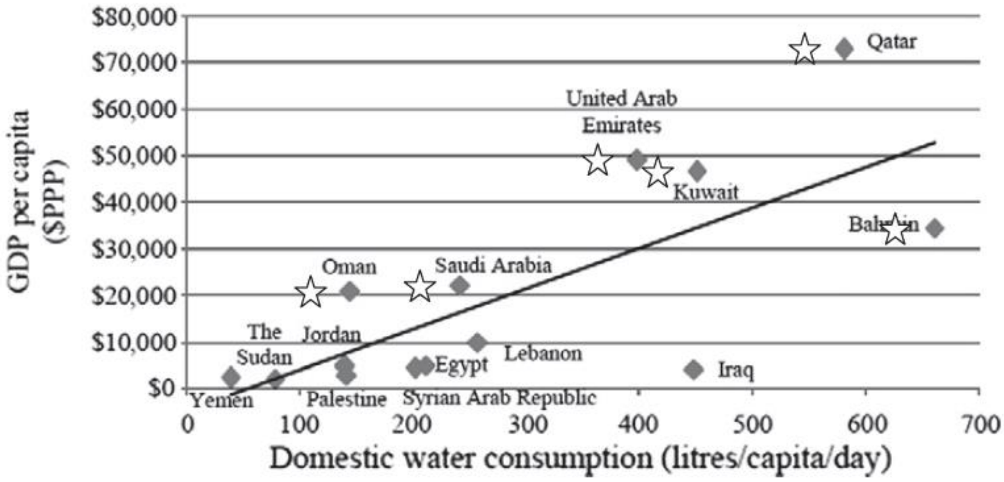


Figure1.6: Domestic water consumption in GCC countries (ESCWA 2009)

According to statistical findings (in Table 1.4), UAE holds a 14 percent share when compared to the rest of the world on desalinated water capacity, which keeps growing considering the rate of domestic water consumption in the region.

Table 1.4: countries with high desalination capacity (ESCWA 2009)

Country	Capacity (m^3/day)	Share of global production (%)
KSA	10,598,000	17
UAE	8,743,000	14
USA	8,344,000	14
Spain	5,428,000	9
China	2,553,000	4
Kuwait	2,390,000	4
Qatar	2,049,000	3
Algeria	1,826,000	3
Australia	1,508,000	2
Japan	1,153,000	2

ESCWA (2009) reports that most of the desalination in the region (UAE) is through MSF process. Although it is clearly understood that MSF process desalination is the most energy extensive, it was one of the first commercially available option in the region as, which has lead to its high prominence in the UAE as illustrated in figure (1.7). A good shift is seen towards reverse osmosis plants nowadays as it only relies on electric energy and RO membrane technology has been highly developed since 2009.

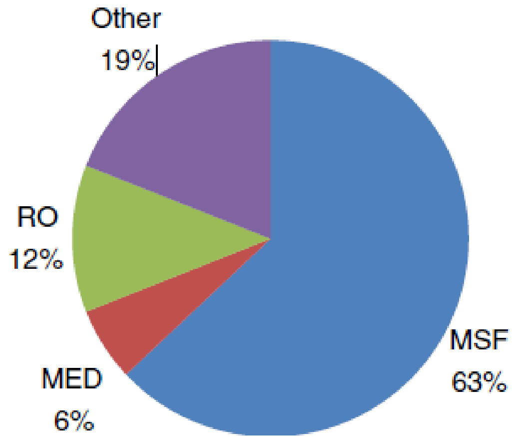


Figure1.7: Distribution of desalination technologies in the UAE (ESCWA, 2009)

It is inevitable to point out the main reason for MSF plants to be in use as the relative inexpensiveness of fuel/energy. Most MSF in UAE are cogeneration plants with the steam used for generation of electricity. The reverse osmosis plants are considerably few in number but are gaining popularity as they are seen to have potential to couple with renewable technologies. Pilot plant projects are being done by Masdar from 2015-2016 to evaluate four different type of RO technologies that can be utilized in the future for a sustainable desalination option.

In UAE, the main regions that use desalination technology are Abu Dhabi, Dubai, and Sharjah. The table (1.5) illustrates some of the desalinations plants in those areas.

Table 1.5: Major desalination Plants in UAE (Mehezer et al. 2011)

Abu Dhabi			Dubai			Sharjah		
Project	Technology	Capacity	Project	Technology	Capacity	Project	Technology	Capacity
Shuweihat S1	MSF	100 MGD	Jebel Ali L1	MSF	317,800 m^3/day	Layyah plant	Hybrid (MSF + MED + RO)	63.5 MGPD
Taweelah B extension	MSF	98 MGD	Jebel Ali G	MSF	272,520 m^3/day	Saja'a plant	RO	5.50 MGPD
Taweelah A1	Hybrid (MED + MSF)	84 MGD	Jebel Ali L2	MSF	250,000 m^3/day	Hamriyah plant	RO	1.15 MGPD
Taweelah B	MSF	75 MGD	Jebel Ali	MSF	121,134 m^3/day	Kalba plant	RO	5.50 MGPD
UAN west B	MSF	62.8 MGD	Jebel Ali M	MSF	477,330 m^3/day	Khor Fakkan (KFK) plant	RO	2.50 MGPD
UAN west	MSF	53.2 MGD	Jebel Ali K2	MSF	182,000 m^3/day			
Taweelah A2	MSF	50 MGD	Jebel Ali K1	MSF	125,000 m^3/day			

Portable water is inevitable to live without, and in arid areas like the UAE, the evolving population tends to have more demands considering this resource. The forecast for the water demand and the installed capacity is shown in the figure (1.8). It is seen clearly that there is an increasing linear indication towards demand and thus will lead to more desalination plants. This increase in desalination plants will lead to a lot of energy usage, thus demanding a more sustainable solution to this energy water nexus.

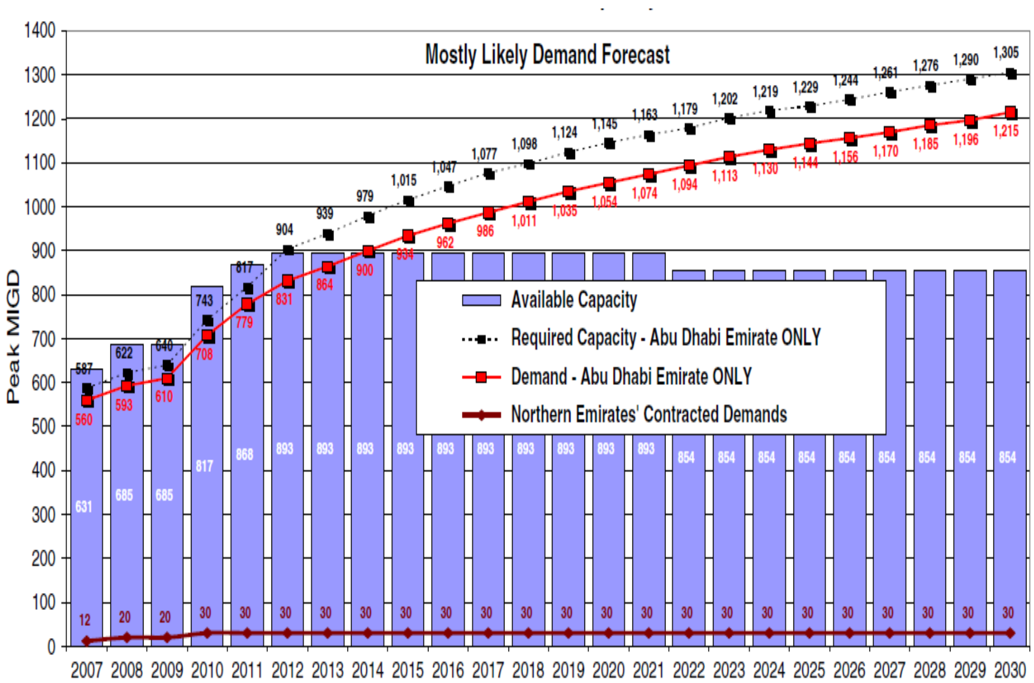


Figure1.8: Water demand forecast (ADWEC, 2010)

1.2.2 UAE AND RENEWABLE ENERGY- SOLAR AND WIND

The geographical location of UAE has bestowed upon it an abundance of solar irradiation as illustrated in figure (1.9).UAE gets an average of 10 hours of solar irradiation for about 300 days a year with clear skies. Solar energy that falls on this region comes up to about 6.5 kWh/m2/days with the direct normal radiation to be 4-6 kWh/m^2/day. This gives tremendous opportunities in solar power utilization using photovoltaic, CSP, and solar thermal options in various systems. In the current scenario, solar PV has high demand considering RE technology in UAE due to its technological advancements, scalability of PV modules, functionality in utilizing diffused lights, lower unit costs compared to earlier years and reliability factor(Sgouridis et al., 2016).

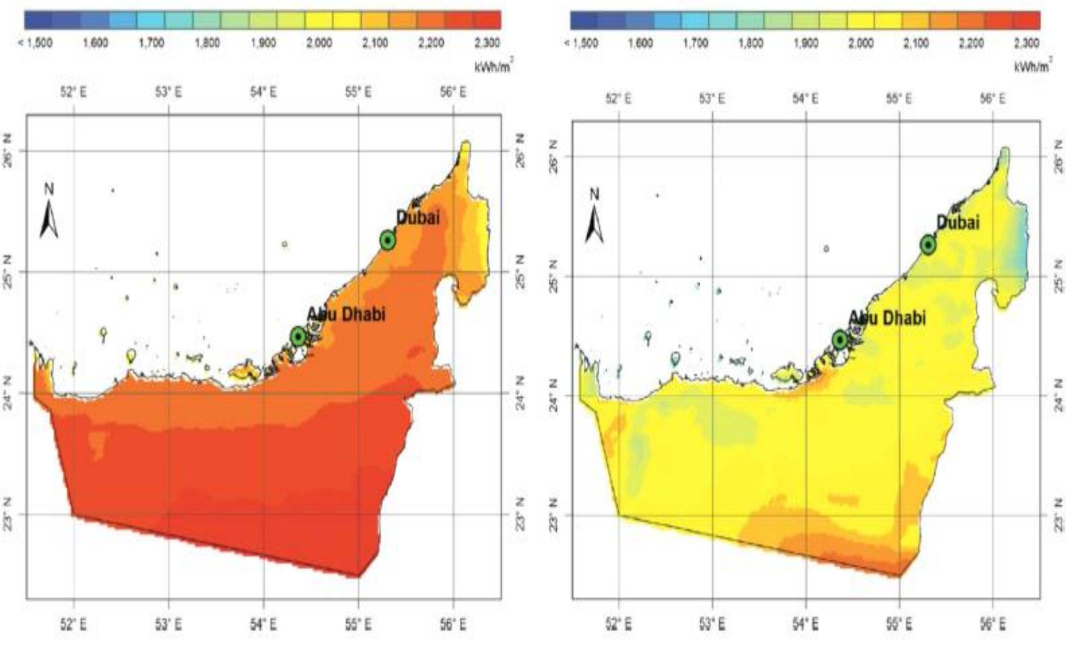


Figure 1.9: UAE global horizontal (left) and direct solar (right irradiance.
(ReCREMA, 2013)

In the figure (1.10), good wind potential is seen mainly in the northern emirates. Although it is less abundant in UAE with average wind speeds of 3.5 -4.5 m/s, there is significant potential for its utilization.

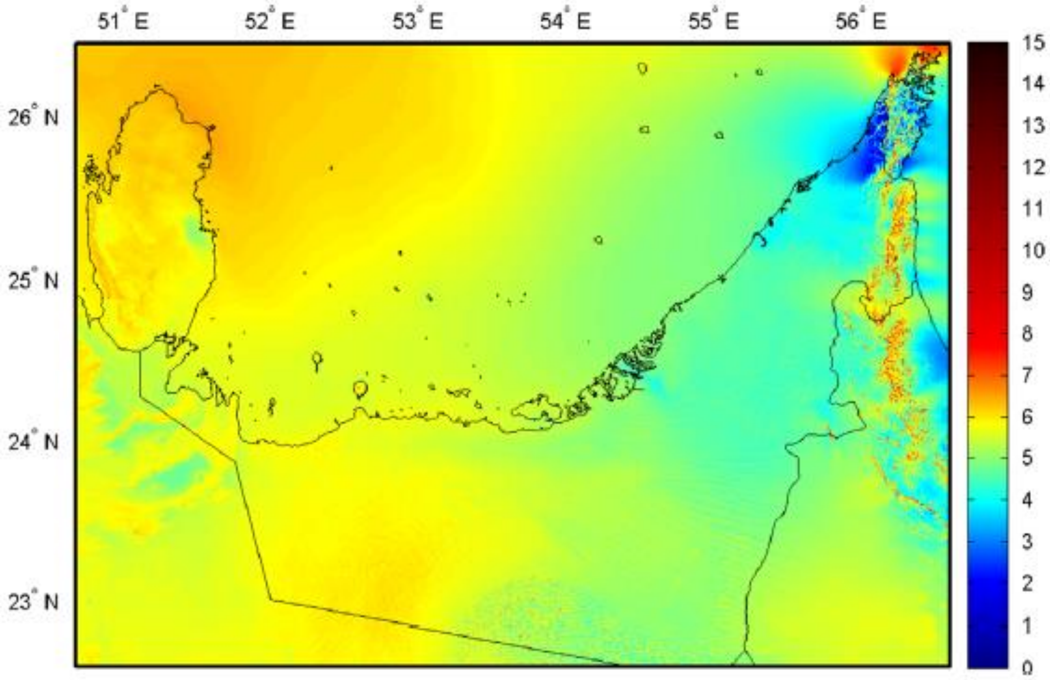


Figure1.10: UAE wind resource- wind speed in m/s at 80 m mast height
(ReCREMA 2014)

1.3 RESEARCH PLAN

The current dissertation deals with water desalination using RO technology and how renewable energy specifically solar energy and wind energy can be in-cooperated within desalination plants in the UAE. Thus, the study would discuss how physical water scarcity can be overcome by reverse osmosis desalination plants in the UAE in the most sustainable manner. At first, comprehensive literature review would be done in order to understand the domain concerning desalination, solar energy as well as wind energy resources and technology. Secondly, the research methodology would be chosen after scrutinizing different methodologies in the subject area and then finding the most suitable methodology to be used in this dissertation. This would be then followed by a case study of a live and operating reverse osmosis plant in the UAE. The case study would act as the base model to understand the complications and significance in using renewable energy resources in the desalination plant. The technical, economical, and environmental analysis of the situation would conclude the project.

1.3.1 AIM

To assess the performance of a Sea Water Reverse Osmosis (SWRO) desalination plant when it is introduced to renewable resources of energy (Solar Photo voltaic and Wind) by comparative analysis and evaluation of its technical, economic, and environmental aspects. The research would try to attempt different configurations of the standalone renewable systems and grid connected renewable systems to understand which would be the most feasible option in terms of the technical and economical domain.

1.3.2 OBJECTIVES

- Understand the process of desalination and the main working principles used, stressing on the variables that affect performance and cost aspects of a RO desalination plant.
- Study upon the latest innovations in desalination plants and understand its current state of technological development.
- Recognise the types of renewable energy that can be used in desalination plants and its benefits over conventional fossil fuel.
- Identify potentials and barriers in using renewable energy in desalination plants such as permits by the government in the region.
- Identification and selection of possible options (renewable systems in the market) for integration of PV's and wind turbines in the existing RO desalination plant considering the location and weather data.
- Analysis of standalone renewable systems and grid connected system in varied conditions and combinations to understand the most feasible option in terms of cost, technical efficiency, and environmental impact.

1.3.3 STUDY RATIONALE

The study is intended to get a clear understanding on how we could tactfully utilize the abundant resources of energy such as solar and wind in desalination systems. Water is one of the most essential need for a country, and for an arid one like UAE, it is very important to find alternatives to water generation in the most sustainable and efficient manner with least environmental impacts.

The renewable sources of energy such as wind and solar are usually used in independent systems and their combination is not widely studied in areas of desalination integration. This study would help evaluate considering the unpredictable nature of the two resources, if it would give a better outcome if they are integrated to the system and if they would complement each other in the climatic conditions of UAE. The economic analysis would also help evaluate if there is any need to look into this hybrid option and if would be economically viable. Thus, the study would help in bringing knowledge to this domain and to raise the standard of our built environment when it comes to potable water generation.

1.3.4 LIMITATIONS

The study would try to cover all aspects considering the topic in the most comprehensive manner. Due to limitations of time, in the live case study, the annual profile of energy consumption in the desalination plant would be taken in average after considering the daily profile for two months. Even though this may not affect the techno-economical analysis in a large scale, it still brings in a factor of accuracy in the calculations and simulations.

2 CHAPTER 2 – LITERATURE REVIEW

2.1 RENEWABLE ENERGY

In the current world, electricity is a necessary and essential element for the smooth functioning of the country. With the limited fossil fuel reserves and the high awareness for reduction on green house gasses have led to a positive impact towards renewable energy in the energy dependent planet. In principle, it is argued that the potential of renewable energy is such that it can provide and exceed more than what is utilized on earth, thus creating its significance in the world future energy portfolio (Ellabban, Abu-Rub and Blaabjerg, 2014).According to the statistics (illustrated in figure 2.1) by REN21 2015 report, it is seen that nowadays the human population consumes 19.1 percent of renewable energy in the total energy mix.

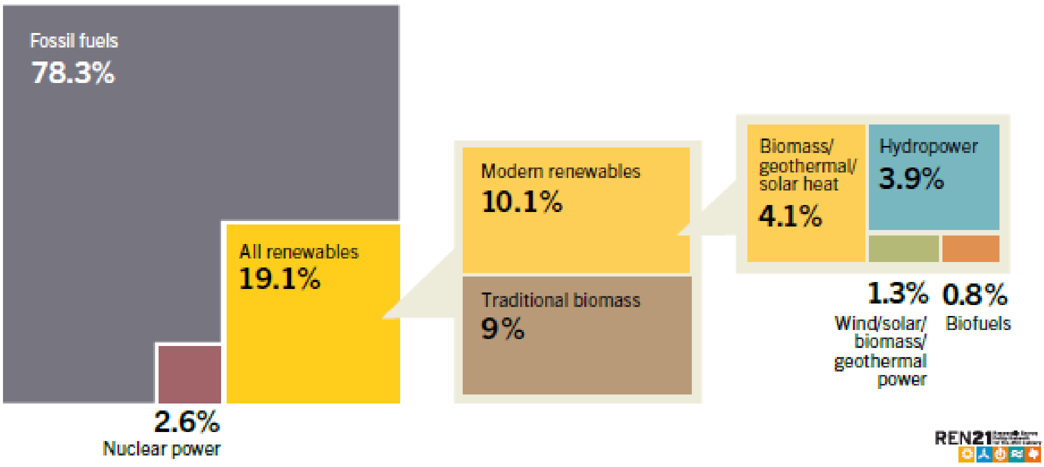


Figure2.1: world energy consumption (REN21, 2015)

In layman terms, it can pointed out that renewable energy sources are those which can be replenished within a period of time or constantly. They occur in various forms but have origins from the sun or the heat produced by the earth's core. The main stream technologies in renewable resources are namely solar, wind, biomass, hydro, ocean, and geothermal resources. These are explained in brief in the coming sections, however as the project focuses upon the use of solar and wind resources, they will be explained in detail.

Renewable energy is growing significantly even after the drop in oil prices and the consumption rate of renewable have rather grown. It is also noted that developing countries are shifting rather quickly to renewable (like China) to keep up with the rising demand for energy and to be energy independent. Statistics from many studies show that the global economy has grown but the carbon emissions have stayed stable through 2014 showing the awareness and increasing trend to renewable energy. In the figure (2.2), it is seen how IEA has forecasted a positive trend to increasing renewable energy capacity in the world.

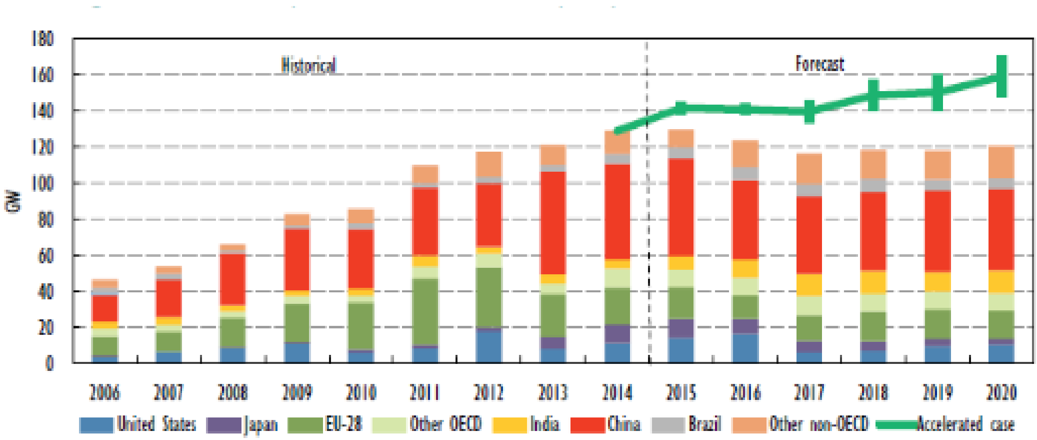


Figure2.2: Renewable power capacity projected (IEA, 2015)

2.1.1 HYDROPOWER

Hydro power is the energy that is tapped in water systems that can be used to generate electricity. Utilizing the kinetic energy of running water by turbines is the most fundamental way of generating energy. This condition is found in rivers or reservoirs (both manmade and natural) from where the kinetic energy of the water is converted to mechanical or electrical energy (IEA, 2016). The current global capacity of hydropower is around 1000 GW with China leading the market producing 260 GW followed by Brazil, United States, Russia and India (REN21, 2014).

Being a mature and economically competitive resource, hydro power plays a huge role in the renewable energy mix. The figure (2.3) illustrates the renewable energy market for hydro power where it is clearly seen that there is steady increase predicted in its growth. It can also be noted that hydro electricity will play a huge role in stabilization of demand and supply fluctuations as the percentage of share of other renewable electricity resources like wind and solar tend to increase drastically. Hydropower developments usually tend to increase efficiency in drought control, food and water supply etc. if planned accordingly (IEA, 2016).

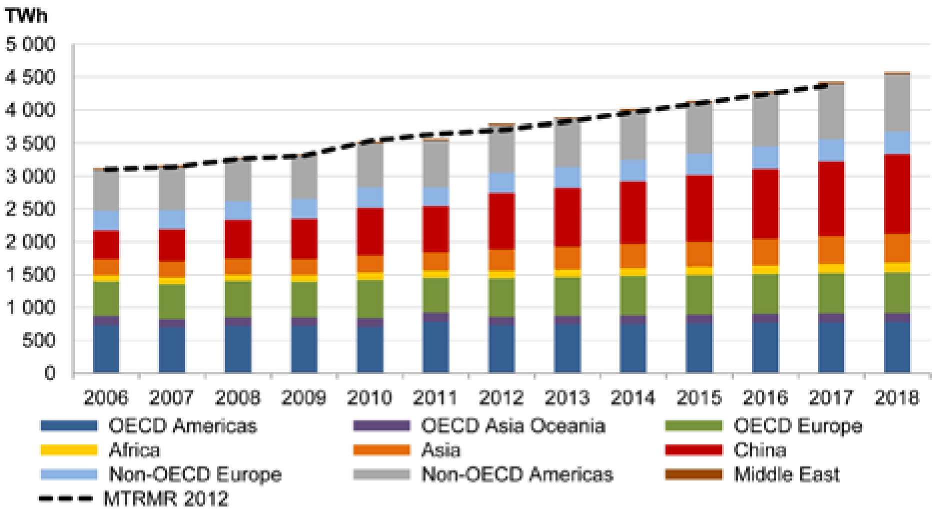


Figure 2.3: Renewable energy market for hydro power (IEA, 2013)

Most common technologies in hydro power include Run-of-river hydropower plant, reservoir hydropower plant and pumped storage plants. All these technologies basically use turbines which may be low, medium or high hydraulic heads which are classified by the type of propellers such as pelton, francis or cross flow turbines. The configuration and capacity of the hydro plant can be scaled to power a single household to a large grid connected system as listed in the table (2.1).

Table 2.1: Capacity and main application of hydro electric schemes (Allsaintpreston.org, 2010)

Usual term	Capacity	Main applications
Pico-hydro	few tens of Watts - 5 kW	single household
Micro-hydro	5 kW - 100 kW	mini-grids, small communities, rural industries
Mini-hydro	100 kW - 1 MW	mini-grids, villages, industries, or grid connected
Small-hydro	1 MW - 15 MW	usually grid connected
Medium-hydro	15 MW - 100 MW	grid connected
Large-hydro	> 100 MW	grid connected

Another section of hydro power is through the utilization of tides, waves, and ocean currents. These forms of energy are still under research and technologies such as Ocean thermal energy conversion (OTEC) have not reached economical feasibility. Thus, commercialization and technological advancement in this section needs to improve to promote this domain of hydropower resources and it can be clearly understood from the figure (2.4).

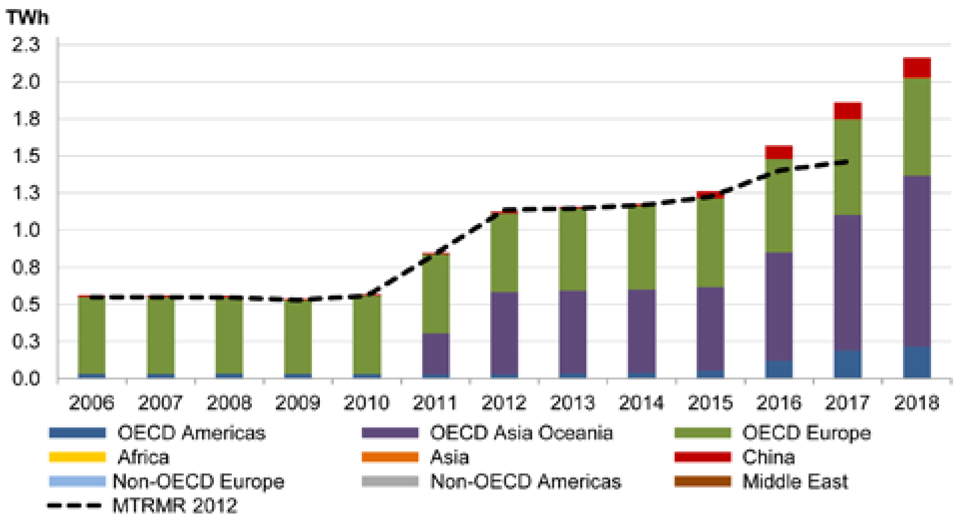


Figure 2.4: Ocean power generation (IEA, 2013)

The current technologies governing ocean energy are tidal power, tidal (marine) currents, wave power, temperature gradients, and salinity gradients. These technologies are not yet exploited in large scale and ocean energy only constitute around 0.54 GW of ocean power capacity in the year 2012.

2.1.2 GEOTHERMAL ENERGY

Geothermal energy is the energy which is derived from deep within the earth which can provide low carbon energy supply. Geothermal energy is usually used for heating and cooling purposes as well as for electricity generation. Geothermal energy is considered reliable and non intermittent as it is not affect by weather patterns and does not show any type of seasonal variations. Thus, it is very reliable as a base load generator unlike other sources of renewable energy which have variable power. Areas where geothermal energy is used for electricity generation includes Iceland, Kenya, Philippines, Costa Rica and El Salvador.

Another important use of geothermal energy is its use for heating spaces, swimming pools, industrial process heating, etc. (IEA, 2016). From the figure (2.5), it is forecasted by IEA (2013) that the geothermal power generation has a scope of steady increment especially in Asia and Europe.

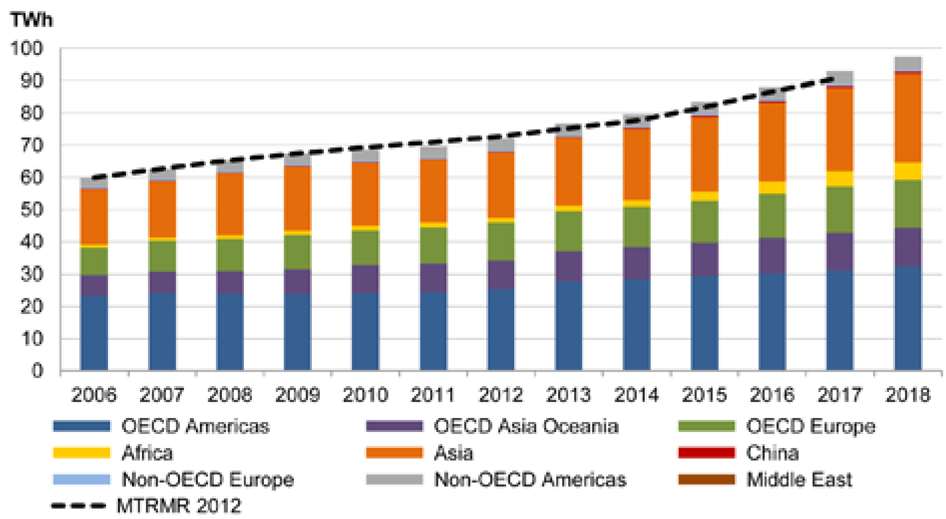


Figure 2.5: Geothermal power generation (IEA, 2013)

The technologies used in geothermal energy vary according to its use for power generation or for heating uses. In case of power generation systems using geothermal energy, as illustrated in figure (2.6), the technologies include Flash steam plants which make about two thirds of the total generation capacity and the rest is usually by a technology using Dry steam plants. Binary plants which can utilize low to medium temperature are coming into more popularity nowadays (IEA, 2016). In case of heating systems using geothermal energy, there are two major categories; open and closed loop systems. However, these systems are further categorized into horizontal, vertically and pond loop systems as per the need and geography conditions of the area (Johnston et al. 2011).

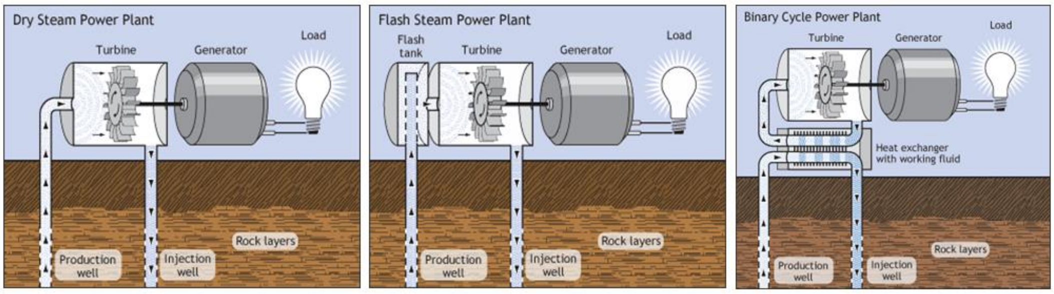


Figure 2.6: Geothermal electricity generation technologies (US department of energy, 2010)

2.1.3 BIO ENERGY

Bio energy is derived from biomass, which is any organic matter that can degrade itself and produce energy. Wood, crops, organic waste, manure are the major forms of biomass used to produces energy by directly burning, or used after processing into liquids or gaseous forms. Bio Energy is usually seen on developing countries like China (as seen in figure 2.7) and account for almost 10 percent of the world primary energy supply. However, bio energy is not used efficiently thus are not consumed or utilized to the maximum. Basic forms of the use of bio energy is for heating purposes (IEA 2016)

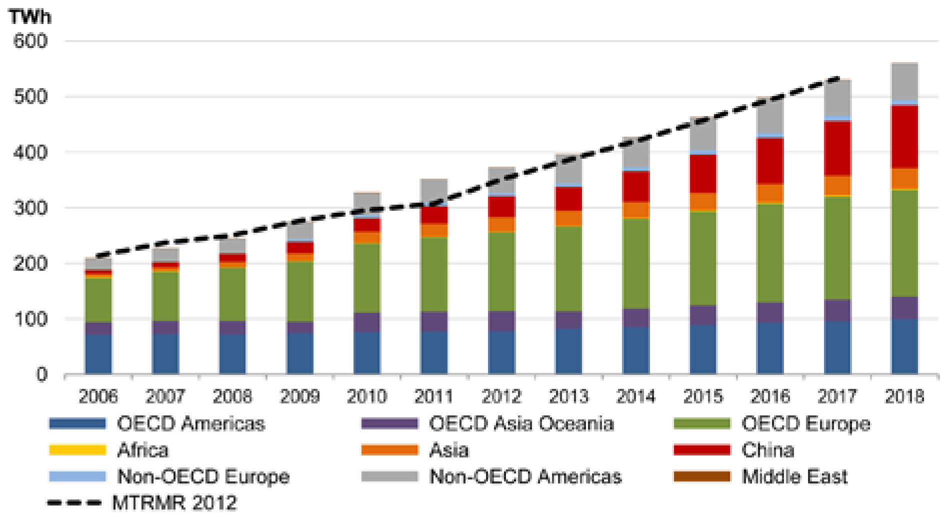


Figure 2.7: Bio energy generation (IEA, 2013)

Bio energy has a multi-faceted nature when it comes to the types of energy usage, thus making difficult to measure considering the knowledge data gaps (REN 21, 2015).From the illustration (Figure 2.7), it can be noted that during the year 2012, 370TWh of bio energy was produced which was about 1.5 percent of the world electricity generation at that time (IEA 2013).

The technologies that govern bio energy exist in the domains of heat and electricity. Solid wood heating are use in buildings whereas biogas digesters are used in terms of generation power. Furthermore, biomass gasification plants are also operating for large scale power and heat production (IEA 2016).The bio energy conversion pathways illustrated in figure (2.8) depicts how oils, sugars, biodegradable municipal waste, etc. can be converted to energy by gasification, pyrolysis, and many other conversion routes. Bio energy if efficiently used can play a significant role in creating a sustainable and emission less future.

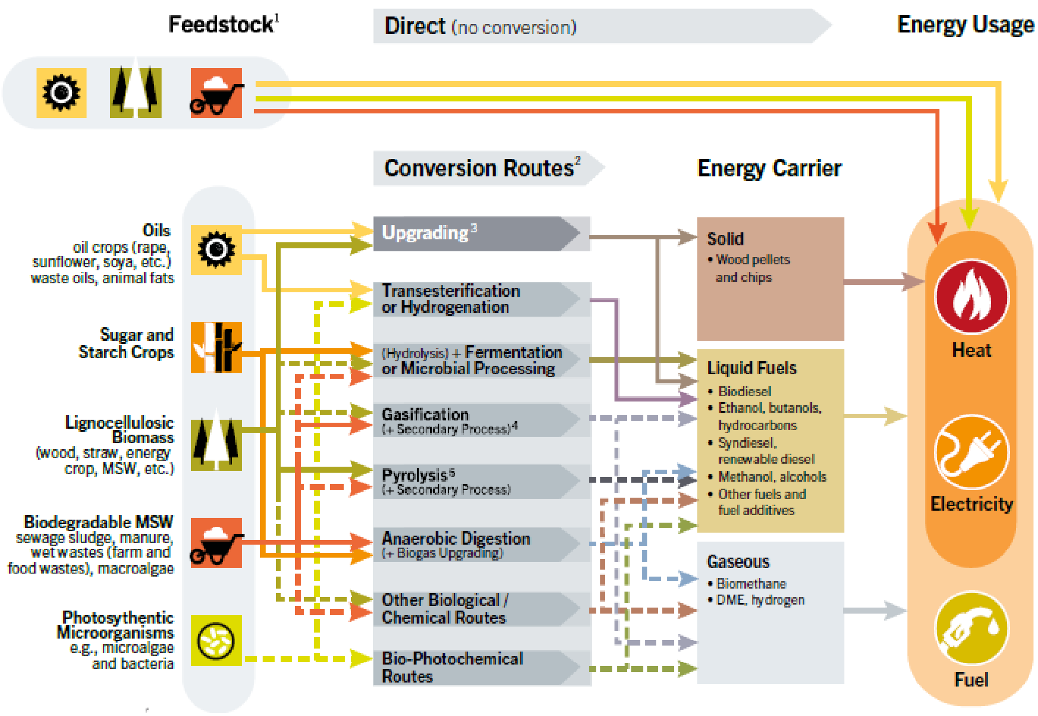


Figure 2.8: Bio energy Conversion pathways (REN21, 2015)

2.1.4 SOLAR ENERGY

Solar energy is the most fundamental source of energy that is received by the planet earth. With the rate of 3.8 x 10^{23}kW of energy being emitted by the sun, of which 40 percent is reflected by the atmosphere, there is still plenty of solar irradiation that can be used to power the earth for all its needs atmosphere (figure 2.9) . When looking at the current electricity generated on the earth, it is significant to realize that if 1 percent of the sun irradiation hitting the earth, if utilized at 10 percent potential, then it can provide 4 times the same energy generated (Thirugnanasambandam, Iniyan and Goic, 2010).

The major divisions in solar energy are solar thermal energy and solar photovoltaic energy. While the former utilizes the heat emitted by the solar irradiance for heating purposes or power generation through the use of different technologies, the latter uses PV cells to directly convert solar irradiance to electricity.

Solar energy is characterized by its intermitted availability of source and vast potential.

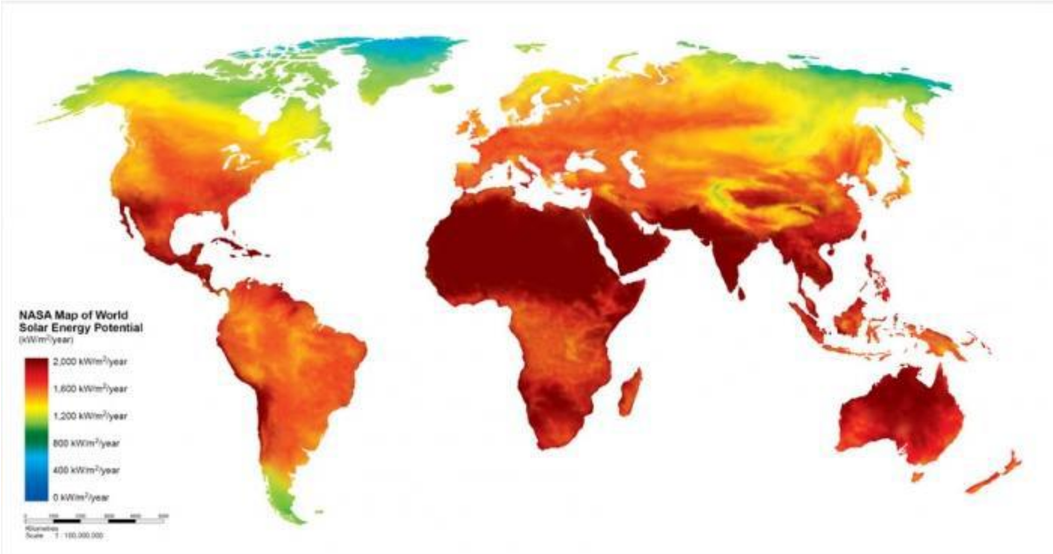


Figure 2.9: solar energy potential on earth (NASA)

In this report, we will be concentrating on solar Photo Voltaic (PV) as the author is interested to integrated PV systems on the base case model as it would be the feasible choice compared to solar thermal systems. There is only need for the creation of electricity for the base case model, thus making PV a more suitable choice. Thus, a review of literature on the PV systems will be done and presented below.

From the graph (depicted in figure 2.10), it is forecasted that solar energy generation is seen to be led by Chine followed by Germany and the US. From the solar potential map, it is understood that the solar irradiance received by each country would be a decisive factor in production of electricity using solar PV technology.

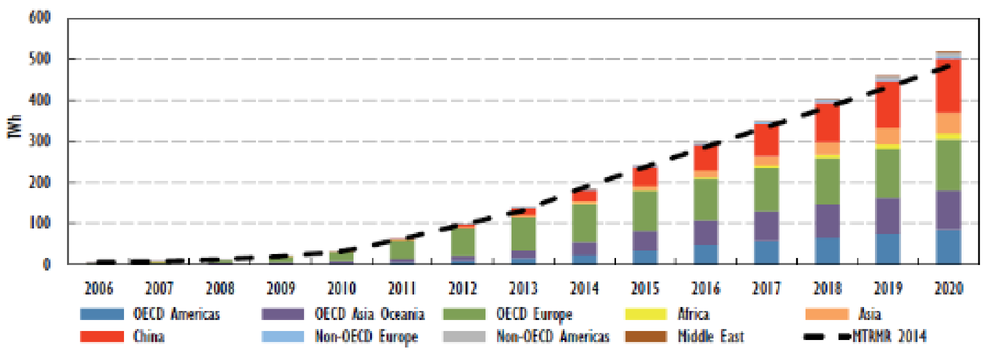


Figure 2.10: Solar photovoltaic energy generation and forecast (IEA, 2015)

Basic working principle of Solar PV:

Solar PVs are usually made of doped semiconductor matter which has the ability to generate electricity if light hits them. Its basic section, illustrated in figure (2.11), would show a p-n junction. With regard to the cell technology, the semiconductor may vary from mono-crystalline, poly-crystalline, or amorphous silicon, indium, selenium, copper, and gallium arsenide. Solar PVs have the ability to generate electricity using the phenomenon called photovoltaic effect. As illustrated in the figure (2.11), it can be explained as follows; two different doped semiconducting material (for example; silicon and germanium) are kept close to each other such that there can be flow of electrons between them. This flow of electrons happen as the photons from the sunlight excite the electrons and give them enough energy to pass on through the junction in only one direction. This flow of electrons and creation of holes creates a negative charge in one side of the junction and a positive charge on the other, thus creating voltage and generating Direct current (IRENA, 2013).

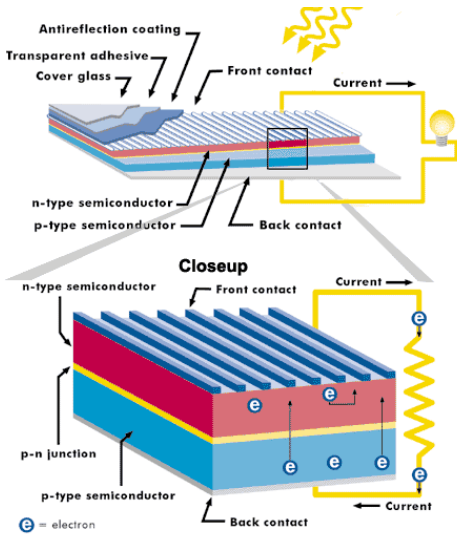


Figure 2.11: Photo voltaic cell (Solarcellcentral, 2013)

Main Elements of a PV system:

The most elementary part of the PV system is the PV cell which generates electricity when hit by photons. Slicing of purified silicon castings or ingots creates these cells. During its process of manufacturing, metal contacts, charge separating junction, anti-reflective layers of coating and passivation layers incorporated into the slice, which eventually forms the solar PV cell (IEA, 2014). These PV cells are connected electrically to form PV modules. These PV modules are further connected electrically in series or parallel connections, to adjust the voltage and current to be produced; this is called a PV array (figure 2.12).

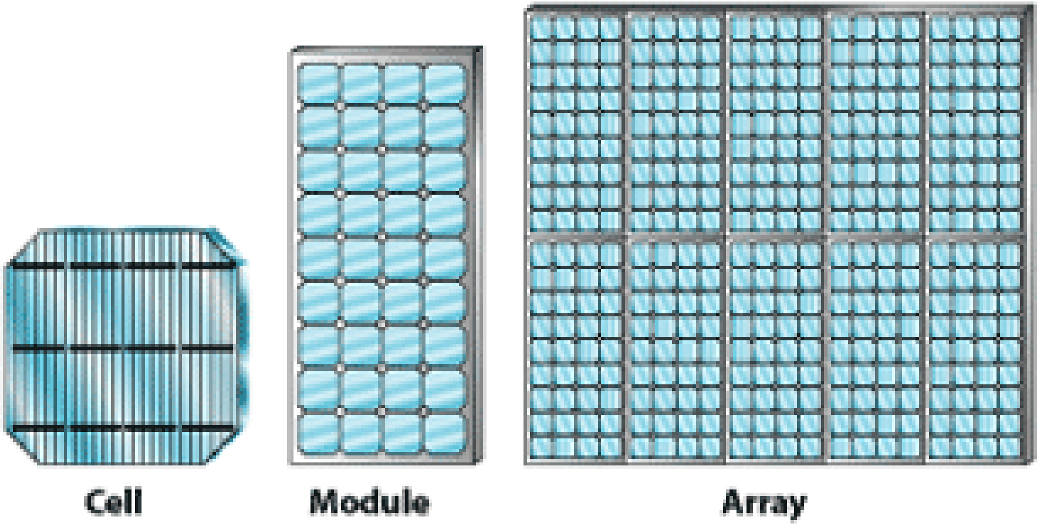


Figure 2.12: PV cell, module, and array (solareis.anl.gov, 2016)

In a basic PV system, the electricity produced goes into the charge controller which helps to regulate the voltage .the DC current can be directly used from the charge controller or can be used to charge batteries to store the electricity. An inverter is usually used to convert DC into AC to facilitate in using most appliances which run using AC current (illustrated in figure 2.13). Thus these parts are the balance of system which together with the modules form the PV system (IRENA, 2013).With regard to balance of system, it also includes any wiring, structural elements used to mount the panels and tracking systems which may be one axis or two axis depending upon the type on concentration system deployed (IEA, 2014).

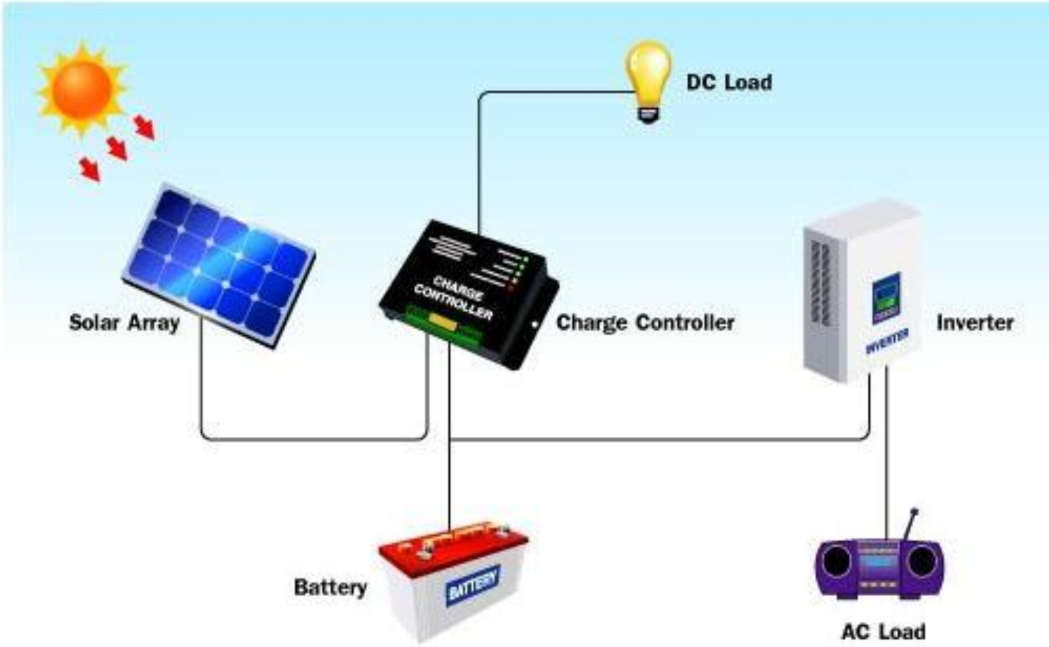


Figure 2.13: Basic PV System (lenonics.com, 2016)

Solar PV system- pros and cons:

The advantages of Solar PV technology is many considering that it produces energy which is devoid green house gasses, it is run by the inexhaustible sun, high availability of resource, rapidly growing technological advancements, no intermediate generators- directly produces electricity from sunlight, Acoustically pleasant, works without any moving parts, thus reducing operations and maintenance cost and the fact that most countries provide incentives for the use of PV systems.

Even though solar PV technology is considered highly advantageous compared to other renewable sources, its disadvantages can be pointed out as high cost for storage systems(batteries need to be changed every 5 years), high maintenance in some climactic conditions due to weekly need of cleaning procedure of cells, resource(sun) is intermittent, high balance of system costs, relatively low efficiency and energy intensity compared to other renewable systems thus needs a lot of space (land costs) to generate more power .

PV Technologies, performance and development:

Research and development in the domain of solar PV has been quite significant when looking at the rapid price reductions of commercially available PV cells and well as increase in efficiency of the cells. Even thought the reduction in price and increase in efficiency may not be translated as commercially affordable high efficiency modules, nevertheless in many cases it has seen this trend as well (Zheng and Kammen, 2014).

At the present market, basically three categories of PV cells are available (refer table 2.2), generally classified as generation 1, 2 and 3.The 1st generation cells are water based crystalline silicon cells (c-Si) which has a 90 percent dominance in the commercial market. The 2nd generation cells are thin –films (TF) which shows research and development towards increasing their efficiency and durability. The 3rd generation are the emerging and novel technologies in the PV industry which includes the organic PV, advanced thin films and low and high concentrating PV. Figure (2.14) depicts a graph that shows the efficiencies of PV cells without concentration and it can be seen that SPW X-Series shows the highest efficiency and is a technology that was developed in recent years.

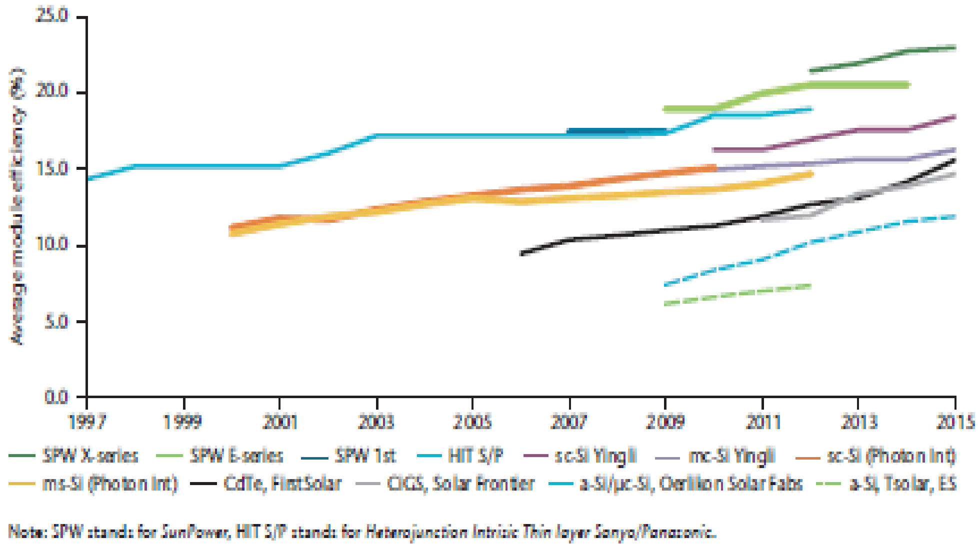


Figure 2.14: Commercial efficiencies of 1-sun (PV without concentration) modules (Schalten, 2013)

Table 2.2: Overview of current PV technologies (IRENA, 2013)

	Cell effic. (%)	Module effic. (%)	Record commercial and (lab) efficiency, (%)	Area/kW (m2/KW)[a)]	Life-time (yr)
c-Si					
Mono-c-Si	16 - 22	13 - 19	22 (24.7)	7	25 (30)
Multi-c-Si	14 -18	11 - 15	20.3	8	25 (30)
TF					
a-Si	4 - 8		7.1 (10.4)	15	25
a-Si/µc-Si	7 - 9		10 (13.2)	12	25
CdTe	10 - 11		11.2 (16.5)	10	25
CI(G)S	7 - 12		12.1 (20.3)	10	25
Org.Dyes	2 - 4		4 (6-12)	10 (15)	na
CPV	na	20 - 25	>40	na	na

a) A module efficiency of 10% corresponds to about 100 W/m²

Water-based Crystalline Silicon Technology / c- Si modules: The rudimentary manufacturing process of c-Si modules starts with the high purification of metallurgical silicon to solar grade poly-silicon, which is then melted to form ingots which is further sliced into wafers usually by a laser cutter or a wire saw (wire saw may produce wastage of silicon to as high as 40 percent).The wafer is then transformed into cells by incorporating p-n junctions, metal contacts and metallisation. These cells are then transformed into modules with materials like transparent glass or thin polymers as protective layers and a metal frame to increase rigidness. The c-Si cells are of three forms- single crystal (sc-Si), multi crystalline (mc-Si) and ribbon sheet grown c-Si. The most efficient type is sc- Si as mc-Si has random atomic structure which makes them cheaper than sc-Si. (shown in table 2.3) (IRENA, 2013) (IEA, 2014).

A standard module is made of an average of 60- 72 cell units and has an average power from 120-300 Wp and an average area of 2.5 m^2 .The efficiency in these cells which are commercially available are increased by various processes and technologies such as ;Buried Contacts made by laser cut groves, Back Contacts that achieve 22 percent efficiency, Improved absorption by surface texturing used by Suntech to achieve 19 percent efficiency, Sanyo Electrics uses hetero junction with an intrinsic thin layer to achieve an efficiency of 19.8 percent. Commercially unavailable cells like multi junction cells using materials other than silicon by Sharp and Boeing Spectrolab have efficiencies of 35.8 % (without concentration)and 41.6 % (with 364 times concentration) respectively (IEA, 2014).

Table 2.3: c-Si modules performance (IRENA, 2013)

	1980	2007	2010	2015-20	2030+
Module effic., % Mono-c-Si Mult-c-Si TF	 ≤8 na	 13-18 4-11	 13-19 11-15 4-12	 16-23 19 8-16	 25-40 21 na
c-Si material use, g/Wp			7	3	<3
c-Si wafer thick, mm			180-200	<100	na
Lifetime, yr	na	20-25	25-30	30-35	35-40
En. payback, yr	>10	3	1-2	1-0.5	0.5

Thin Film Technology: This technology is based on the fact that a thin layer of active materials are deposited on materials such as steel, glass, plastic, etc. Its manufacturing process starts with coating the substrate with a transparent conducting layer. Later, a chemical, physical or vapour deposition of active layer is done. Further, metallization and metal connections are done on the backside usually with laser scribbling and screen printing and finally the cell is encapsulated in glass-polymer casing. The four main types of commercially available Thin Film modules are; amorphous silicon (a-Si) films, multi junction silicon (a-Si/µc-Si), cadmium-telluride (CdTe) films and copper-indium-[gallium]-[di]sulphide film (CI[G]S).Table (2.4) lists out the TF module efficiencies now and forecasted to 2030.

Table 2.4: TF Module efficiencies (IRENA, 2013)

a-SI	2010	2015-2020	2030-
Max. effic., %	9.5-10	15	Na
Commercial effic., %	4-8	10-11	13
a-SI/µc-SI			
Max. effic., %	12-13	15-17	Na
Commercial effic., %	7-11	12-13	15
Cd-Te			
Max. effic., %	16.5	na	Na
Commercial effic., %	10-11	14	15
CI(G)S			
Max. effic., %	20	na	Na
Commercial effic., %	7-12	15	18

From the table (2.4), it can be stated that a-Si cells offers the least commercial efficiency and are also known for its issues concerning degradation whereas micro crystalline silicon and amorphous crystalline combinations tends to have higher efficiencies . First Solar, leading manufacturer of CdTe technology cells have targeted 19 percent commercial efficiency whereas Solar Frontier, manufacturer of CIGS technology aims 20 percent efficiency in research cells by 2017 (IEA 2014).

Emerging and Novel PV technologies:

The technologies such as concentrating PV (CPV), organic cells, thermo photovoltaic (TPV), inorganic thin films and novel PV devices such as dye sensitized calls, quantum dots and thermo electric cells are technologies that have significant promise for the future to come and are listed out in the table (2.5) (IEA 2014).

Concentrating Photovoltaic (CPV) use the concept of using sun tracking devices to concentrate the suns irradiation on the PV modules. The CPV are of two type's low concentrating PV and high concentrating PV. The low concentrating PV devices usually use the best in line c-Si cells whereas the high concentrating PV uses multi-junction PV cells. The lenses, refraction and reflection systems combine to form the concentration aspect of the PV system.CPV can only work with direct sunlight thus can only be used in the solar belt regions.

Table 2.5: emerging PV technology (IRENA 2013)

	2010	2015-2020	2030-
CPV			
Effic.(lab-effic.),%	20-25 (40)	36 (45)	>45
Major R&D areas and targets	lifetime; optical efficiency (85%), sun-tracking, high concentration, up-scaling;		
Inorganic TF (spheral cells, poly-c Si cells)			
Effic.(lab-effic.),%	(10.5)	12-14 (15)	16-18
Major R&D areas and targets	deposition, interconnection, ultra-thin films; up-scaling, light tailoring		
Organic cells (OPV, DSSC)			
Effic.(lab-effic.),%	4 (6-12)	10 (15)	na
Major R&D areas and targets	Lifetime (>15 yr), industrial up-scaling		
Novel active layers			
Effic.(lab-effic.),%	Na	(>25)	40
Major R&D areas and targets	Materials, deposition techniques, understanding quantum effects, up-scaling from lab production		
Up/down converters			
Module effic., %	+10% over ref. Material		
Major R&D areas and targets	(nano) materials, physical stability, up-scaling		

Organic cells are made of active organic layers which are made of very low cost materials and technology. They tend to be easily scalable but are quite inefficient and not durable. These include the dye sensitized solar cells but only have commercial efficiency of 4 percent thus making them go under intensive research and development to improve their competiveness in the market.

Advanced inorganic thin films are a step beyond thin film technology and it concentrates on areas such as spherical CIS approach and multi –crystalline thin silicon films .the former approach is when glass beads are covered by a thin multi-crystalline later and these spheres are interconnected to make modules and the latter is in research by COG Solar to get up to the efficiency of 15 percent in the lab. These emerging and novel PV technologies have great scope in the future as specific market needs like weightlessness, transparency, flexibility, color, organic forms, etc. would help in bringing these technologies into the commercial sector with better efficiencies and durability(IRENA, 2013) (IEA 2014).The national renewable energy laboratory has advocated from their market research, the current cell technologies and its efficiencies which shows that multi junction cells are most efficient, followed by crystalline Si cells, thin film technologies and emerging PV technologies (Figure 2.15).

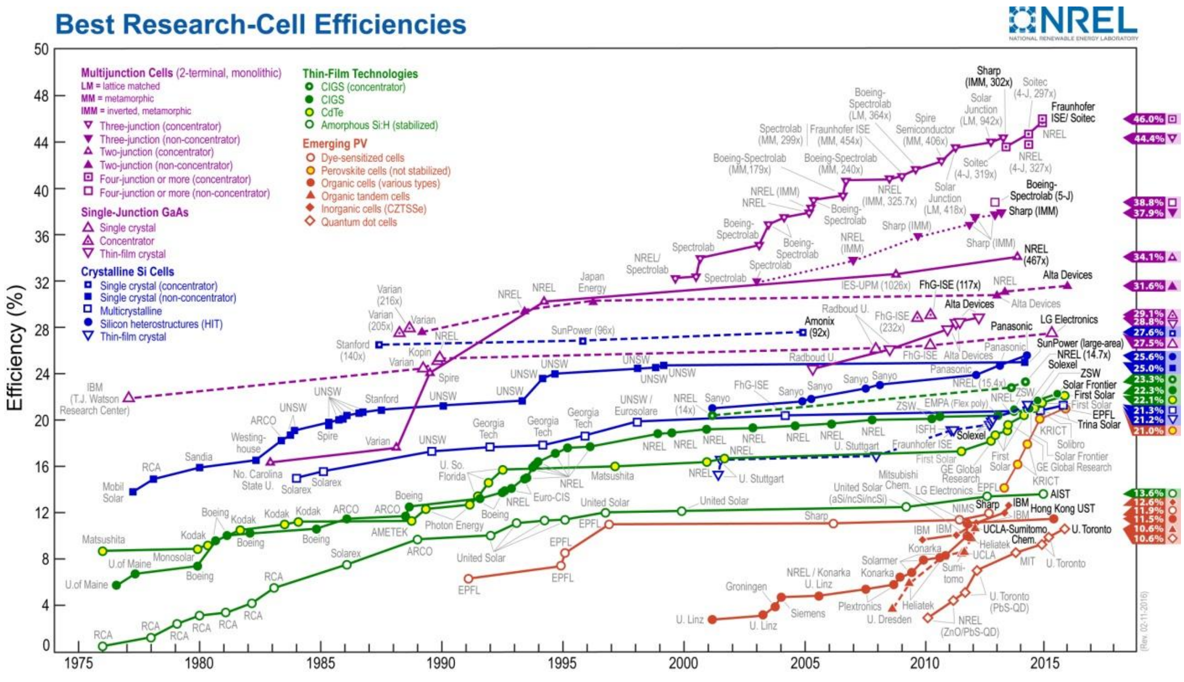


Figure 2.15: Cell Efficiency (NREL 2016)

Balance of system:

The balance of system, as mention previously, consists of all the non module aspects of the PV system. Most of the balance of system technologies are mature but inverters and batteries are still on the roadmap to create more efficient, durable, increased lifetime and commercial less costlier units as the cost of the PV modules have sharply declined thus giving weight on the fact that the balance of system costs comes in as higher than the PV modules.

PV system configurations:

PV system configurations are basically of three types; the stand alone system, the grid connected system and the hybrid system. These systems are selected basically after considering the load profile to be achieved and the PV system that can be installed in the given area.

Stand alone systems are ones provide only PV power to the end user. The system consists of a PV array that is connected to a charge controller. The charge controller is connected to the battery and switches of the PV array when the battery is full and switches the load before the battery becomes fully discharged. The size and capacity of the battery is as per the load needed by the system.

Grid connected systems are similar to power generation plants. The PV array (most likely to be of large scale) will be connected to the grid after going through a charge controller and an inverter. The system does not contain batteries which in turn reduce the cost of the system, but in case of grid blackout, this system cannot work as a standalone system.

A hybrid system is one when the PV system is complimented by other sources of power generation system such as wind energy systems, diesel generators, etc.
These systems are more complex than standalone systems due to sophisticated controls regarding charge controllers, inverter and battery systems. They may be cheaper than standalone system and can use variable resources of energy for power generation.

Barriers in development, efficiency and outlook of PV systems

Barriers in of PV systems can be categorised as the economic barriers and technical barriers. In the case of technical barriers, there are many parameters that affect the performance and efficiency of PV systems like the tilt and orientation at different regions, efficiency decrement due to temperature increase (approximately .5 percent for every 1 degree Celsius increment), weather, dirt, shadowing, age of PV modules and humidity. The table (2.6) gives a wide range of sources of loss found to be relevant by many authors.

Table 2.6: PV system losses (Parida et al, 2011)

Source of loss									Reference
Reflection (%)	Temperature (%)	Inverter (%)	Low irradiance (%)	Shading (%)	Soiling (%)	Ohmic (%)	Mismatch (%)	MPPT (%)	
–	3.0	7.8	–	7.1	–	–	3.8	–	Sugiura et al. (2003)
–	8.0–17.0	10.0–16.0	–	–	3.5–5.0	1.0–1.5	0.15–0.17	2.0–5.0	Mukadam et al. (1995)
–	–	15.0	–	–	–	2.5	2.0	–	Decker et al. (1992)
–	–	–	–	–		–	–	15.0	Caamaño and Lorenzo (1998)
–	–	–	–	35.0	10.0	–	–	–	Becker et al. (1997)
3.1	7.6	4.0	0.9	0.3	–	1.2	5.7	–	Iliceto and Vigotti (1998)
–	3.3	5.3	–	3.5	–	0.24	–	–	Steinhardt et al. (1998)
–	3.8	17.5	4.6	11	–	1.2	5.7	–	Baltus et al. (1997)
–	2.8	13.2	–	1.7	–	2.1	9.8	4.5	Schaub et al. (1994)
–	2.2	6.9	–	4.1	–	–	5.1	–	Kurokawa (1998)
–	4.0	8.0	–	7.0	–	–	6	–	Kato et al. (2002)
–	3.3	5.3	–	3.5	–	–	–	–	Jahn et al. (1998)
–	–	–	–	–	4.0	1.2	0.2	0.6	Durand et al. (1990)
–	–	10.0	–	–	3.0	–	5.0	–	Lloret et al. (1998)
2	4	15	7		1.5	1.0	1.0	2	Mondol et al. (2007)

In economic barriers, it is noted that due to the intermittent resource, the capacity factor of the system make it a more costly option considering other conventional electricity generation systems. In most countries, governments give tax incentives and feed in tariffs to promote the use of PV systems. However, it is useful to note that since 2001 the global PV market has grown significantly in terms of technology and commercial viability (IRENA, 2013).

The current future outlook of PV technology looks good with the great shift to renewable energy in many parts of the world. Incentives and tariffs in many countries have promoted use of PVs and have contributed in making a more sustainable environment. The many innovations and emerging technologies have risen with the market needs and competing against other conventional forms of energy effectively. If the current pace in placing economic incentives and technological advancements is kept, then the future outlook of PV tends to be very proficient.

2.1.5 WIND ENERGY

Wind is phenomenon of air in motion (convectional currents) due to temperature differences between distinct parts of the earth, especially between water bodies and land masses. Sea breeze and mountain valley winds are some examples where, due to the different rate of heating and cooling capacity of the land and water body thus creating low pressure and high pressure regions which eventually leads to generation of wind.

Wind energy is one of the abundant renewable resources which is inexhaustible and give out no emissions or polluting agents. Onshore wind energy is the energy produced by wind turbines on land whereas off shore wind energy is produced by wind turbines that are deployed in the sea which can be very far around several tens of kilometres from coastlines (IEA 2016). The world map (figure 2.16) illustrates the onshore wind potential, which shows areas like Africa, Greenland, and South America having a lot of wind potential at 9 m /s wind speeds.

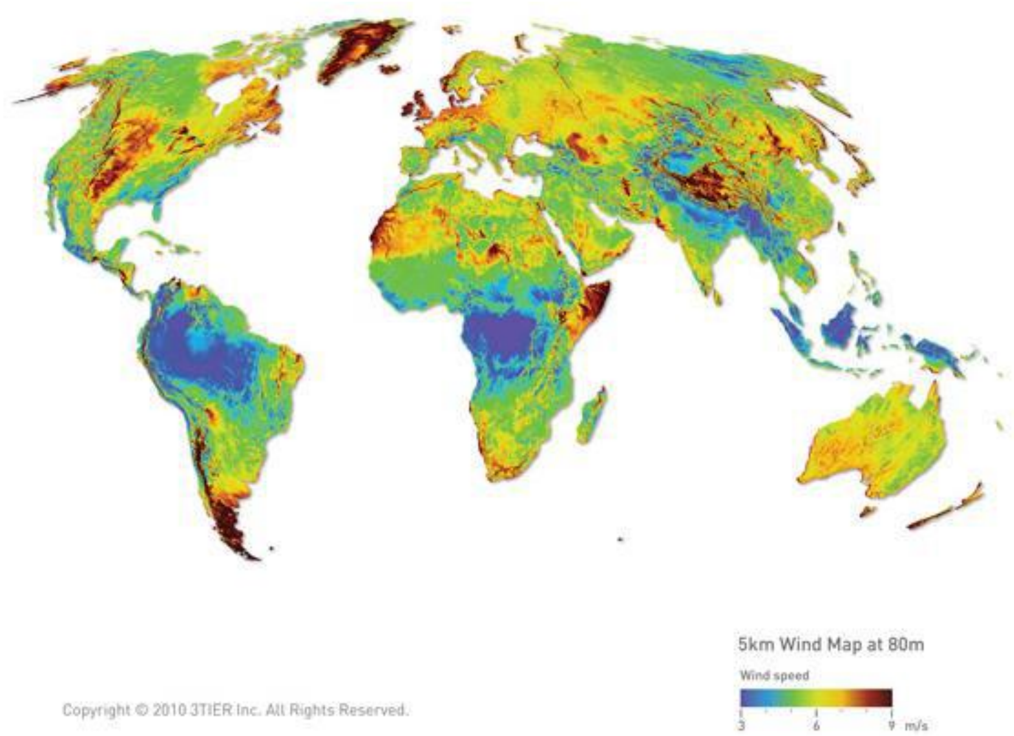


Figure 2.16: wind potential at 80 m (3TIER Inc, 2010)

The overall wind potential is still not completely detailed and mapped due to lack of onsite measurements especially in the developing countries and offshore sites. WBGU (2003) states that if we combine the onshore and offshore (close by) potentials, it may estimate to as high as 39000 TWh.

The global wind generation capacity (figure 2.17) is seen to have increased over the years. A slight slowdown was seen in 2013 which has been overcome in 2014 by around 4.4 percent increase (REN21, 2015).China, United States, Germany, Spain, India and United Kingdom are the leading countries in wind generation capacity. It is clearly seen that China is spending spectacularly on renewable energy generation which is mainly due uncertainties about future policies, reducing pollution and to be power independent.

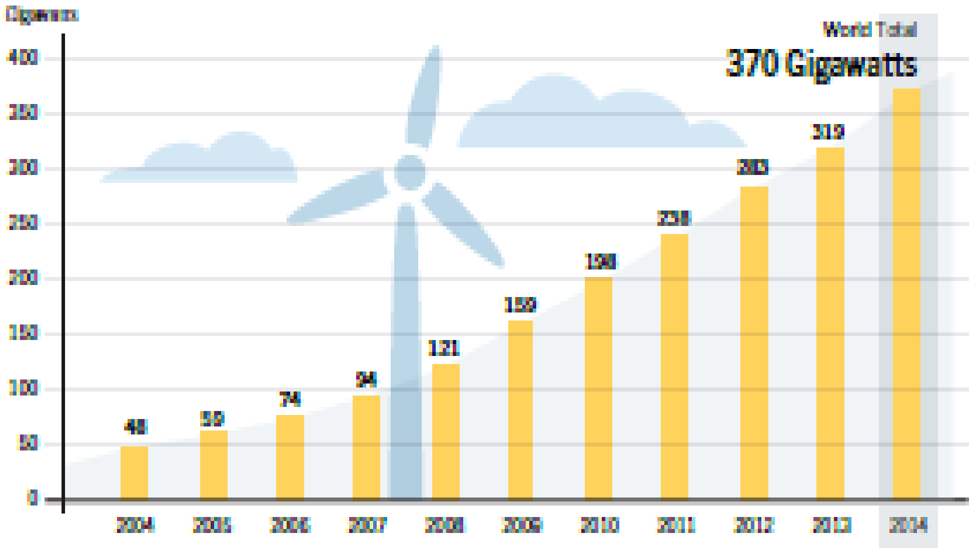


Figure 2.17: wind power global capacity (REN12, 2015)

From the figure (2.18), the wind turbine price and its variations from the year 1997 to 2011 is illustrated. It can be seen that from the year 2005, the amount of investment in the turbines have increased which has also led to the increase in the turbine prices till the year 2008. However, due to advancements in technology and increased market have reduced the prices of these turbines from the year 2009 onwards.

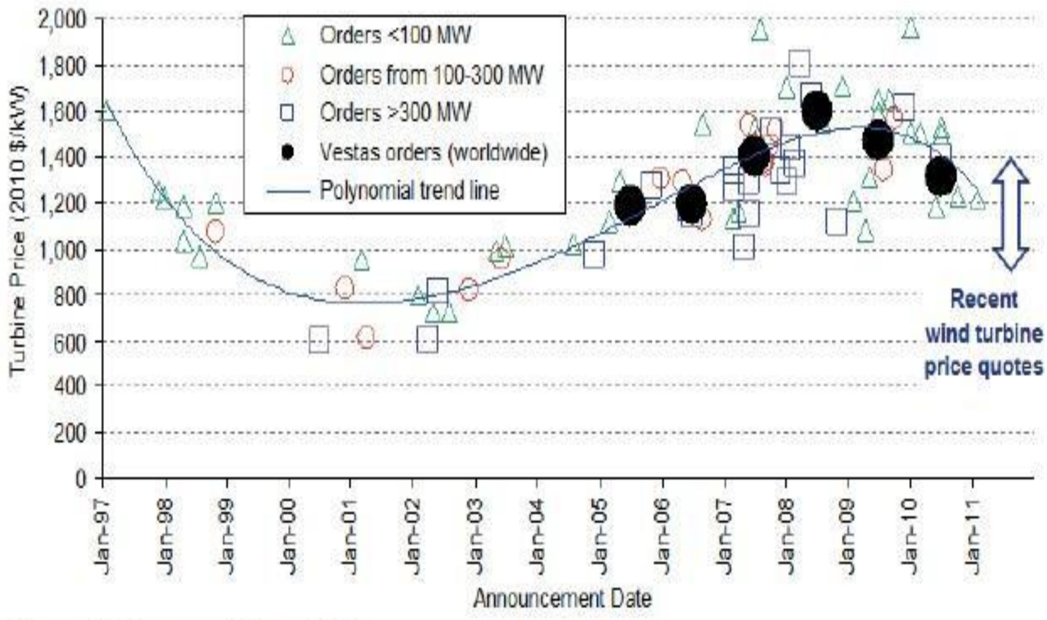


Figure2.18: wind turbine price trends (Bolinger and Wiser, 2011)

Wind generation is considered most affordable renewable power generation system that can be installed in developing countries (REN21, 2015).The main capital cost is for the turbine itself as illustrated in figure (2.19) which is mainly a onetime installation but the maintenance also needs to be considered. Currently, most of the wind farms are located onshore, and however there is a sharp interest towards offshore wind farms as the wind power and potential is high in these areas (figure 2.20 and 2.21).

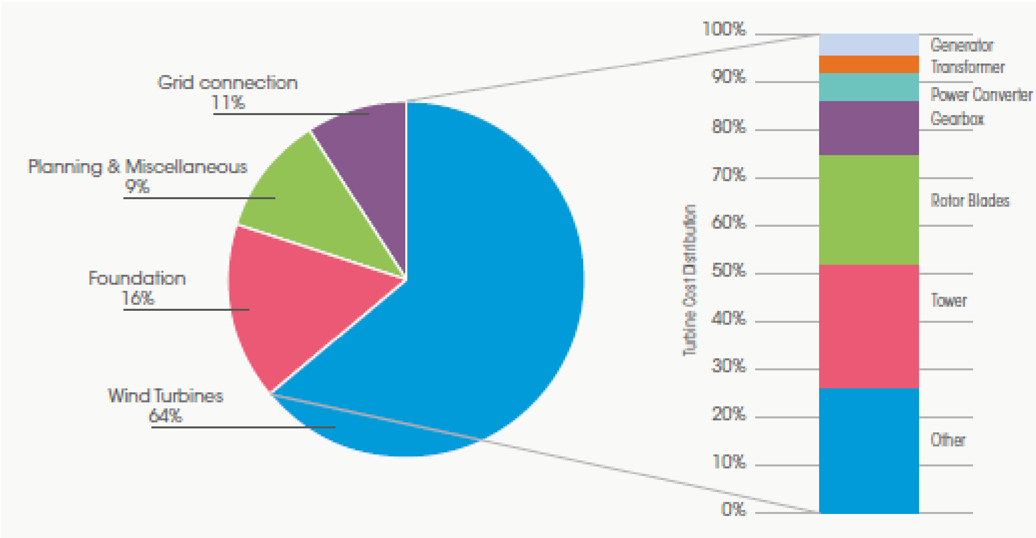


Figure 2.19: capital cost for wind power generation-onshore plants (Blanco, 2009)

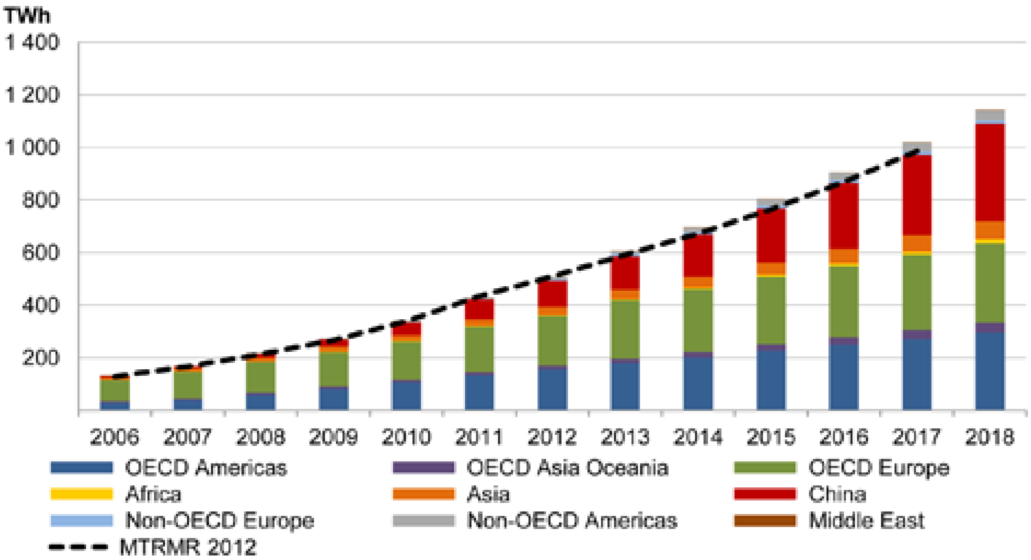


Figure 2.20: Onshore wind generation capacity (IEA, 2013)

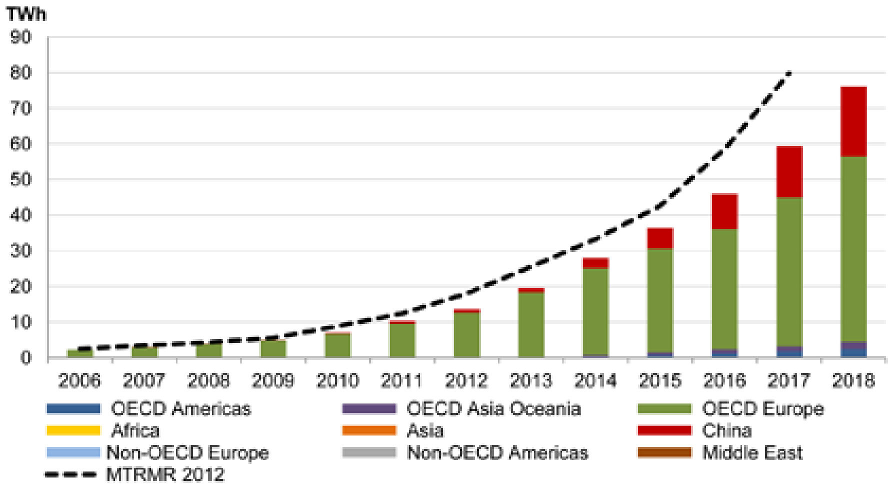


Figure 2.21: offshore wind generation capacity (IEA, 2013)

Wind turbines-working principle and power generation

The wind turbine (blades) basically captures the kinetic energy in the wind and converts it into mechanical energy, which is then converted to electrical energy through different power generation systems.

The rotor of the wind turbine moves due to lift and drag forces. The movement is created as the air on top of the blade creates a pressure on the bottom thus creating a lift and the axial setup would create a drag force (depicted in figure 2.22). This mechanism is quite similar to the wings of the aero plane as the air moves around the blade (Harvey, 2010).

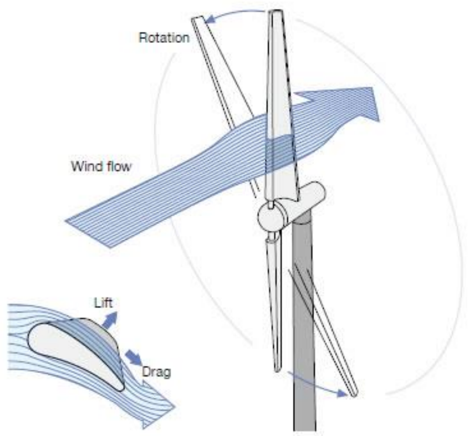


Figure 2.22: forces on a wind turbine (Clean Energy Brands, 2012)

When analyzing the energy from wind, it is simply the kinetic energy of moving air. Kinetic energy is understood from the equation $K = ½\ mv^2$; where m is the mass of air at the time in kilograms and V is the velocity in m/s. When we further do the calculation to find the power in wind, we can use the equation;
$P= ½\ \rho AV^3$, where ρ is the density of air, A is the area of cross-section and V is the velocity of air.

In wind turbines, there is downstream and upstream wind due to the volume of air in and volume of air out through the turbine blades. Thus the power produced in wind turbines can be equated as $P= ½\ \rho AV^3.C_p$, where Cp is the power coefficient (downstream / upstream wind).Theoretically, it has been calculated that the maximum value of C_p is 0.593.

Thus, the ideal efficiency or maximum efficiency from a wind turbine would be 59 %, which is called the Betz Limit (figure 2.23). The tip speed ratio would be speed at the tip of the blade divided by the velocity of the wind (Ragheb and Ragheb, 2011).

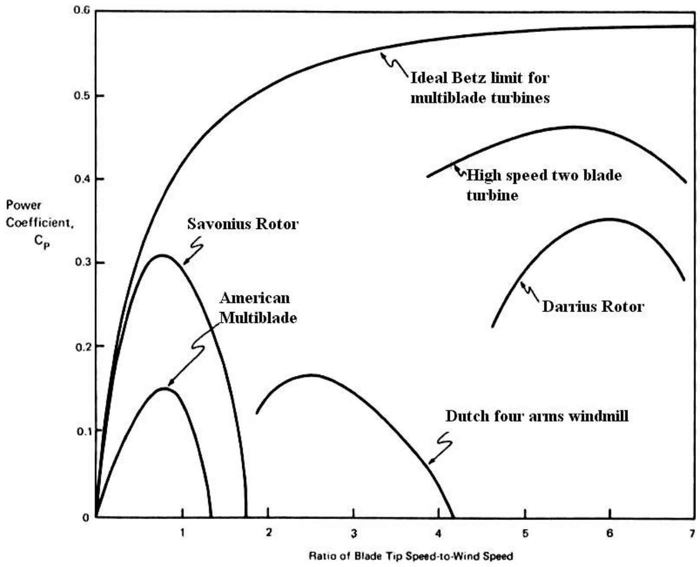


Figure2.23: Power coefficient for wind turbines (intechopen.com, 2016)

The power generated by different wind turbines varies with their characteristic wind speed- power curve this curve would define the amount of power the turbine can generate under certain wind conditions. This graph (figure 2.24) can also illustrate the cut in speed of the wind turbine, which is the minimum wind speed at which the turbine starts to rotate and generate electricity. The shut down speed is also depicted in the graph, at which point the turbine would shut down to save itself from technical and mechanical problems (Ackeramann, 2000).

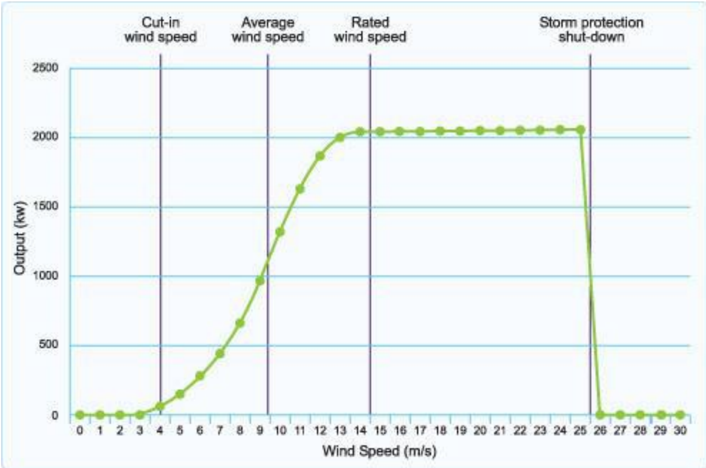


Figure 2.24: wind speed – power curve (PFR, 2016)

Many other factors such as availability of the turbine, roughness of the wind, load factor and variations (seasonal and annual) wind velocities affect the power generated by the turbines. As discussed above, the power generated is directly proportional to the cube of the wind velocity, thus making the velocity of wind and wind turbulence a major factor is the power generated.

While designing wind turbines, the height, and the span of the swept area of the rotor plays a major role considering the atmospheric boundary layer and the area of wind flow (figure 2.26 and table 2.7). The wind gradient in urban, suburban, flat and marine areas are different, which makes marine and flat areas best for installation of wind turbines as the turbulence would be low and power generated at shorter heights would suffice (figure 2.25).

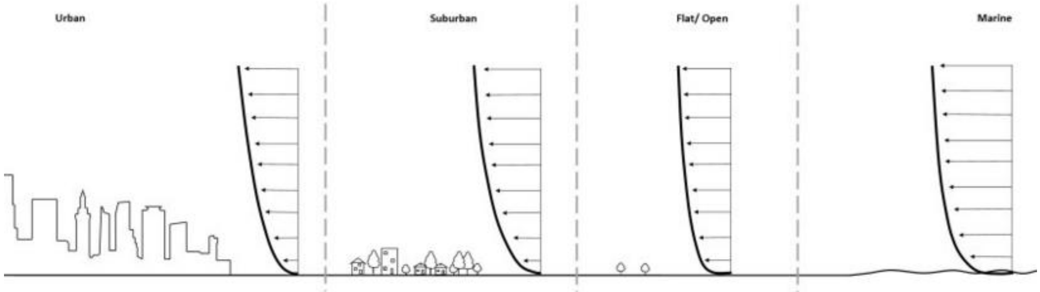


Figure 2.25: wind boundary layer (fiu, 2016)

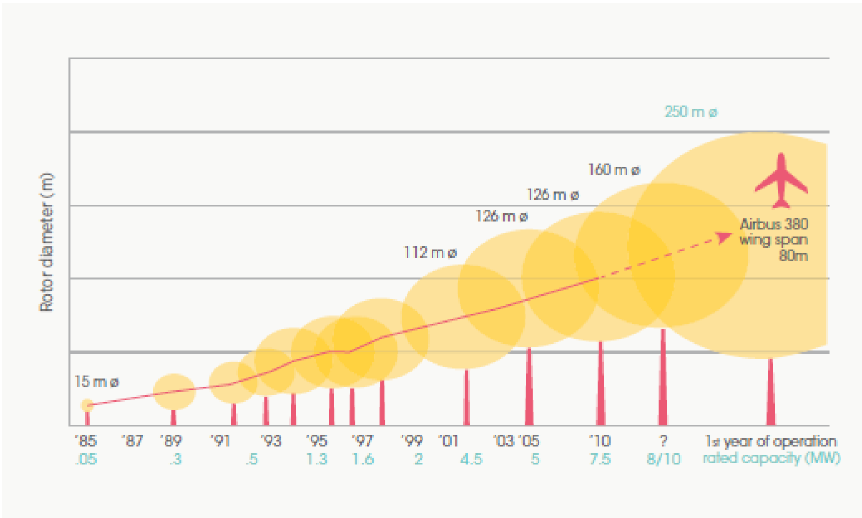


Figure 2.26: wind turbines – growth in size and capacity (UpWind, 2011)

Table 2.7: Impact of turbine size, rotor diameter and hub height in power generation of wind turbine (Nielsen et al, 2010)

Generator size, MW	Rotor, m	Hub Height, m	Annual production, MWh
3.0	90	80	7 089
3.0	90	90	7 497
3.0	112	94	10 384
1.8	80	80	6 047

Therefore, it is necessary to site the wind turbines in areas with high wind speeds and at a height where the wind would flow in a consistent speed with least turbidity. The higher and colder air temperature also affects wind power generated as the colder (denser) air contains more energy (IRENA, 2012).Thus this explains the main advantages of shifting to offshore wind farms other than the wind potential in the marine areas. At sea it would be easier to build very large turbines with just as large rotors but the factor of building, deploying and maintenance reduces the economic robustness of offshore plants. The Table (2.8) points out the different types of offshore wind turbine technology and concepts with their respective advantages and disadvantages.

Table 2.8: Offshore wind turbine types (EWEA, 2004)

FoundationType/ Concept	Aplication	Advantages	Disadvantages
Mono-piles	Most conditions, preferably shallow water and not deep soft material. Up to 4 m diameter. Diameters of 5-6 m are the next step.	Simple, light and versatile. Of lengths up to 35 m.	Expensive installation due to large size. May require pre-drilling a socket. Difficult to remove.
Multiple-piles (tripod)	Most conditions, preferably not deep soft material. Suits water depth above 30 m.	Very rigid and versatile.	Very expensive construction and installation. Difficult to remove.
Concrete gravity base	Virtually all soil conditions.	Float-out installation	Expensive due to large weight
Steel gravity base	Virtually all soil conditions. Deeper water than concrete.	Lighter than concrete. Easier transportation and installation. Lower expense since the same crane can be used as for erection of turbine.	Costly in areas with significant erosion. Requires a cathodic protection system. Costly compared with concrete in shallow waters.
Mono-suction caisson	Sands, soft clays.	Inexpensive installation. Easy removal.	Installation proven in limited range of materials.
Multiple-suction caisson (tripod)	Sands and soft clays. Deeper water.	Inexpensive installation. Easy removal.	Installation proven in limited range of materials. More expensive construction
Floating	Deep waters	Inexpensive foundation construction. Less sensitive to water depth than other types. Non-rigid, so lower wave loads	High mooring and platform costs. Excludes fishing and navigation from areas of farm.

Wind Power Technologies:

The technologies governing wind power are mainly categorized considering its vertical axis and horizontal axis. The wind turbines with vertical axis are called VAWT and the ones with horizontal axis are called HAWT. Most widely used turbines are the ones with horizontal axis and they are made in large scale usually with three rotating blades and used in most power generation utilities .The turbines with vertical axis have less market share compared to HAWT and are said to be theoretically less aerodynamic and less efficient. Brief explanations on both the systems are given below.

Horizontal Axis Wind Turbine (HAWT)

The horizontal axis wind turbines are usually further classified technically with relationship to the placement of their rotor (upwind or downwind), the number of blades, the generators output regulation system, the connection to the hub and the rotor (rigid or hinged), the type of gearbox used, the stable rotational speed of rotor and the turbine capacity (IRENA, 2012).

The HAWT usually contains a nacelle mounted on a vertical tower. The generator, gearbox, and rotor are contained within the nacelle (figure 2.27). This nacelle can be controlled in different ways to easily point it towards the oncoming wind and away from the wind in case of high speed winds that may damage the turbine (Ackermann, 2000). The design of HAWT is such that it has to be always pointed at the direction of the wind to get maximum power out of the wind energy. The most differentiating factor of HAWT is its number of blades and most power generating wind farms use two or three bladed wind turbines (Eere Energy, 2012).

They are usually termed as high solidity devices and low solidity devices depending upon the number of blades with which shows disc like solidity or have voids instead. HAWT can be further divided into Dutch windmills (used for grinding grains), multi blade windmills (used to pump water on low wind speeds), and high speed propeller machines (used to generate electricity) depending on its functionality.

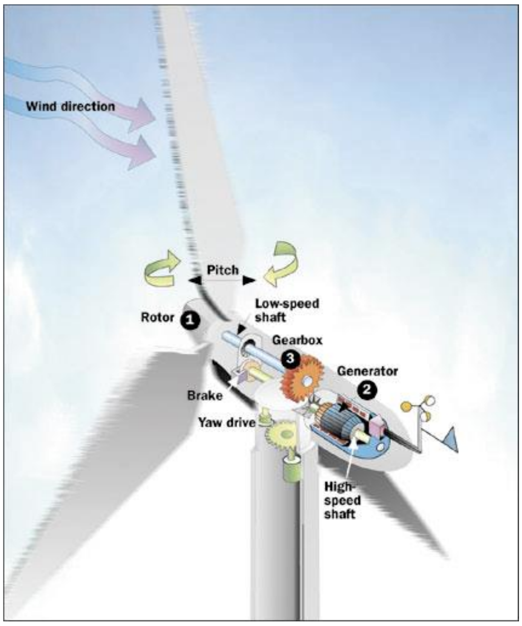


Figure2.27: HAWT Turbine parts (Charlotte Hill, 2012)

Vertical Axis Wind Turbine (VAWT)

Vertical axis wind turbines are much rarer in the market due to their low technological advancements and issues in efficiency. The mechanism in capturing the wind power is through aerofoil or air scoops that would rotate perpendicular to the direction of the wind thus making them able to use the wind in any direction.

The structure of the vertical turbine consists of a vertical rotor shaft connected to the gearbox and generators which can be mounted on the ground (figure 2.28) .They cannot handle high wind pressures as it may lead to fatigue thus making them efficient only in low level areas where the wind pressures are not as high. The VAWT turbines are classified further into the Darries (efficient, large torque ripple and less starting torque), Savonius (drag turbines, vertical shaft with scoops), and Giromill (straight blades, variable pitch and self starting) rotors. (Vijay and Sethi, 2011). Table (2.9) that compares the HAWT and VAWT type wind turbines.

Figure 2.28: VAWT turbine (Vijay and Sethi, 2011)

Table 2.9: comparison between HAWT and VAWT (windturbinestar, 2016)

Performance	Horizontal axis	Vertical axis
Power generation efficiency	50% - 60%	Above 70%
Electromagnetic interference	YES	NO
Steering mechanism of the wind	YES	NO
Gear box	Above 10KW:YES	NO
Blade rotation space	Quite large	Quite small
Wind-resistance capability	Weak	Strong (it can resist the typhoon up to 12-14 class)
Noise	5-60dB	0-10dB
Starting wind speed	High (2.5-5m/s)	Low (1.5-3m/s)
Ground projection effects on human beings	Dizziness	No effect
Failure rate	High	Low
Maintenance	Complicated	Convenient
Rotating speed	High	Low
Effect on birds	Great	Small
Cable stranding problem	YES	NO
Power curve	Depressed	Full

Outlook of wind power systems

Currently the wind resource has increased generation and installation rates compared to the last years. Wind technology is advancing in terms of power generating turbines with many software available to understand the efficiency rates that can be achieved by these wind farms. More research needs to be involved in creating innovative turbine designs to reach maximum efficiency.

The market trend shows a stabilized growth in wind power generation in most wind potential countries. On the medium outlook, the global capacity might double in terms of the market research by IRENA (2014) and may reach up to 600 GW in 2020 (figure 2.29). With global incentives and feed in tariffs, advanced technology, good grid integration, and reduced cost, wind energy has many opportunities to grow into a leading renewable energy generator.

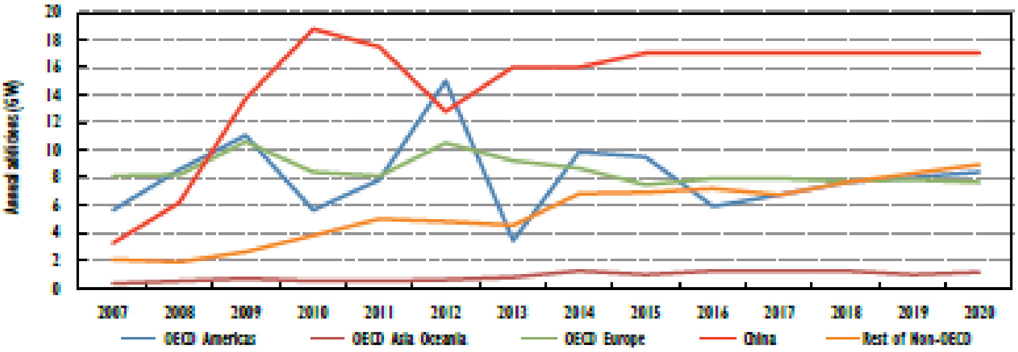


Figure 2.29: annual capacity addition for onshore wind turbines (IRENA, 2014)

2.2 WATER DESALINATION – CURRENT TECHNOLOGIES AND DEVELOPMENTS

Water desalination is a process by which portable water is deduced from saline water by the use of many processes. Desalination is an energy intensive process a as explained in the section 1.2 and also a very important one in the regions with physical water scarcity. Desalination of water is governed by many principle technologies such as thermal technologies and membrane based technologies.

Nowadays innovative and alternatives technologies are also under development for commercial based utilization.

2.2.1 THERMAL BASED DESALINATION TECHNOLOGY

In thermal based desalination technology, the most matured ones are multi stage flash distillation, multi effect distillation and Vapour compression. Other emerging technology in this domain include membrane distillation, humidification-dehumidification, adsorption desalination and pre-vaporization (Subramani and Jacangelo, 2015).

Multi Stage Flash (MSF) is the most rudimentary technology in thermal based desalination technologies. Flashing of water i.e. quickly evaporating it, is the basic principle used for desalinating the water. The MSF process has many stages (as illustrated in figure 2.30), through each stage, saline water which is heated to 90-110 degree Celsius is made to pass through. These stages have decreasing pressure which makes part of the water flash through each stage. Finally, the flashed water is cooled using a condenser and then processed as portable water (IRENA, 2012).

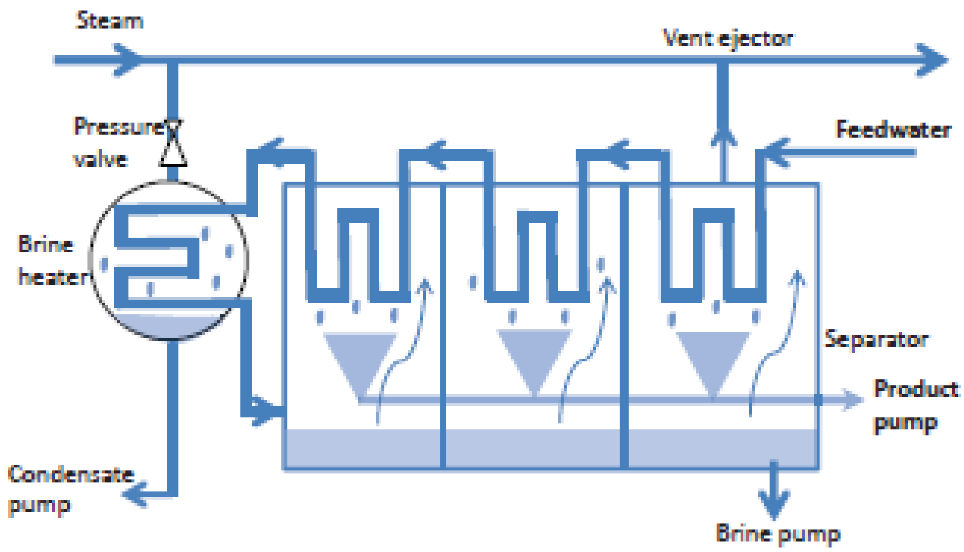


Figure 2.30: Multi stage flash distillation (Fichtner, 2011)

Multi Effect Distillation (MED) is a process of desalination that is considered most thermodynamically efficient as the heated water passes through many stages or effects with the ambient temperature being gradually decreased in each effect. In the first effect, the seawater is raised to boiling temperatures and then is sprayed into preheated tubes to induce evaporation. These tubes are generally heated by the steam from a dual purpose power plant. The steam condensate is used by the power plant for its boiler feed water. The number of effects plays a significant role in the economy of the desalinated water. During the process of MED, in the first effect the remaining saline water after evaporation is fed into the second effect where it is introduced into a second bundle of tubes. The continual process and evaporation and condensation in each effect leads to the production of portable water (Khawaji, Kutubkhanah and Wie, 2008).

Vapour Compression (VC) is a process of desalination by which the heat needed for the evaporation of the brine comes from compression of vapour. Methods used to compress the vapour are usually through a mechanical compression and a steam jet (Khawaji, Kutubkhanah and Wie, 2008). This type of distillation is usually done in combination with MED processes to achieve a better efficiency (IRENA, 2012).

Below are some emerging technologies in thermal desalination processes that are still under research and development for better efficiency and economic viability.

Membrane distillation (MD) is an emerging technology in thermal desalination technology where the desalination is through a thermally driven process in membrane technology. In the process of desalination, the water vapour is made to pass through a hydrophobic membrane induced by the temperature differential across the membrane which results in a difference in the vapour pressure. This in turn results in the transfer of the produced vapour to the condensation surface, from which the portable water is collected (Wan and Chung, 2015).

Humidification- dehumidification (HDH) is the process which utilizes the fact that air has an increased ability to carry water vapour at higher temperatures. The process involves the heated air or carrier gas that would be in contact with the saline water which produces a certain quantity of water vapour. This is then condensed by dehumidification methods and distilled water is obtained (Kabeel et al., 2013).

Adsorption desalination is a process which uses highly porous silica gel beds, evaporator, and condenser in corporation with waste heat or solar heat to power the sorption cycle. The main process can be described as vaporization of water using an evaporator followed by vapour sorption /desorption into the silica gel, which is then condensed using a condenser (Ng et al., 2013).

Pervaporation is a process that combines membrane permeation and water evaporation. The technology is such that it separates the saline mixtures in contact with a membrane using preferential removal of one of the components of the mixture according to its better affinity on diffusing through the membrane. This is still very much in the research and development stage as membranes that are a viable option to this process is still not found (Xie et al., 2010).

2.2.2 MEMBRANE BASED DESALINATION TECHNOLOGY

Membrane based desalination uses membranes to filter out or separate the salt and other minerals in the saline feed water. The feed water is made to pass through the membranes which would selectively filter out the unwanted salts. Reverse osmosis process and electro dialysis are the dominant technologies in membrane based technologies (IRENA, 2012). Many new technologies concerning novel membranes, forward osmosis and semi batch reverse osmosis are in development in this domain (Subramani and Jacangelo, 2015). As the study involves a RO desalination plant, this process would be studied in detail to achieve a greater understanding about this technology.

Reverse Osmosis desalination (RO) is the process by which the pressure of the feed in water is increased above the osmotic pressure such that the saline water passes through the membrane leaving the salts behind. The main components of a single pass Sea Water Reverse Osmosis (SWRO) plant are; feed water intake, pre-treatment units, high pressure pumps, membrane units and post treatment units (illustrated in figure 2.31).

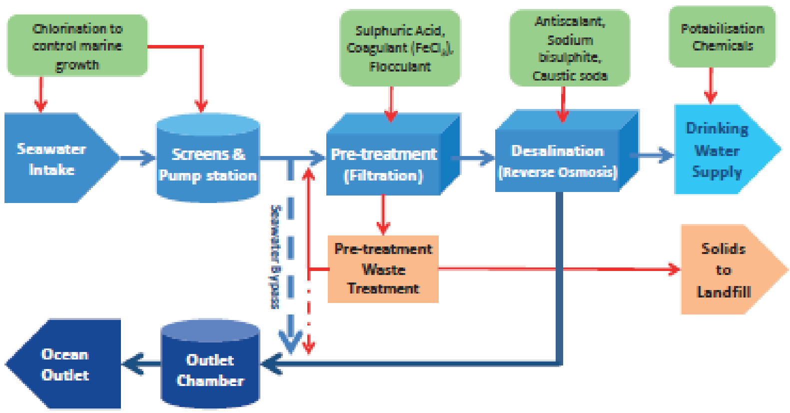


Figure 2.31: Reverse Osmosis desalination process (Fichtner, 2011)

The feed water is pumped usually from the sea well which is not so far away from the plant site. The quality of the feed in water such as temperature, salinity, and turbidity plays a major role in desalination using RO membranes. Pre-treatment is done to avoid scaling in the membranes, which is a process by which the membrane deteriorates due to deposition of salts on the surface of the membrane. The basic pre-treatment would include chlorination using sodium hypo chloride, coagulation, acid addition, multi media filtration, micron cartridge filtration, and de-chlorination (with sodium bisulphate).

The pre-treatment starts with particle filtration usually using a multi media gravity filter or a dual media filter. The media usually used are anthracite, silica, granite, or sand. This primarily filtered water flows through a micron cartridge filter which usually filters out particles more than 10 microns in size. Further filtration is done using 5 micron and 1 micron cartridge filters with a minimum of 2 bar pressure kept for the feed water .The filtered feed water starts its pre-treatment before entering the membrane array where as the brine is discharged into the sea after reducing its concentration. The feed water is then treated with various chemicals according to the quality and characteristics of the feed water. Various chemicals like sodium hypochlorite (to prevent micro organism growth), ferric oxide (as flocculent), sulphuric acid (for adjustment of pH, control of hydrolysis and scale formation) and sodium bisulphite (de-chlorination).

The pre-treated water is introduced to the high pressure pumps, usually centrifugal pumps, that increases the pressure of the pre-treated water to the appropriate pressure that can be handled by the membrane. The membrane configurations that are commercially used includes spiral wound membranes and high recovery low energy membranes. The membrane lets the water pass through and retains the salts behind. The water that is obtained from the membranes goes through the process of post treatment to make it suitable for drinking purposes. The usual post treatment comprises ph adjustment using caustic soda, addition of lime, removal of dissolved gasses and disinfection. This water obtained can be used as portable water for drinking purposes.

A development that has helped reduce the energy consumption in RO plants are called the energy recovery device. These devices are connected to the discharge water that comes from the RO membrane with usually only 1-4 bar difference pressure from the initial pressure of the feed water before it enters the membranes. These devices are of many kinds and they practically convert the kinetic energy in the water to mechanical energy which can be used in the system. This is the basic principles and function of a reverse osmosis seawater treatment plant. Many other processes using the membrane technology is further discussed.

Electro Dialysis (ED) is the process through which the electrical potential is utilized to relocate the salt through the membrane and leave behind the fresh potable water. As the energy consumption for the process is determined by the feed water salt concentration, usually only brackish water and not sea water is used in the ED desalination plant (IRENA, 2012).

Developments in technology for membrane based desalination are through the development of new membrane materials and technology that can increase the efficiencies of the desalination plants. **Novel Membranes** for RO desalination deals with new and different membranes that can be used in the reverse osmosis process such as Nano-composite membranes, Aquaporin membranes, Nanotube membranes, and graphene based membranes (Subramani and Jacangelo, 2015).

Semi-batch RO process puts together a portion of raw feed water and another portion of circulating concentrate. In this process, energy consumption is reduced by making use of different operating pressure with internal recirculation of the concentrate and using a membrane array with only three or four units per pressure vessel; this holistically reduces the feed in pressure needed thus reducing energy consumption (Efraty et al., 2011).

Forward Osmosis is a process by which a concentrated draw solution is made instead of using high pressure as in conventional reverse osmosis plants. This concentrate creates a high osmotic pressure which enables the water from the feed in solution to be pulled in through a semi permeable membrane. The solute (usually mixture of ammonia and carbon dioxide) in the drawn water is further recycled (usually heated) and then the final portable water is obtained (Subramani and Jacangelo, 2015).

2.3 DESALINATION AND RENEWABLE ENERGY

Desalination coupled with renewable energy can be considered a very sustainable way for the production of fresh potable water. The trend towards renewable energy has given a positive light to using renewable energy with desalination due to more economic feasibility. The most effective way to use renewable energy in desalination is to select a type of renewable resource that is locally available, such as solar power in desert areas. Areas which are off the grid or have less capacity of transmission and distribution of energy can benefit by using renewable technologies with desalination.

The main renewable resources used for desalination purposes are solar thermal, solar photovoltaic, geothermal and wind energy (figure 2.32 and figure 2.33).

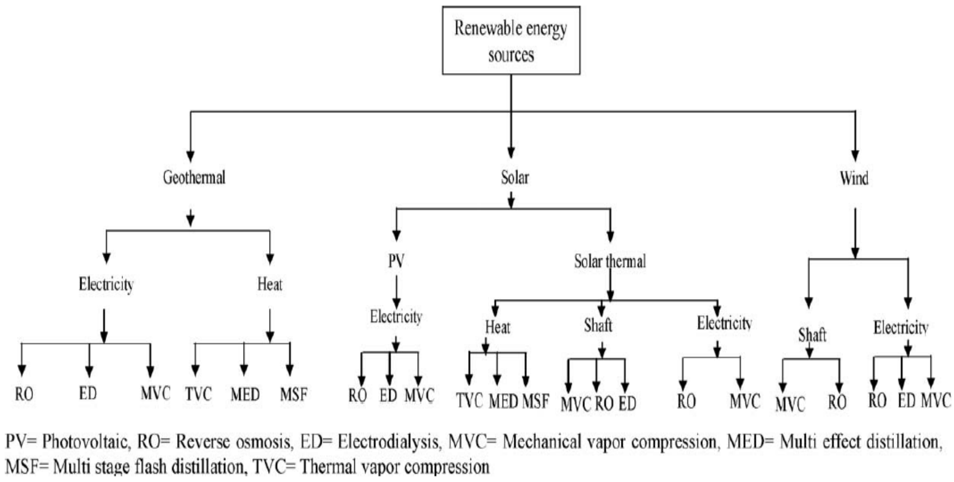


Figure 2.32: combinations possible for desalination with renewable energy (Eltawil, Zhengming and Yuan, 2009).

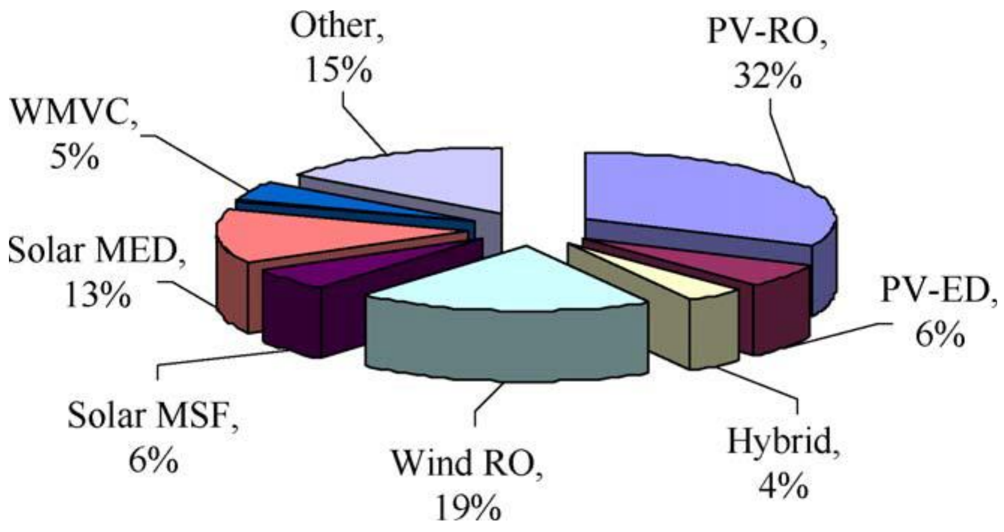


Figure 2.33: Renewable energy combined with desalination (Eltawil, Zhengming and Yuan, 2009).

Even though desalination using renewable energy is very less- around 1% of total desalination capacity in 2008 (EU, 2008), the market tread seems to be going towards use of renewable resources in desalination to reduce carbon footprint and with increased technological efficiencies. This type of desalination falls into two domain, the former one uses the thermal heat from the renewable resource whereas the latter uses the electricity generated or the mechanical energy for desalination purposes (Eltawil, Zhengming and Yuan, 2009).

The most dominant desalination technology that uses renewable energy is by reverse osmosis with around 62 % followed by MSF and then MED (EU, 2008).Photo voltaic technology is the most commonly used renewable energy technology in desalination, especially in membrane processes.

It is very important to understand the factors concerning the selection of the renewable energy and the type of desalination technology. Most importantly, the technical feasibility and the economic viability should be well analysed.

In the comprehensive analysis concerning renewable technology and desalination technology selection; many factors come into play such as geographical location, feed water input quality (turbidity and salinity), locally available renewable resources, plant capacity, grid capacity and connection, O and M requirements, etc. The figure (2.34) shows the flows of steps to be considered in designing an appropriate renewable energy desalination plant, which shows the first steps as identifying the water shortage areas and the technology database. Taking these factors into consideration, many RE desalination plants have come into development especially in arid regions like Saudi Arabia, Morocco, Abu Dhabi, Turkey, Egypt, Jordan, Cyprus and Canary Islands (IRENA, 2012).

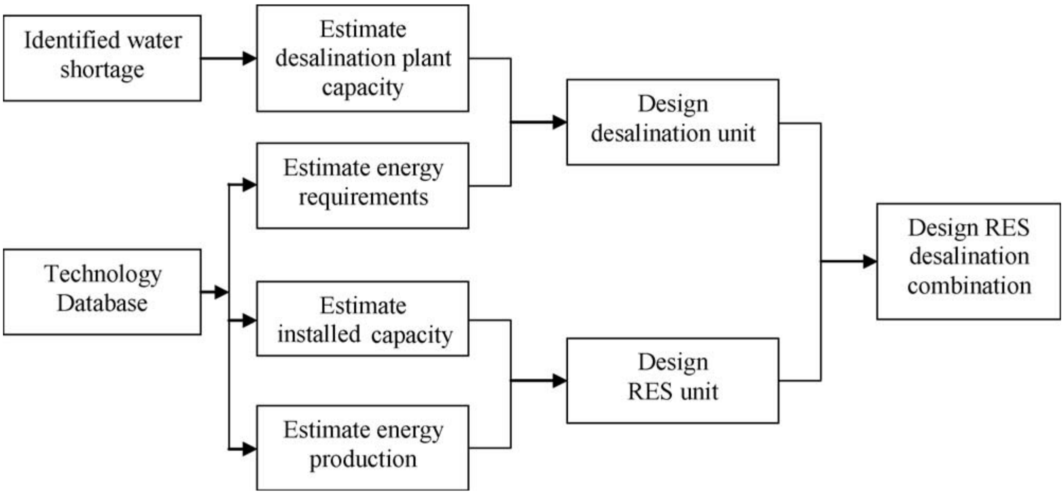


Figure 2.34: designing the appropriate RE desalination plant (Eltawil, Zhengming and Yuan, 2009).

2.3.1 DESALINATION WITH SOLAR THERMAL ENERGY

Solar thermal energy is usually used for MSF and MED desalination plants where thermal energy is used in the process of desalination. The desalination associated with MSF and MED plants can be using direct and indirect processes, where the former process is through direct integration with all components of the plant whereas the latter uses heat from solar collectors and solar ponds (Kalogirou, 2005).

Another combination for using solar thermal energy is through the use of CSP plants with desalination. By the use of CSP plants, both heat and electricity can be generated thus can be also combined with reverse osmosis plants. Combination with CSP plants can be used for medium and large scale desalination units and can be used in multipurpose ways as illustrated in figure (2.35).

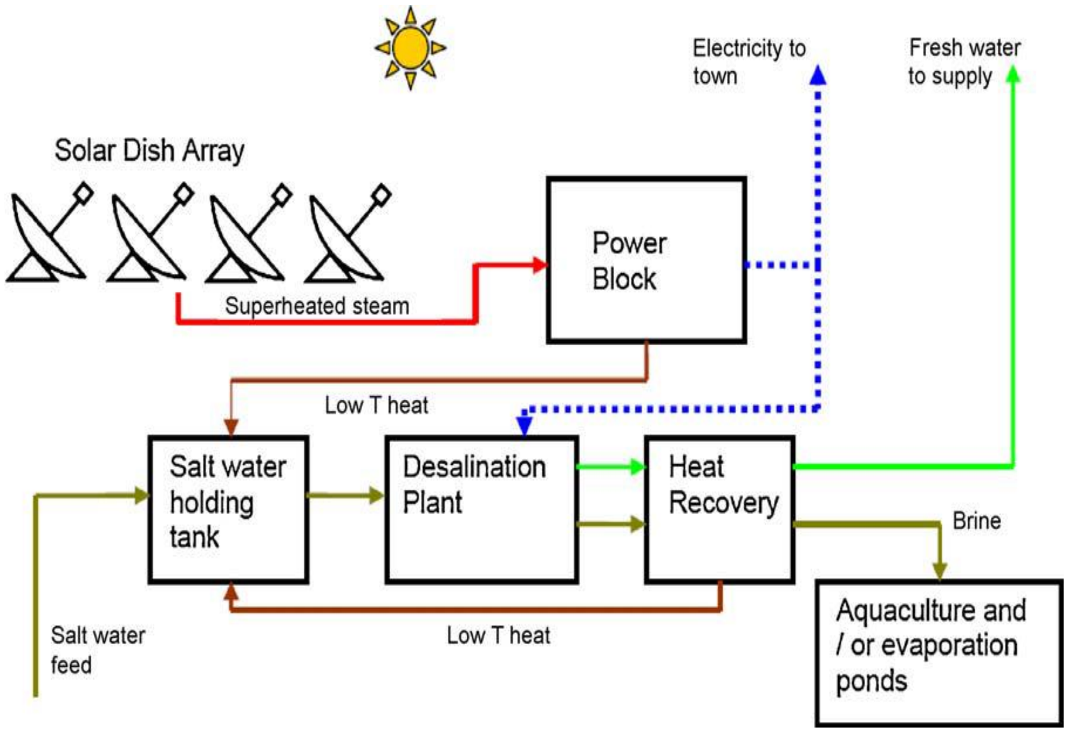


Figure2.35: RO system with solar thermal power (Eltawil, Zhengming and Yuan, 2009).

2.3.2 DESALINATION WITH PHOTOVOLTAIC ENERGY

By using photovoltaic energy, we can obtain electricity directly from the photovoltaic array thus making it a suitable option for reverse osmosis and electro dialysis desalination units as these units need only electricity as the input energy source. This type of coupling has been demonstrated on various remote parts of the earth who usually have physical water scarcity like in Canary Islands where a PV powered RO plant which uses seawater is functional, Saudi Arabia with a PV – RO plant which uses brackish water and in Ohshima Island which has a functional PV – ED desalination plant (Kalogirou, 2005).

In the figure (2.36), a schematic diagram of the PV-RO desalination unit is shown, and it is clearly seen that the energy generated through PV is usually used to power the pumps as they are very energy intensive. The main issues concerning these photovoltaic integrated systems is the high cost of the storage systems (batteries) needed to store the electrical energy. The maintenance and correct operation also place a big role in the battery life thus making it a very important part of the system to consider economically. More advancements in electrical storage may enhance further use of these resources as it would then become much more economically viable.

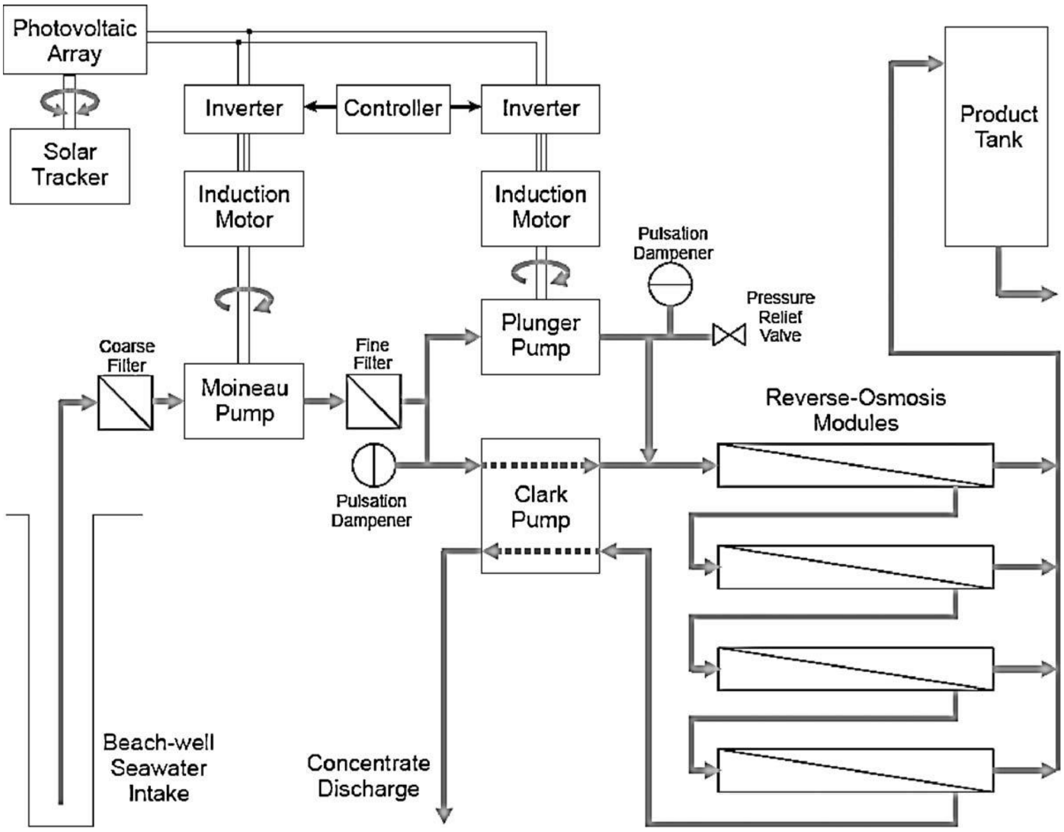


Figure 2.36: Schematic diagram of PV- RO desalination plant (Thomson, 2003).

2.3.3 DESALINATION WITH WIND ENERGY

Wind energy can be used in mechanical form as well as electrical form in desalination units; the former can be used in vapour compression units, especially in mechanical vapour compression, whereas the latter form of energy can be used in reverse osmosis units and ED desalination units. Areas with high wind potential (like islands and coastal areas) would be the most viable option for using wind energy for desalination processes.

The many functional desalination units that use the power of wind includes Canary Island (wind- reverse osmosis unit using seawater), Fuerteventura Island (wind – diesel hybrid system using seawater) and Centre for Renewable Energy System technology in UK which has an operational wind – RO plant using seawater (Al-Karaghouli et al., 2009). The main problem in integrating wind in RO is that wind being an intermittent source of renewable energy can lead to need for electrical storage or alternative energy resources in case of electrical energy and in case of mechanical energy, another alternative source of energy may be needed.

2.3.4 DESALINATION WITH GEOTHERMAL ENERGY

From geothermal energy, one can derive both thermal energy as well as electricity thus making it an option for both membrane type and thermal technology desalination. For multi effect distillation process desalination, the low temperature geothermal energy of about 70-90 degree Celsius is ideal. An example of such a system is proposed in Milos Island, Greece. The system proposed is a MED desalination unit that can produce 1920 m3/d of portable water .It is run by dual systems; either an organic Rankie cycle or a 470 kWe turbine to generate energy from the hot water obtained from geothermal wells. Coupling of geothermal energy with desalination is quite rare due to the fact that it can be utilized only in certain geographical areas and mostly the upfront capital costs for such systems are very high (IRENA, 2012).

2.4 DESALINATION COSTS

The economic feasibility of a desalination plant mainly depends on the cost that is spend on running it using energy. Thus if the cost of energy is locally cheap, then the desalination costs would decrease as mentioned before, desalination is a very energy intensive process (Zejli et al., 2002).The site where the desalination plant is located also plays a very important role in considering the economic feasibility considering feed water temperature, fee water transportation, fresh water transportation, disposal of brine, etc.

In reverse osmosis plants, the maintenance and operations costs are quite high due to the high complexity and membrane segments incorporated in the plant. When we consider the case of a typical desalination plant that runs with electricity (price of 5-6 US cents /kWh), it can be observed that 30 % of the costs are due to the use of electricity. When the case of desalination plants with renewable energy is considered, the economical feasibility is analysed after looked at the investments costs of renewable technology and the area or location where the plant is placed. Table (2.10) lists down the different type of technology and its energy demand, cost of water produced and its development stage. It is observed that solar stills, solar multiple effect humidification, PV osmosis and wind reverse osmosis are in the application stage where as the rest are still in the research and development stage.

Table 2.10: Renewable desalination comparative costs (IRENA, 2012)

	Technical Capacity	Energy Demand (kWh/m^3)	Water Cost (USD/m^3)	Development Stage
Solar stills	< 0.1m^3/d	Solar passive	1.3–6.5	Application
Solar-Multiple Effect Humidification	1–100 m^3/d	thermal: 100 electrical: 1.5	2.6–6.5	R&D Application
Solar- Membrane Distillation	0.15–10 m^3/d	thermal: 150–200	10.4–19.5	R&D
Solar/CSP-Multiple Effect Distillation	> 5,000 m^3/d	thermal: 60–70 electrical: 1.5–2	2.3–2.9 (possible cost)	R&D
Photovoltaic-Reverse Osmosis	< 100 m^3/d	electrical: BW: 0.5–1.5 SW: 4-5	BW: 6.5–9.1 SW: 11.7–15.6	R&D Application
Photovoltaic-Electrodialysis Reversed	< 100 m^3/d	electrical: only BW:3–4	BW:10.4–11.7	R&D
Wind- Reverse Osmosis	50–2,000 m^3/d	electrical: BW: 0.5–1.5 SW: 4–5	Units under 100 m^3/d, BW:3.9–6.5 SW:6.5–9.1 About 1,000 m^3/d, 2–5.2	R&D Application
Wind- Mechanical Vapor Compression	< 100 m^3/d	electrical: only SW:11–14	5.2–7.8	Basic Research
Wind-Electrodialysis	–	–	BW: 2.0–3.5	–
Geothermal-Multi Effect Distillation	–	–	SW: 3.8–5.7	–

Solar Stills: simple and old technology where the incident short wave radiation is transmitted and absorbed as heat
Multiple Effect Humidification: use of heat from highly efficient solar thermal collectors to induce multiple evaporation/condensation cycles
Membrane Distillation: thermally driven distillation process with membrane separation
Reversed Electrodialysis: same principle as **Electrodialysis** (ED) except for the fact that the polarity is reversed several times per hour
CSP: Concentrated Solar Power
BW: Brackish Water; **SW**: Sea Water
Note: cost calculated at the exchange rate of 1.3 from euro to USD.

2.5 BARRIERS TO RENEWABLE DESALINATION

Barriers in development of renewable desalination can come in technical, economic and organizational levels.

- Technically, the intensive energy need for desalination would put stress on the type of renewable technology that can be used in the plant. The variable nature in the renewable energy sources also plays a major role in determining the best technical feasibility.
- Environmental issues that puts stress in the organizational level is mainly due to the disposal of brine. The increasing capacity of desalinations plants means that there would be more brine to dispose. Brine being highly saline can cause problems to ecosystems and create negative environmental impacts .Thus, a feasible and sustainable solution for brine disposal should be observed.
- To have economic feasibility, niche markets should be identified and regulations and policies that would promote the investment on renewable desalination plants should come in place.

The energy water nexus should be understood properly and trained personals in this field would increase more potential to go towards a sustainable future consisting of renewable energy desalination.

2.6 SHARJAH, UAE –CLIMATIC CONDITIONS

Sharjah is one of the seven emirates in UAE and is on the north eastern part of the country. The location of the emirate on the north eastern belt characterises it with tropical desert climate which consists of hot humid summers and short warm winters. The hot summers gives a high potential in solar energy as it can be observed in figure (2.37) and (2.38), which shows high irradiation levels in the months May to August, whereas, the temperature ranges between a low of 71°F to a high of 94°F with months May to August showing exceptionally high temperatures.

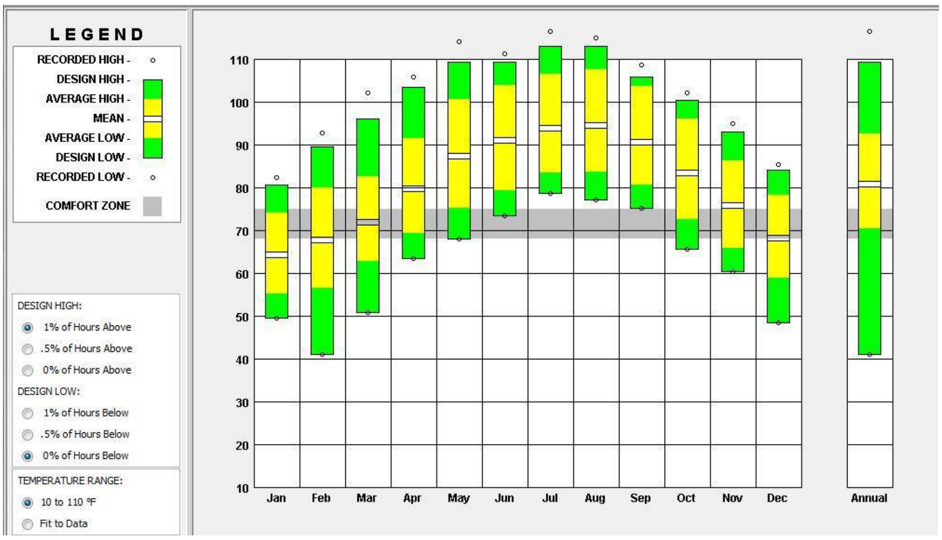


Figure 2.37: temperature ranges (climate consultant 5.5, 2015)

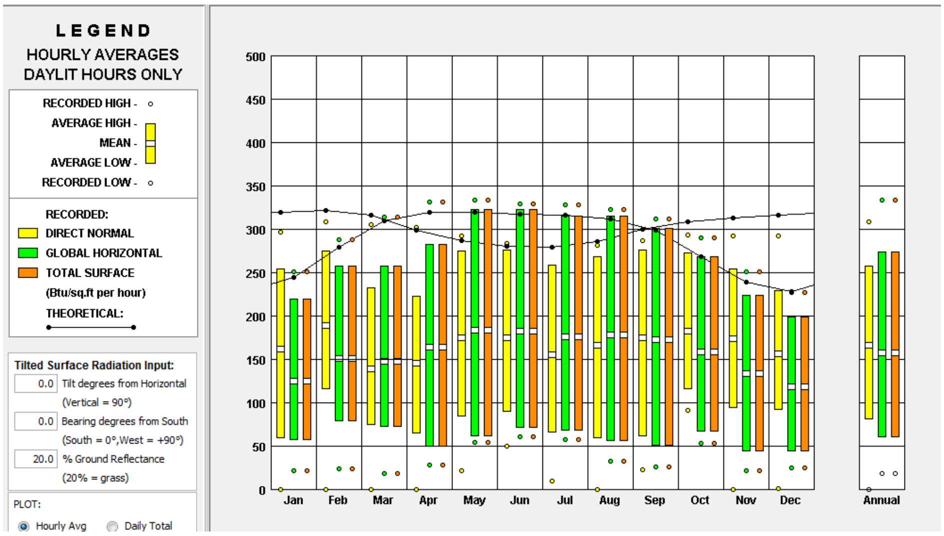


Figure 2.38: radiation levels (climate consultant 5.5, 2015)

From the climatic data (figure 2.39) it is further observed that the direct normal radiation remains almost the same for most of the year and is observed at its highest 270 Btu/sq ft in June .The illumination (figure 2.40) rages to 11000 lux in the month of august, which further stresses on the fact that a lot of intense direct daylight is observed in this region.

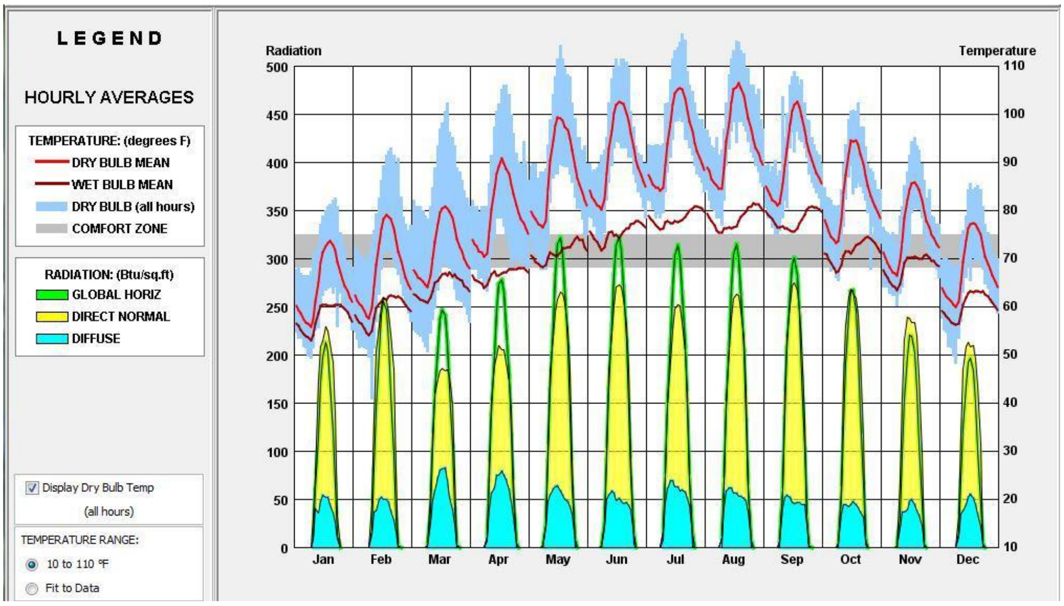


Figure 2.39: Monthly diurnal average (Climate consultant 5.5, 2015)

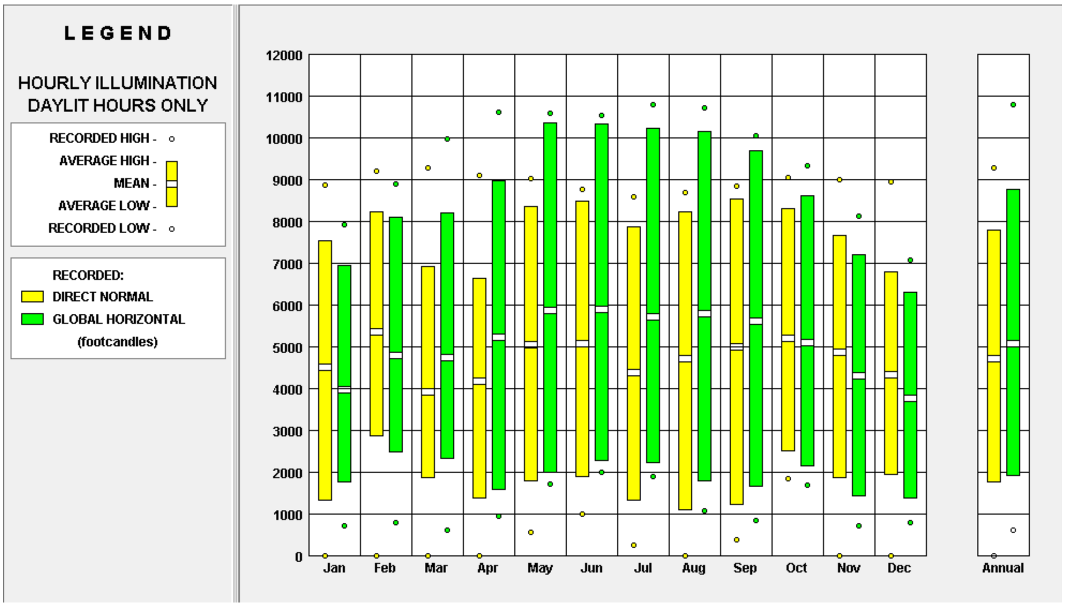


Figure 2.40: Illumination rages (Climate consultant 5.5, 2015)

Figure (2.39) depicts that solar radiation is felt in high levels throughout the year in this region, which shows good solar potential. The recorded high direct normal illumination is again in the hottest months of May, June, July, August, and September.

As observed, the region is humid at most time of the year, especially in the evenings. The relative humidity with respect to the dry bulb temperature in this region is depicted in the figure (2.41). It is seen that high humidity is observed in the early mornings and evenings when the dry bulb temperatures are lower. However, low relative humidity is seen during the daytime from 8 AM till 4 PM most of the year. The months from November to March show high levels of humidity.

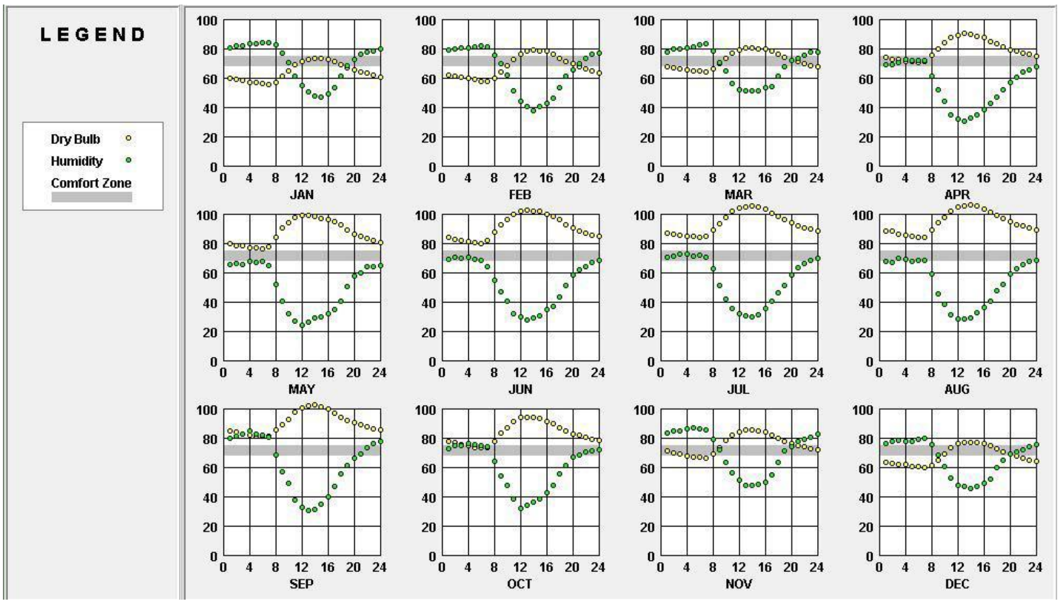


Figure 2.41: Dry bulb temperature and relative humidity (climate consultant 5.5, 2015)

The meteorological data (table 2.11) from the NASA SSE database further shows a monthly averaged direct normal radiation of 6.81 kWh/m^2/day which depicts the high potential in using solar PV in this region to harness energy. The average monthly daylight hours are in the range of 10 to 13 hours per day which is also a good mention for the use of solar energy to harness electricity. The monthly averaged maximum solar angle relative to the horizon range from 43.8 to 87.7 thus adjusting the tilt of the solar panel twice a year (during summer and winter) would result in the most efficient capturing of the suns energy (Table 2.12).

Table 2.11: Parameters for sizing and pointing of solar panels (NASA SSE Database, 2016)

Parameters for Sizing and Pointing of Solar Panels and for Solar Thermal Applications:

Monthly Averaged Diffuse Radiation Incident On A Horizontal Surface ($kWh/m^2/day$)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	1.06	1.24	1.71	1.86	1.89	1.97	2.18	1.97	1.59	1.16	0.95	1.01	1.55
Minimum	0.79	0.91	1.33	1.40	1.45	1.78	2.00	1.76	1.40	0.96	0.71	0.75	1.27
Maximum	1.29	1.48	1.92	2.14	2.12	2.14	2.29	2.10	1.71	1.39	1.29	1.25	1.76
22-year Average K	0.60	0.62	0.57	0.62	0.66	0.65	0.59	0.61	0.64	0.67	0.66	0.59	0.62
Minimum K	0.48	0.53	0.47	0.53	0.60	0.61	0.56	0.56	0.61	0.61	0.53	0.39	0.54
Maximum K	0.69	0.71	0.68	0.71	0.74	0.69	0.64	0.66	0.68	0.72	0.73	0.69	0.69

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Parameter Definition

Monthly Averaged Direct Normal Radiation ($kWh/m^2/day$)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
22-year Average	6.03	6.61	5.86	6.90	7.84	7.87	6.42	6.58	7.05	7.60	7.16	5.78	6.81

Minimum And Maximum Difference From Monthly Averaged Direct Normal Radiation (%)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Minimum	-17	-9	-15	-10	-3	-5	-4	-5	-2	-7	-18	-37
Maximum	12	12	19	15	12	4	8	8	6	3	3	12

NOTE:	*Diffuse radiation, direct normal radiation and tilted surface radiation are not calculated when the clearness index (K) is below 0.3 or above 0.8.*

Parameter Definition

Table 2.12: Solar Geometry (NASA SSE Database, 2016)

Solar Geometry:

Monthly Averaged Daylight Hours (hours)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	10.7	11.3	12.0	12.7	13.3	13.6	13.5	13.0	12.3	11.5	10.9	10.5

Parameter Definition

Monthly Averaged Maximum Solar Angle Relative To The Horizon (degrees)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average	43.8	52.2	62.8	74.3	83.4	87.7	85.8	78.4	67.7	56.1	46.4	41.7

Parameter Definition

Table (2.13), gives us the monthly means of the different parameters to analyse the climatic conditions of the area. The sky conditions in the region is clear for almost all year thus making it favourable for PV systems as it can achieve maximum efficiency using direct solar irradiation than diffused light.

Table 2.13: Monthly Means (Climate consultant, 2015)

MONTHLY MEANS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	
Global Horiz Radiation (Avg Hourly)	125	151	147	163	183	182	175	178	172	158	133	118	Btu/sq.ft
Direct Normal Radiation (Avg Hourly)	162	189	138	145	175	175	155	166	175	182	173	156	Btu/sq.ft
Diffuse Radiation (Avg Hourly)	37	37	53	54	46	42	50	46	41	37	34	37	Btu/sq.ft
Global Horiz Radiation (Max Hourly)	251	287	313	331	333	329	328	322	311	290	251	226	Btu/sq.ft
Direct Normal Radiation (Max Hourly)	296	309	305	302	292	283	279	281	287	293	292	292	Btu/sq.ft
Diffuse Radiation (Max Hourly)	116	135	155	170	144	81	148	111	79	110	126	110	Btu/sq.ft
Global Horiz Radiation (Avg Daily Total)	1337	1687	1757	2062	2420	2463	2347	2287	2099	1809	1444	1248	Btu/sq.ft
Direct Normal Radiation (Avg Daily Total)	1730	2107	1648	1832	2311	2364	2074	2137	2127	2078	1876	1645	Btu/sq.ft
Diffuse Radiation (Avg Daily Total)	404	422	640	687	607	579	674	597	505	426	375	392	Btu/sq.ft
Global Horiz Illumination (Avg Hourly)	3974	4789	4736	5224	5872	5890	5722	5787	5607	5101	4298	3776	footcandles
Direct Normal Illumination (Avg Hourly)	4504	5361	3910	4174	5050	5077	4386	4727	5004	5215	4865	4343	footcandles
Dry Bulb Temperature (Avg Monthly)	64	67	72	79	87	91	94	94	90	83	75	68	degrees F
Dew Point Temperature (Avg Monthly)	53	53	59	59	63	68	72	71	73	65	64	55	degrees F
Relative Humidity (Avg Monthly)	70	64	69	55	49	52	54	53	61	59	70	65	percent
Wind Direction (Monthly Mode)	320	290	320	330	320	300	320	320	160	80	310	310	degrees
Wind Speed (Avg Monthly)	6	7	8	8	9	9	8	8	8	7	6	8	mph
Ground Temperature (Avg Monthly of 3 Depths)	76	72	70	70	74	78	84	88	90	89	86	81	degrees F

The prevailing wind direction is observed to be from NW to SE (figure 2.42) from the wind rose with wind speeds ranging from 3-6km/h. The average wind speed at 50 m above the ground is 5.29 m/s whereas for 10 m above the ground for terrains similar to airports is 4.53 m/s which would be more relative to the desalination plant site, which is situated near an open sea area (table 2.14).

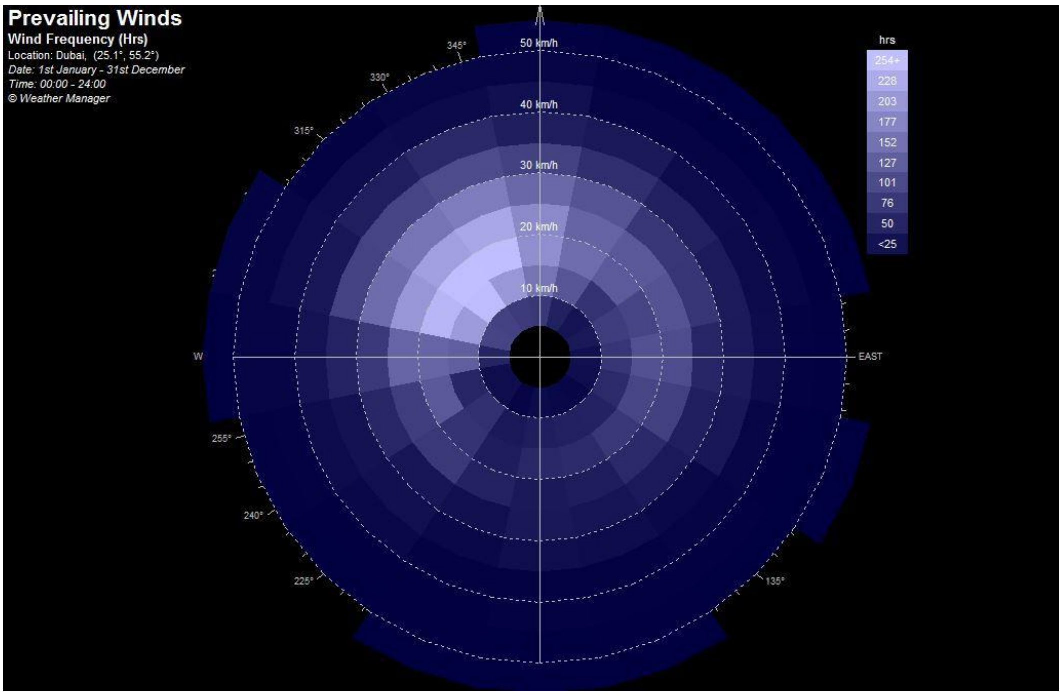


Figure 2.42: Wind rose for Dubai (EcotectAnalysis, 2015)

Table 2.14: Wind meteorological data (NASA SSE Database, 2016)

Meteorology (Wind):

Monthly Averaged Wind Speed At 50 m Above The Surface Of The Earth (m/s)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.93	5.67	5.45	5.49	6.10	5.91	5.57	5.33	5.17	4.79	4.32	4.88	5.29

Minimum And Maximum Difference From Monthly Averaged Wind Speed At 50 m (%)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
Minimum	-14	-16	-11	-19	-13	-5	-8	-11	-17	-17	-8	-20	-13
Maximum	16	23	12	10	11	8	10	20	18	20	9	20	15

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.	*All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.*

Parameter Definition *Units Conversion Chart*

Monthly Averaged Percent Of Time The Wind Speed At 50 m Above The Surface Of The Earth Is Within The Indicated Range (%)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
0 - 2 m/s	16	11	10	9	7	9	11	12	14	18	22	16	13
3 - 6 m/s	60	55	59	57	46	48	54	57	59	60	63	62	57
7 - 10 m/s	21	28	27	32	44	40	33	29	24	18	14	19	27
11 - 14 m/s	2	5	3	1	2	2	2	2	2	2	1	2	2
15 - 18 m/s	0	1	0	0	0	0	0	0	1	1	0	1	0
19 - 25 m/s	0	0	0	0	0	0	0	0	0	0	0	0	0

Parameter Definition

Monthly Averaged Wind Speed At 10 m Above The Surface Of The Earth For Terrain Similar To Airports (m/s)

Lat 25.358 Lon 55.391	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Average
10-year Average	4.22	4.84	4.66	4.68	5.22	5.05	4.76	4.56	4.42	4.09	3.69	4.18	4.53

It is recommended that users of these wind data review the SSE Methodology. The user may wish to correct for biases as well as local effects within the selected grid region.	*All height measurements are from the soil, water, or ice/snow surface instead of "effective" surface, which is usually taken to be near the tops of vegetated canopies.*

3 CHAPTER 3 - RESEARCH METHODOLOGY

The research methodology is selected after a comprehensive study of different methodologies used in the subject area. The main variables that come into play are the desalination technology used and the type of renewable energy system integrated into the plant. As the base line considered in this study is a reverse osmosis desalination plant of medium capacity, studies involving renewable energy (wind and solar) in RO desalination plant is mostly considered.

3.1 A REVIEW OF DIFFERENT RESEARCH METHODOLOGIES USED IN THE SUBJECT DOMAIN

A wide range of methodologies have been opted for the study of renewable technologies integrated with reverse osmosis desalination plants. The main methodologies used are observational study (field monitoring), literature review and simulation studies. Examples of each of these methodologies incorporated in this domain are explained in this section so as to understand the ways through which the studies can be conducted can be understood.

Observational studies or field experiments can be done in many different ways depending on the parameters to be studied. Weiner et al. (2001) had conducted an experimental study using a demonstration reverse osmosis desalination plant to understand the operation experience of the plant when solar and wind power was incorporated. The research paper had recorded the designing, erection and operational performance of a standalone reverse osmosis desalination plant connected to wind and solar photovoltaic energy producing systems. The demonstration plant site meteorological data was used to understand and predict the feasibility of the wind turbine and the solar PV string. A backup diesel generator system was incorporated into the system for any power deficiencies the plant may observe. A service factor of 33% to be achieved has been designed. The demonstration unit has also been provided with a two day battery storage.

Experimental measures concerning the amount of energy the solar PV system and the wind system can provide, battery bank behaviour and water produced parameters were taken in the course of a year. The energy balance was then analysed using this collected data and it was found that the RO energy demand was too high to be met by the renewable technology in the area.

Mohamed et al. (2008) conducted a comparative experimental study using a PV-sea water reverse osmosis plant which had no battery backup but that contains Energy Recovery Devices (ERD) with a system that uses battery backup and has a water production of .35 m3/d during the winter. This study was to understand the technical and economic maturity of each system and to conclude which would be a better choice in isolated communities and islands. The battery based system was observed for10 consecutive days in the month of November to observe and analyse the quantity and quality of the water produced by the plant and also the energy consumption with regard to the feed pressure and flow which was kept at a constant. In the direct coupled configuration model, the DC motor was connected directly to the PV array and then the performance of the system was recorded for seven days in November. The parameters that were considered to be analysed in this system was the reverse osmosis system under variable flow and pressure. The advantage of this system was its simplicity in hardware as no batteries and charge controllers were involved. In the above methods, the water cost for production was calculated using the life cycle cost method. Finally, the technical and economic analysis was done using comparative data derived from the experimental observations.

Carta et al. (2015) introduced a small scale reverse osmosis plant which demonstrated how it would use the variable power of the wind turbine system by using mass energy storage in batteries and super capacitor bank which is to be used as the regulation system. The methodology used to undertake the experimental tests in the plants were divided into two sections. The first section dealt with the deduction of the permissible operating limits of the desalination plant in theoretical levels. This was provided by a software called Toray Design

System v.2.0 that gave the theoretical values of the admissible pressure and feed flow rate. The second section dealt with the operating strategy of the reverse osmosis desalination plant as there should be a balance between the power generated by the variable power system and consumed power. Standard procedures were followed in the tests concerning experimental determination of the flow rates and the reference pressure for the operating system, determination of the power generated by the wind turbine system and the variable operating conditions of the plant. The data from the observations were analysed and compared using charts and graphs with a reference points and the experimental points. The feasibility of such a system was studied, analysed and various conclusions, according to location and wind potential was argued by the authors.

Literature Review would provide a comprehensive study of the subject area thus would help in creating a solid understanding of the renewable technologies that can be incorporated into desalination units. Ali, Fath and Armstrong (2011) had conducted ‘A comprehensive techno- economical review of indirect solar desalination’. The paper had concentrated specifically on all indirect solar desalination technologies accompanied by technical data which were specific to this type of desalination technology. The paper reviews technologies such as desalination using solar stills, humidification-dehumidification technology and indirect solar desalination process. A section which classifies indirect solar driven technologies into thermal, mechanical and electrical technologies has also been conducted. Finally, a review of each desalination technology that uses indirect solar energy is assessed with respect to economic feasibility and other parameters that may affect the cost.

Sharon and Reddy (2015) had conducted ‘A review of solar energy driven desalination technologies’. The paper had extensively reviewed the operating principles, advantages, disadvantages and limitations of desalination plants that worked with the technology of solar power incorporated into it. A section has been dedicated to novel technologies like freezing, desalination using adsorption, natural vacuum desalination and forward osmosis. Finally, the barriers and issues concerning desalination plants have been discussed and from the literature, the steps that can be used to overcome these problems have been identified and suggested briefly. The objective of the review by the author was to create a base for researchers to select an appropriate technology in desalination to be further developed in terms of technology and operational efficiency.

Eltawil, Zhengming and Yuan (2009) conducted ‘A review of renewable energy technologies integrated with desalination systems’. Firstly, the paper presents a techno economic review of the state of the art renewable technologies coupled with desalination systems worldwide. The parameters of the review also include the source of water, demand for desalinated water, scarcity of portable water and methods of purification. Referring to the basis of classification in literature review till the year 2008, the classification of distillation units has been done. A study of comparison is done between the renewable energy technologies in desalination with inclusion of economic feasibility has been done. The problems concerning the technologies have been identified. It was also pointed out by the authors that the economic feasibility is far from an accurate assessment as different technologies within renewable desalination concentrated on different aspects such as system capacity, energy sources, water source, components, etc. The paper tries to show the maturity of each system and the socio- technical – economic feasibility of different desalination systems.

Simulation studies have been conducted using a variety of software and mathematical models in the recent years. Fthenakis et al. (2015) had conducted a study on the environmental and economic efficiency of a reverse osmosis desalination system using photovoltaic energy. The base case model was the case study of a medium scale RO desalination plant in Saudi Arabia. The software used for the study was Hybrid Optimization Model for Electric Renewable (HOMER) and Desalination Economic Evaluation Program 5.0 (DEEP). The software enabled the author to do a comparative study on model capital expenses and energy inputs of grid connected photovoltaic reverse osmosis plant. A constant load of 1MW was assumed throughout the year for the simulation. The scenarios created for the PV systems were for 1 MW and 3 MV sizes. The former would account for the load for most of the days and the latter would be used to compensate energy needed for the 24 hour operation in case if any shortage. The purchased power and selling power would be calculated at the same rate. Based on the results from the simulation, the potential for large scale projects in arid areas is discussed.

Mohamed and Papadakis (2004) used a simple spreadsheet model to represent the design of a standalone hybrid wind – photovoltaic system that can be used to power a seawater RO desalination unit with energy recover systems involved in Greece. The design methodology (figure 3.1) involved many steps to understand if the system would satisfy the water and energy requirements needed for the working of the desalination plant. The first design step was to evaluate the water needs in the area by looking at the consumption statistics annually and daily. The second and third step was to decide on the SWRO unit size and to decide on the components used for the system. For this, the population water needs was considered and the type of technology to be best suited for the site. The fourth design step was to calculate the energy needs of the system to understand how much electricity needs to be generated every month with regard to the climatic conditions and operations and maintenance scheduled. The fifth step was to evaluate the PV sizing that could theoretically cover all the energy needs of the system. This involved deciding on the PV module tilt angle looking at the meteorological data, peak PV power needs, number of PV panels and arrangement of the PV arrays, Balance of system and water tank capacity. The sixth design step was to understand the wind potential in the area. Then the process would be to size the hybrid system with various configurations and then finally an economic analysis was conducted on all feasible configurations. After the economic analysis, the hybrid system was finalized and a system simulation was done for the peak days to show that the system would produce the energy needed by the desalination plant in a feasible economic value.

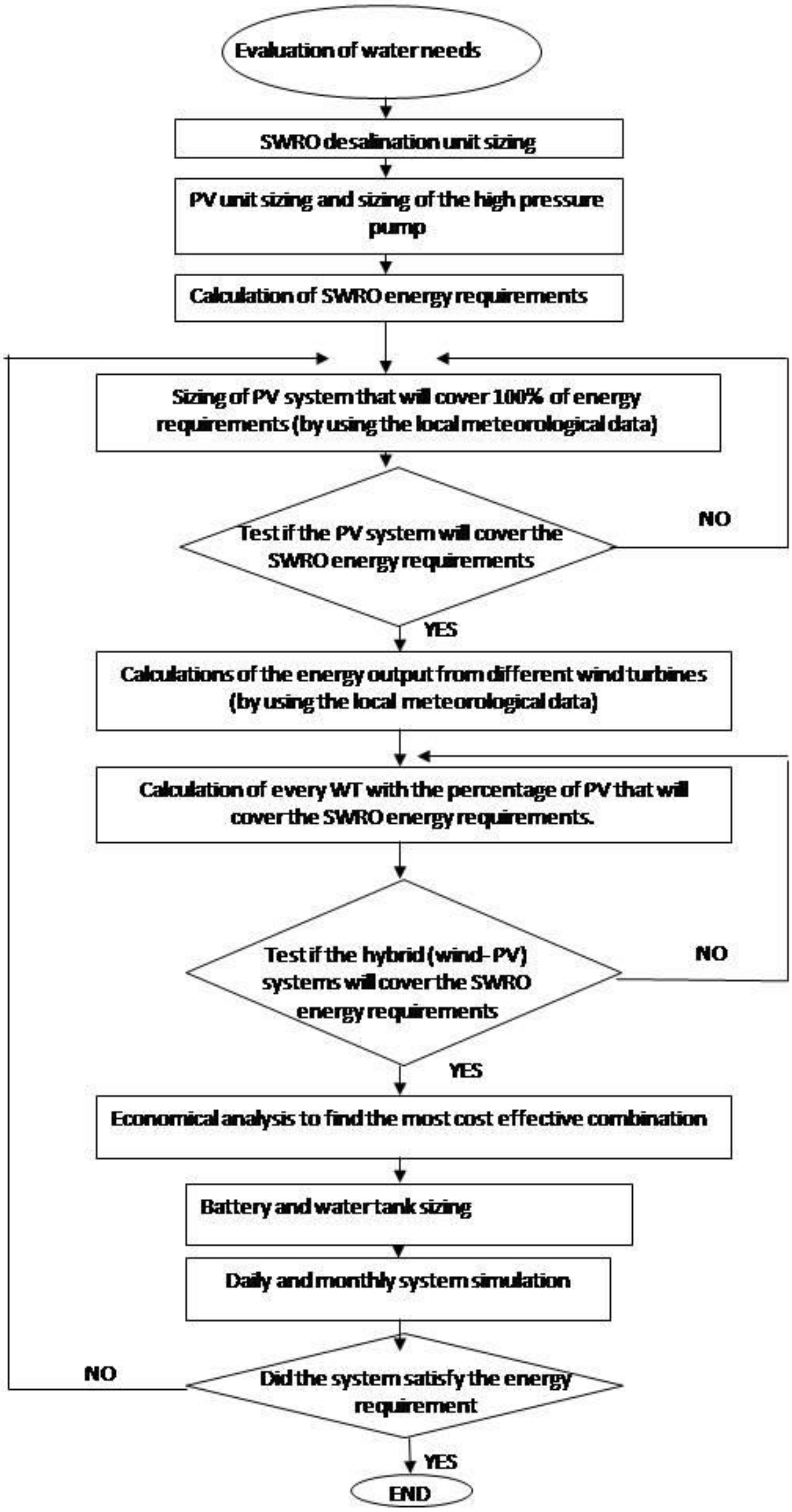


Figure 3.1: Design Methodology Flowchart for RO design (Mohamed and Papadakis, 2004)

Novosel et al. (2015) developed a study that introduced six different scenarios in Jordan to develop its energy systems till 2050, considering a case study of a SWRO plant using wind and PV technology. The year 2011 was used as the reference point. The model validation was done by using the data from IEA. The analysis is done with an energy modelling software called EnergyPLANversion 11 which has the ability to analyze annually the different energy systems on an hourly basis. The inputs were (a) the hourly electricity and heat demand, (b) energy generated from the renewable resources, (c) installed capacities of each energy generator, (d) energy mix and demand and, (e) economic data on fuel costs etc. The results derived from the software includes the annual carbon dioxide emissions, capital cost of system, energy production analysis and fuel consumption. In the case of the desalination plant scenario, the annual fresh water demand, system efficiency, portable water storage, process of desalination and capacity of the desalination plant needs to be indicated. The results indicate that some of the configurations show that there is a high feasibility to use these intermittent sources of energy as they can make up to 76 % of the energy needs thus reducing fuel consumption and carbon dioxide emissions.

3.2 SELECTION AND JUSTIFICATION OF CHOSEN METHODOLOGY

Through exploring the methodologies used in the subject domain, it is understood that the most prominent ones is simulation studies, literature review and observational studies or field experiments. the pros and cons of each methodology is analysed with regard to the limitations that the author will face to choose the methodology that would be best suited for the study.

In studies that used observational and field experiments, it can be observed that the pilot projects are very important to deem the feasibility of the large scale incorporation of the technology. With adequate equipment, expertise and financial support, these kinds of experiments tend to give the most natural outcome than induced experiments using other methods thus giving the researcher an unbiased result. These types of experiments should be done for a minimum of a year so that the measurements during different seasons are accounted for correctly and a more accurate analysis can be done. However, due to limitations of financial aid and other resources, this type of methodology cannot be taken forward by the author.

Concerning the literature review methodology, it is understood by the author that to get a good base knowledge on any domain, the literature review is the most important aspect to be followed. Through literature review, the main parameters that are involved in the research can be understood a repetition of the same studies or mistakes can be avoided. Literature review helps to do gap analysis in the domain as the researcher is fuelled with a lot of information from many scientific sources. Literature review can also be considered as the cheapest way to conduct research as the access to public libraries and online libraries are almost of no cost to the researcher. Through literature review, different methods, approaches and frameworks of research in this domain can be understood. Thus, the author would start the dissertation with a comprehensive literature review, as seen in the earlier chapter, to have a solid base on the technologies concerned and other parameters to be understood in the course of the study. Only scientific journals and valid sources are looked into as it is understood that literature review is secondary information, thus can have mistakes or can be biased. Information that is seen to be repeated and validated is used in the literature review for more accurate details. Obsolete literature is avoided where possible as it may result in invalid results. Thus, it can be argued that literature review would help in adding knowledge to the authors study but will not help in discovering any new results, analysis, innovations or characteristics in the domain.

Simulation modelling methodology can be suitable for this dissertation due to many factors that needs be analysed in the project. The simulation modelling approach would be complimented by the literature review as well as a case study to create a base case model for simulation. The benefit for using this approach would be that the author can create 3D environments and conduct complicated mathematical models by the use of many efficient and validated software and a laptop. The technology that has been introduced nowadays is very powerful in terms of analysis and has advanced computational powers that would help in creating very accurate results. It is understood that the inputs into the software should be thoroughly checked to obtained results that can be validated. A lot of resources such as time and money can be saved by the use of simulation method compared to observational study and field experiments. The graphical outputs obtained through simulations can help in providing a better platform for the audience to understand the analysis. Thus by the use of adequate and reliable simulation software, which the author has experience on, a literature review to create the backbone of the study and a case study of a currently operating SWRO desalination plant in the desired location to create a base case model would be the comprehensive and adequate methodology that can be used to complete this dissertation successfully.

3.3 DETAILS OF CHOSEN METHODOLOGY

The chosen methodology has simulation modelling as the core methodology, which is complimented by a case study and a literature review. Firstly, a literature review would be conducted for a comprehensive understanding of desalination systems, its operations and energy needs. Further study would be done on renewable systems like solar and wind power generation systems that can be integrated to desalination units. Thus during the literature review, three main domains would be concentrated on; reverse osmosis desalination, solar photovoltaic energy generation systems and wind energy generation systems.

Secondly, a case study would be conducted on presently operating reverse osmosis desalination plant in the UAE. The operations of the plant would be studied in detail and the energy consumption of the plant would be thoroughly analysed for a period of two months. The energy need for the office use and for the desalination use would be noted separately for more accuracy of simulation. The climatic conditions of the area as well as the dimensions and infrastructure of the plant would be observed for simulation needs.

Finally, the core methodology of the research, simulation modelling would be conducted with the information obtained from the case study and literature review. The simulation modelling would be conducted in two parts as for such analysis there would be the need to use two simulation software. For the first part, the simulation software selected (IES VE) would be used to create a 3D model of the structure (desalination plant) to understand and estimate where the solar panels and wind turbines can be placed.

The load profile would be formulated after manually observing the electricity load for two months and the proper electrical demand can be estimated for the plant. This load profile would be given as input for the HOMER software that would be used to do necessary simulations in different scenarios (explained in the simulation modelling section) to understand which would be the best suited configuration that might lead to techno economic feasibility in using renewable energy in the desalination system process.

A brief outline of the software to be used in given below:

- Integrated Environmental solutions (IES VE 2015): This software is a comprehensive suit that would help in investigating the micro climate and infrastructural environment of the project. It would help in obtaining the most resource efficient design by incorporating the material characteristics, solar orientation, building form, renewable potential, passive strategies and resource availability. The software also offers good visuals that would be used in the report. Information regarding the validation of this software can be found at the official website: https://www.iesve.com/software/software-validation
- HOMER Energy: Hybrid Optimization of Multiple Energy Resources (HOMER) software is used to simulate the different operation scenarios of a system by calculating the energy balance of the system for 8760 hours a year. This software would analyse the feasibility of the scenarios considering facts such as if it is off grid or grid connected, use of batteries,

generators, PV systems, wind systems, etc. This software would help provide the end results for the paper to estimate which scenario and under which circumstance can the techno economic feasibility may be succeeded. Information regarding the validation of this software can be found at the official website: http://www.homerenergy.com/

3.3.1 DETAILS OF DATA ANALYSIS:

The data analysis would be the main domain of importance as it leads to the outcome of the study. The data analysis would be done in three sections.

a) Examine the different parameters that would affect the technical efficiency for electricity generation using PV's and the grid systems in different configurations and analyze if demand meets supply in the most efficient configuration.
b) Comparative analysis of the costs involved in producing fresh water from different technical configurations.
c) Potentials, barriers and environmental impacts through review of analysed data.

4 CHAPTER 4 – CASE STUDY AND SIMULATION MODEL

4.1 CASE STUDY DESCRIPTION

The selected case study is a 4800 m^3/day sea water reverse osmosis desalination plant located in Hamriyah free zone (25°28’32.8”N, 55°29’30”E), Sharjah, UAE. The area experiences hot and arid climate as discussed in the section 2.6 and it should be noted that a sea breeze which are hot humid winds are experienced in this area due to its close proximity to the Arabian Gulf. Figure (4.1) depicts the aerial view of the desalination plant with the Arabian Gulf situated on its north-eastern side and Figure (4.2) depicts the plant from its eastern entry.

Figure 4.1: Aerial view of the desalination plant (Google earth, 2016)

Figure 4.2: Eastern entry to desalination plant (Source: Author)

The desalination plant constitutes of a main shed that contains the RO membranes and high pressure pumps, a service and office block, two tanker filling areas, a recreational area and three storage tanks that have a total capacity of one million gallons of portable water (illustrated in figure 4.3).The plot area comes to about 10,690 sq m with a built up area of 2774.52 sq m which does not include the tanker filling areas. Therefore, it is quite impossible and undesired by the desalination plant operators to have any renewable energy systems to be installed on the ground or above the tanker filling areas as they prefer to use the land to extend their desalination unit in the coming years. Figure (4.4) is a model done in the software REVIT Architecture by the author which depicts the next extension (by using a part of the tanker filling area) decided by the owners of the desalination unit to increase their capacity by 2018.

The desalination plant is up and running for 24 hours a day for maximum efficiency and stabilized power consumption. It has a maximum load of 1.4 MWh daily, which includes all the plant needs and well as office and service block requirements. Currently no means of renewable energy systems are implemented on the plant as the legislations and policies concerning renewable units being integrated to the gird and large off grid units are still in progress as per Sharjah Electricity and Water Authority (SEWA).The owners of the desalination unit has a strong tendency to shift to renewable energy as part of their CSR program, thus have given access to the author to have a feasibility study done to understand the technical, economical and environment effects in integrating renewable energy systems into the base case model.

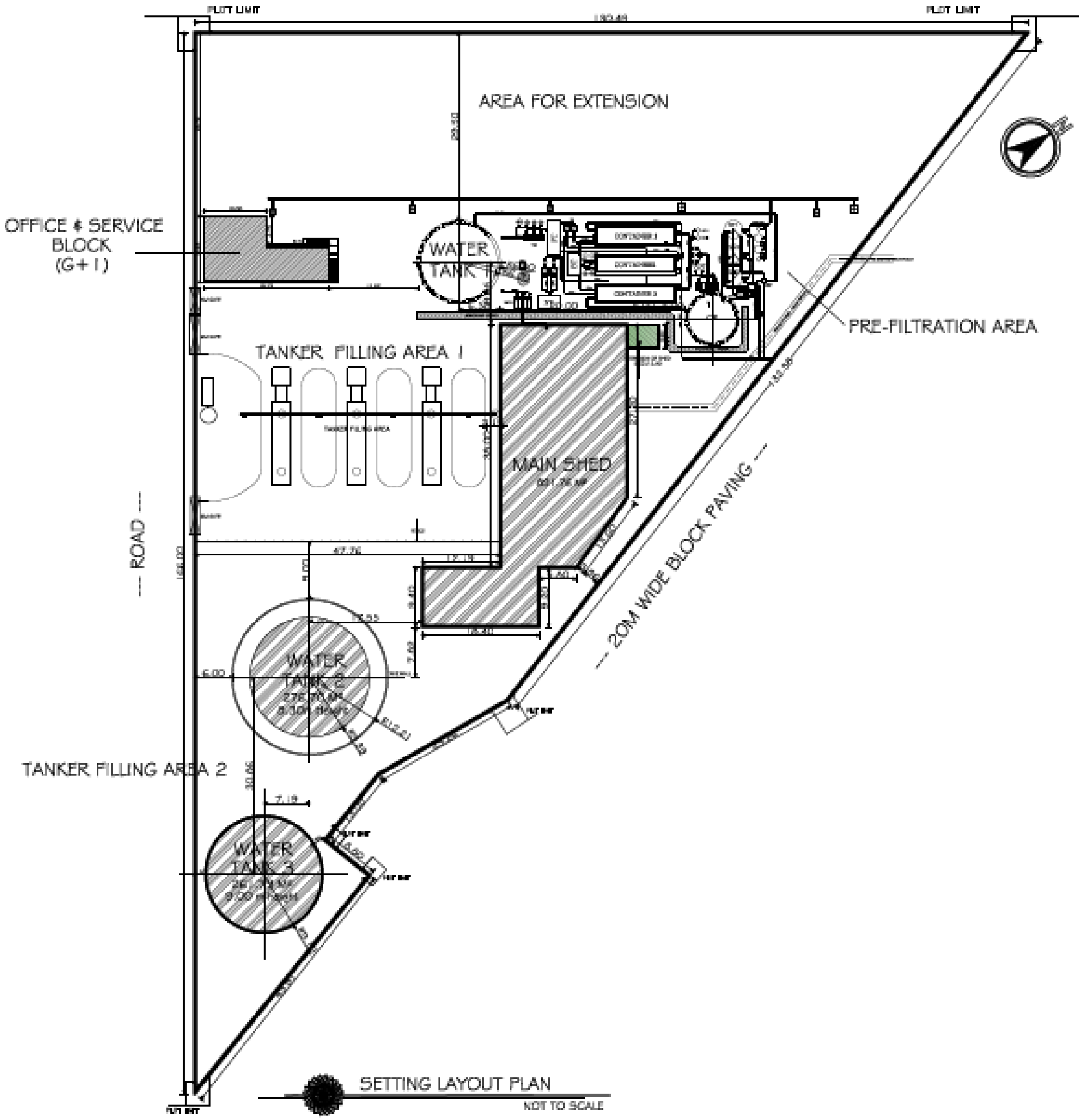


Figure 4.3: Site layout of the desalination plant

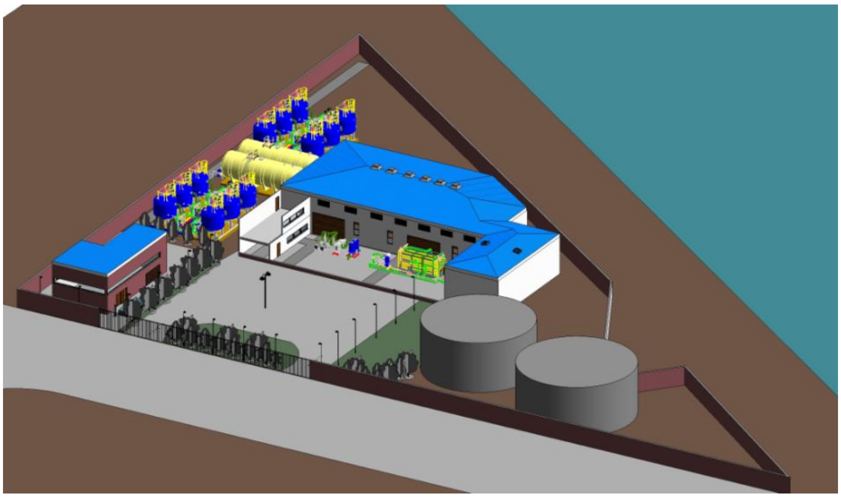


Figure 4.4: REVIT model of future plant extension for 2018

As mentioned, the technology used in this desalination plant is sea water reverse osmosis .The desalination plant has four Sea Water Reverse Osmosis (SWRO) Units. The desalination plant have added unit after unit with regard to its extension in the following years. The first unit has a capacity of 500 m^3/day (commissioned in 2008). The second and third unit has a total capacity of 1300 m^3/day (commissioned in 2011) and the fourth unit has a capacity of 2500 m^3/day (commissioned in 2015). In total the desalination plant functions at a capacity of 4800m^3/day. The first three units SWRO -1, 2 and 3 works together using one SEWA line and are the old units of the desalination plant. The load on this line also includes the power consumed by the office block, recreational area, streetlights, and other plant facilities .However, SWRO 4 is the most recent unit which works using another SEWA line or the new SEWA line. The details of all the equipment used in all the units are summarized in Table (4.1). All the units have the same technology used, thus the SWRO unit 4 is discussed in the coming paragraph to understand the working principles of the unit. For more accuracy regarding the fact that if the desalination unit can be powered by a renewable resource, the unit SWRO-4 is only taken for simulation modelling. As the primary load consist of only the power needed by the 2500 m^3/day desalination unit.

Table 4.1: Equipment details of desalination plant

Sr. No.	Description	Pump Make	Pump Capacity	Motor Make	Motor Ratings	Quantity
1. SWRO-1						
1.1	Beach Well Pumps	Grundfos	46m3/hr	Grundfos	11kW	2
1.2	Feed Water Transfer Pumps	Grundfos	95m3/hr	Siemens	18.5kW	1
1.3	Energy Recovery	Eri	28m3/hr			2

1.4	Booster Pumps	Fedco	248GPM	Marathan	11.2kW	1
1.5	High Pressure Pump	Fedco	30m3/hr	Marathan	112kW	1
2. SWRO-2						
2.1	Beach Well Pumps	Grundfos	46m3/hr	Grundfos	11kW	2
2.2	Feed Water Transfer Pumps	Grundfos	95m3/hr	Siemens	18.5 kW	1
2.3	Energy Recovery	Eri	28m3/hr			2
2.3	Booster Pumps	Fedco	248GPM	Marathan	11.2 kW	1
2.4	High Pressure Pump	Fedco	30m3/hr	Marathan	112 kW	1
3. SWRO-3						
3.1	Beach Well Pumps	Grundfos	46m3/hr	Grundfos	11kW	3
3.2	Feed Water Transfer Pumps	Grundfos	110m3/hr	Siemens	18.5kW	1duty +1standby
3.3	Pressure Exchanger	Fedco-Ert	42m3/hr			
3.4	High Pressure Pump	Fedco	110m3/hr	Marathan	187kW	1
4. SWRO-4						
4.1	Beach Well Pumps	Grundfos	55.53m3/hr	Grundfos	15kW	5 DUTY +3

						STANDBY
4.1	Feed Water Transfer Pumps	Sulzer	72.4l/sec	ABB	132kW	1 duty +1 stand by
4.2	Energy Recovery	Eri	52.1 m3/hr			3
4.3	Booster Pumps	Energy Recovery		Balder	45kW	1
4.5	High Pressure Pump	Sulzer	105 m3/hr	ABB	315 kW	1
5. COMMON PRODUCT WATER TRANSFER						
PUMPS (SWRO-1,2,&3)						
5.1		Grundfos	90m3/hr	Siemens	15kW	1 duty& 1 stand by
6. COMMON PRODUCT WATER TRANSFER						
PUMPS(SWRO-4)						
6.1		Grundfos	90m3/hr	Siemens	30kW	1 duty& 1 stand by
7 .FILLING BAY TRANSFER PUMPS(1)						
7.1		Grundfos	90m3/hr	Siemens	18.5 kW	2
8. FILLING BAY TRANSFER PUMPS(2)						
		Ebara	132m3/hr	Ebara	15kW	1 duty& 1 stand by
9. BACKWASH PUMPS						
		Grundfos	275m3/hr	Siemens	37kW	1 duty& 1 stand by

10. AIR BLOWERS						
		Mapro		Mapro	9.2kW	2duty& 1 stand by

In the unit SWRO 4, saline water of around 44,000 ppm TDS value is used as the feed water and is supplied to the plant by eight beach wells that is situated five meters away from the plant. It is noted that in these eight beach well pumps, five are always operational while three are kept at standby. The feed in water is supplied at a design pressure of 6.56 bar to the main header, where all the pumps are connected in parallel. The pumps used are multi stage centrifugal pumps with a motor power of 22 kW each.

The pre-treatment is done by using six dual media filters with a capacity of 210 m3/h. These filters have sand and pumice to reduce the turbidity of the water. This water is then stored in a filtrate break tank. The filtered water from the break tank is then passed on to a 2 stage micron cartridge filter which removes particles more than 10 microns. In the first micron cartridge filter removes particles up to 5 microns and in the second stage, it achieves to remove particles up to 1 micron with a stable pressure of 2 bar. This filtered water then goes through a series of processes such as coagulation, acid addition, biocide, and addition of an anti scaling agent. This pre-treatment is done so as to protect the RO membranes from damage and increase its durability and efficiency.

The reverse osmosis system unit consists of a high pressure centrifugal pump with an energy recovery device that feeds pressurized water into the membrane configuration. The system is required to operate at 40% recovery rate on average; which means that at least 40% permeate should be obtained from the RO membrane system based on average and worst case quantities from the source water. This recovery is limited mainly due to reasons such as the silica content, total dissolved solids, and the temperature of the feed in water. The RO permeate is later post treated with chlorine before distribution to service and portable water tanks from which it is transferred to the filling bay. The technical process flow diagram is attached in the appendix (A) for SWRO unit 4. A schematic bock diagram describing the process for SWRO-4 is illustrated in figure (4.5).

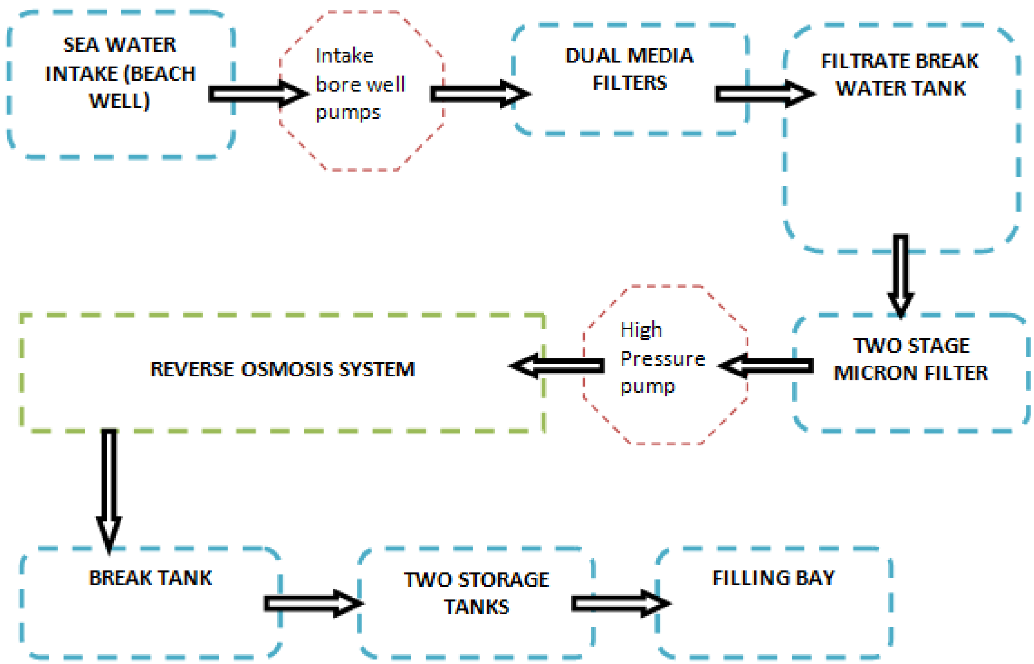


Figure 4.5: Schematic block diagram for SWRO 4

The SEWA electricity bills for this SWRO unit has been obtained as well as the energy meter reading for this unit has been collected for the study to understand the load profile of the desalination unit. Further explanations and input regarding the electricity load profile of the desalination unit SWRO -4 will be explained in the later sections.

4.2 SIMULATION MODELLING PROCESS

Simulation modelling is adopted as the method for conducting the technical and economical analysis. Firstly, the current desalination plant is modelled in REVIT architecture to help understand its dimensions and further extensions that would be involved. This is just to help understand the structure and to be included in the report. Secondly, a base model is created in the software IES VE to help locate the areas of maximum irradiation and minimal shading so as to help locate the PV arrays. By using IES VE, the wind rose would also be used in accordance to the site to understand where the wind turbine(s) can be placed. From this simulation, the total area that would be allocated for the PV cells as well as for the turbines can be understood. Finally, HOMER energy would be used to understand the technical and economical feasibility for introducing the renewable system. For the input data, a market study would be done to select the most feasible systems to use for PV and wind power generation systems. A text matrix would be followed and a number of scenarios would be simulated. Further explanations concerning the simulation process would be discussed in the following chapter. Finally a comprehensive analysis of all the models would be done to estimate which option would be most economically and technically viable.

4.3 SIMULATION MODELLING – IES VE

In IES VE 2015 the simulation modelling is performed to understand where would be the most effective location to place the PV arrays and the wind turbines.

Firstly, a block model of the desalination plant is created using ModelIT and the north direction specified as depicted in figure (4.6).

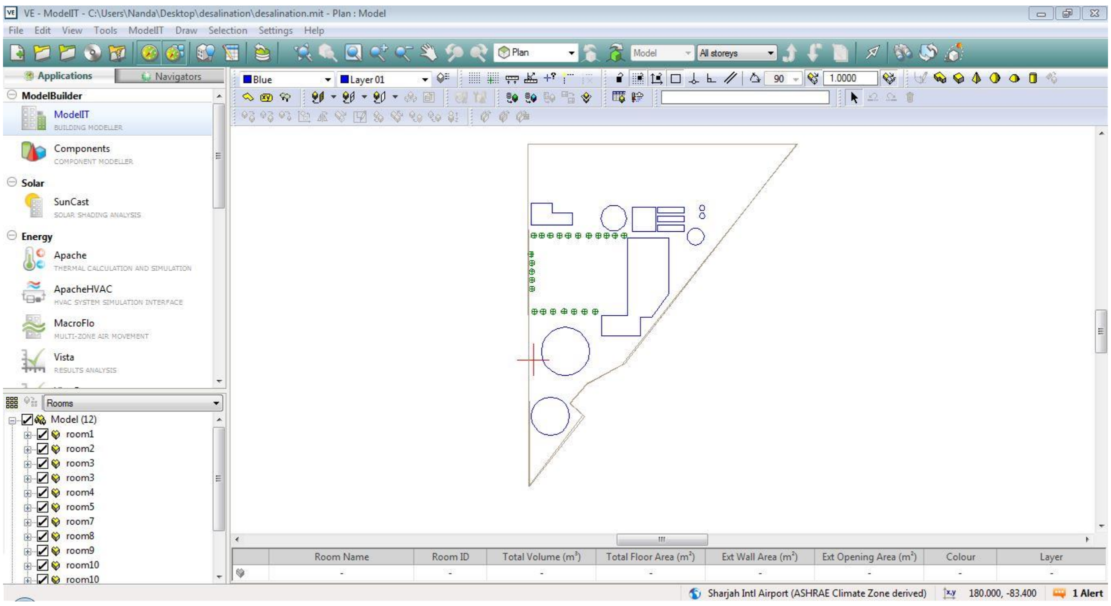


Figure 4.6: IES VE layout

The weather data used was acquired from the ASHRAE design weather database v5.0 and the located selected was Sharjah international airport as it was the nearest to the site (illustrated in figure 4.7).

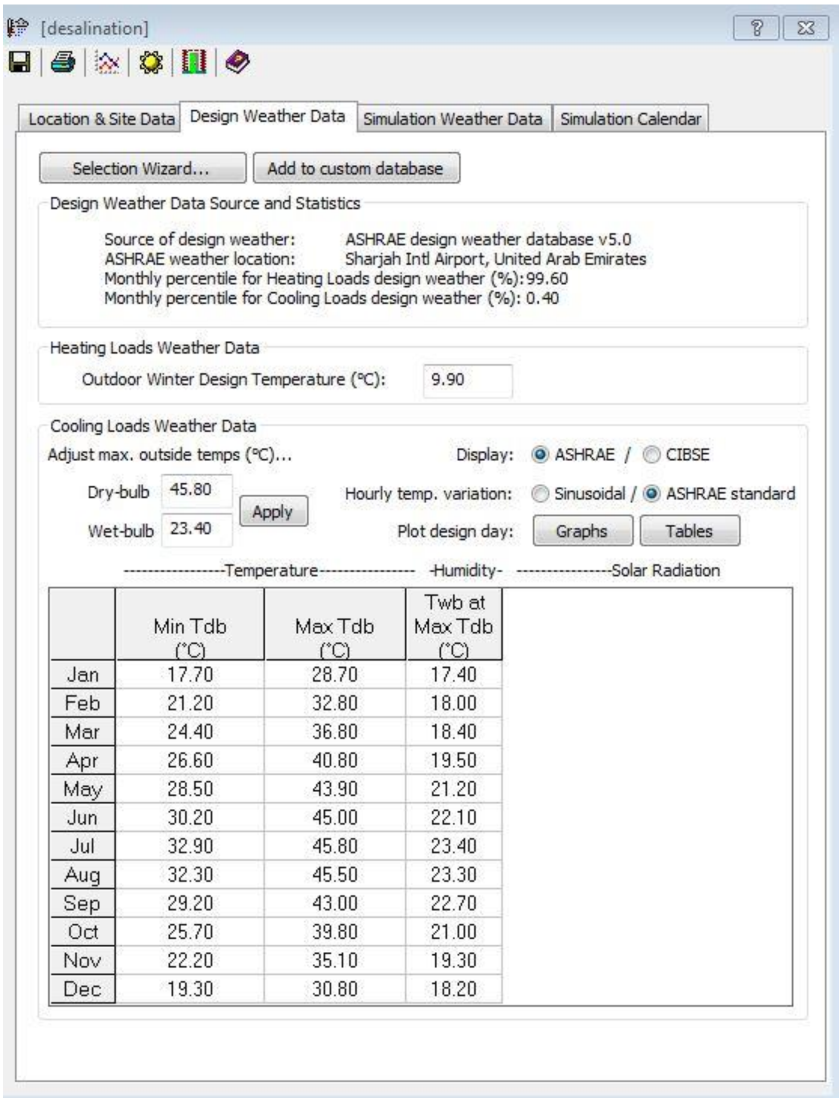


Figure 4.7: Weather data used in IES VE

To understand the solar intensity on the building the Analysis tab on SunCast is utilised. This feature would help view the solar energy on the block diagram and help understand the solar irradiation on the external facade of the building. Thus, it would enable us to understand where the photovoltaic array could be placed and if it would be feasible. In the Analysis tab the solar energy analysis and the solar exposure analysis is simulated and the period is taken as one year, i.e. from

January 1st to December 31st using a high resolution grid of 1m.The simulated results for solar energy analysis are shown in two ways, cumulative KWh/m2 and cumulative percentage availability, whereas for the solar exposure analysis it is shown in sunlight hours and the percentage of hours available. The shading report (see appendix B) as well as the solar exposure (see appendix B) is also generated for the whole year to understand the feasible locations for the PV system.

From the figure (4.8) it is clearly understood that there is a high potential for solar PV to be placed on the roof of the main shed, service and office block .The large storage tanks will not be a feasible location as they are prone to water leaks and cleaning processes which require the tanks to be open from the top. From the legend it is understood that within a range of 921.12 kWh/m2 to 862.41 kWh/m2 is the available external surface incident solar flux on the main shed and office/service block roof structure which is quite abundant solar resource.

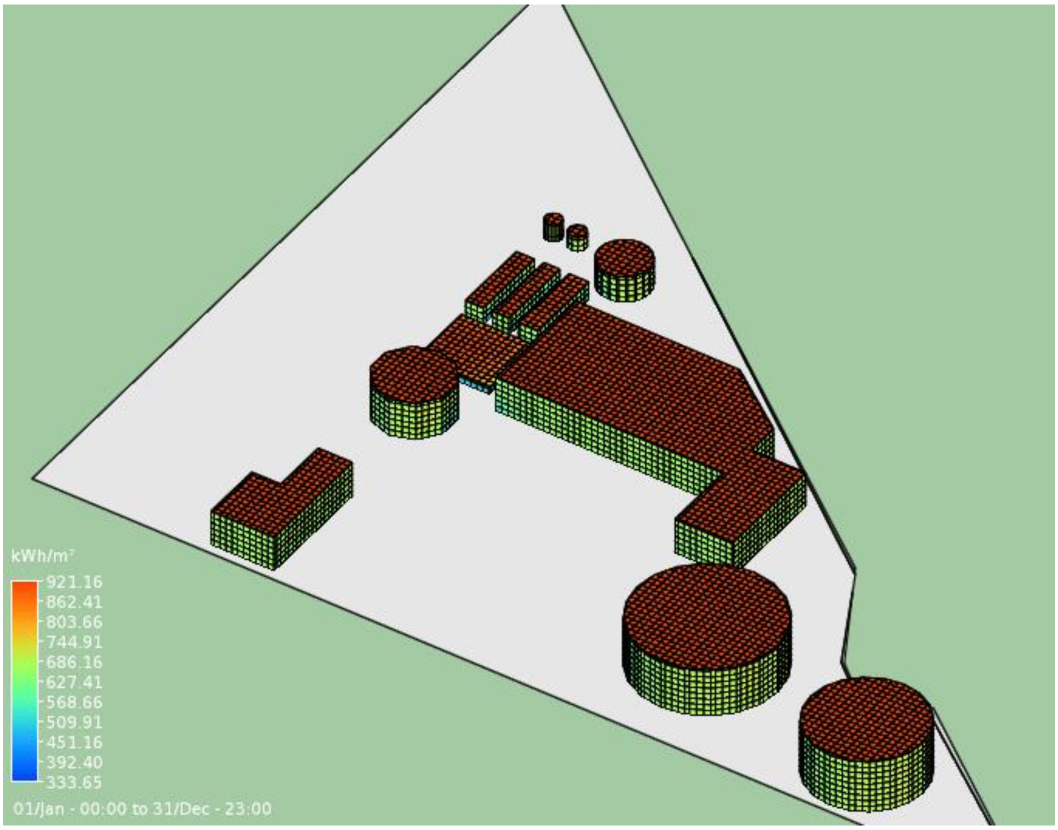


Figure 4.8: Solar Energy Analysis using IES VE

In the figure (4.9) describes the sunlight hours available on the building structure and simulates the direct shading in the structure. The analysis shows a positive result in introducing PV systems into the roof structures as it is seen that from a range of 4379 hrs to 3941 hrs is available on the roof systems in the main shed and the service/office building structure. Thus, it can be calculated approximately that an area of 880 m2 on the main shed roof and an area of 90 m2 in the service and office block roof will be available to place PV panels.

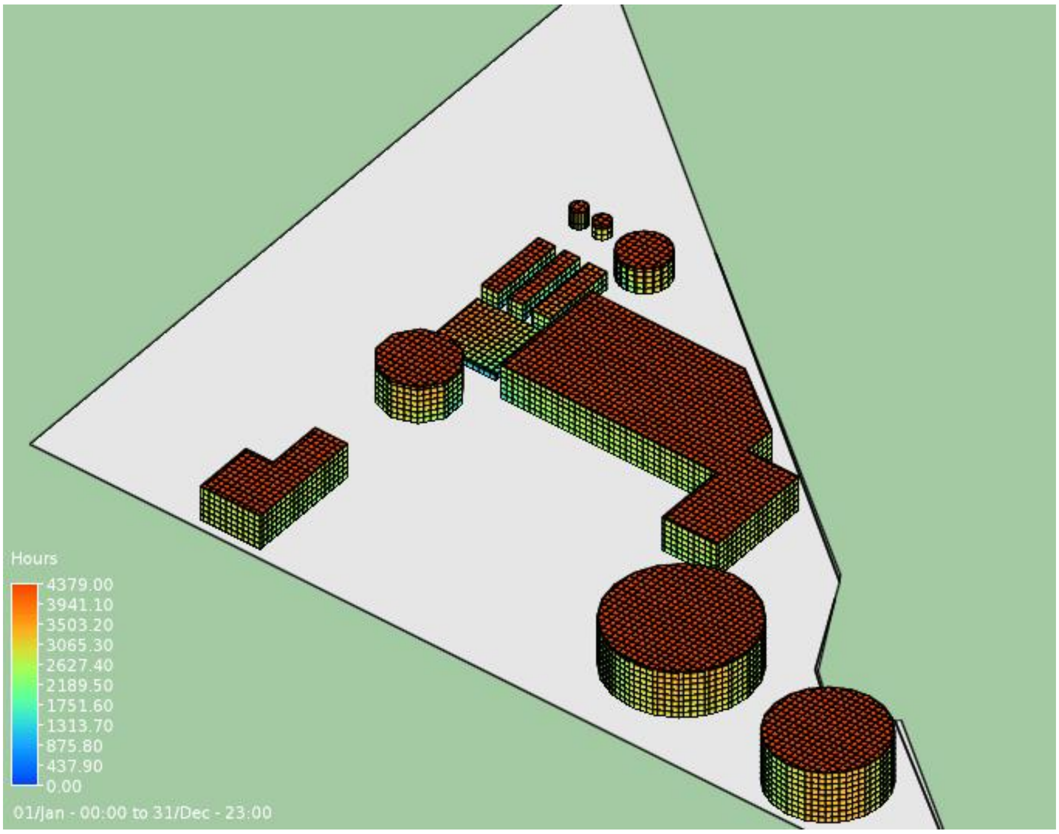


Figure 4.9: Solar Exposure Analysis using IES VE

For the purpose of locating the wind turbine system, a wind rose diagram is generated in IES VE using the same climatic data from ASHRAE illustrated in figure (4.10).It is seen that the wind intensity is more from north west to south east but it should also be kept in mind that the prevailing winds in the area is from north west to south east. Thus, it would be most feasible to locate the wind turbine in the north western region of the plot so as to tap in most of the wind resource available.

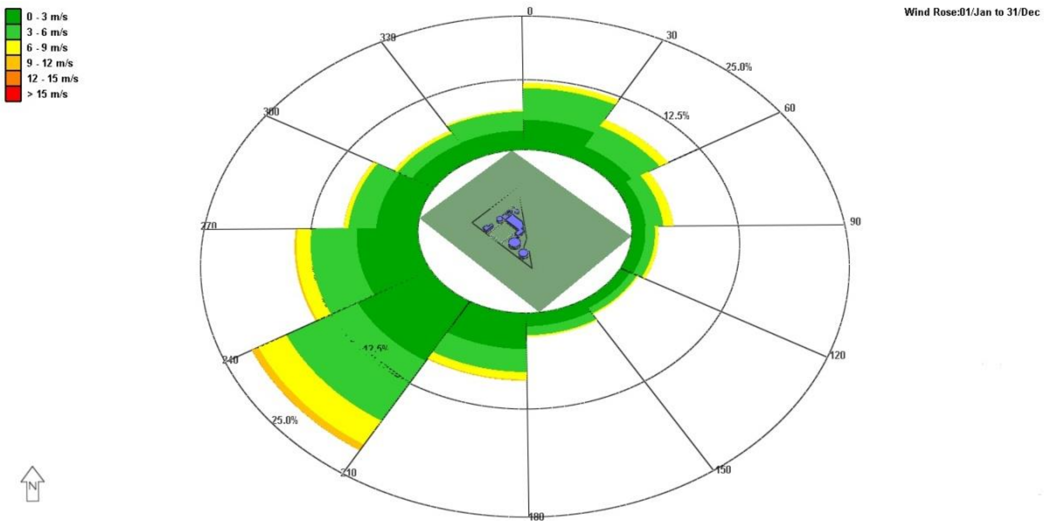


Figure 4.10: Wind rose generated using IES VE

It is also noted that the wind speed in the area ranges between 4-5 m/s at 80 m mast height (also described in chapter 1, figure 1.10), thus it is understood that the wind potential is quite low in the region which will require careful selection of the wind turbine system to be used. However, as the plant lies near the Arabian Gulf the wind speed is expected to be higher than the inland wind speed; thus increasing the feasibility for using wind turbines. From this simulation model, an approximate understanding of the renewable resources available at the site as well as where the solar photovoltaic system as well as the wind systems could be potentially placed is derived.

4.4 SIMULATION MODELLING – HOMER ENERGY

HOMER Energy is used in this study to simulate the different system configurations, combination of system components to be used, optimal number, and size of the components and the net present cost of each configuration. The software would give all possible configurations to consider by calculating the energy balance equation. Then an optimization is done by the system considering the net present cost. Furthermore, a sensitivity analysis is done for different sensitivity variables specified.

From the results derived from HOMER Energy, a technical and economical assessment would be done to come to a conclusion on which configuration would be best suited for the desalination plant.

For the simulation process, the following parameters would be first finalised;(a) Electrical load profile of the desalination unit, (b) PV panel selection, (c) Wind turbine selection, (d) Battery and converter selection and (e) simulation case configurations. In the literature review, it was mentioned that a charge controller is needed to smooth out the current flow in the hybrid system, however, in HOMER Energy charge controller inputs is not simulated as the software assumes that the flow of current is smooth based on the selection of the appropriate battery.

4.4.1 ELECTRICAL LOAD PROFILE OF THE DESALINATION UNIT

The primary load profile with the data for 8760 values needs to be given as the input for HOMER Energy and is one of the first and most important step in the simulation. It can be assumed that an industrial load profile would be most convenient for the desalination unit as it works 24 hours a day and is not stopped in-between. There are two primary loads involved ; primary load 1 consist of the electricity used by the SWRO units 1,2 and 3 from SEWA line 1 whereas primary load 2 consists of the load used by SWRO 4 from SEWA line 2. From the case study, the author has collected the daily load profile for the year 2015 from January to December for both of the primary loads but only the primary load 2, which is the load taken by the SWRO unit 4 will be taken into account for modelling. The energy meter reading for the year can be found in appendix A. From this data, an average hourly load is calculated to be entered into the software as illustrated in figure (4.11). The average hourly load is also validated by taking live hourly readings for the month of November and December 2015 for a week (see appendix A). The SEWA electricity bill is also evaluated against the input load values for validation (see appendix A).While taking only the load of the desalination unit SWRO 4, more focus can be given on the desalination unit alone whereas if we consider the load in SEWA line 1, there are high chances for an inaccurate load profile as this energy meter reading consists of three desalination units, office block, service block and other recreational facilities utilised by the desalination plant.

By analyzing the load profile, we can see that the load in the month of January 2015 is very low. This is due to the fact that the desalination unit SWRO 4 was only commissioned at this time, thus it was not fully functional and was in a test mode. In the months of February, March and April the plant was functional only from 10 to 12 hours a day as the demand for portable water was not as high as expected. Thus the plant was kept working only for producing the water required as surplus amount of water will cause overflow of the storage tank. As per records, the plant was fully functional for 24 hours from June 11th and from then has been using its full potential. From June to November the sales have also increased due to the high temperatures and new clients. The month of December had lower sales due to the setting of winter thus decreasing the demand for portable water at that time. It is observed that the months of December, January, and February the sales are lower than the rest of the year due to the fact that it is winter.

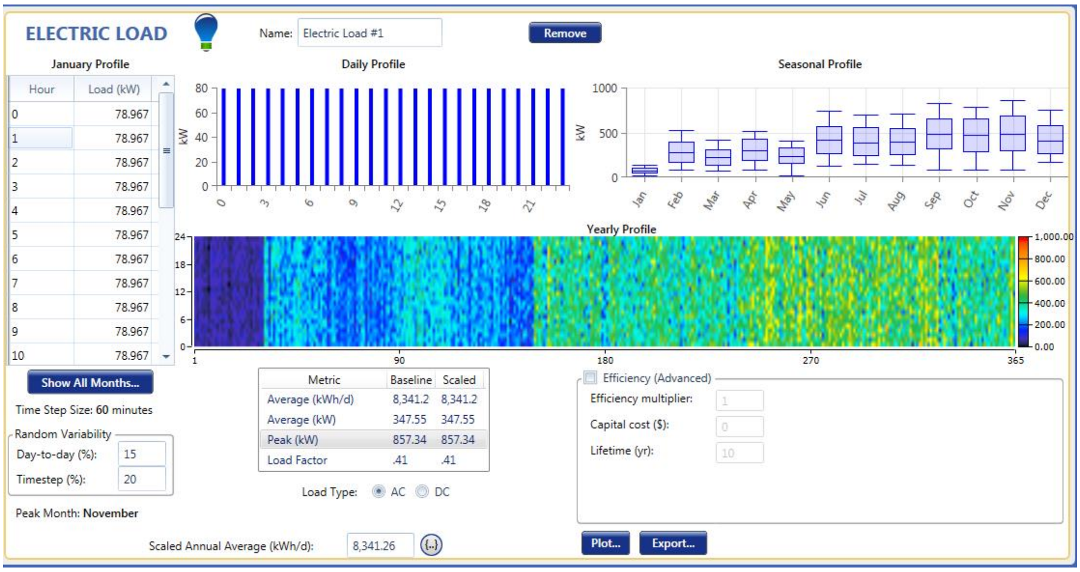


Figure 4.11: Electric Profile input in HOMER for desalination SWRO unit -4

It should be noted that in HOMER Energy the hourly load profile is requested at the input, however, only the values for the daily load profile is available for the whole year. Thus, an average hourly load is estimated from the daily average profile. From the month of June to December 2015, the hourly profile can be deemed accurate as the plant was functioning for 24 hours. Slight changes in the load profile in these months were based on high demand, changes in feed pumps and feeding pumps, shutdown and repairing of parts due to mechanical problems occurred and maintenance of functioning parts. It is estimated that the scaled annual average electric load of the plant to be 8,341.26 kWh/day and the peak load would be 857.34 kW for SWRO -4 unit.

4.4.2 PHOTO VOLTAIC PANEL SELECTION

From the climatic data collected for the actual site using NASA SSE database and with IES VE, the scope of using PV in the project area looks very reliable and optimistic. For the HOMER Energy data input, the data from NASA SSE is used for simulations as illustrated in the figure (4.12) where we can observe that the annual average solar horizontal irradiance is an optimistic value of 5.75kWh/m2/day and has a high clearness index for most of the year. The available space to place PV panels has been approximated to 880 m2 and 90 m2 on the roofs of the main shed and the service/office block using IES VE, respectively.

A market study was conducted to select the most feasible PV modules to be used for the system. From the literature review it was concluded that poly-crystalline, mono-crystalline and thin film modules are the most used in the market currently. But, it should be noted that each type of cell works best in a certain climatic condition and factors like temperature, dirt, age of PV module and humidity plays a great role in their efficiency (Parida et al, 2011).

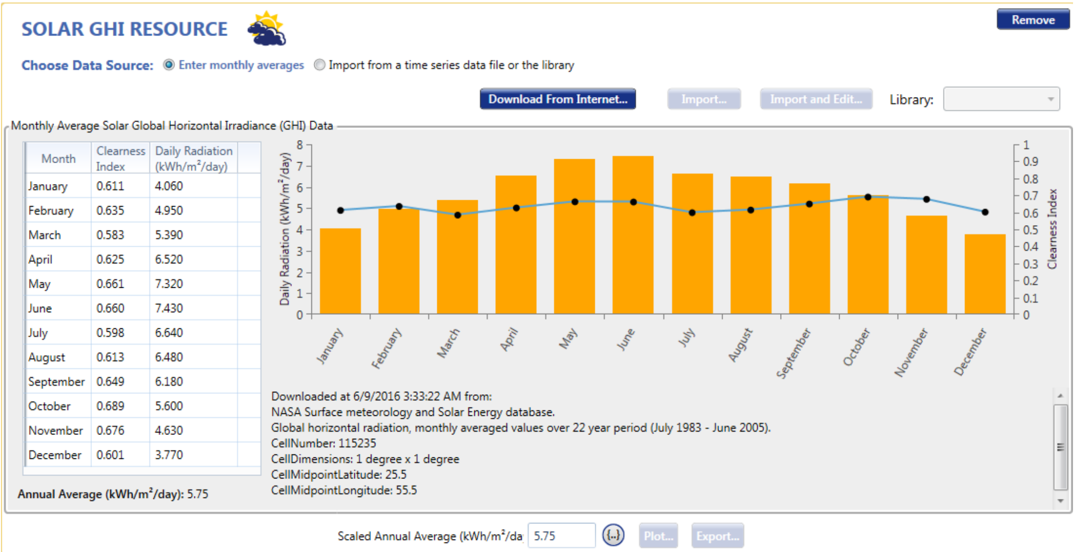


Figure 4.12: Solar Global horizontal irradiance input in HOMER

From the market study it was understood that PV manufactures that are most preferred in UAE for commercial, industrial and utility scale generation are Jinko Solar, First solar and Suntech power. First solar currently focus on utilities scale productions and are more prominent in the thin film technology. Even though they are economically viable, at present the company only deals with utility scale production. Jinko Solar and Suntech power are the two viable options as they are said to be more efficient and more commonly used in the region as per the market survey. Suntech is ruled out as it was faced with bankruptcy in 2013 and is still in the process of stabilizing with its investors. Thus A module by Jinko Solar will be selected for the plant. While considering the type of cell technology to select, the pros and cons of mono-crystalline and poly –crystalline modules is analysed. After comparison from the data sheet provided by the manufacturers (see appendix B), a polycrystalline PV module manufactured is selected which has a module efficiency of 16.49 % and temperature coefficient of Pmax at -41%/°C. The 72 cell Ve module with dimensions, 1956 × 992 × 40mm would be best suited for the large rooftop of the main shed considering the dimensions of the rooftop when analysed by the author using AutoCAD. The Nominal Operating Cell Temperature (NOCT) is 45±2°C which would be the best option considering the climatic conditions of the region (Jinkosolar.com, 2016).

4.4.3 WIND TURBINE SELECTION

Currently, the desalination plant is restricted in terms of land area thus making small wind turbines a viable option for installation. Based on a market study, it was found that Bergey 10kW utility interactive turbine with 7m rotor diameter would be one of the options to consider due to the low wind potential in the region. The turbine has a low cut in speed of 2.5 m/s which is very apt considering the wind data acquired from the NASA SSE database. While comparing the two options from Bergey, 10kW and 5kW utility integrated turbines, the 10kW was selected as it has a better annual energy production (measured:7135 kWh) for wind speed of 4 m/s and it has a viable cost (Bergey.com, 2016). However, this initial option was not viable while it was simulated in HOMER with the calculated primary load. It was found that by using 15 Bergey Excel 10 units it served only a mere 6.88 % of the renewable fraction when connected to the grid. Thus the simulation was run again using a 100 kW turbine (Northern Power NPS100C-24) from which it was derived that 5 units would provide a renewable fraction of 23.8%.The turbine has rotor diameter of 24.4 m and a cut in speed of 3m/s (Northernpower.com, 2016). Further simulation was done with a 275 kW turbine (Vergnet GEV MP-C) and it was noticed that by using 2 units a renewable fraction of 26.5% was achieved in a grid connected system. The wind turbine had a rotor diameter of 32 meters and a cut in speed of 3.5 m/s (Vergnet.com, 2016). It was further probed to simulate the with a 500kW turbine (Windflow 33-500) which had a 33.2 meter rotor diameter (Windflow.co.uk, 2016). But it was observed that 2 units only produced a renewable fraction of 21.1 % which may be due to the higher cut in speed of 5.5 m/s. Thus through these set of simulations it was decided upon to use the 275kW wind turbine for being the most productive with fewer numbers.

The Vergnet GEV MP-C (275kW turbine) has a two blade rotor and a hub height of 55-60 meters. It is corrosion resistant thus a good option for salty environments as observed in the case study area (datasheet attached in appendix B).

The NASA SSE wind resource data is entered as input into the homer system for wind resource as shown in figure (4.13) where we can see that the annual average wind speed is 5.3 m/s which may work in a satisfactory manner for the 275 kW wind turbine.

Figure 4.13: Wind resource input in HOMER

4.4.4 BATTERY AND CONVERTER SELECTION

Battery is an option that can be utilised in hybrid and stand alone renewable systems as per the literature review. As the peak load for the desalination plant is quite high, a battery of suitable characteristics should be selected. A variety of batteries are already provided in the Homer Energy software and by looking through the data sheets from the manufacturers, it is concluded that CELLCUBE FB 200- 1600 (data sheet attached in appendix B) by Gildemeister would be the best option to consider as it could take the peak load needed by the plant as at least a capacity of 1200 kWh is needed for the plant to run smoothly. The CELLCUBE FB 200-400 is based on a vanadium redox flow battery which in its round trip also represents as an AC-DC-AC conversion thus will act as a converter as well .The input values for the converter section in HOMER Energy will be as follows; it would be sized at 400kW (twice the rated power of the battery), the cost parameters would be set to 0, the lifetime would be set as same as the battery lifetime, inverter input efficiency and relative capacity would be kept at 100% and all the loads would be connected to the AC-Bus. The many advantages of this battery include high lifetime of 20 years, unlimited charging/discharging cycles, 100% deep discharge, non-flammable and non-explosive, low maintenance, negligible self discharge, homogeneous energy medium and Vanadium is a widespread raw material making its resourcing more sustainable than other materials (Energy.gildmister.com, 2016).

4.4.5 SIMULATION CASE CONFIGURATIONS

The simulation case configurations would be as pointed out in the Table (4.2).it should be noted that the scenarios are derived by considering each system (base case, solar PV, wind generation, hybrid system) at different output potential ratio (0%, 25%, 50%, 75%, 100% and surplus) with respect to the demand load profile of the desalination plant, when connected to the grid and when not connected to the grid. The net present cost for all scenarios would be taken into account for the economical evaluation.

Table 4.2: Technical simulation case configurations

Case configurations	Base case	PV system	Wind turbine system	Hybrid system
No grid connection (stand alone system)	×	×	×	×
25% grid connected		×	×	×
50% grid connected		×	×	×
75% grid connected		×	×	×

100% grid connected	✗	✗	✗	✗

Firstly, the base case configuration would be simulated and the model would be validated with the current energy readings. Secondly, the PV system configurations and the wind turbine system configurations should be simulated individually and the results compared and validated in order to understand and justify if to go ahead with a hybrid case configuration system. In each set of results, the optimised result would be selected for analysis and a sensitivity analysis is also conducted using HOMER on the specified range of variables. Finally, all the system configurations can be compared with regard to its technical aspects and economical aspects. Table (4.3) lists down the unit cost and models used for the simulation.

Table 4.3: Unit cost and references for items selected

Sr. No.	Item	Model	Unit Cost ($)	Reference
1	Wind Turbine	Vergnet GEV MP-C	900,000	Vergnet.com, 2016 Singh, 2015
2	PV module	Jinko Solar JKM320P-72	256	Jinkosolar.com,2016 ACOsolar.com,2016
3	Battery	CELLCUBE FB 200-1600	1,600,000	Energy.gildemeister.com, 2016 BetterWorldSolutions - The Netherlands, 2015
4	Generator	Innovus VSG1200	170,000	Innovus-power.com, 2016 Alibaba.com, 2016

4.4.6 MODEL VALIDATION

The simulation software used in the study utilises data from resources such as ASHRAE (for IES VE) and NASA SSE data base (for HOMER Energy). Both the resource inputs are verified so as to validate the data used and to avoid any errors in the climatic data used. The load profile is validated and calibrated as per the readings observed in the energy meter as well as validated with the SEWA electricity bills for a whole year 2015 (attached in appendix A).

5 CHAPTER 5 - RESULTS AND ANALYSIS

The simulation results from HOMER and IES VE have been analysed to understand what would be the most technical, economical and environmentally feasible solution to the present base case model.

5.1 TECHNICAL AND ECONOMIC ANALYSIS

The technical analysis would be done by looking at which would be the most feasible option concerning renewable energy and its balance systems. The analysis would look into the fact if the primary load supply is met, if there are any unmet loads, if there are any capacity shortage and maximum renewable capacity permissible. It should be noted that HOMER optimizes output considering the net present cost and would consider making more economically viable options than technical ones.

The economical analysis is done with the simulation results from HOMER. The factors that will be considered are the initial capital cost, operating cost, net present cost, the levelized cost of energy (LCE).It should also be taken into note that the HOMER software optimizes its results with regard to the net present cost and not the cost of energy due to the fact that the result is arbitrary and disputable in the case of the cost of energy. The economical inputs are derived from the market study and similar recent case studies and are given in US dollars. The economic viability is very important for the acceptance of any configuration in an industrial business.

Each case configuration would be technically and economically analysed to understand which would be the best case to consider viable in the current situation.

5.1.1 BASE CASE ANALYSIS –NO RENEWABLE SYSTEMS INTEGRATED

The base case technical analysis is done to understand and validate the present condition of the plant. For the base case analysis two scenarios are considered; scenario 1: The desalination plant is connected to the grid, scenario 2: the desalination plant is made to run using a generator 9 (illustrated in figure 5.1 and 5.2).

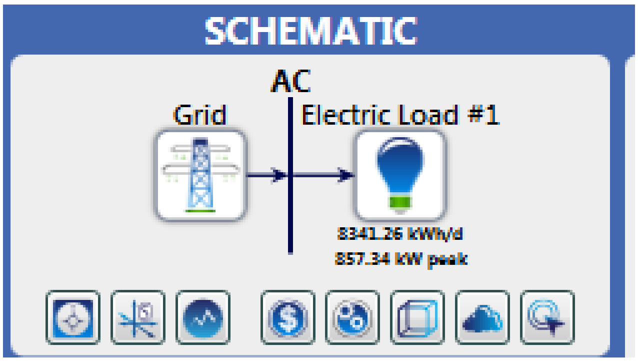


Figure 5.1: scenario 1- Grid connected

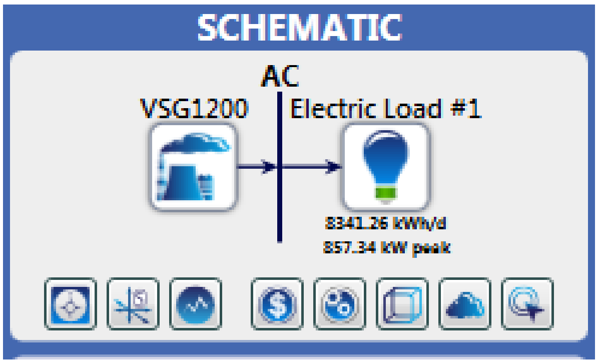


Figure 5.2: Scenario 2 – Connected to an independent generator

In scenario 1: The primary electric load is defined as per figure 4.11 in the earlier chapter. The grid is defined as a simple grid and the grid power price is given as 0.12 $/kWh (which is .44 AED as per the SEWA electricity bills for the plant for the year 2015). The grid sell back price is kept as 0.0 $/kWh as there is no system of net metering in SEWA. In scenario 2: the desalination unit is connected to the diesel generator Innovus VSG1200 which has a capacity of 1200kW (Innovus-power.com, 2016). This generator is selected as when considering the peak load of the desalination unit, which is about 857.34 kW, the generator capacity must be a minimum of 1200kW (25 % backup capacity). The capital cost was found to be $170,000 (Alibaba.com, 2016). The replacement is kept at zero considering the lifetime of the project and the operation cost is taken at 1$/hr considering the mechanical disruptions and labour cost for running the generator as suggested by the operations and maintenance engineer at the desalination unit. The diesel fuel rate is taken at 0.48$/L as per the statistics from the Ministry of Energy, UAE (2016).

In scenario 1a, the simulation was run using the peak load requirement of 858 kW for the yearly power supply to the desalination unit. From the figure (5.3), it is clearly seen that the simulation results show a capacity shortage of 298.8 kWh/yr. This may be due to the high start-up loads for the high pressure pumps that are needed to run the RO unit and the high peak power needed in the summer months. Thus to get a more realistic value for the grid to provide electricity without any capacity shortage a series of calculations were simulated with the peak load above the scaled average. Finally, it was found that a 944kW would be the most optimal peak load to be considered as the capacity shortage was met using this load (figure 5.4).

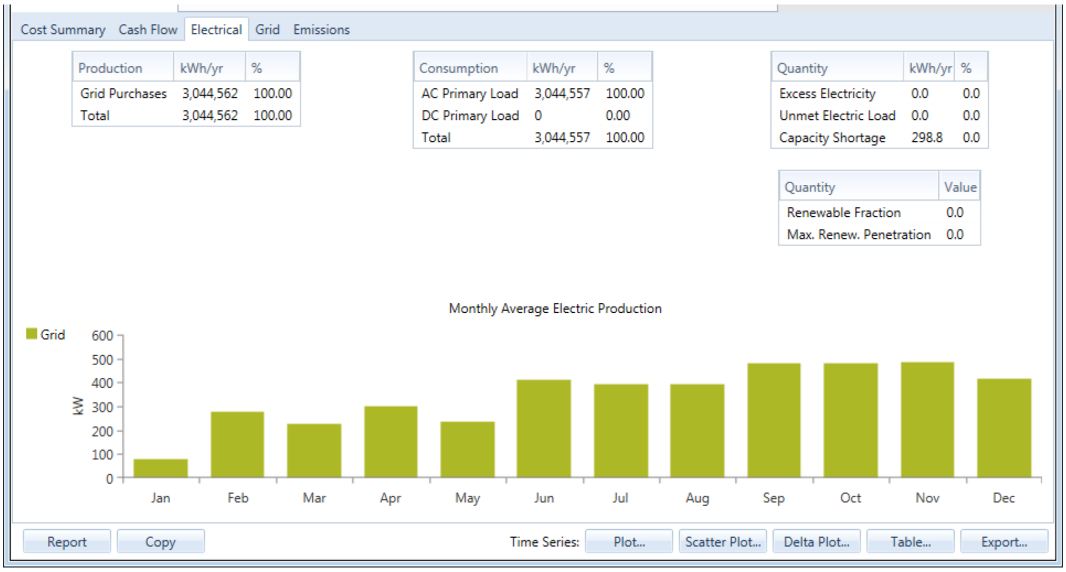


Figure 5.3: Simulation result in HOMER for 858 kW peak power

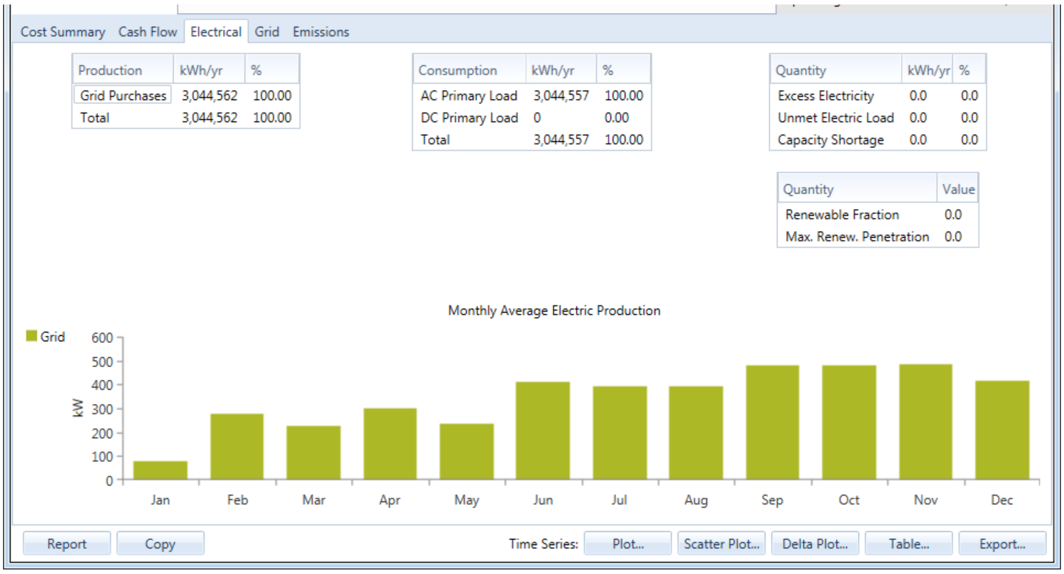


Figure 5.4: electric production at 944kW peak power

For the most realistic and safe measures, the optimal peak power is taken at 1200kW for the grid to be used in the later simulations. This ensures that the capacity shortage is met for 25 percent higher peak loads as it is assumed that the load profile would be an industrial one from the year 2016 onwards. It is also noted that the low energy consumptions from January to May 2015 are due to the fact that the plant was in an initial test phase. The simulation was run with the peak load as 1200kW for the grid (figure 5.5) and HOMER had taken the 1200 peak value as more optimized than the 944 kW peak value which may be due to the increase in the capacity shortage.

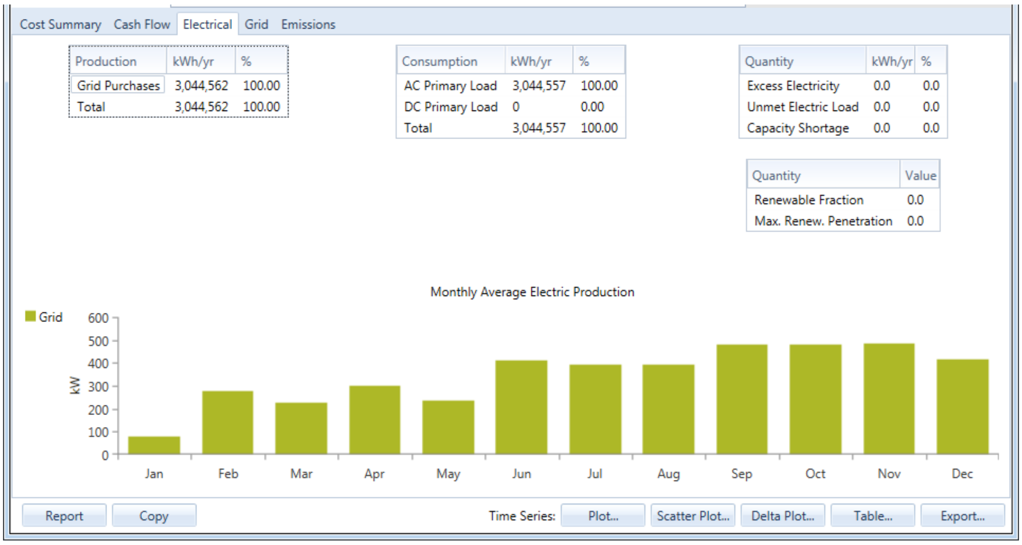


Figure 5.5: electricity production at 1200kW peak power

From the grid tab in the simulation results, the energy purchased from the grid is given in monthly kWh. This result (figure 5.6) is compared and validated with the energy meter reading from the months July – December 2015 (appendix A) as the plant was fully operational in these months. While looking at the net present cost (NPC), it is seen to be $1,195,957.98. This cost may vary from region to region thus will not be given most importance while analysing the economics of different systems. The LCOE is a very important factor to evaluate the overall economic feasibility of the configurations but as HOMER considers the calculated LCOE in the software to be disputable, only the NPC would be considered to economically rank the systems as it is found through a simple formula. Firstly, the method of calculating LCOE by HOMER is formulated by considering and dividing the amount of electrical load that is served by the system rather than the total electric demand , which will tend to certainly differ if the user would accommodate for some unmet load. Secondly, thermal energy produced is neglected in the software but grid sales are included as a factor for useful energy production. Finally from these preferences for formulating the method of calculating LCOE by the software it is understood that these parameters are somewhat arbitrary thus making the definition of LCOE by HOMER also as arbitrary. However, it is noted that the Net present cost is not impaired by such ambiguity through definition which makes it to be considered as the primary economic figure of merit.

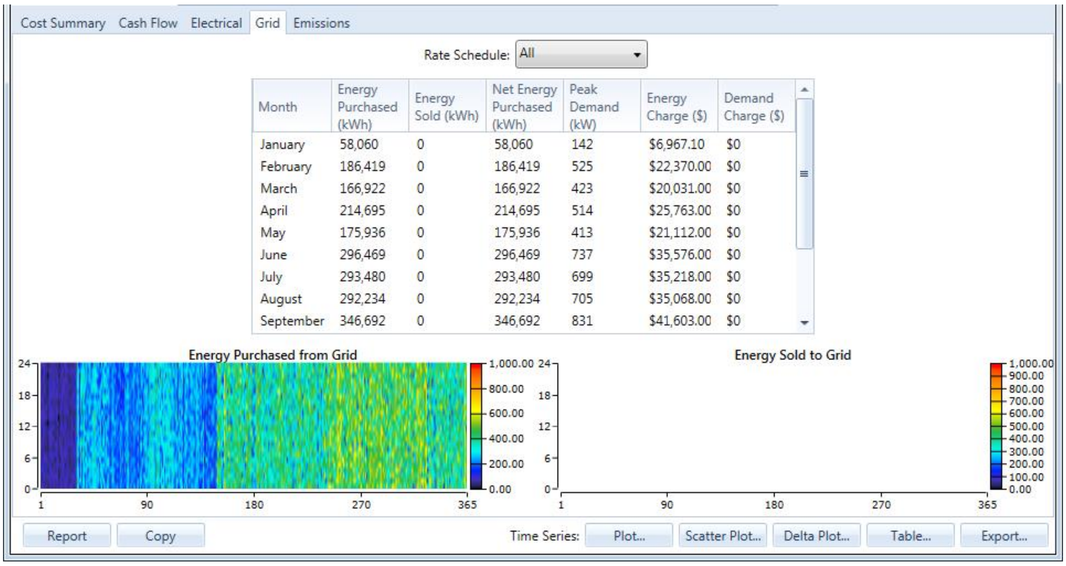


Figure 5.6: Energy purchased from the grid-monthly average simulation

In scenario 2: the electric supply from the grid is not used whereas the desalination plant is run by a power generator with a capacity of 1200kW.It is seen from the results that the capacity shortage is met and 1% excess electricity is produced which is acceptable (figure 5.7 and 5.8).

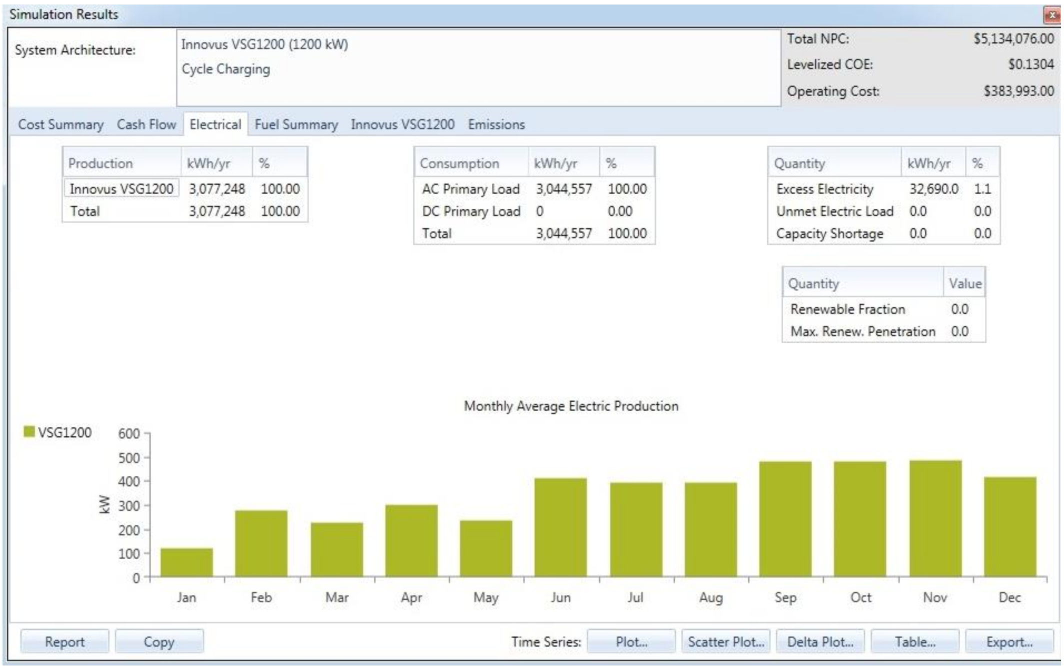


Figure 5.7: Simulation result after using 1200kW generator.

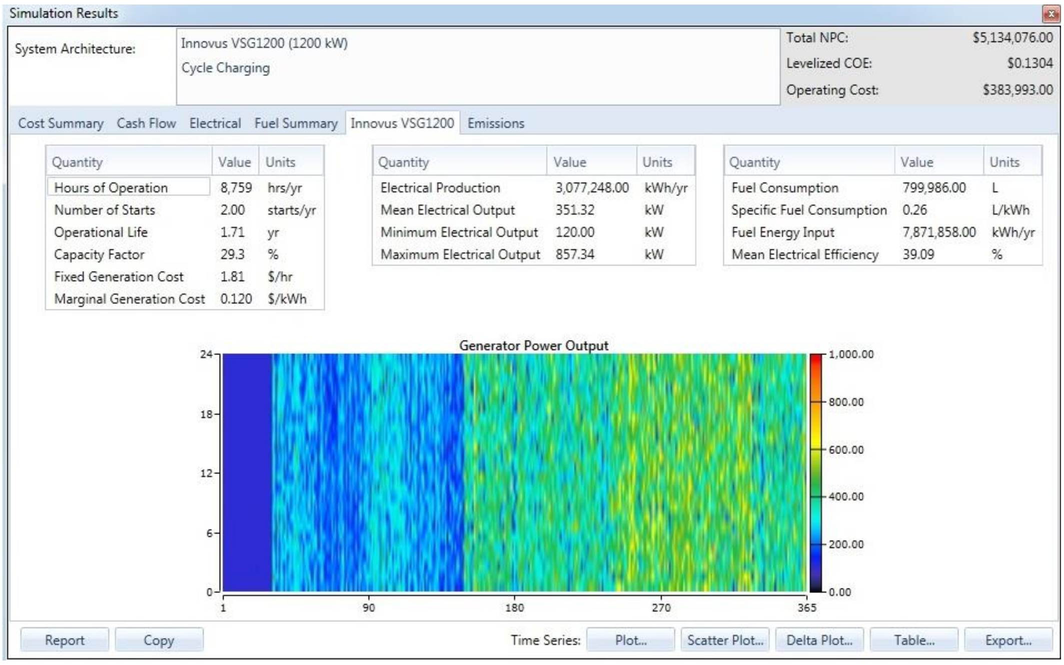


Figure 5.8: data representing the power generation output values for the generator

As it is seen that the excess electricity produced is only 1.1%, it is recommended to have a backup generator in case of extending or increasing the productivity of the plant by increasing any mechanical parts.

In this configuration, the total NPC comes at $5,134,076.00 which is more than the NPC while using only the grid. This may be due to the reduced price of grid produced power in the region. Thus this cannot be compared rationally, looking at the fact that the operating cost of the grid may be lower than the current scenario configuration.

5.1.2 CASE CONFIGURATIONS USING PHOTOVOLTAIC PANELS (PV)

From the previous base case configurations, the peak power was assessed as 1200kW. When considering the available rooftop area for installing PVs, the maximum number of modules that can be installed would be 500 panels which would yield a PV array of 160 kW. From such a scenario, only 9.82% production can be utilized. Thus considering the fact that areas above the tanker filling area, pre filtration area and the new area bought by the plant can be utilized to installs more PVs a number of hypothesis case configurations concerning PV would be simulated in an incremental manner . Case configurations ranging from 25% PV renewable fraction and 100 % renewable fraction when connected to the grid (illustrated in figure 5.9), and PV standalone system with will analyzed. Renewable fraction in HOMER Energy is considered as the fraction of energy that is delivered to the load and which was originated from the renewable resources. Different permutations and combinations are derived from HOMER and the optimal case is studied.

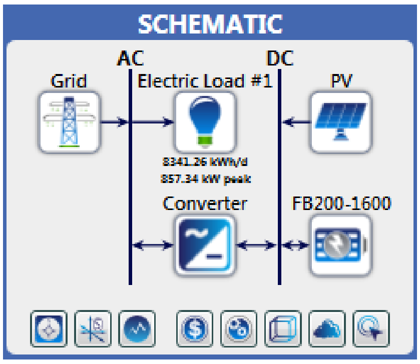


Figure 5.9: Schematic layout for PV and Grid connected system

For the economical analysis, the cost of the PV panels are taken at the market cost of 256 $ per panel and the replacement costs are given to be the same considering that the whole panel has to be changed and from literature it is understood that PV panels are more prone to wear and tear considering the climatic conditions of the region. The operations and maintenance cost is kept at 0 as it would be considered with the replacement of the PV panel. The battery used would be FB 200-1600 with price ranging from 750 – 1000 $/ kWh as per market review (BetterWorldSolutions - The Netherlands, 2015). Even though these batteries cost more than the other electrolyte batteries, they are much more efficient (80% efficiency) and compact. It is also speculated that the battery price would go down in the coming years as this technology is considerably new compared to the others. It should also be noted that the price for land in the free zone per sq meter has gone higher in the recent years, which makes systems that are more compact more economically sustainable.

25% renewable fraction using PV –grid connected

In this scenario, 25 % of the PV energy will be delivered to the primary load and rest would be derived from the grid. As HOMER inputs the specific data of 320 W PV panel selected is entered and the PV array was set to a minimum of 320 kW to 544kW by step by step increment of 32kW.The grid purchase capacity was kept at 900 kW to give 75 % but it should be noted that irrespective of the findings, the desalination unit will run smoothly all year round as it is connected to the grid.0 to 2 batteries was considered and two converters of 400 kW and 800 kW capacity was considered.

After analysing a set of simulations that gave approximately 25 % renewable fraction, it is noted that the system illustrated in figure (5.10) that contains 544 kW array, one battery and one 400kW converter was a technically feasible option as it has 0 capacity shortage and 0 unmet electric load. It should also be noted that the energy produced by the PV array is 28.03 % but the renewable fraction is 25.9 %, this is due to the fact that there is an excess production of renewable energy production that was not delivered to the load. The balance of 71.97% of power production is from the grid. The minor amount of excess energy may be due to the fact that the batteries did not absorb it during the surplus production by the PV at periods when its minimum output exceeds the load. The NPC in this case is $5,713,236.00 where the cost of batteries plays a major contribution as well as the grid operating cost. The PV array costs the least with $87,473.00 as per HOMER with regard to the initial input into the system.

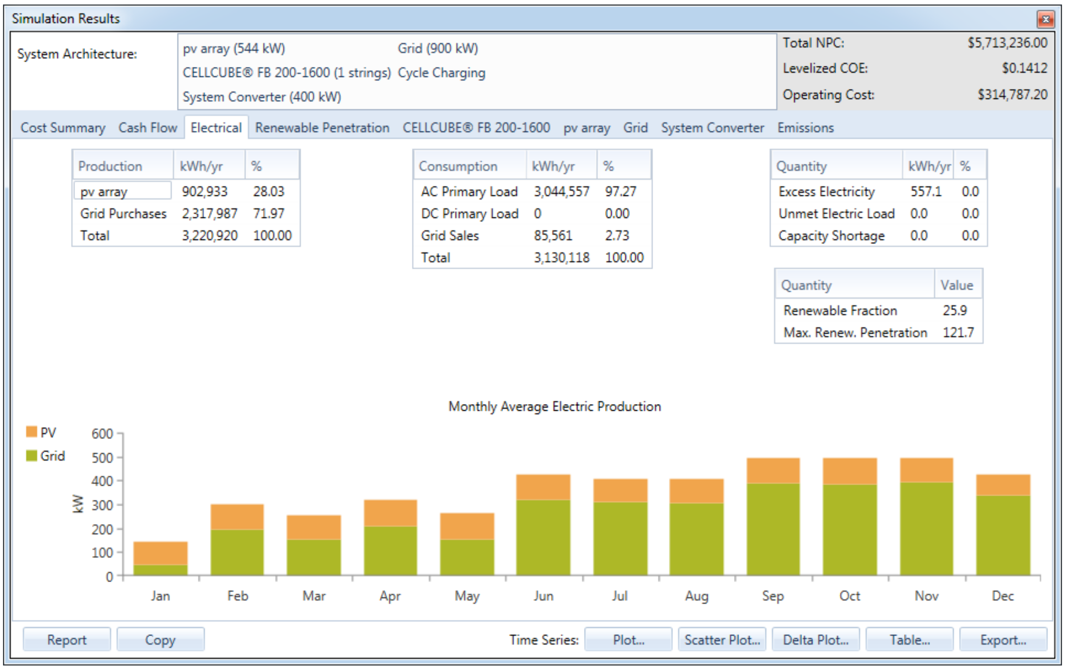


Figure 5.10: Electrical output for 25.9% renewable fraction using PV

Another optimization case was with the same system but without batteries which lowered the NPC considerably from $5,713,236.00 to $3,683,774.00. However, this would be most feasible for the desalination plant as it has a capacity shortage of 48.4 kWh which may not create a problem in peak months and can be neglected as the system is connected to the grid and it should be noted that in the simulation the grid capacity is kept at 900kW .Thus the system without batteries would be the most feasible option.

50% renewable fraction using PV –grid connected

The scenario simulated in this case configuration was by setting the renewable fraction by 50% and connected to the grid from 900 kW to 600kW. Converter capacity from 400kW to 1600 kW was considered and four batteries were considered. The PV capacity was kept from 544 kW to 1280 kW with 32kW step by step increment.

From analysis of the simulated results, it is understood that the technical feasibility for 50% renewable fraction may look likely for the system illustrated in figure (5.11) which consists of two batteries, converter of 1200kW capacity and

1280 kW PV array .The renewable fraction is at 50.3% and it is seen that there is 0 excess energy, 0 capacity shortage and 0 unmet loads. The renewable fraction and the electricity produced by the PV have very minimal difference which shows that the renewable energy produced have be utilized most efficiently by the unit and the whole production was used to serve the primary load. The NPC comes at $7,183,832 where the majority of the cost is due to the batteries.

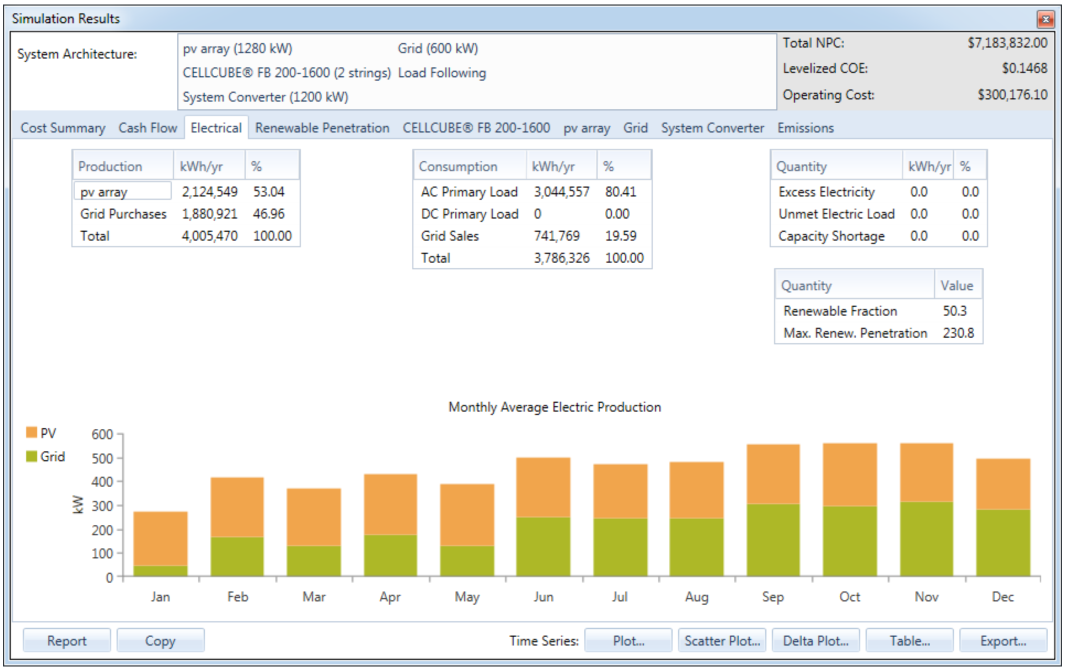


Figure 5.11: Electrical output for 50.3% renewable fraction using PV and two batteries.

While analysing the other optimized result it was with the system considering no batteries, 1280kW PV array, and a 800kW system controller with NPC of $ 3,124,551.00. The system is considered as the batteries are a very huge component when it comes to the economics of the system. However, the system had excess electricity of 0.8%, unmet loads (0.4%) and capacity shortage (1.2%) which would not create technical difficulties during peak periods as it should be noted that the system is connected to the grid thus the grid can smoothen out the power supply at the peak hours and the grid provided in this simulation is limited to 600kW. In another economically optimised system with one battery 1280kW PV array and 1200kW converter, it is seen that there was very minimal unmet load and a capacity shortage of 0.1% which may be the best technically optimized solution when connected to the grid. The NPC comes at $5,154,369.00 where the major cost is considered to be of the grid, followed by the battery.

75% renewable fraction using PV –grid connected

In this case simulation, the renewable fraction was kept at 75% and the rest is produced by the 300 kW grid. PV array was kept from 1280kW to 3360 kW with a step by step increment of 32 kW. 8 number of batteries were considered and the converter capacity was kept from 400 kW to 2000 kW.

The optimized results show that the most technically feasible while ignoring the fact that the grid would provide for capacity shortages is the output with 75.3% renewable fraction (illustrated in figure 5.12) is by using a PV array of 2912 kW, 4 batteries and 1600kW converter connected to the grid having a NPC of $10,628,770.00.

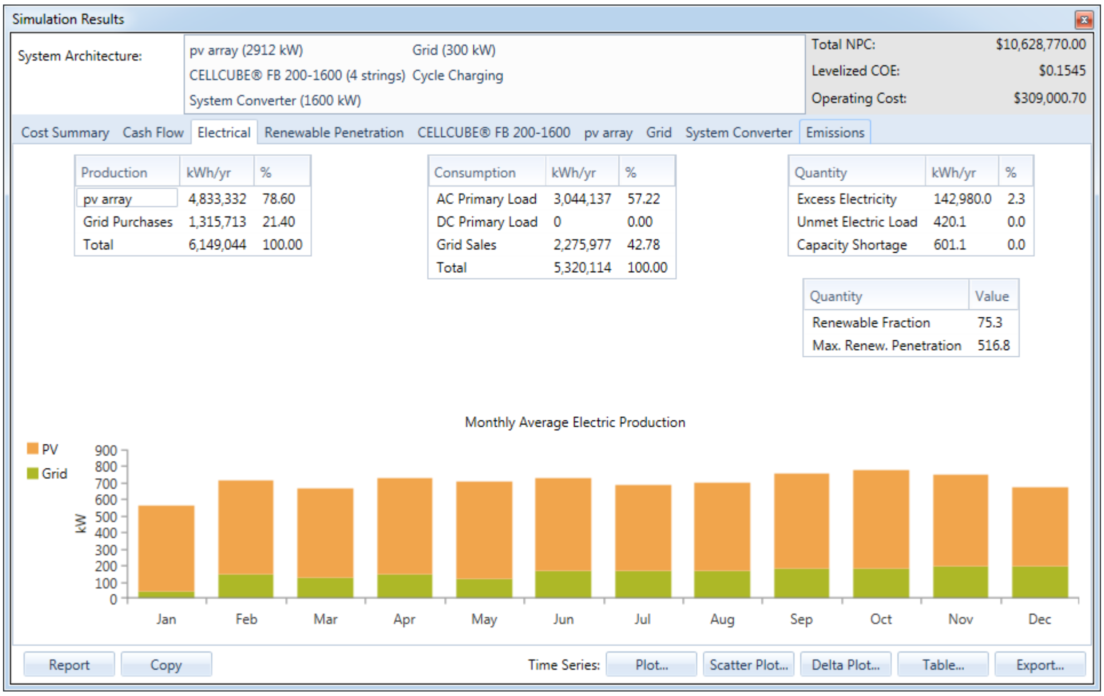


Figure 5.12: Electrical output for 75 % renewable fraction using PV

It is seen that there is an excess energy output for 2.3% which would be seen as wastage considering that currently SEWA does not have any net metering systems. It also shows that introducing more battery would not be feasible due to its huge capital cost and size. Other simulations with optimization variables with higher rated PV (more than 2912kW) show more percentages of excess electricity while results using lower rated PV (less than 2912kW) show high unmet electric load and capacity shortage percentage. In the former case, the simulation software does not want to introduce any more batteries due to its high capital and replacement cost whereas in the later case the PV array is not able to produce the required load to meet the 75 % renewable fraction and also increases the unmet load and capacity shortage as the electric demand is not served due to the electric production falling short of it. As a HOMER optimal case, a PV array of 2624 kW with a 2000kW system controller can produce the 75% renewable fraction but will have a capacity shortage of 18.5% and an unmet load of 13.6 % which again may be smoothened out by the grid but may bring technical difficulties during peak hours.

100% renewable faction using PV- grid connected

To simulate 100% renewable fraction from the PV while connected to the grid, the grid was kept from a mere fraction of 0.0001Kw. Even though this scenario can be considered as a standalone case, it would give more understanding on how the results would vary if the grid is not connected. The PV array is kept from 2642 kW to 6944kW.Converter capacity was given from 400 kW to 5200 kW and the number of batteries were kept to 15 strings.

It was analysed that the renewable fraction reached 100% by using a minimum PV array of 3904 kW (illustrated in figure 5.12), 13 batteries and a 1200kW system converter. There is 0.1 % unmet electric load and capacity shortage and a 11.1% excess electricity produced. The NPC comes at $27,011,980.00 of which 90% is due to the cost of the battery .Whereas, by using a PV array of 5984kW (depicted in figure 5.13), 9 batteries and a 1200kW converter the renewable fraction of 100% was achieved with 0 capacity shortage and 0 unmet load and an excess electricity production of 31.3 %, making it the most technically and economically viable system to be connected to the grid with the NPC at $19,228,580.00 due to reduced battery costs.

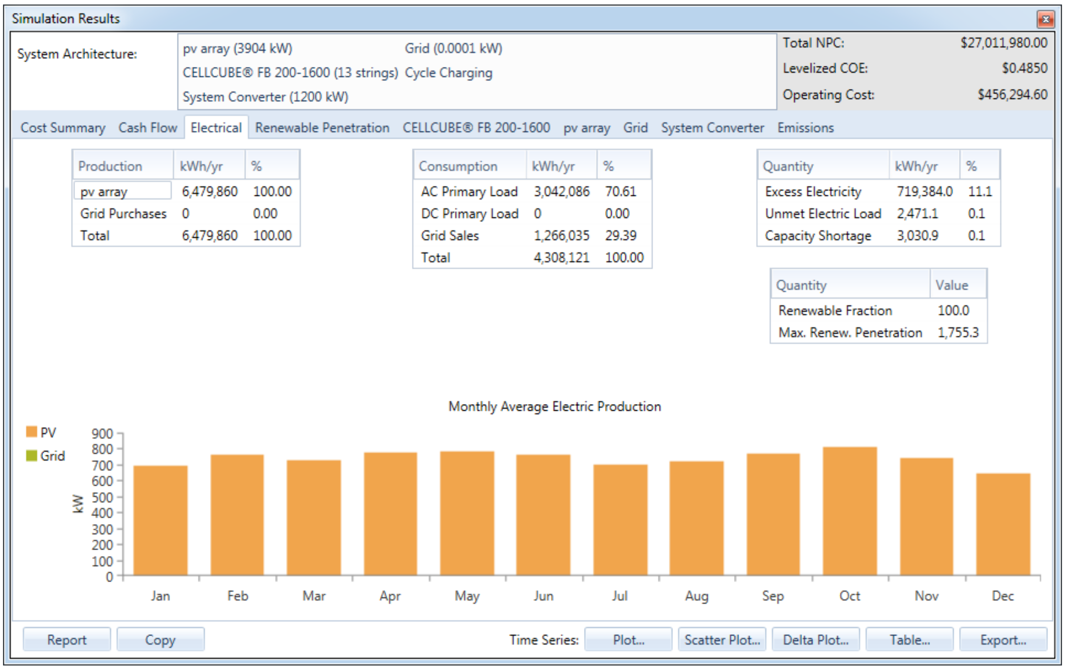


Figure 5.12: Electrical output for 100% renewable fraction connected to grid with 3094 kW PV array.

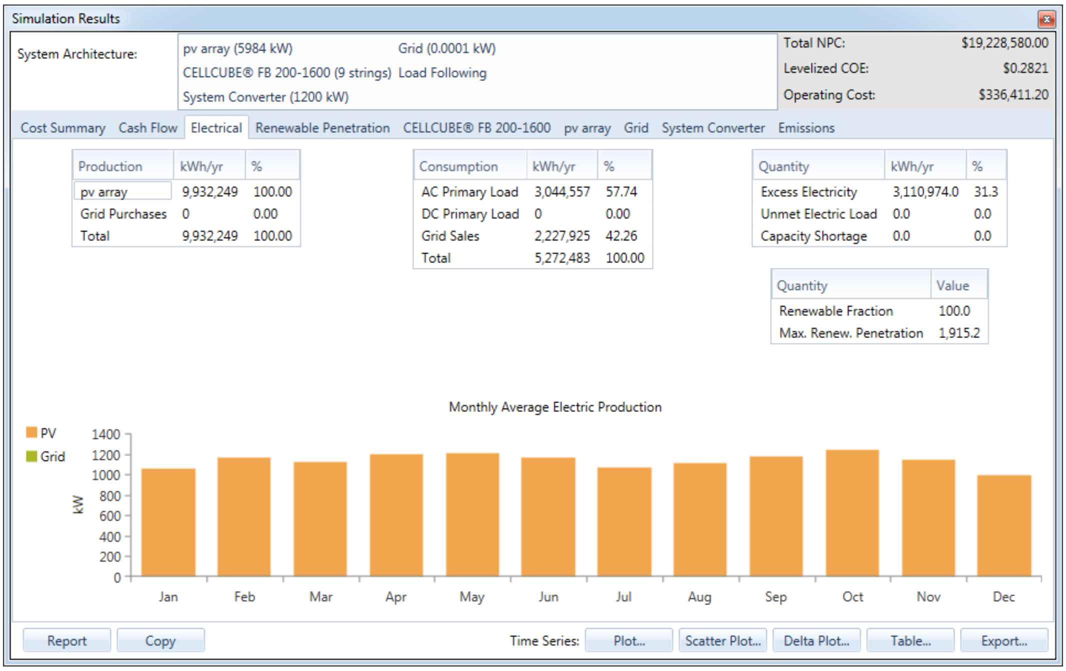


Figure 5.13: Electrical output for 100% renewable fraction when connected to the grid with 5984 kW PV array.

It is also noted that by decreasing the PV array capacity the excess electricity is decreased but the number of battery keeps increasing in numbers which may not be feasible considering the high initial capital of the battery. For instance, a 5024kW PV array will need 15 number of batteries and a converter of 1200kW to meet the 100% renewable fraction with a 47.8% quantity of excess electricity produced.

PV standalone system – 100% renewable fraction.

In this case onfigureation, the same values were provided as the 100 % renewable fraction PV system connected to the grid except for the fact that the system is not connected to the grid.The results observed was that the excess electricity increased from 31.3 % to 56.2% with a 5984 kW PV array.

From figure (5.14) the battery properties and characteristics show that, there is a loss of 957148 kW/year as this energy is not used in the system. The state of charge lies always above 50% throughout the year even at the highest peak demand .The PV array shows that it has a maximum output of 5353kW with a mean output of 27.212 kWh/day with a penetration of 326%.The hours of operation is seen to be 4347 hours/year which is gives a presentation of the solar resource available throughout the year. $19,228,580 would be the NPC for the system which as same as the previous case with 100 renewable fraction and connected to the grid. Thus if we consider the grid capital cost, extension cost and other service costs, the stand alone system may be more feasible.

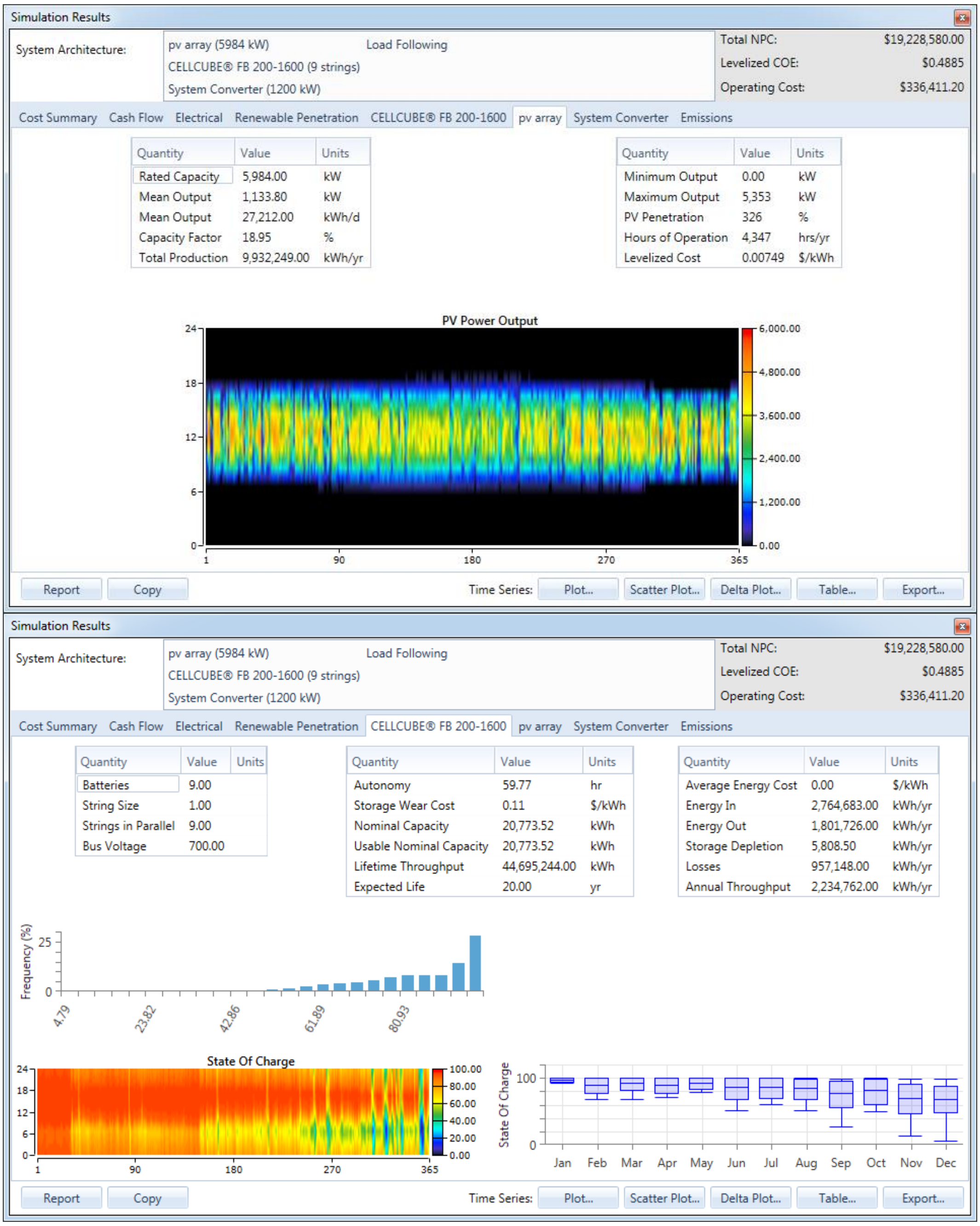


Figure 5.14: PV array and battery capacity and other characteristics for a 5984kW PV standalone system.

5.1.3 CASE CONFIGURATIONS USING WIND TURBINE (WT)

The case scenarios concerning wind turbines will be done using a 275kW wind turbine- Vergnet GEV MP-C (illustrated in figure 5.15), mentioned in chapter 4 as it was analysed as the most optimal turbine to be used by testing with the wind conditions of the area concerned. In reality, when observing the space that can be allocated for wind turbines considering their wake effects and other factors, it is very minimal. Thus, a hypothetical study would be done to estimate the technical feasibility of the wind turbine power production in the area. The hypothetical case configurations will be done in a similar fashion as the PV case configurations ranging from 25% renewable fraction to 100% renewable fraction WT connected to the grid and standalone system. The grid would be modulated with a certain capacity for each configuration. The battery system and other balance of components used would be as same as the one used in the PV configuration for having equal grounds for final analysis.

For the economical analysis, the price of the wind turbine Vergnet GEV MP-C is taken to be $900,000 per wind turbine with the operating and maintenance cost at $18,000 as per the information provided by a current study by Singh (2015).the cost of the batteries and other components remain as per the inputs given for the PV system.

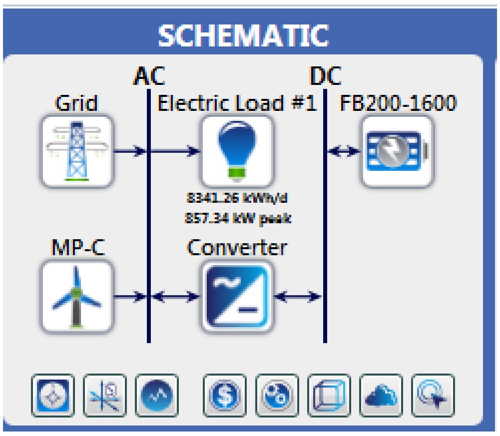


Figure 5.15: Schematic layout for Wind turbine-grid connected.

25% renewable faction using WT- grid connected

The case configuration consisted of the renewable fraction being set at 25% and the grid kept at 75% which is 900kW. The number of wind turbines were kept to 0- 4 in quantity. Converter capacity was kept from 400kW to 1200 kW and the batteries were given from 0 to 4 in number.

From the simulation results it was observed that a combination of two 275kW wind turbines, one battery and a 499kW system converter, a renewable fraction of 25 % was achieved with no capacity shortage or unmet electrical load (illustrated in figure 5.16). Whereas another optimization case configuration with the same number of wind turbines and a 400kW system converter but with no batteries involved also gave a renewable fraction of 25.4% but there was a capacity shortage of 14.5 kWh/yr which is 0.0% thus very negligible . Therefore, the case configuration without the batteries may be a more preferred technical configuration as when connected to the grid; such a small capacity shortage will not affect the system. While looking at the economics of both the systems, there is a huge difference in the net present cost due to the absence of the battery. The system avoiding the battery cost becomes $5,936,843.00 from $7,966,709.00 (with batteries).The highest cost is seen for the grid operations in these configurations.

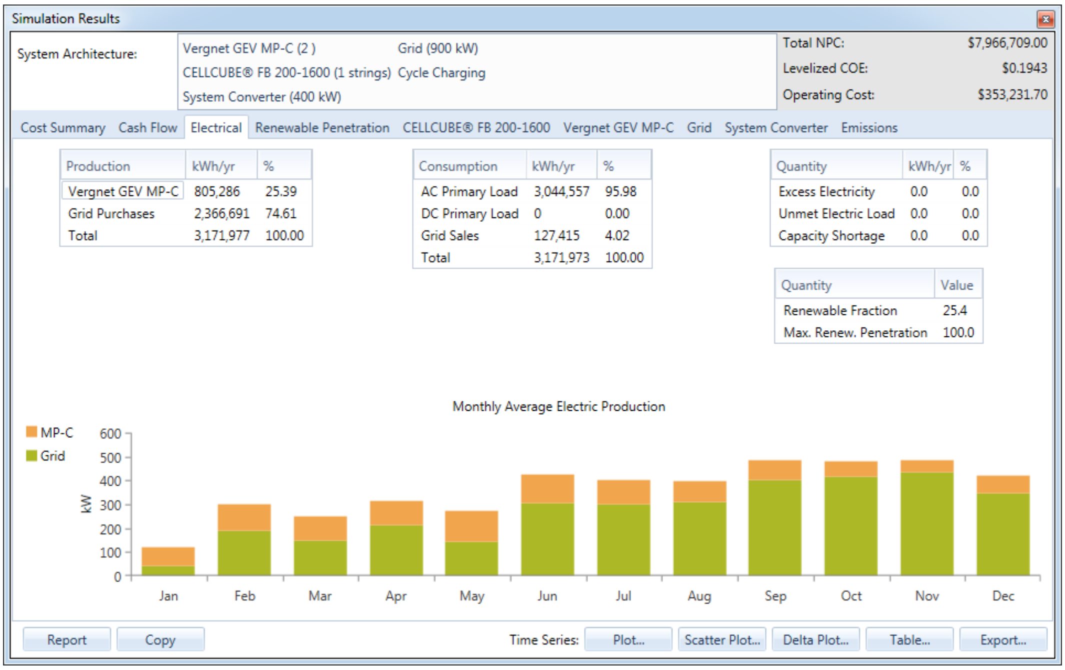


Figure 5.16: 25.4% renewable fraction using WT connected to the grid

50% renewable faction using WT- grid connected

In this scenario, the renewable fraction was kept at a constraint of 50% and the grid was kept at 600kW.The wind turbines were kept from 2 to 8 numbers, batteries from 0 to 4 numbers and the converter capacity was kept from 400kW to 1600kW for the simulation process.

From the primary assessment, it was observed that the closest renewable fraction achieved when the constraint was given at 50% renewable fraction was 51%.This was achieved by using 5 wind turbines (figure 5.17). When the simulation was investigated by using 4 turbines, a maximum renewable fraction of 44% only could be achieved. Thus, the optimised cases for 51% renewable fraction were observed. In one of the optimised cases, the renewable fraction was achieved using a combination of 5 wind turbines, one battery, and 400kW system converter. A negligible capacity shortage and unmet load is observed but as the system is connected to the grid, this will not create a disruption in reality. Another optimised cased consisted of 5 wind turbines, 2 batteries, and 400kW converter. In this case however, there was no unmet loads or capacity shortage, but an additional battery would put more strain on the economics of the system thus the former optimal scenario with the NPC of $10,672,210.00 will be most suitable. The wind turbines constitute of the highest cost in these scenarios.

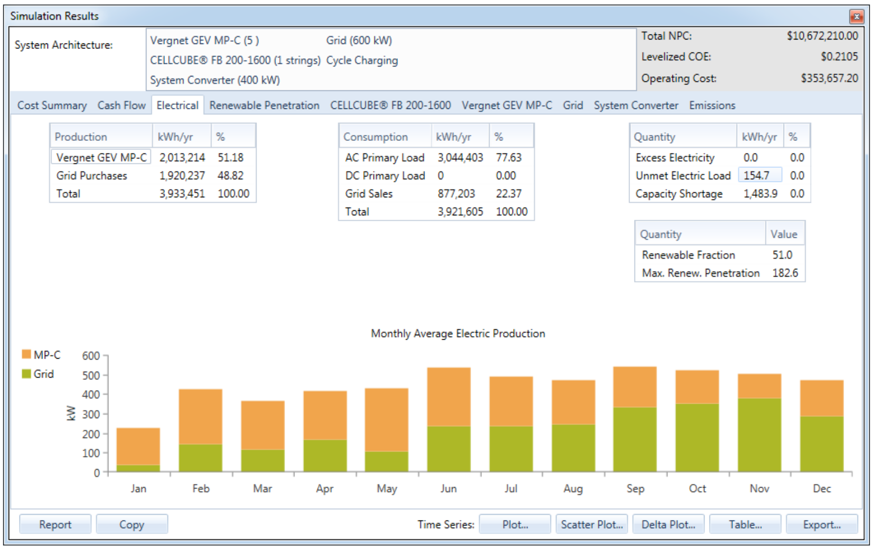


Figure 5.17: 51% renewable fraction using WT connected to the grid

75% renewable faction using WT- grid connected

In this case configuration, a primary simulation was run using 5 – 15 wind turbines, 400kW to 2000 kW system converters, 0 to 12 batteries, and a 300kW grid. The renewable fraction was kept at 75% for optimal results. As illustrated in figure (5.18) a 75.2% renewable fraction combination was achievable with 10 wind turbines, 4 batteries, and a 800 kW converter when connected to the grid. It can be seen that 76% production is from the turbines whereas 23.46 % is from the grid. There is a slight % of unmet loads and capacity shortage of 3.8% and 5.6% respectively.

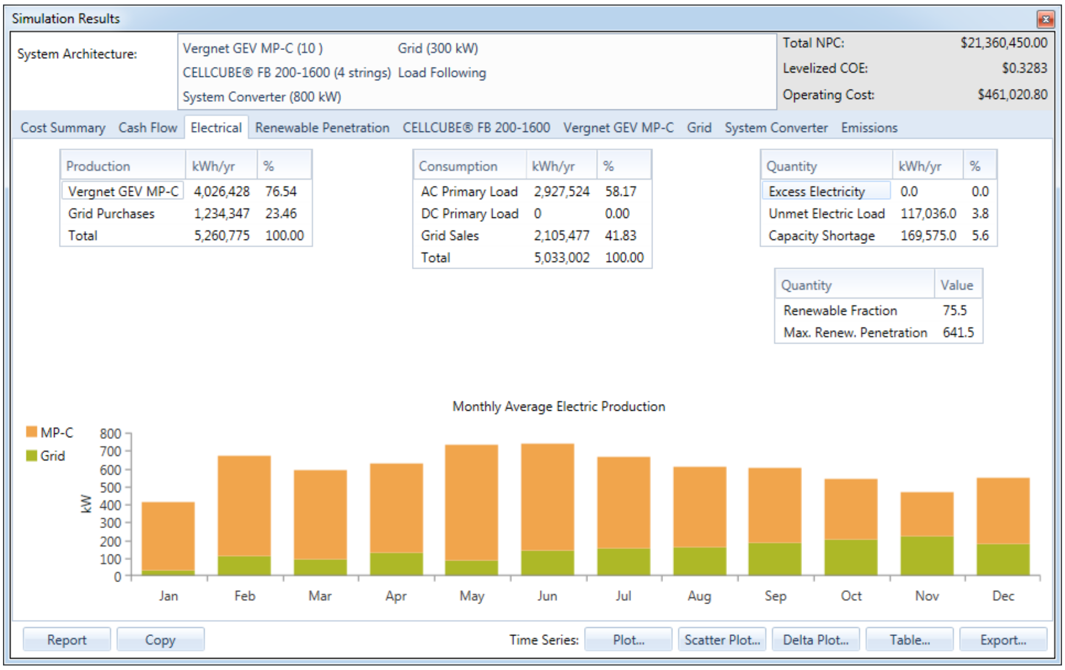


Figure 5.18: 75.5% renewable fraction using WT connected to the grid

Further investigation led to a combination of 10 turbines, 10 batteries and a 2000kW converter connected to a 300kW grid which produced a renewable fraction of 75.2% but with 2.2 % unmet electric load and 3.2 capacity shortage. But the huge number of batteries makes it a very unrealistic option to consider.

To achieve 0 unmet electric load and 0 capacity shortage, a system containing 44 wind turbines, 10 batteries and a 2000kW converter is used with a 300 kW grid. It was observed that until the use of 42 turbines, there is capacity shortage above 0%

with a 95% renewable fraction in all the combinations .Thus a case configuration was observed using a 600kW grid and it was found that a renewable fraction of 76% is observed with 12 turbines, one battery and a 400kW system converter with 0% unmet loads and capacity shortage. Thus the first configuration discussed, using 10 wind turbines, 4 batteries and a 800kW converter connected to a 300kW grid may be technically and economically feasible option if the grid capacity is increased. The net present cost is $21,360,450.00 where the maximum cost factor is from the wind turbine component followed by the battery and then the grid.

100% renewable faction using WT- grid connected

The constraints set in this system were at 100% renewable fraction and a 0.0001 kW grid similar to the PV system of 100% renewable capacity connected to the grid. Considering the problem of capacity shortage, the case configuration was analysed with 50 wind turbines, converters from 400kW to 6000kW, 0 to15 batteries and connected to the grid. The a number of economically feasible case by HOMER when a maximum annual capacity shortage constraint was given to be 10% as there was no feasible solution with 0% was studied. The optimised case configuration with least capacity shortage was with 28 wind turbines, 15 batteries and 3200kW converter .the capacity shortage was 5.4% and the unmet electric load was 4.4 %.

It would be economically unfeasible to probe to more batteries to decrease the capacity shortage but an investigative simulation with 0-45 batteries, 1- 53 wind turbines, and converter ranging from 400kW to 6000 kW was simulated. This resulted in a combination of 40 wind turbines, 33 batteries, 6000kW converter connected to a 0.0001 kW grid. This system combination has 0% unmet electric load and capacity shortage and 0 % excess electricity (illustrated in figure 5.19). The NPC is observed as $112,286,100.00 with the highest component cost from the batteries which is followed by the wind turbines.

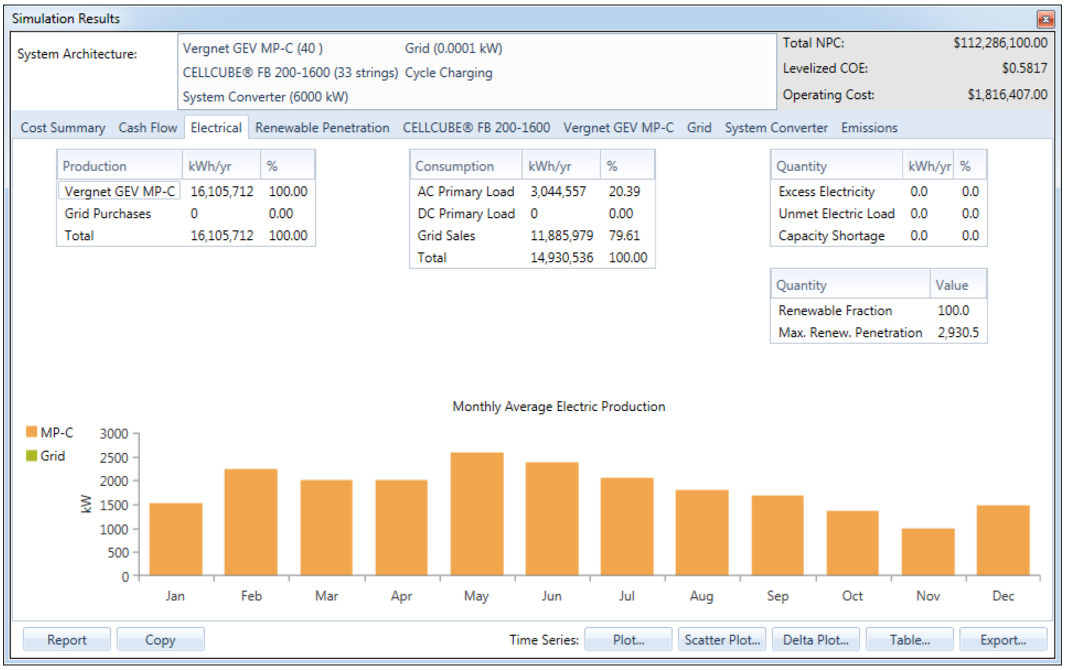


Figure 5.19: 100% renewable fraction using WT connected to the grid

WT standalone system – 100% renewable fraction.

For the stand alone case, the gird component is not used. The components involved for the simulating process are wind turbines, converters, and batteries. The renewable fraction is kept at 100% and the simulation is run with 53 wind turbines of 275 kW, 10 to 45 batteries and 400kW to 6000kW capacity converters. The result resonates with the case configuration using 100% renewable faction with grid connection technically and economically. The technical optimal configuration was found to be with 40 wind turbines. 33 batteries and a 6000 kW system converter. It is noticed that there is an excess electricity production of 73.8% which would be a wastage if net metering is not involved. The unmet electric load and capacity shortage is at 0 kWh/year thus the system will be able to handle all peak loads.

Further characteristics of the standalone system with regard to battery and the wind turbine is illustrated in figure (5.20).Due to the low cut in speed of the wind turbine, it is seen that the hours of operation tends to be 6238 hrs/year. But as the average wind speed lie in the range of 5.5 m/s, the electricity generated during these hours are not so high. The mean output is 1838.60 kW and the total production in a year is 16,105,712 kWh for 40 turbines together. While analysing the storage properties, it is observed that the batteries have a loss of 687,166 kWh/yr which is quite high. It can be analysed that due to the low wind potential in the area is wind energy produced is put into sufficiency by the state of charge of the battery by utilizing it a lot.

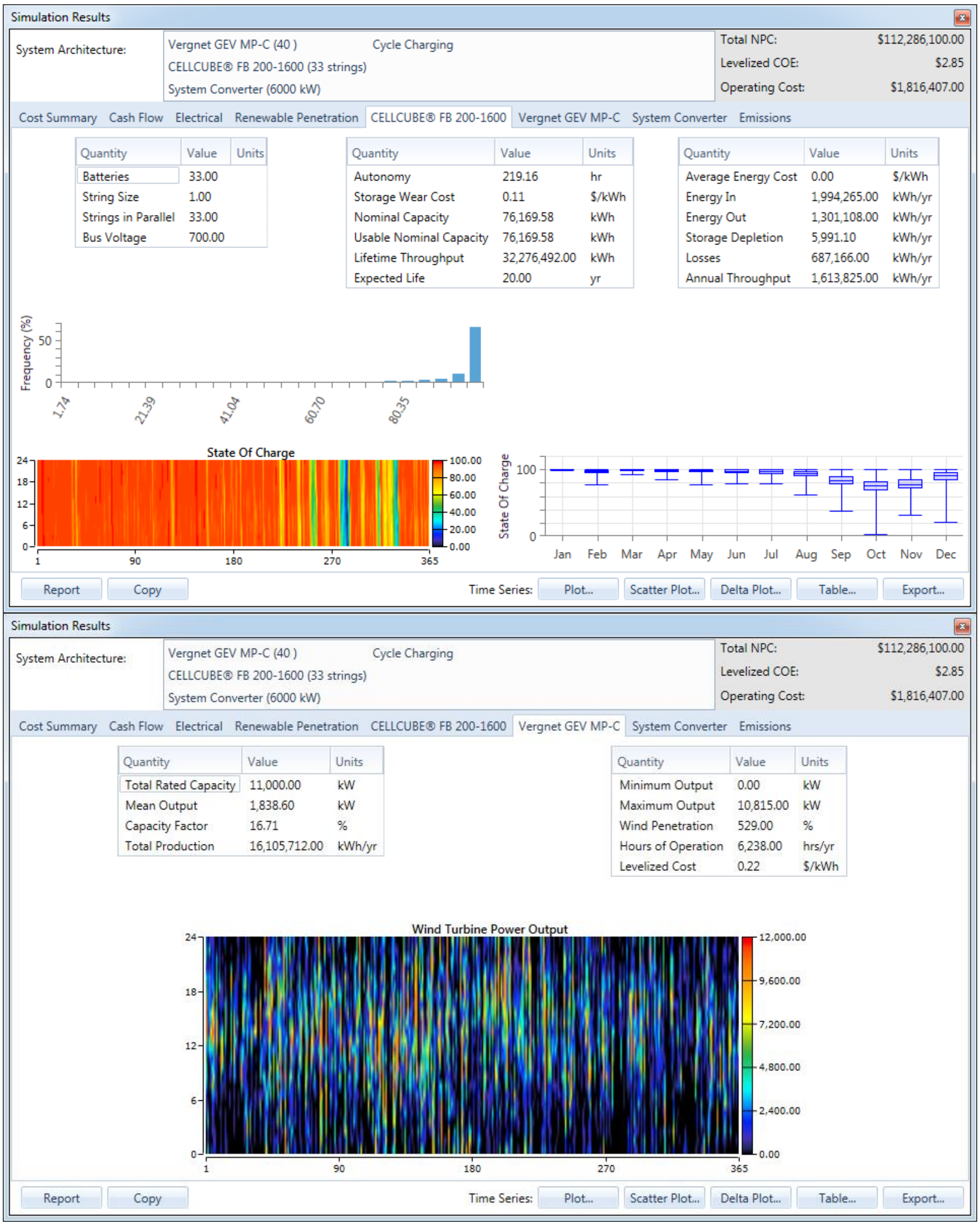


Figure 5.20: WT standalone case configuration battery and turbine characteristics

5.1.4 CASE CONFIGURATIONS USING PV ARRAY AND WIND TURBINE – HYBRID CASE CONFIGURATION

The hybrid case configurations would be simulated just as the other case configurations. With renewable fraction set from 25% to 100% -grid connected stand alone system. The system would involve PV array, 275 kW wind turbine, batteries, and converters with and without the grid as illustrated in figure (5.21). From the literature review, it was observed that hybrid systems tend to work better in many cases than standalone system. Thus, this simulation modelling will help to estimate whether it would be an effective and viable option. As the combinations for PV system and wind system have been done separately, the values and numbers of component system will be incorporated accordingly. All the cost inputs will resonate with the earlier configurations.

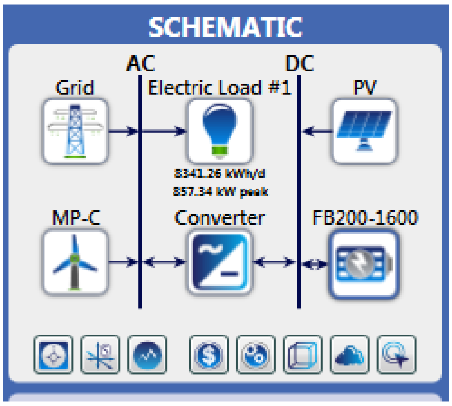


Figure 5.21: schematic of hybrid case configuration connected to the grid

25% renewable faction using hybrid configuration- grid connected

In this configuration, the system set up for the 25% renewable fraction configuration for wind turbine and PV array was observed and a similar system components were set up. The renewable fraction was set at 25% and the grid at 900kW. The PV array was set from 160kW to 544 kW and the wind turbines were kept from 0 to 2 numbers. 0 – 2 batteries and converters ranging from 400kW to 1200 kW was considered.

From the primary simulation results, it was observed that with the inputs provided, renewable fractions of 21.4 % and 28.4% could only be achieved using one turbine each and 160kW PV array in one and 320kW PV array in the other. Thus, further simulations were done with more detailed PV array search space within 160 kW and 320 kW. From this simulation, an optimal result (illustrated in figure 5.22) with a renewable fraction of 25.1% was observed to be a system with a 240kW PV array, one 275 kW wind turbine, 400kW converter and no batteries connected to the grid. There is no excess electricity observed, the unmet electric load and capacity shortage is at 0% and the net present cost is at $3,964,293.00 which is mainly due to the grid operating cost.

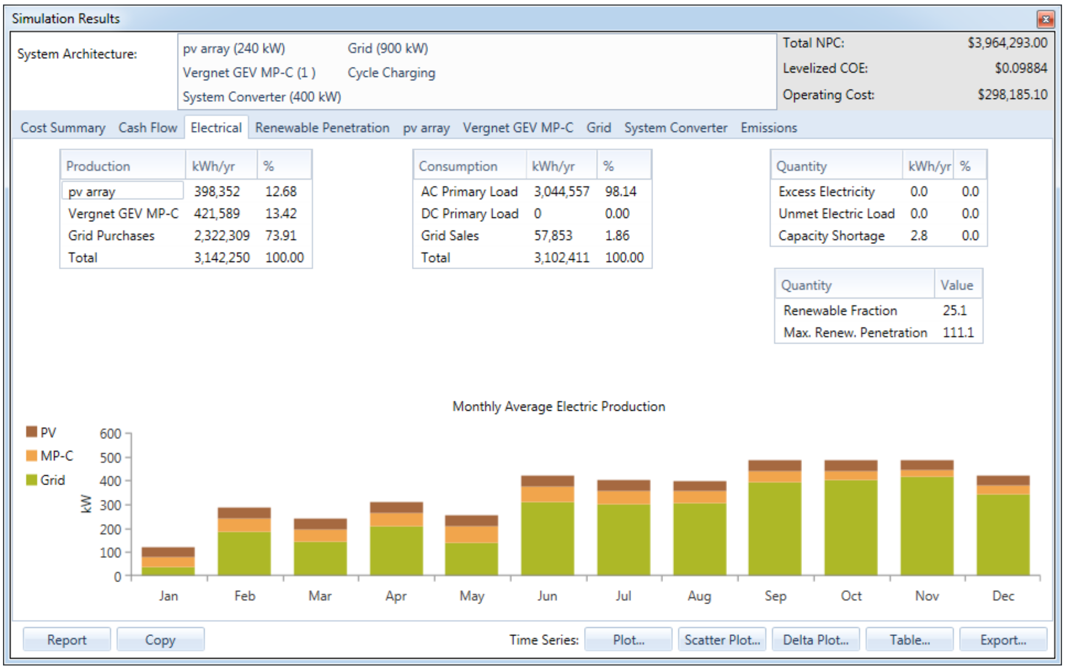


Figure 5.22: hybrid system with 25% renewable fraction – connected to the grid

It is also observed that the percentage of electricity production from both the resources is almost the same with 12.68% for PV array and 13.42% for wind turbine with the grid purchases at 73.91%.

50% renewable faction using hybrid configuration- grid connected

In this scenario, the renewable fraction was set to 50% with a grid at 600kW.The PV array was kept from 320 kW to 3200 kW and wind turbines were kept from 1 to 8 numbers. The converter ranged from 400kW to 2000 kW and the batteries ranged from 0 to 6 numbers. The optimised results show that at a renewable fraction of 50.5% a system configuration consisting of 1280kW PV array, one wind turbine, one battery and a converter of 400kW. It is also observed that there is excess electricity produced at 15% and the capacity shortage and unmet electric load is 0%. This excess electricity is not recommended to be stored in a battery by HOMER due to the high costs of the battery.

An investigative simulation was done to understand if the excess electricity could be reduced without increasing the number of batteries. It was observed that with 49.5% renewable penetration (illustrated in figure 5.23), a system consisting of 896kW PV array, 1 wind turbine, 1 battery and a 800kW converter was technically feasible. There is 0 excess load and 0% capacity shortage as well as 0% unmet electric load. The PV array production is 40.23% where as the wind turbine production is at 11.40%. The abundant availability of solar resource compared to the wind resource can be understood from these figures. It should be also noted that the economics also play a huge role in optimising these cases which are technically feasible in HOMER. The NPC for the system with 49.5% renewable fraction is \$5,271,193.00 whereas for the 50.5% renewable fraction system, the NPC is \$5,225,491.00. The slightly higher NPC in the 45.5% scenario is due to a higher operating cost of the grid and the use of a smaller converter. Thus while looking at both the economical and technically feasibility, the system having the renewable fraction of 50.5 % with a 1280kW solar PV array, 1 wind turbine, 1 battery and a 400kW system converter would be the most apt.

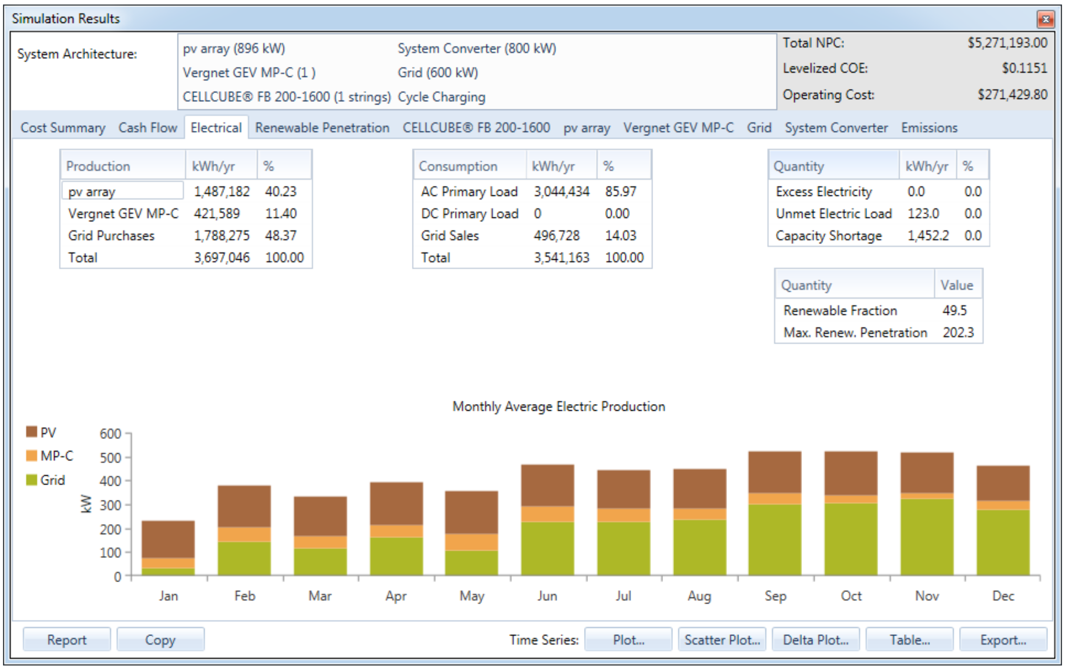


Figure 5.23: hybrid system with 49.5 % renewable fraction – connected to the grid.

75% renewable faction using hybrid configuration- grid connected

In this case scenario the renewable fraction is kept at 75% and is connected to a 300kW grid. The PV array was kept from 896 kW to 3200 kW and the wind turbines were kept from 1 to 10 numbers. The converter ranged from 400kW to 4000kW and the batteries were kept from1 to 10 numbers.

The simulation results for 75% renewable fraction showed that to get exactly 75% was not possible using a hybrid system .The most feasible system technically and economically was the system with renewable fraction of 76.5% (as illustrated in figure 5.24) having a 2752 kW PV array, 2 wind turbines, 800kW converter and three batteries .It was observed that 69.92% power production was from PV, 12.91% production from the wind turbines and the rest from the grid. A capacity shortage and unmet electric load of 0.1% is observed, but this will not cause any disruptions in the grid connected system. There is an excess electricity of 19.3% but it is opted by HOMER that this excess electricity wasted would be more economically viable that introducing another battery to the system. The NPC of the system is $8,918,045.00 with the operating cost coming to $287,548.20. It is seen that the batteries are the main reason for the high cost of the system and comes up to 60% of all costs.

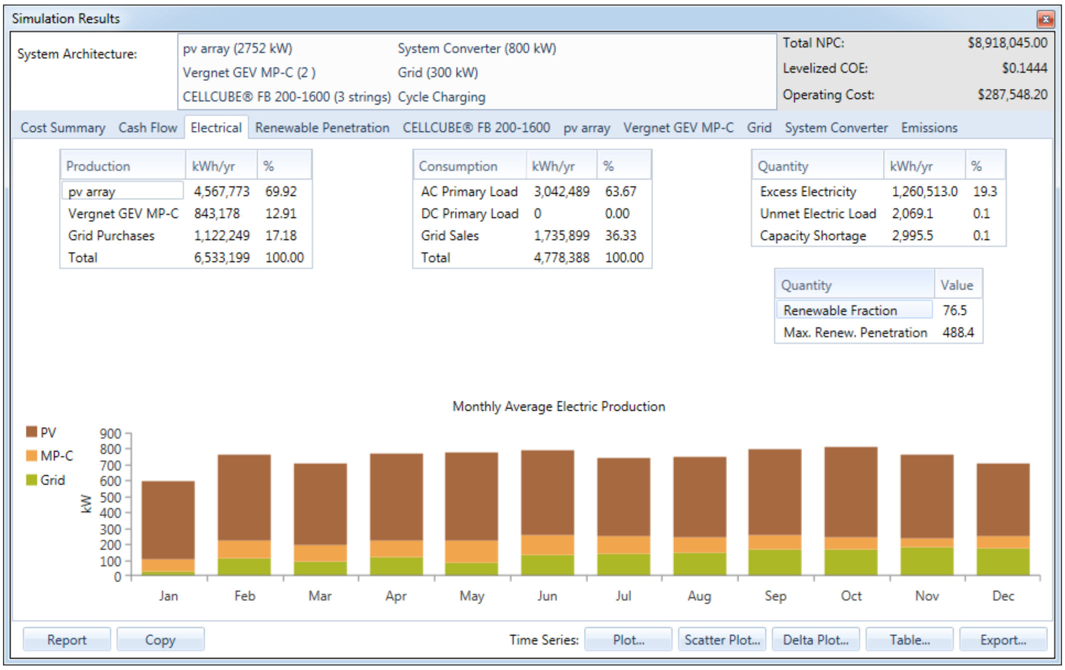


Figure 5.24: hybrid system with 76.5 renewable fraction connected to the grid

100% renewable faction using hybrid configuration- grid connected

The configuration was set up with a 100% renewable fraction as the constraint and a grid of 0.0001kW.the wind turbines were kept from 1 to 40 numbers and the PV array from 2752 kW to 6080kW. The batteries were suggested from 0 to 15 numbers and the converter was ranging from 400kW to 4000 kW.

The optimal technical configuration observed was a system with 5760kW PV array, 8 wind turbines, 7 batteries and a 1200kW converter.73.92% of the electricity production is through PV array whereas 26.08 % is through wind turbines (figure 5.25).The net present cost is $17,715,200.00 with the cost of batteries coming up to 80% of the system costs and around 15 % of the system cost was due to the wind turbines. There is 0 unmet electric load and capacity shortage but an excess electricity of 28.2% is produced. Thus, further simulations were done to investigate if there would be a system with reduced excess load and fulfilling other criteria. Other configurations showed that to reduced excess electricity produced, the number of wind turbines was increased and the PV array was decreased, but this led to higher costs thus were not optimised solutions as per the software.

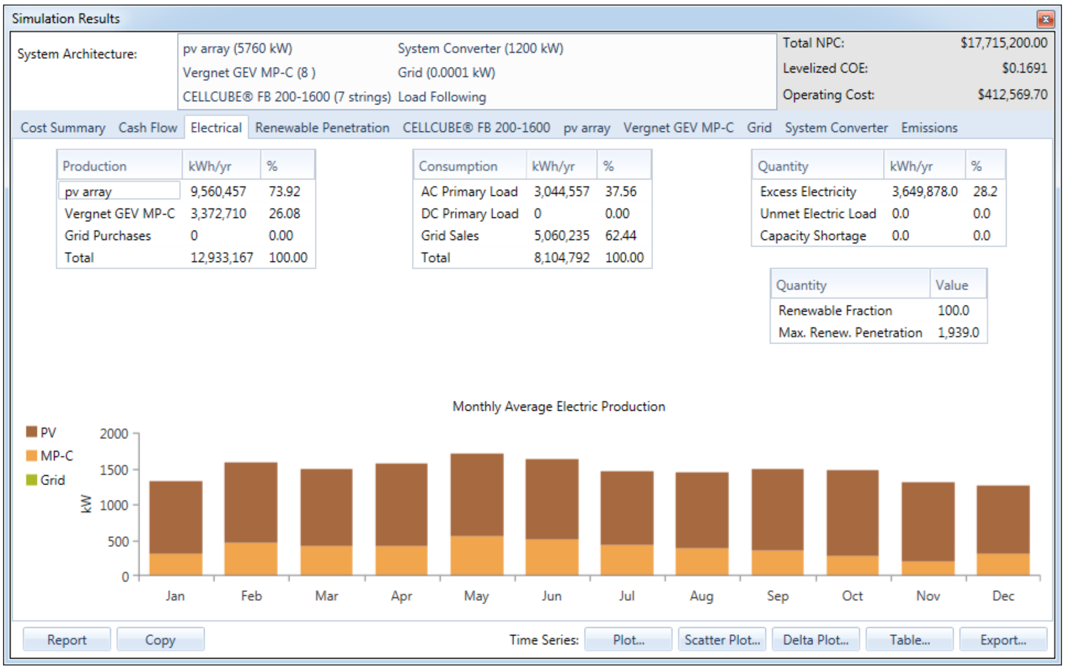


Figure 5.25: Hybrid system with 100% renewable fraction connected to the grid

Standalone hybrid configuration

In this case configuration the search space in HOMER was set to 400kW to 4000kW converter, FB 200-1600 batteries from 0 to 10, PV capacity ranging from 3520kW to 6080 kW and MP-C 275kW wind turbines ranging from 1 to 20 numbers with no grid component.

The optimal case categorised depicted in figure (5.26) has a PV array of 5760kW, 1200 kW converter, 8 wind turbines and 7 batteries and with the same NPC as the grid connected, 100% renewable fraction system. There is 0 capacity shortage and no unmet electric load. It is however noticed that there is a very high amount of excess electricity produced which is due to the fact that more electricity is being produced by the renewable system than the system can use and the batteries cannot absorb the surplus amount and as the grid is not connected in this system, the grid is also unable to absorb any of the excess load. The power production is done mainly using the PV array at 73.92% and as illustrated in figure (5.27) the PV array operates for 4347 hrs/yr whereas the wind turbine produces 26.08% with 6238 hours of operation a year. This depicts the efficient use of the high solar irradiation in the region by the use of PV and the efficient use of the wind resource during the winter months.

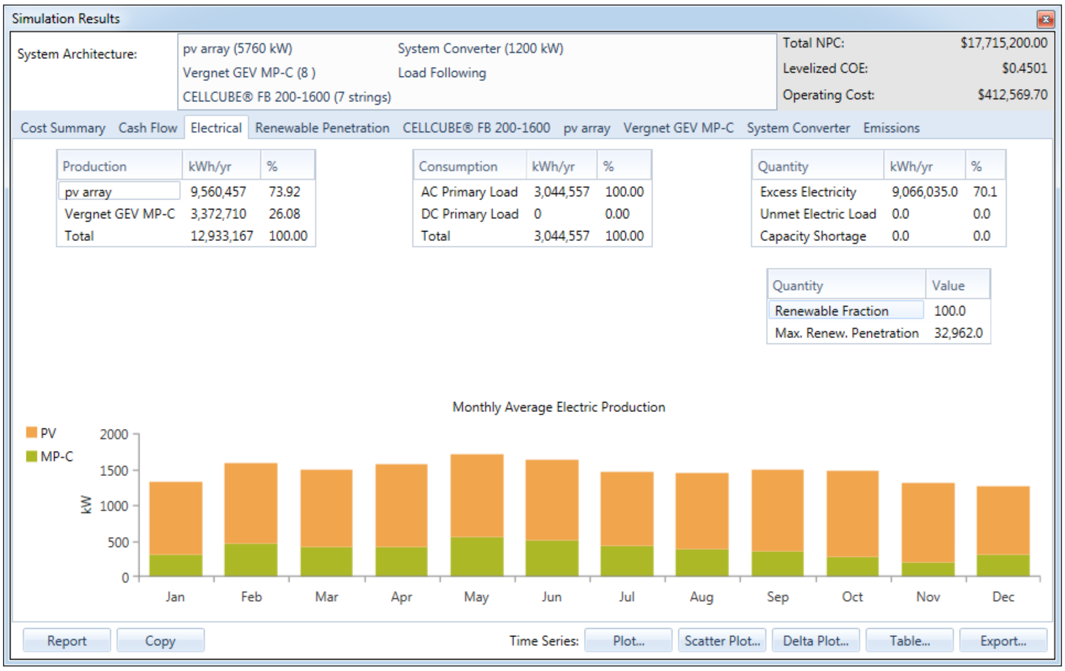


Figure 5.26: hybrid standalone system

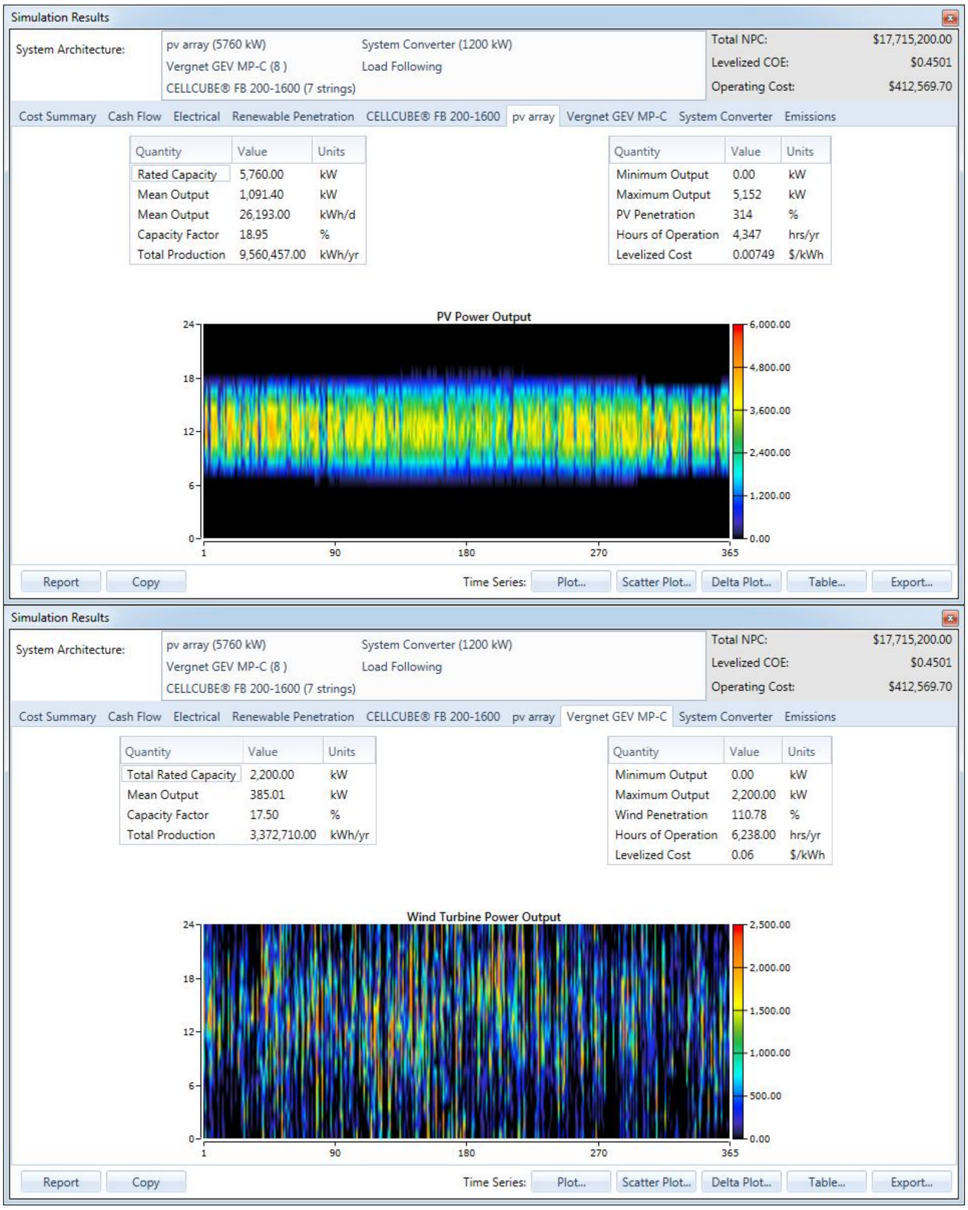


Figure 5.27: Wind turbine and PV array characteristics for hybrid standalone system.

5.1.5 SUMMARY AND COMPARATIVE STUDY OF ALL CASE CONFIGURATIONS

The techno-economic assessment in each case configuration has resulted in the selection of the most viable option both technically and economically for each case configuration. These optimal case configurations will be further discussed in this subsection to understand which system would be best opted for a certain renewable fraction. Thus, the renewable fraction would be the basis of each categorization. The production parameters, cost parameters and the components used will be discussed for each section.

Table (5.1) compares the production, cost, and component parameters for the photovoltaic system case configuration, the wind turbine system case configuration, and the hybrid PV-WT system case configuration. In the 25% renewable fraction case configurations, it is observed that all the optimised systems do not have a battery and are connected to the grid. There is no excess energy, capacity shortage, or unmet electric load seen in either of the systems. When comparing the total net present cost, the PV system has the least NPC of $3,683,774.00 followed by the hybrid system with $3,964,293.00. It is seen that the wind turbine system has NPC $ 5,936,843.00 which makes it the least favourable in term so of economy. The LCOE values also favour PV system as a more economically favourable option considering that the LCOE for PV systems is 0.091$/kWh whereas for Wind turbine system it is 0.14$/kWh. This is due to the high cost of the wind turbine when compared to the PV panels. However, when a further comparison is done between the components used, the hybrid system seems to be the best technical and economical option considering the fact that; it can be installed with less area as land costs are quite high in the region of study. In this system, the primary loads are met with no capacity shortage, the renewable fraction obtained and the renewable production rate show that very negligible electricity is not used by the system.

Table 5.1: Summary for 25% renewable fraction case configurations connected to the grid

Description	**Photo Voltaic System**	**Wind Turbine System**	**Hybrid system(PV and WT)**
Production			
Excess Electricity (%)	0.0	0.0	0.0
Unmet Electric Load (%)	0.0	0.0	0.0

Capacity Shortage (%)	0.0	0.0	0.0
Renewable Fraction (%)	25.9	25.4	25.1
Wind turbine Production (%)	-	25.39	13.42
PV Production (%)	28.03	-	12.68
Cost			
Total Net Present Cost ($)	3,683,774.00	5,936,843.00	3,964,293.00
Levelized Cost of Electricity ($/kWh)	.09104	.1448	.09884
Operating cost ($)	281566.40	320,002.90	298,185.10
Components			
PV Array (kW)	544	-	240
Wind turbine Vergnet GEV MP-C	-	2	1
Cell Cube FB-200-1600 Battery (Strings)	-	-	-
Converter (kW)	400	400	400
Grid (kW)	900	900	900

Table (5.2) summarises the 50% renewable fraction case configurations for PV system, WT system and hybrid PV -WT system. While analyzing the production parameters, it is observed that there is an excess electricity production of 15% in the hybrid system whereas the other systems have 0% excess electricity production. This electricity excess is due to the higher PV production in the system. The renewable fraction is met in each case with the optimal case being the PV system followed by the hybrid system and the wind turbine system. While considering the cost parameters, the NPC for PV system is at the lowest with $5,162,149.00 followed by the hybrid system with $5,225,491.00 and finally the wind turbine system with $10,672,210.00.The LCOE is also very high for the Wind system making it very uneconomical compared to the other two systems. By observing the components used in each system, it can be derived that the high NPC in the wind turbine system is due to the capital costs and the operation and maintenance cost for the wind turbines. While comparing the components in the hybrid system and the PV system, it can be seen that the PV system would fare better as the same amount of PV array is used in both systems. The PV system has a higher capacity converter of 1200kW whereas the hybrid system has a converter of 400kW and one wind turbine. Thus in the 50% renewable fraction case, the PV system would be the most technically and economically apt due to the components used, least net present cost and apt PV production rates.

Table 5.2: Summary for 50% renewable fraction case configurations connected to the grid

Description	**Photo Voltaic System**	**Wind Turbine System**	**Hybrid system(PV and WT)**
Production			
Excess Electricity (%)	0.0	0.0	15.0
Unmet Electric Load (%)	0.0	0.0	0.0
Capacity Shortage (%)	0.1	0.0	0.0
Renewable Fraction (%)	50.2	51.0	50.5
Wind turbine Production (%)	-	51.18	9.88
PV Production (%)	52.97	-	49.81
Cost			
Total Net Present Cost ($)	5,162,149.00	10,672,210.00	5,225,491.00
Levelized Cost of Electricity ($/kWh)	0.1054	.2105	.1165
Operating cost ($)	267,557.10	353,657.20	265,541.40

Components			
PV Array (kW)	1280	-	1280
Wind turbine Vergnet GEV MP-C	-	5	1
Cell Cube FB-200-1600 Battery (Strings)	1	1	1
Converter (kW)	1200	400	400
Grid (kW)	600	600	600

The table (5.3) summarises the case configurations for 75% renewable fraction for the PV system, wind turbine system and the hybrid PV-WT system. Technical feasibility is most prominent in the PV system configuration with 0% unmet electric load and shortage of capacity where as the wind turbine system has 3.8% unmet electric load and 5.6% capacity shortage, and the hybrid system has 0.1% each for unmet electric load and capacity shortage. But as all the systems are connected to the grid, the hybrid system will fare well and will be a technically feasible option. However, there is a high excess electricity percentage of 19.3 in the hybrid system which shows that the system cannot use or store the electricity produced at some periods leading to loss and wastage.

Table 5.3: Summary of 75% renewable fraction case configurations connected to the grid

Description	Photo Voltaic System	Wind Turbine System	Hybrid system(PV and WT)
Production			
Excess Electricity (%)	2.3	0	19.3
Unmet Electric Load (%)	0	3.8	0.1
Capacity Shortage (%)	0	5.6	0.1
Renewable Fraction	75.3	75.5	76.5

(%)			
Wind turbine Production (%)	-	76.54	12.91
PV Production (%)	78.60	-	69.92
Cost			
Total Net Present Cost ($)	10,628,770.00	21,360,450.00	8,918,045.00
Levelized Cost of Electricity ($/kWh)	0.1545	.3283	.1444
Operating cost ($)	309,000.70	461,020.80	287,548.20
Components			
PV Array (kW)	2912	-	2752
Wind turbine Vergnet GEV MP-C	-	10	2
Cell Cube FB-200-1600 Battery (Strings)	4	4	3
Converter (kW)	1600	800	800
Grid (kW)	300	300	300

The cost parameters show that the hybrid system has the least net present cost of $8,918,045.00 and the least LCOE (0.14 $/kWh) which is due to the fact that this system uses only three batteries whereas the other systems have 4 strings. The wind turbine system shows a very high NPC and LCOE due to the high costs regarding the turbines and the low wind potential in the area. Through the comparison of all the systems, it can be seen that the optimised economical and technical option would be of the hybrid case with a PV array of 2752kW, 2 wind turbines, 3 batteries, 800kW converter and connected to a 300kW grid. If a system of net metering is introduced by SEWA, then more financial gains can be made using this system.

Table (5.4) depicts the case configurations of all the systems in 100% renewable fraction and connected to the grid. All the systems are hypothetically technically feasible as they are able to provide for the required primary load but it can be seen that there is an excess electricity of 31.3% produced in the PV system and 28.2% produced in the hybrid system. This excess electricity produced is due to the fact that the grid and the battery are unable to absorb it .

Table 5.4: Summary of 100% renewable fraction case configuration when connected to the grid

Description	Photo Voltaic System	Wind Turbine System	Hybrid system(PV and WT)
Production			
Excess Electricity (%)	31.3	0	28.2
Unmet Electric Load (%)	0	0	0.0
Capacity Shortage (%)	0	0	0.0
Renewable Fraction (%)	100	100	100
Wind turbine Production (%)	-	100	26.08
PV Production (%)	100	-	73.92
Cost			
Total Net Present Cost ($)	19,228,580.00	112,286,100.00	17,715,200.00
Levelized Cost of Electricity ($/kWh)	0.2821	.5817	.1691
Operating cost ($)	336,411.20	1,816,407.00	412,569.70
Components			
PV Array (kW)	5984	-	5760
Wind turbine Vergnet GEV MP-C	-	40	8

Cell Cube FB-200-1600 Battery (Strings)	9	33	7
Converter (kW)	1200	6000	1200
Grid (kW)	0.0001	.0001	.0001

While considering the economics of the systems, the hybrid system has the least NPC of $17,715,200.00 followed by the PV system with $19,228,580.00.The NPC is of the wind turbine system is 6.3 times the NPC of the hybrid system . This high cost of the wind turbine system is due to the insufficient resource available thus leading to the use of high number of turbines and batteries to meet the load requirement. While considering the LCOE, it is seen that the hybrid system would be the best viable option with LCOE 0.16 $/kWh compared to 0.28$/kWh for PV systems.

By observing the components involved in each system, the hybrid system has the least number of batteries with a PV array of 5760kW and 8 wind turbines. Thus in this case, the hybrid system is most technically and economically viable.

Finally, the standalone system configurations (Table 5.5) show the same components as the 100% renewable fraction systems. There is a case of high excess electricity produced in the system. This is due to the fact that HOMER Software will first make the renewable energy meet the primary electric load, and then the batteries are charged before selling to the grid. In the standalone case the grid is not involved .if the cost of wear is too high for the batteries, then HOMER will choose not to discharge the batteries to meet the load. If more batteries are added to the system to store the excess power, this will prove to be economically unviable.

Table 5.5: Summary of standalone system configuration

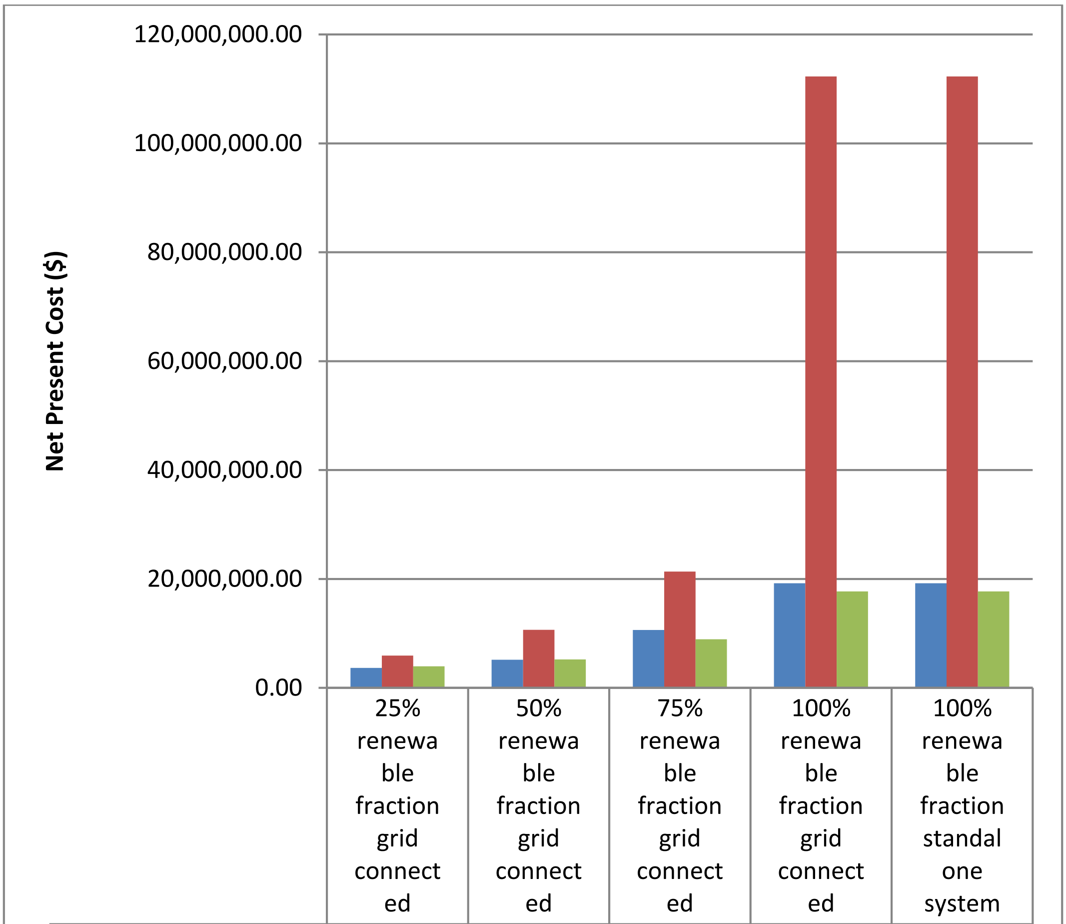
Description	Photo Voltaic System	Wind Turbine System	Hybrid system(PV and WT)
Production			
Excess Electricity (%)	56.2	73.8	70.1
Unmet Electric Load (%)	0	0	0.0
Capacity Shortage (%)	0	0	0.0
Renewable Fraction (%)	100	100	100
Wind turbine Production (%)	-	100	26.08
PV Production (%)	100	-	73.92
Cost			
Total Net Present Cost ($)	19,228,580.00	112,286,100.00	17,715,200.00
Levelized Cost of Electricity ($/kWh)	0.4885	2.85	.4501
Operating cost ($)	336,411.20	1,816,407.00	412,569.70
Components			
PV Array (kW)	5984	-	5760
Wind turbine Vergnet GEV MP-C	-	40	8
Cell Cube FB-200-1600 Battery (Strings)	9	33	7
Converter (kW)	1200	6000	1200

When considering all the case configurations, the hybrid case configurations are most viable technically and economically. The use of both the resources will help in higher space optimization with importance given for least shading effects in PV arrays and good positioning of wind turbines for least wake effects. The figure (5.28) illustrates with a graph on the NPC values of each system. Considering the LCOE values of each system, it should be kept in mind that HOMER considers the COE formulation as arbitrary and disputable (it is well explained in the "Help Index" of the software). Thus only the NPC will be considered to be the primary metric for choosing the best system in terms of economics.

Many factors like the price of land, feed in tariff, net metering systems, governmental support, financing, carbon taxing among many others would play a major role in implementing such systems in reality.

The major factor through which a system is deemed profitable in the desalination industry is through the cost of water produced. With the current system which is connected to the grid, the plant produces 0.21 m^3 water with 1 kWh. But many other factors add to the cost of water such as the finance cost, administrative and management cost, chemical cost (anti scalent, ph balance, chlorination, etc.), consumables cost (cartridge changes every 15 days, membranes changes every three years), quality assurance and quality control, human resources and machinery depreciation costs.

When considering the 25% case configuration using hybrid PV –WT 1kWh of electricity costs $0.09 and the for the PV system 1kWh of electricity costs $0.1 this is quite low considering the cost from the grid at $0.12 for 1 kWh. But this calculation method by HOMER and causes ambiguity thus making it an inappropriate and inaccurate measurement. This calculation also does not take into account on financing, feed in tariffs, net metering systems and other governmental supports. Thus with such provisions, introduction of renewable energy systems would be much more feasible to such industries.



	25% renewable fraction grid connected	50% renewable fraction grid connected	75% renewable fraction grid connected	100% renewable fraction grid connected	100% renewable fraction standalone system
PV system	3,683,774.0	5,162,149.0	10,628,770.	19,228,580.	19,228,580.
WT system	5,936,843.0	10,672,210.	21,360,450.	112,286,100	112,286,100
Hybrid PV -WT system	3,964,293.0	5,225,491.0	8,918,045.0	17,715,200.	17,715,200.

Figure 5.28: Economic Summary-NPC

5.2 ENVIRONMENTAL FEASIBILITY

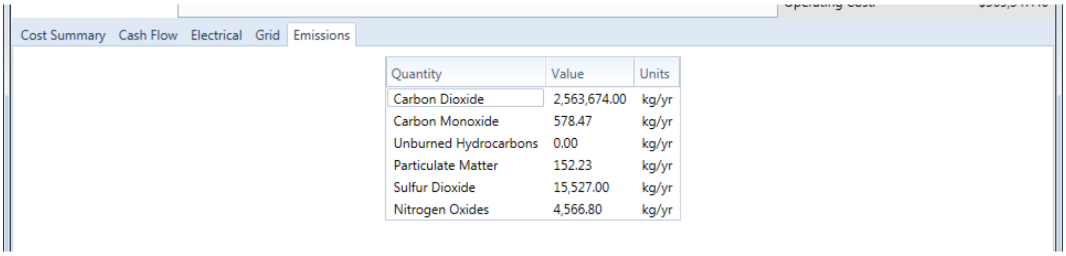
The environmental aspects will be looked upon by evaluating the CO2 emissions reduction by each configuration as that would be the only common aspect that can be compared with respect to each of the configurations simulated using HOMER Energy.

5.2.1 EMISSIONS BY BASE CASE MODEL

In scenario 1a where the grid is connected to the desalination plant, it is important to note that the grid derives it power from fossil fuel which is used in power plants to generate electricity. The emissions factors is derived from the greenhouse gas inventory report by the Environment Agency Abu Dhabi (2012).The values entered as input in HOMER are as illustrated in figure (5.29).

Figure 5.29: Emissions input in HOMER

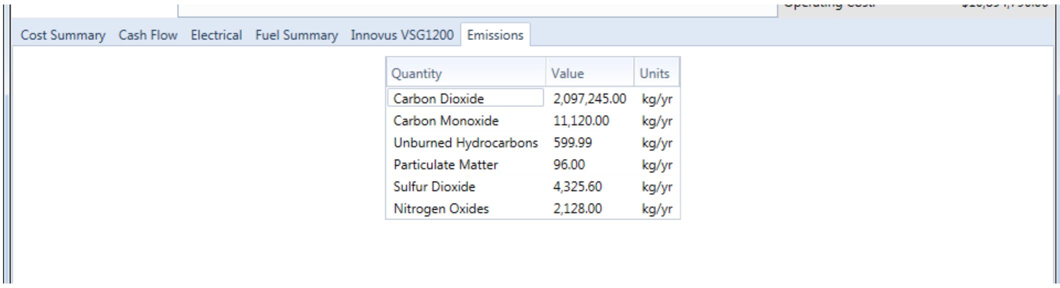
The results simulated for the 1200 kW peak power grid (illustrated in figure 5.30) show that the local grid has high emissions of GHG considering 2,563,674.00 kg of CO2/year, 578.47 kg of CO/year, 152.23 kg of particulate matter /year, 15,527.00 kg of sulphur dioxide/year and 4566.80 kg of nitrogen oxides /year.



Quantity	Value	Units
Carbon Dioxide	2,563,674.00	kg/yr
Carbon Monoxide	578.47	kg/yr
Unburned Hydrocarbons	0.00	kg/yr
Particulate Matter	152.23	kg/yr
Sulfur Dioxide	15,527.00	kg/yr
Nitrogen Oxides	4,566.80	kg/yr

Figure 5.30: Emissions for 1200kW grid

In scenario 1b where the desalination unit is run by an independent power generator which is fuelled by diesel, the input parameters are as per the specifications by the manufacturer already present in the HOMER software. The results are illustrated in the figure (5.31) which show that the generator would emit 2,097,245.00 kg of CO2/year, 11,120.00kg carbon monoxide kg of CO /year, 599.99 kg of unburned hydrocarbons / year, 96.00 kg of particulate matter /year, 4325.60 kg of sulphur dioxide /year and 2,128.00 kg Nitrogen Oxides/year.



Quantity	Value	Units
Carbon Dioxide	2,097,245.00	kg/yr
Carbon Monoxide	11,120.00	kg/yr
Unburned Hydrocarbons	599.99	kg/yr
Particulate Matter	96.00	kg/yr
Sulfur Dioxide	4,325.60	kg/yr
Nitrogen Oxides	2,128.00	kg/yr

Figure 5.31: Emissions by generator

Figure (5.32) depicts a graphs which compares the emissions from both the sources and it is seen that the generator shows surprisingly lower emissions due to the fact that the generator selected varies its engine speed according to the system load allowing it to produce the needed power with significantly lower fuel quantity.

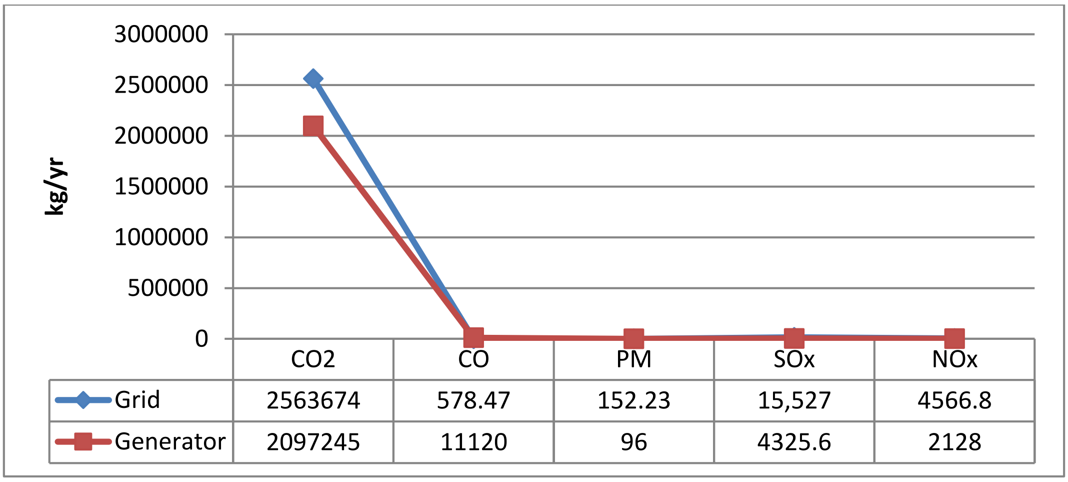
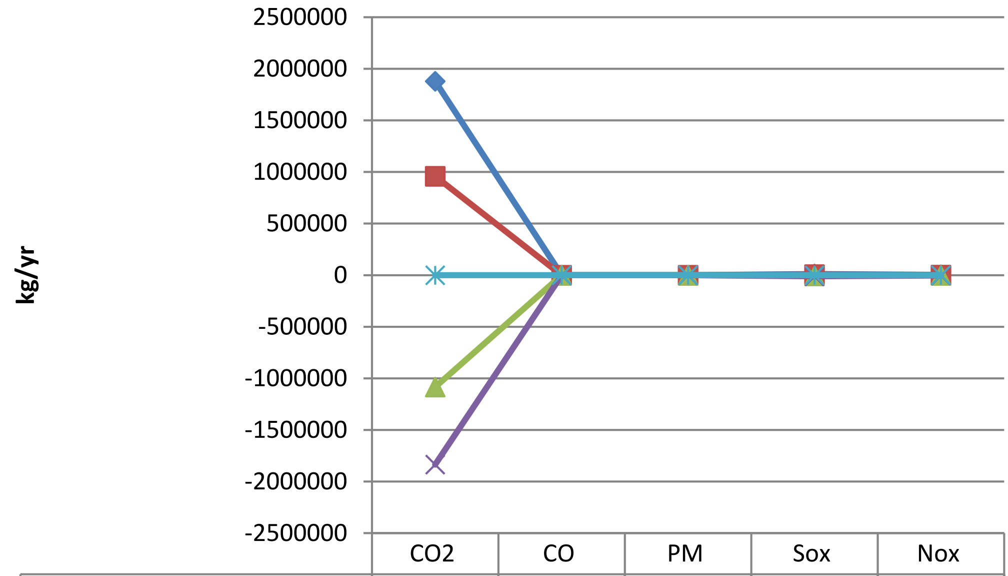


Figure 5.32: Emissions by grid and generator

5.2.2 EMISSIONS BY PV ARRAY CASE CONFIGURATIONS

Through renewable integration, it is evident from the case studies that the emission levels would decrease considerably. The graph (5.33) summarizes the different energy configurations and the emissions by each configuration.

It can be quickly analysed that with increasing renewable fraction, the CO2 emissions are reduced. It should also be noted that in HOMER energy the emissions is calculated in a grid connected system by the simple formula; net grid purchases multiplied by the grid related emissions for each pollutant. Thus it can be analysed that in the 75% and 100% renewable fraction system, the net grid purchases is in negative as the system is simulated such that it sells more power to the grid than it purchases from the grid .



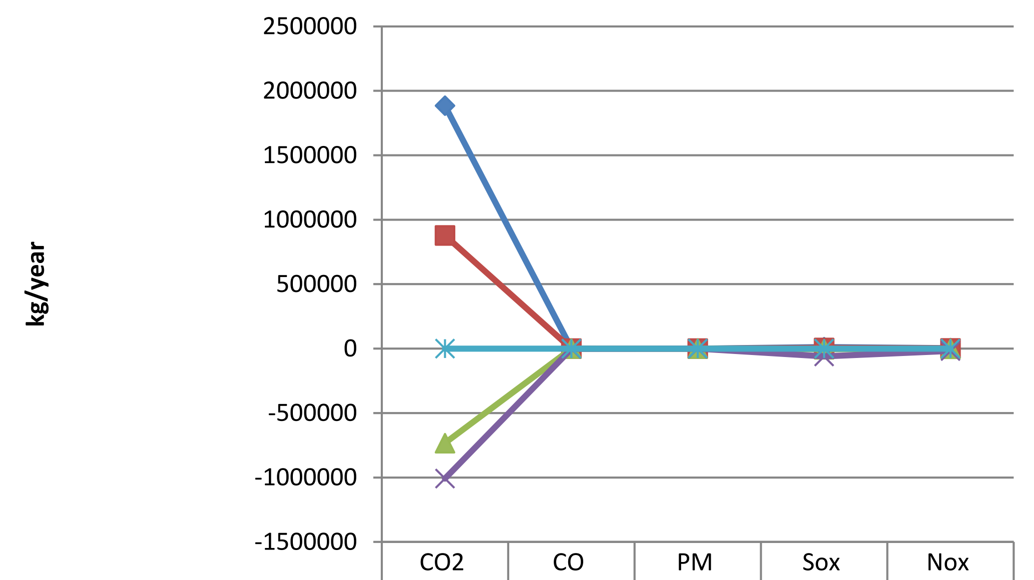
	CO2	CO	PM	Sox	Nox
25% renewable fraction-grid connected	1879703	424.16	111.62	11385	3348.69
50% renewable fraction-grid connected	959166	216.44	56.96	5809.7	1708.7
75% renewable fraction-grid connected	-1084145	-244.64	-64.38	-6566.7	-1931.4
100% renewable fraction-grid connected	-1835810	-423.31	-111.4	-11362	-3341.9
100% renewable fraction-standalone	0	0	0	0	0

Figure 5.33: Emissions by PV system case configurations

5.2.3 EMISSIONS BY WIND TURBINE CASE CONFIGURATIONS

As discussed with PV arrays, the optimal case configurations of wind turbines are taken and its emissions are analysed. The most evident emission is the carbon dioxide emissions released for power production by the grid. The graph depicted in figure (5.34) illustrates the emissions levels for wind turbine case configurations.

In the graph, the negative emission value for 75% and 100% renewable fraction when connected to grid is due to the negative net grid purchases. It is seen that the system sells more power to the grid than it buys from the grid over the year, the net grid purchases will be negative and so will the grid-related emissions of each pollutant. As in the previous case, the emissions have become less for every step of increment in the use of renewable energy, but it should be noted that the emissions are dependent on the grid usage rather than the percentage of the grid connectivity.

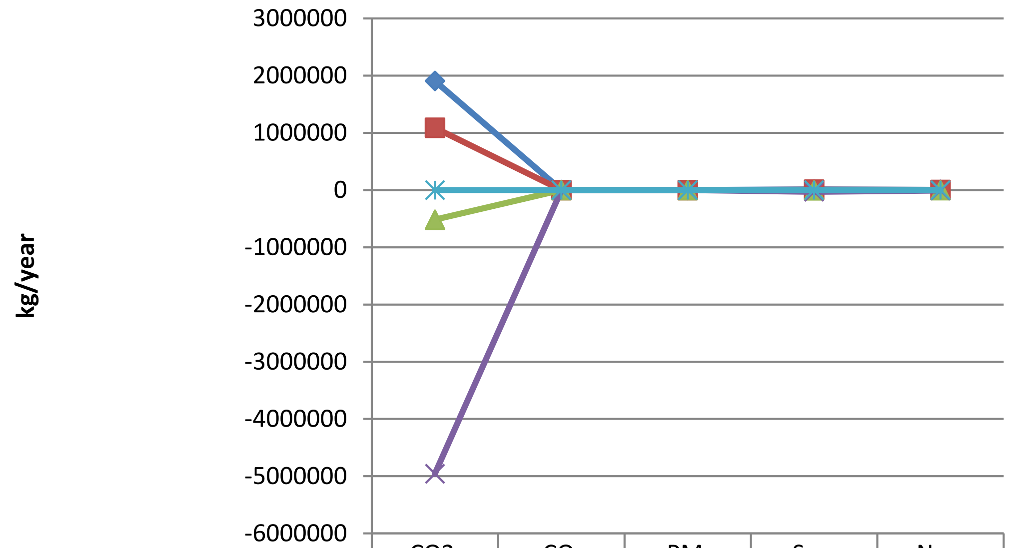


	CO2	CO	PM	Sox	Nox
25% renewable fraction-grid connected	1885470	425.46	111.96	11420	3358.9
50% renewable fraction-grid connected	878235	198.18	52.15	5319.5	1564.6
75% renewable fraction-grid connected	-733492	-165.51	-43.56	-4442.8	-1306.7
100% renewable fraction-grid connected	-1007994	-2258.3	-594.3	-60618	-17829
100% renewable fraction-standalone	0	0	0	0	0

Figure 5.34: Emissions by wind turbine system case configurations

5.2.4 EMISSIONS BY HYBRID WT-PV CASE CONFIGURATIONS

The hybrid system configurations have solar photovoltaic arrays and wind turbines working together to get the brat of both resources in the area. Illustrated in figure (5.35) is the graph depicting the emissions by these configurations. Again the negative emission values are observed for the 75% and 100% grid connected system due to negative grid purchases as the system gives a lot of power to the grid.



	CO2	CO	PM	Sox	Nox
25% renewable fraction-grid connected	1906672	430.25	113.22	11549	3396.7
50% renewable fraction-grid connected	1087482	245.39	64.58	6586.9	1937.3
75% renewable fraction-grid connected	-516694	-116.59	-30.68	-3129.6	-920.48
100% renewable fraction-grid connected	-4956574	-1119.1	-294.51	-30040	-8835.3
100% renewable fraction-standalone	0	0	0	0	0

Figure 5.35: Emissions by hybrid PV-WT case configurations

Similar to the previous observations regarding integration of renewable into a system, it is seen that the emissions are considerably reduced. It is also noted that the emissions are the least when using solar arrays and most while using a hybrid system. But it is also noted that these differences are not so drastic but very subtle.

In conclusion, it can be seen that by the introduction of renewable systems into the desalination plant, the emissions are lowered at a very satisfactory rate thus improving the environment and helping to create a more sustainable future.

6 CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

6.1 CONCLUSIONS

The energy water nexus is a very indispensable niche in today's scenario making desalination and renewable energy a very important topic of discussion .from the literature it is well understood that desalination of water requires a lot of energy which is predominantly produced by fossil fuels due to its economic benefits. In this study, a reverse osmosis desalination unit located United Arab Emirates which is a hot arid region where there is a physical scarcity of drinking water as well as abundant solar resources, is studied closely to understand the impact of renewable energy integration to the desalination plant. The technical, economical, and environmental aspects in integrating the desalination unit is studied by conducting a comprehensive literature review followed by computer simulation studies.

The main aim of the research was to assess the performance of the sea water reverse osmosis plant when the renewable energy is introduced into its system using a step by step process. The main results have been obtained from the simulation modelling process using the software IES VE and HOMER Energy. Firstly, IES VE was used to understand the solar potential and wind potential in the actual site and the best locations to place the system unit. The maximum available area and other barriers and limitations were analysed. Secondly, HOMER Energy was used to simulate case configurations containing the PV system, wind system and hybrid PV-WT system in a step by step manner starting from 25% renewable fraction and connected to the grid to a standalone system with 100% renewable fraction. Finally, the results were analysed and inferences regarding the data were made.

The technical and economic analysis showed that hybrid PV-WT systems could be very proficient option to consider in this region where more emphasis is only made in the PV industry. Even though results show a very good outcome from the PV system, when restrictions regarding the space needed in considered and the higher technical feasibility of the hybrid system makes it a more superior option. The wind turbine configurations did not fare well in all the case scenarios except the 25% renewable fraction and attached to the grid. The low wind resource in the area plays a huge role in establishing these systems as many number of turbines and batteries are need to support the primary load which is not economically beneficial.

When comparing to the current price of electricity from the grid in this region, the renewable energy produced in many studies show high costs. The net present cost is used to identify the economic feasibility of the systems used in the study which show that the least cost incurring system is when the unit is connected to the grid with the NPC of $1,195,957.98. This is followed closely by configurations where 25% renewable fraction is integrated with PV systems and hybrid systems with NPC $3,683,774.00 and $3,964,293.00 and respectively. However, through many propositions which may not be always technical, a change to renewable energy can be introduced in this region such as; introduction of net metering, feed in tariffs, government incentives, improving the desalination process, more efficient and cheaper renewable system components through new noble technologies. Though these renewable case configurations may give a higher cost for electricity, it is seen clearly from the emissions reduced how this transition from fossil fuel to renewable will help save the world from a point of never coming back.

Thus from this study, it is understood that most of the configurations are technically achievable and the load demand can be fulfilled in the most optimal way in many cases. Some cases such as the 25% and 40% PV system and hybrid system cases can be considered economically viable than the rest when considering if carbon taxes are introduced in the region. It is clearly seen from the study that carbon emissions are reduced when the renewable system is connected to the grid. In the case of PV system which has just 25% renewable fraction and the rest connected to the grid shows a carbon dioxide reduction from 2563674 kg/year when only connected to the grid to 1879703 kg/year. The case where the renewable fraction is more, the carbon dioxide produced is also seen to be lesser.

In the cases of 75% and 100% renewable fraction when connected to the grid , it is seen that negative emissions are obtained. . It is seen that the system sells more power to the grid than it buys from the grid over the year, the net grid purchases will be negative and so will the grid-related emissions of each pollutant. The emissions have become less for every step of increment in the use of renewable energy, but it should be noted that the emissions are dependent on the grid usage rather than the percentage of the grid connectivity. Thus from the simulation, it is understood that by the introduction of renewable systems into the desalination unit, a large amount of emissions can be reduced which will in turn make a very positive impact on the environment.

6.2 RECOMMENDATIONS FOR FUTURE WORK

The current research has many limitations considering time and a more accurate calculation can be obtained if the reading for every hour of the plant is taken for the input parameters in HOMER. Further work can be researched in this context by looking if the renewable systems can be introduced in sections of the plant such as the feed in pumps and pre-filtration units and avoiding the high pressure pump sections thus reducing the primary load and peak load. This may give more opportunities than may be more economically viable and help in reducing harmful emissions into the biosphere.

Thus from this research it is understood that many technically feasible options are available for the integration for renewable into desalination systems but theses systems do not prosper due to many economical reasons discussed in this study. Though there is hope that in the coming years, the increased awareness among people and higher technological achievements would lead the world into a renewable and sustainable future. Furthermore, a pilot study would be the best way to understand the actual implications for such mega projects as many parameters that may have gone unnoticed in the theoretical and simulative study might come into play as major factors in the feasibility of the project.

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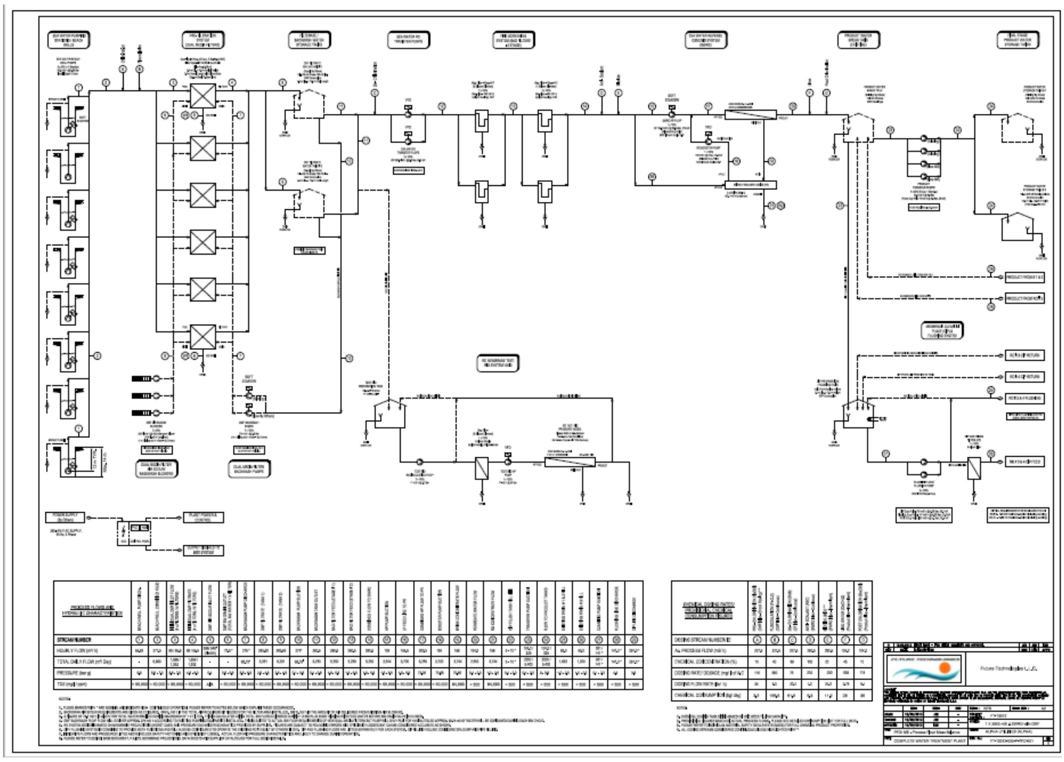
APPENDIX A – DESALINATION PLANT DATA

PROCESS FLOW DIAGRAM FOR SWRO UNIT 4



POWER CONSUMPTION FOR THE YEAR 2015

Monthly Data

JANUARY		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
227840	230080	2240
230080	232000	1920
232000	234240	2240
234240	236480	2240
236480	238720	2240
238720	243840	5120
243840	256000	12160
256000	260800	4800
260800	263680	2880
263680	266560	2880
266560	269440	2880
269440	274560	5120
274560	286400	11840
286400	291200	4800
291200	297920	6720
297920	300800	2880
300800	309440	8640
309440	312960	3520
312960	315840	2880
315840	318400	2560
318400	324800	6400
324800	330880	6080
330880	333760	2880
333760	336640	2880
336640	339520	2880
339520	342400	2880
342400	347840	5440
347840	355840	8000
355840	361280	5440
361280	372800	11520
372800	374720	1920
	daily average load	4738.064516
	Hourly average load	78.96774194

FEBRUARY		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
374720	376640	1920
376640	378880	2240
378880	380800	1920
380800	382720	1920
382720	391040	8320
391040	401280	10240
401280	403200	1920
403200	405440	2240
405440	407360	1920
407360	408640	1280
408640	417600	8960
417600	430080	12480
430080	442240	12160
442240	454400	12160
454400	464000	9600
464000	475840	11840
475840	481600	5760
481600	488320	6720
488320	500160	11840
500160	512320	12160
512320	524480	12160
524480	534720	10240
534720	540160	5440
540160	552640	12480
552640	555200	2560
555200	558080	2880
558080	560960	2880
560960	569280	8320
	daily average load	6948.571429
	Hourly average load	289.5238095

MARCH		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
569280	578240	8960
578240	580480	2240
580480	582400	1920
582400	584640	2240
584640	592640	8000

592640	598720	6080
598720	601600	2880
601600	604480	2880
604480	607360	2880
607360	615680	8320
615680	624640	8960
624640	627520	2880
627520	630400	2880
630400	633280	2880
633280	636160	2880
636160	639040	2880
639040	644800	5760
644800	654080	9280
654080	660160	6080
660160	671040	10880
671040	673920	2880
673920	676800	2880
676800	682880	6080
682880	689920	7040
689920	692800	2880
692800	695680	2880
695680	698560	2880
698560	703040	4480
703040	715200	12160
715200	726720	11520
726720	737920	11200
	daily average load	5440
	Hourly average load	217.6

APRIL

INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
737920	748160	10240
748160	760000	11840
760000	771848	11848
771848	776640	4792
776640	788480	11840
788480	792000	3520
792000	795520	3520
795520	798720	3200
798720	801600	2880
801600	811520	9920
811520	823680	12160

823680	833280	9600
833280	836160	2880
836160	839040	2880
839040	842240	3200
842240	850880	8640
850880	862080	11200
862080	865280	3200
865280	868160	2880
868160	874880	6720
874880	887360	12480
887360	893760	6400
893760	895360	1600
895360	906880	11520
906880	917760	10880
917760	919680	1920
919680	922880	3200
922880	930880	8000
930880	942720	11840
942720	951260	8540
	daily average load	7111.333333
	Hourly average load	296.3055556

MAY		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
951260	952960	1700
952960	954880	1920
954880	956480	1600
956480	959360	2880
959360	971520	12160
971520	975680	4160
975680	977920	2240
977920	990080	12160
990080	994240	4160
994240	999040	4800
999040	1005760	6720
1005760	1011520	5760
1011520	1023680	12160
1023680	1028160	4480
1028160	1034560	6400
1034560	1047040	12480
1047040	1050240	3200
1050240	1058880	8640

1058880	1066880	8000
1066880	1078720	11840
1078720	1080960	2240
1080960	1082880	1920
1082880	1092160	9280
1092160	1101760	9600
1101760	1107200	5440
1107200	1108800	1600
1108800	1110720	1920
1110720	1117120	6400
1117120	1128960	11840
1128960	1131520	2560
1131520	1133120	1600
	daily average load	5866.451613
	Hourly average load	244.4354839

JUNE		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
1133120	1142720	9600
1142720	1154560	11840
1154560	1161600	7040
1161600	1164480	2880
1164480	1168320	3840
1168320	1178880	10560
1178880	1180800	1920
1180800	1187200	6400
1187200	1199040	11840
1199040	1202880	3840
1202880	1213120	10240
1213120	1224960	11840
1224960	1236800	11840
1236800	1248640	11840
1248640	1260480	11840
1260480	1272640	12160
1272640	1284480	11840
1284480	1296640	12160
1296640	1307840	11200
1307840	1309440	1600
1309440	1316480	7040
1316480	1328320	11840
1328320	1340480	12160
1340480	1352320	11840

1352320	1364480	12160
1364480	1376640	12160
1376640	1388800	12160
1388800	1400640	11840
1400640	1412800	12160
1412800	1424960	12160
	daily average load	9728
	Hourly average load	405.3333333
JULY		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
1424960	1436800	11840
1436800	1448960	12160
1448960	1451840	2880
1451840	1453440	1600
1453440	1463360	9920
1463360	1475840	12480
1475840	1488000	12160
1488000	1499840	11840
1499840	1512000	12160
1512000	1524480	12480
1524480	1536640	12160
1536640	1548800	12160
1548800	1552640	3840
1552640	1563520	10880
1563520	1575680	12160
1575680	1588160	12480
1588160	1600320	12160
1600320	1605120	4800
1605120	1608640	3520
1608640	1620800	12160
1620800	1632960	12160
1632960	1644160	11200
1644160	1646080	1920
1646080	1653440	7360
1653440	1665600	12160
1665600	1677760	12160
1677760	1680320	2560
1680320	1686400	6080
1686400	1698560	12160
1698560	1710080	11520
1710080	1721920	11840

	daily average load	9579.354839
	Hourly average load	399.1397849
AUGUST		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
1721920	1723840	1920
1723840	1731200	7360
1731200	1741440	10240
1741440	1752000	10560
1752000	1761600	9600
1761600	1773120	11520
1773120	1785600	12480
1785600	1798080	12480
1798080	1802880	4800
1802880	1807680	4800
1807680	1819200	11520
1819200	1831680	12480
1831680	1844160	12480
1844160	1848640	4480
1848640	1853120	4480
1853120	1865280	12160
1865280	1868480	3200
1868480	1875840	7360
1875840	1888000	12160
1888000	1899840	11840
1899840	1911680	11840
1911680	1914880	3200
1914880	1926400	11520
1926400	1938560	12160
1938560	1942080	3520
1942080	1953280	11200
1953280	1965440	12160
1965440	1974400	8960
1974400	1977600	3200
1977600	1989440	11840
1989440	1999680	10240
	daily average load	8960
	Hourly average load	373.3333333
SEPTEMBER		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day

1999680	2011520	11840
2011520	2022080	10560
2022080	2034240	12160
2034240	2045760	11520
2045760	2057920	12160
2057920	2069760	11840
2069760	2082240	12480
2082240	2093760	11520
2093760	2105920	12160
2105920	2117760	11840
2117760	2129920	12160
2129920	2141440	11520
2141440	2153600	12160
2153600	2165440	11840
2165440	2177600	12160
2177600	2189760	12160
2189760	2201920	12160
2201920	2213760	11840
2213760	2225600	11840
2225600	2237760	12160
2237760	2249600	11840
2249600	2261440	11840
2261440	2273280	11840
2273280	2284800	11520
2284800	2296320	11520
2296320	2300480	4160
2300480	2312000	11520
2312000	2323520	11520
2323520	2329920	6400
2329920	2341760	11840
	daily average load	11402.66667
	Hourly average load	475.1111111

OCTOBER		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
2341760	2353280	11520
2353280	2365120	11840
2365120	2376640	11520
2376640	2388480	11840
2388480	2400000	11520
2400000	2404160	4160
2404160	2414080	9920

2414080	2426240	12160
2426240	2438400	12160
2438400	2450506	12106
2450506	2462400	11894
2462400	2474560	12160
2474560	2486720	12160
2486720	2498560	11840
2498560	2509760	11200
2509760	2521600	11840
2521600	2533760	12160
2533760	2545600	11840
2545600	2557760	12160
2557760	2569920	12160
2569920	2581440	11520
2581440	2592960	11520
2592960	2604800	11840
2604800	2616640	11840
2616640	2628800	12160
2628800	2640960	12160
2640960	2653120	12160
2653120	2664640	11520
2664640	2676800	12160
2676800	2688960	12160
2688960	2701120	12160
	daily average load	11592.25806
	Hourly average load	483.0107527
NOVEMBER		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
2701120	2713280	12160
2713280	2725440	12160
2725440	2736960	11520
2736960	2749440	12480
2749440	2761280	11840
2761280	2773440	12160
2773440	2785600	12160
2785600	2797760	12160
2797760	2809920	12160
2809920	2821760	11840
2821760	2833920	12160
2821760	2846080	24320
2846080	2858240	12160

2858240	2870400	12160
2870400	2876480	6080
2876480	2888640	12160
2888640	2900480	11840
2900480	2910080	9600
2910080	2922240	12160
2922240	2933760	11520
2933760	2945600	11840
2945600	2957760	12160
2957760	2969600	11840
2969600	2981760	12160
2981760	2993600	11840
2993600	3005760	12160
3005760	3017280	11520
3019280	3029120	9840
3029120	3040640	11520
3040640	3048320	7680
	daily average load	11912
	Hourly average load	496.3333333

DECEMBER		
INITIAL READING-kWh	FINAL READING-kWh	TOTAL POWER CONSUMPTION-kWh/day
3048320	3060160	11840
3060160	3072320	12160
3072320	3084480	12160
3084480	3096320	11840
3096320	3108160	11840
3108160	3120000	11840
3120000	3131840	11840
3131840	3143680	11840
3143680	3155520	11840
3155520	3161280	5760
3161280	3169600	8320
3169600	3181120	11520
3181120	3184960	3840
3184960	3192640	7680
3192640	3203840	11200
3203840	3215040	11200
3215040	3226880	11840
3226880	3238400	11520
3238400	3243520	5120
3243520	3255040	11520

3255040	3258560	3520
3258560	3266240	7680
3266240	3278400	12160
3278400	3290240	11840
3290240	3292160	1920
3292160	3296640	4480
3296640	3308480	11840
3308480	3320640	12160
3320640	3332800	12160
3332800	3344640	11840
3344640	3357120	12480
	daily average load	9961.290323
	Hourly average load	415.0537634

Daily Data (from 25th November 2015 to 14th December 2015)

Energy Meter Reading (correction factor of 320)					
Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
25-11-2015	00:00	9318	9320	2	
	01:00	9320	9322	2	
	02:00	9322	9323	1	
	03:00	9323	9324	1	
	04:00	9324	9326	2	
	05:00	9326	9327	1	
	06:00	9327	9329	2	
	07:00	9329	9330	1	
	08:00	9330	9332	2	
	09:00	9332	9333	1	
	10:00	9333	9335	2	
	11:00	9335	9336	1	
	12:00	9336	9338	2	
	13:00	9338	9339	1	
	14:00	9339	9340	1	
	15:00	9340	9342	2	
	16:00	9342	9343	1	
	17:00	9343	9345	2	
	18:00	9345	9346	1	
	19:00	9346	9348	2	
	20:00	9348	9349	1	
	21:00	9349	9351	2	
	22:00	9351	9352	1	
	23:00	9352	9354	2	
	00:00	9354	9355	1	
				37	493.3333333

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
26-11-2015					
	01:00	9355	9357	2	
	02:00	9357	9358	1	
	03:00	9358	9360	2	
	04:00	9360	9362	2	
	05:00	9362	9363	1	
	06:00	9363	9365	2	

	07:00	9365	9366	1	
	08:00	9366	9367	1	
	09:00	9367	9369	2	
	10:00	9371	9372	1	
	11:00	9372	9374	2	
	12:00	9374	9375	1	
	13:00	9375	9376	1	
	14:00	9376	9377	1	
	15:00	9377	9379	2	
	16:00	9379	9380	1	
	17:00	9380	9382	2	
	18:00	9382	9383	1	
	19:00	9383	9385	2	
	20:00	9385	9387	2	
	21:00	9387	9389	2	
	22:00	9389	9391	2	
	23:00	9391	9393	2	
	00:00	9393	9395	2	
				38	506.6666667

Energy Meter Reading					
Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
27-11-2015	00:00				
	01:00	9395	9396	1	
	02:00	9396	9398	2	
	03:00	9398	9399	1	
	04:00	9399	9401	2	
	05:00	9401	9402	1	
	06:00	9402	9404	2	
	07:00	9404	9405	1	
	08:00	9405	9407	2	
	09:00	9407	9408	1	
	10:00	9408	9409	1	
	11:00	9409	9410	1	
	12:00	9410	9412	2	
	13:00	9412	9413	1	
	14:00	9413	9415	2	
	15:00	9415	9416	1	
	16:00	9416	9418	2	
	17:00	9418	9419	1	
	18:00	9419	9421	2	
	19:00	9421	9422	1	

	20:00	9422	9424	2	
	21:00	9424	9425	1	
	22:00	9425	9427	2	
	23:00	9427	9429	2	
	00:00	9429	9431	2	
				36	480

Energy Meter Reading					
Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
28-11-2015					
	01:00	9431	9432	1	
	02:00	9432	9433	1	
	03:00	9432	9433	1	
	04:00	9433	9434	1	
	05:00	9434	9435	1	
	06:00	9435	9436	1	
	07:00	9436	9437	1	
	08:00	9437	9439	2	
	09:00	9439	9440	1	
	10:00	9440	9441	1	
	11:00	9441	9442	1	
	12:00	9442	9443	1	
	13:00	9443	9444	1	
	14:00	9444	9445	1	
	15:00	9445	9446	1	
	16:00	9446	9448	2	
	17:00	9448	9450	2	
	18:00	9450	9451	1	
	19:00	9451	9453	2	
	20:00	9453	9455	2	
	21:00	9455	9456	1	
	22:00	9456	9457	1	
	23:00	9457	9459	2	
	00:00	9459	9461	2	
				31	413.3333333

Energy Meter Reading					
Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
29-11-2015					
	01:00	9461	9463	2	
	02:00	9463	9464	1	

	03:00	9464	9466	2	
	04:00	9466	9468	2	
	05:00	9468	9470	2	
	06:00	9470	9472	2	
	07:00	9472	9473	1	
	08:00	9473	9474	1	
	09:00	9474	9476	2	
	10:00	9476	9477	1	
	11:00	9477	9479	2	
	12:00	9479	9480	1	
	13:00	9480	9482	2	
	14:00	9482	9483	1	
	15:00	9483	9485	2	
	16:00	9485	9486	1	
	17:00	9487	9488	1	
	18:00	9488	9489	1	
	19:00	9489	9491	2	
	20:00	9491	9493	2	
	21:00	9493	9494	1	
	22:00	9494	9495	1	
	23:00	9495	9496	1	
	00:00	9496	9498	2	
				36	480

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
30-11-2015					
	01:00	9498	9499	1	
	02:00	9499	9501	2	
	03:00	9501	9503	2	
	04:00	9503	9504	1	
	05:00	9504	9505	1	
	06:00	9505	9506	1	
	07:00	9506	9507	1	
	08:00	9507	9508	1	
	09:00	9509	9510	1	
	10:00	9510	9510	0	
	11:00	9510	9511	1	
	12:00	9511	9511	0	
	13:00	9511	9511	0	
	14:00	9511	9511	0	
	15:00	9511	9512	1	
	16:00	9512	9512	0	

	17:00	9512	9514	2	
	18:00	9514	9515	1	
	19:00	9515	9517	2	
	20:00	9517	9518	1	
	21:00	9518	9519	1	
	22:00	9519	9521	2	
	23:00	9521	9522	1	
	00:00	9522	9523	1	
				24	320

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/01/2015					
	01:00	9523	9525	2	
	02:00	9525	9526	1	
	03:00	9526	9528	2	
	04:00	9528	9529	1	
	05:00	9529	9530	1	
	06:00	9530	9532	2	
	07:00	9532	9533	1	
	08:00	9533	9534	1	
	09:00	9534	9536	2	
	10:00	9536	9537	1	
	11:00	9537	9539	2	
	12:00	9539	9541	2	
	13:00	9541	9543	2	
	14:00	9543	9545	2	
	15:00	9545	9546	1	
	16:00	9546	9548	2	
	17:00	9548	9550	2	
	18:00	9550	9551	1	
	19:00	9551	9552	1	
	20:00	9552	9553	1	
	21:00	9553	9554	1	
	22:00	9554	9556	2	
	23:00	9556	9558	2	
	00:00	9558	9560	2	
				37	493.3333333

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/02/2015					
	01:00	9560	9562	2	

	02:00	9562	9564	2	
	03:00	9564	9566	2	
	04:00	9566	9567	1	
	05:00	9567	9569	2	
	06:00	9569	9570	1	
	07:00	9570	9572	2	
	08:00	9572	9574	2	
	09:00	9574	9575	1	
	10:00	9575	9577	2	
	11:00	9577	9579	2	
	12:00	9579	9581	2	
	13:00	9581	9582	1	
	14:00	9582	9583	1	
	15:00	9583	9584	1	
	16:00	9584	9586	2	
	17:00	9586	9587	1	
	18:00	9587	9589	2	
	19:00	9589	9590	1	
	20:00	9590	9592	2	
	21:00	9592	9594	2	
	22:00	9594	9595	1	
	23:00	9595	9597	2	
	00:00	9597	9598	1	
				38	506.6666667

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/03/2015					
	01:00	9598	9599	1	
	02:00	9599	9600	1	
	03:00	9600	9601	1	
	04:00	9601	9602	1	
	05:00	9602	9604	2	
	06:00	9604	9605	1	
	07:00	9605	9607	2	
	08:00	9607	9608	1	
	09:00	9608	9610	2	
	10:00	9610	9611	1	
	11:00	9611	9613	2	
	12:00	9614	9615	1	
	13:00	9615	9617	2	
	14:00	9617	9618	1	
	15:00	9618	9620	2	

	16:00	9620	9622	2	
	17:00	9622	9624	2	
	18:00	9624	9626	2	
	19:00	9626	9628	2	
	20:00	9628	9630	2	
	21:00	9630	9632	2	
	22:00	9632	9633	1	
	23:00	9633	9635	2	
	00:00	9635	9637	2	
				38	506.6666667
Date	**Time**	**Meter-2**			**Total * 320 /24**
		Initial	**Final**	**Total**	**kW/day**
	01:00	9637	9639	2	
	02:00	9639	9641	2	
	03:00	9641	9643	2	
	04:00	9643	9644	1	
	05:00	9644	9645	1	
	06:00	9645	9647	2	
	07:00	9647	9648	1	
	08:00	9648	9649	1	
	09:00	9649	9652	3	
	10:00	9652	9653	1	
	11:00	9653	9655	2	
12/04/2015	12:00	9655	9656	1	
	13:00	9656	9658	2	
	14:00	9658	9660	2	
	15:00	9660	9661	1	
	16:00	9661	9663	2	
	17:00	9663	9664	1	
	18:00	9664	9666	2	
	19:00	9666	9667	1	
	20:00	9667	9669	2	
	21:00	9669	9670	1	
	22:00	9670	9671	1	
	23:00	9671	9673	2	
	00:00	9673	9675	2	
				38	506.6666667
Date	**Time**	**Meter-2**			**Total * 320 /24**
		Initial	**Final**	**Total**	**kW/day**
12/05/2015	01:00	9675	9677	2	

	02:00	9677	9679	2	
	03:00	9679	9680	1	
	04:00	9680	9682	2	
	05:00	9682	9683	1	
	06:00	9683	9684	1	
	07:00	9684	9685	1	
	08:00	9685	9687	2	
	09:00	9687	9688	1	
	10:00	9688	9690	2	
	11:00	9690	9691	1	
	12:00	9691	9693	2	
	13:00	9693	9695	2	
	14:00	9695	9697	2	
	15:00	9697	9698	1	
	16:00	9698	9700	2	
	17:00	9700	9701	1	
	18:00	9701	9703	2	
	19:00	9703	9704	1	
	20:00	9704	9706	2	
	21:00	9706	9707	1	
	22:00	9707	9709	2	
	23:00	9709	9711	2	
	0:00:00	9711	9713	2	
				38	506.6666667

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
6.12.2015	01:00	9714	9716	2	
	02:00	9716	9717	1	
	03:00	9717	9718	1	
	04:00	9718	9719	1	
	05:00	9719	9720	1	
	06:00	9720	9722	2	
	07:00	9722	9724	2	
	08:00	9724	9726	2	
	09:00	9726	9727	1	
	10:00	9727	9728	1	
	11:00	9728	9730	2	
	12:00	9728	9732	4	
	13:00	9732	9734	2	
	14:00	9734	9735	1	
	15:00	9735	9737	2	
	16:00	9737	9738	1	

	17:00	9738	9740	2	
	18:00	9740	9741	1	
	19:00	9741	9743	2	
	20:00	9743	9744	1	
	21:00	9744	9746	2	
	22:00	9746	9747	1	
	23:00	9747	9749	2	
	0:00:00	9749	9750	1	
				38	506.6666667

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/07/2015	01:00	9750	9752	2	
	02:00	9752	9754	2	
	03:00	9754	9755	1	
	04:00	9755	9756	1	
	05:00	9756	9757	1	
	06:00	9757	9759	2	
	07:00	9759	9760	1	
	08:00	9760	9762	2	
	09:00	9762	9764	2	
	10:00	9764	9765	1	
	11:00	9765	9767	2	
	12:00	9767	9769	2	
	13:00	9769	9770	1	
	14:00	9770	9772	2	
	15:00	9772	9773	1	
	16:00	9773	9775	2	
	17:00	9775	9777	2	
	18:00	9777	9778	1	
	19:00	9778	9780	2	
	20:00	9780	9782	2	
	21:00	9782	9783	1	
	22:00	9783	9785	2	
	23:00	9785	9786	1	
	0:00:00	9786	9788	2	
				38	506.6666667

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/08/2015	01:00	9788	9789	1	
	02:00	9789	9791	2	
	03:00	9791	9792	1	

	04:00	9792	9794	2	
	05:00	9794	9795	1	
	06:00	9795	9796	1	
	07:00	9796	9798	2	
	08:00	9798	9800	2	
	09:00	9800	9801	1	
	10:00	9801	9802	1	
	11:00	9802	9804	2	
	12:00	9804	9805	1	
	13:00	9805	9806	1	
	14:00	9806	9808	2	
	15:00	9808	9810	2	
	16:00	9810	9811	1	
	17:00	9811	9813	2	
	18:00	9813	9815	2	
	19:00	9815	9817	2	
	20:00	9817	9818	1	
	21:00	9818	9820	2	
	22:00	9820	9822	2	
	23:00	9822	9824	2	
	0:00:00	9824	9826	2	
				38	506.6666667
Date	**Time**	**Meter-2**			**Total * 320 /24**
		Initial	**Final**	**Total**	**kW/day**
12/09/2015	01:00	9826	9826	0	
	02:00	9826	9828	2	
	03:00	9828	9830	2	
	04:00	9830	9831	1	
	05:00	9831	9832	1	
	06:00	9832	9834	2	
	07:00	9834	9835	1	
	08:00	9835	9837	2	
	09:00	9837	9838	1	
	10:00	9838	9840	2	
	11:00	9840	9841	1	
	12:00	9841	9843	2	
	13:00	9843	9844	1	
	14:00	9844	9846	2	
	15:00	9846	9847	1	
	16:00	9847	9849	2	
	17:00	9849	9850	1	
	18:00	9850	9852	2	

	19:00	9852	9853	1	
	20:00	9853	9855	2	
	21:00	9855	9856	1	
	22:00	9856	9858	2	
	23:00	9858	9861	3	
	0:00:00	9861	9863	2	
				37	493.3333333

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12/10/2015	01:00	9863	9863	0	
	02:00	9863	9864	1	
	03:00	9864	9866	2	
	04:00	9866	9867	1	
	05:00	9867	9868	1	
	06:00	9868	9870	2	
	07:00	9870	9871	1	
	08:00	9871	9873	2	
	09:00	9873	9874	1	
	10:00	9874	9876	2	
	11:00	9876	9876	0	
	12:00	9876	9876	0	
	13:00	9876	9876	0	
	14:00	9876	9877	1	
	15:00	9877	9877	0	
	16:00	9877	9877	0	
	17:00	9877	9877	0	
	18:00	9877	9878	1	
	19:00	9878	9878	0	
	20:00	9878	9878	0	
	21:00	9878	9878	0	
	22:00	9878	9878	0	
	23:00	9878	9880	2	
	0:00:00	9880	9881	1	
				18	240

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
11/11/2015	01:00	9881	9881	0	
	02:00	9881	9881	0	
	03:00	9881	9881	0	
	04:00	9881	9882	1	
	05:00	9882	9882	0	

	06:00	9882	9882	0	
	07:00	9882	9882	0	
	08:00	9882	9883	1	
	09:00	9883	9884	1	
	10:00	9884	9885	1	
	11:00	9885	9886	1	
	12:00	9886	9888	2	
	13:00	9888	9890	2	
	14:00	9890	9892	2	
	15:00	9892	9893	1	
	16:00	9893	9895	2	
	17:00	9895	9897	2	
	18:00	9897	9898	1	
	19:00	9898	9899	1	
	20:00	9899	9900	1	
	21:00	9900	9901	1	
	22:00	9901	9903	2	
	23:00	9903	9905	2	
	0:00:00	9905	9907	2	
				26	346.6666667

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
12.12.2015					
	01:00	9905	9907	2	
	02:00	9907	9908	1	
	03:00	9908	9910	2	
	04:00	9910	9911	1	
	05:00	9911	9912	1	
	06:00	9912	9913	1	
	07:00	9913	9915	2	
	08:00	9915	9917	2	
	09:00	9917	9918	1	
	10:00	9918	9920	2	
	11:00	9920	9921	1	
	12:00	9921	9923	2	
	13:00	9923	9924	1	
	14:00	9924	9926	2	
	15:00	9926	9928	2	
	16:00	9928	9930	2	
	17:00	9930	9931	1	
	18:00	9931	9933	2	
	19:00	9933	9934	1	

Date	Time	Meter-2			Total * 320 /24
	20:00	9934	9935	1	
	21:00	9935	9937	2	
	22:00	9937	9938	1	
	23:00	9938	9939	1	
	00:00	9939	9941	2	
				36	480

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
13.12.2015	01:00	9941	9942	1	
	02:00	9942	9943	1	
	03:00	9943	9944	1	
	04:00	9944	9945	1	
	05:00	9945	9947	2	
	06:00	9947	9948	1	
	07:00	9948	9949	1	
	08:00	9949	9949	0	
	09:00	9949	9949	0	
	10:00	9949	9949	0	
	11:00	9949	9949	0	
	12:00	9949	9950	1	
	13:00	9950	9950	0	
	14:00	9950	9951	1	
	15:00	9951	9951	0	
	16:00	9951	9951	0	
	17:00	9951	9952	1	
	18:00	9952	9952	0	
	19:00	9952	9952	0	
	20:00	9952	9952	0	
	21:00	9952	9952	0	
	22:00	9952	9953	1	
	23:00	9953	9953	0	
	00:00	9953	9953	0	
				12	160

Date	Time	Meter-2			Total * 320 /24
		Initial	Final	Total	kW/day
14/12/2015	01:00	9953	9953	0	
	02:00	9954	9954	0	
	03:00	9954	9954	0	
	04:00	9954	9954	0	
	05:00	9954	9955	1	
	06:00	9955	9955	0	

	07:00	9955	9955	0	
	08:00	9955	9956	1	
	09:00	9956	9956	0	
	10:00	9956	9956	0	
	11:00	9956	9957	1	
	12:00	9957	9959	2	
	13:00	9959	9960	1	
	14:00	9960	9962	2	
	15:00	9962	9963	1	
	16:00	9963	9965	2	
	17:00	9965	9966	1	
	18:00	9966	9968	2	
	19:00	9968	9969	1	
	20:00	9969	9971	2	
	21:00	9971	9973	2	
	22:00	9973	9974	1	
	23:00	9974	9976	2	
	00:00	9976	9978	2	
				24	320

SEWA BILL

(only for the month of October and November – more data to be provided with permission from the plant authorities)

[redacted]

Hamriyah | Off : Halwan

United Arab Emirates

هيئة كهرباء ومياه الشارقة

Sharjah Electricity & Water Authority

135 Sharjah, U.A.E. ص.ب ١٣٥ الشارقة ا.ع.م

Call Center 991 مركز الاتصال

www.sewa.gov.ae

customercare@sewa.gov.ae

Personal ID	[redacted]	معرف المشترك
Account Number	[redacted]	رقم الحساب
Customer Class	[redacted]	فئة المشتركين
Invoice Number	[redacted]	رقم الفاتورة
Invoice Date	[redacted]	تاريخ الفاتورة
Premise ID	[redacted]	معرف العقار
Due Date	[redacted]	تاريخ الاستحقاق
Billing Period	October 2015	الفترة
Last Receipt Date	08/08/2015	تاريخ آخر إيصال

Bill Summary ملخص الفاتورة

Total Amount إجمالي	Adjustments التعديلات	Receipts المدفوعات	Other Chrgs رسوم أخرى	Arrears المتاخرات	Current Amt المبلغ الحالي
441,800.00	0.00	0.00	0.00	361.00	441,439.00

Financial Details تفاصيل الرسوم

Municipal Ser. رسوم البلدية	Gas الغاز	Water المياه	Electricity الكهرباء	Services الخدمات
0.00	0.00	0.00	361.00	Arrears المتاخرات
0.00	0.00	0.00	440,704.00	Current Amount المبلغ الحالي
0.00	0.00	0.00	735.00	Service Charges رسوم خدمات
0.00	0.00	0.00	0.00	Other Charges رسوم اخرى
0.00	0.00	0.00	0.00	Receipts المدفوعات
0.00	0.00	0.00	0.00	Adjustments تعديلات
0.00	**0.00**	**0.00**	**441,800.00**	Net Amount المبلغ الصافي
			441,800.00	Total Amount(E+W+G+S) إجمالي

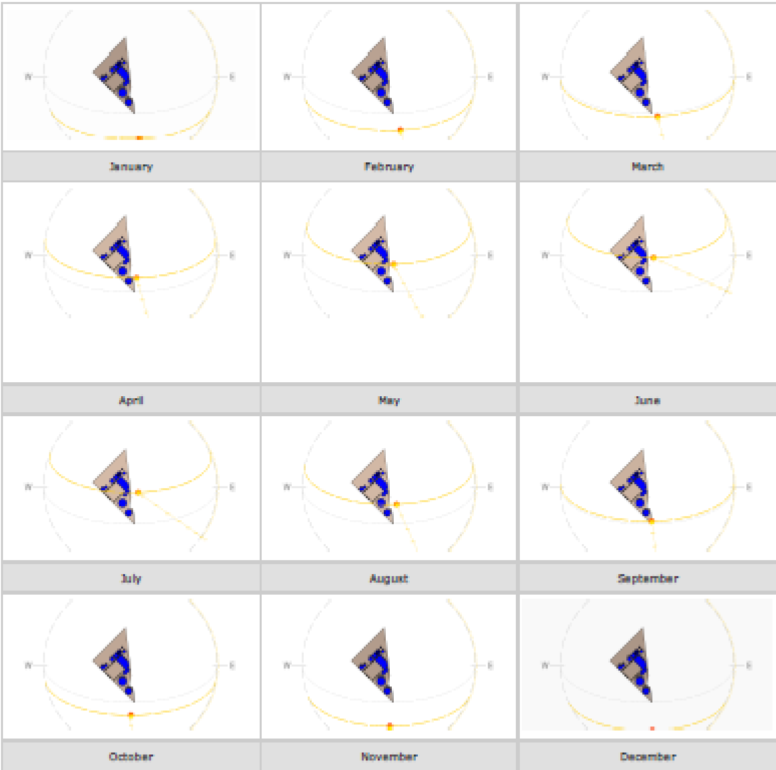
Meter & Reading Details تفاصيل العداد و القراءات

تاريخ القراءة Current Reading Date	تاريخ آخر قراءة Previous Reading Date	الاستهلاك Consumption	التعرفة Rate	عامل الضرب MF	القراءة الحالية Current Reading	القراءة السابقة Previous Reading	رقم العداد Meter No.	Old Consumer Number 30307060175
27/10/2015	25/08/2015	1001600	0.44	320	8313	5183	E-21173169	(CT) Electricity 1 الكهرباء

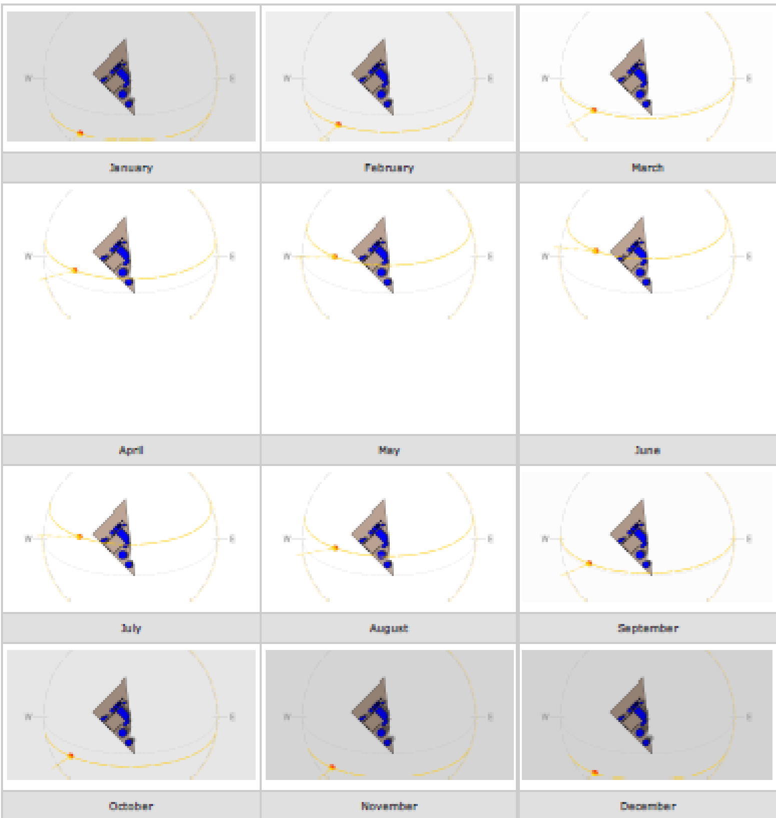
APPENDIX B –SIMULATION DATA

SHADING REPORT –IES VE

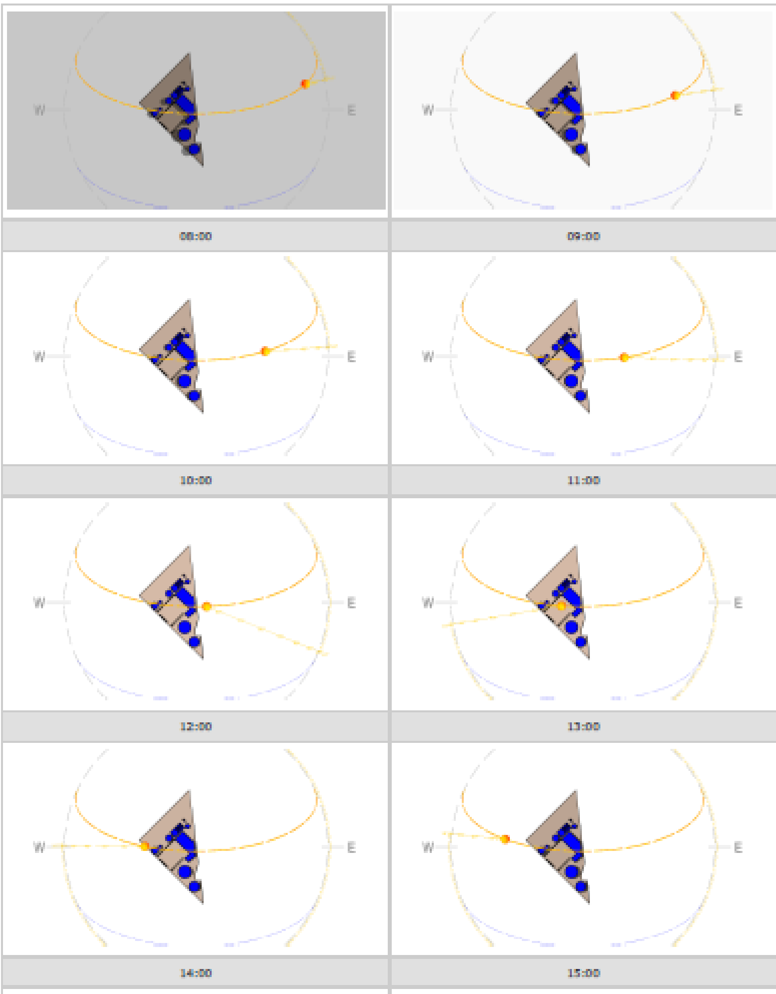
Solar shading: month by month 12:00

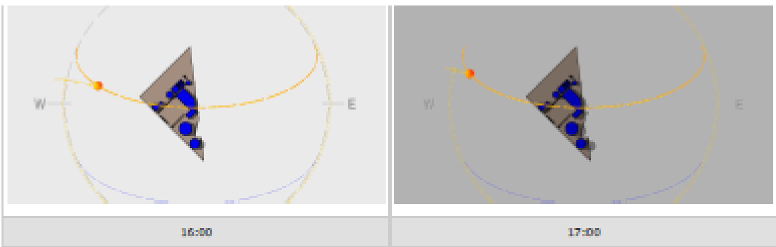


Solar shading: month by month 15:00

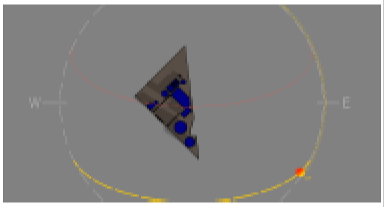


Solar shading: summer solstice

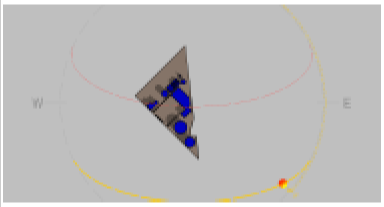




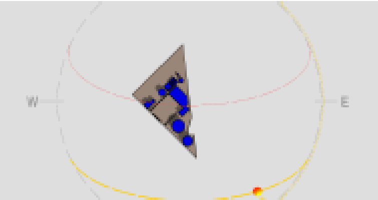
Solar shading: winter solstice



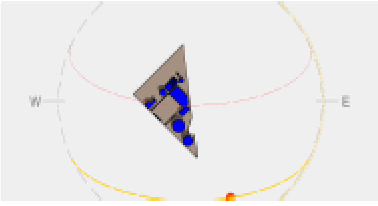
08:00



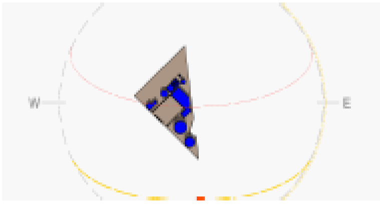
09:00



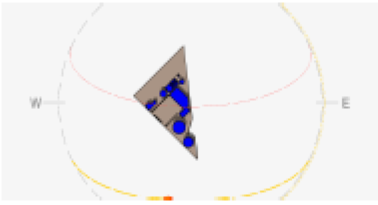
10:00



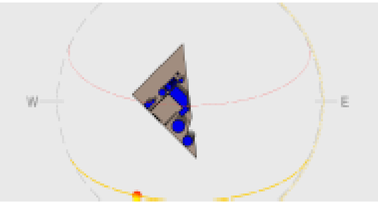
11:00



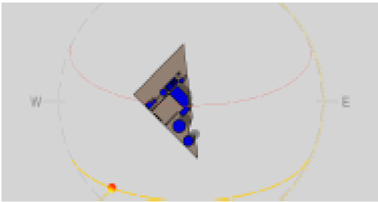
12:00



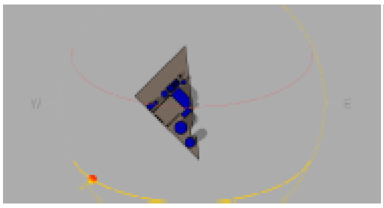
13:00



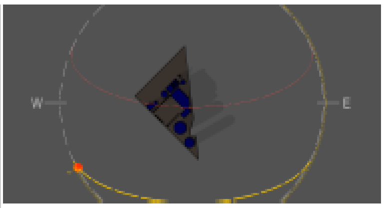
14:00



15:00

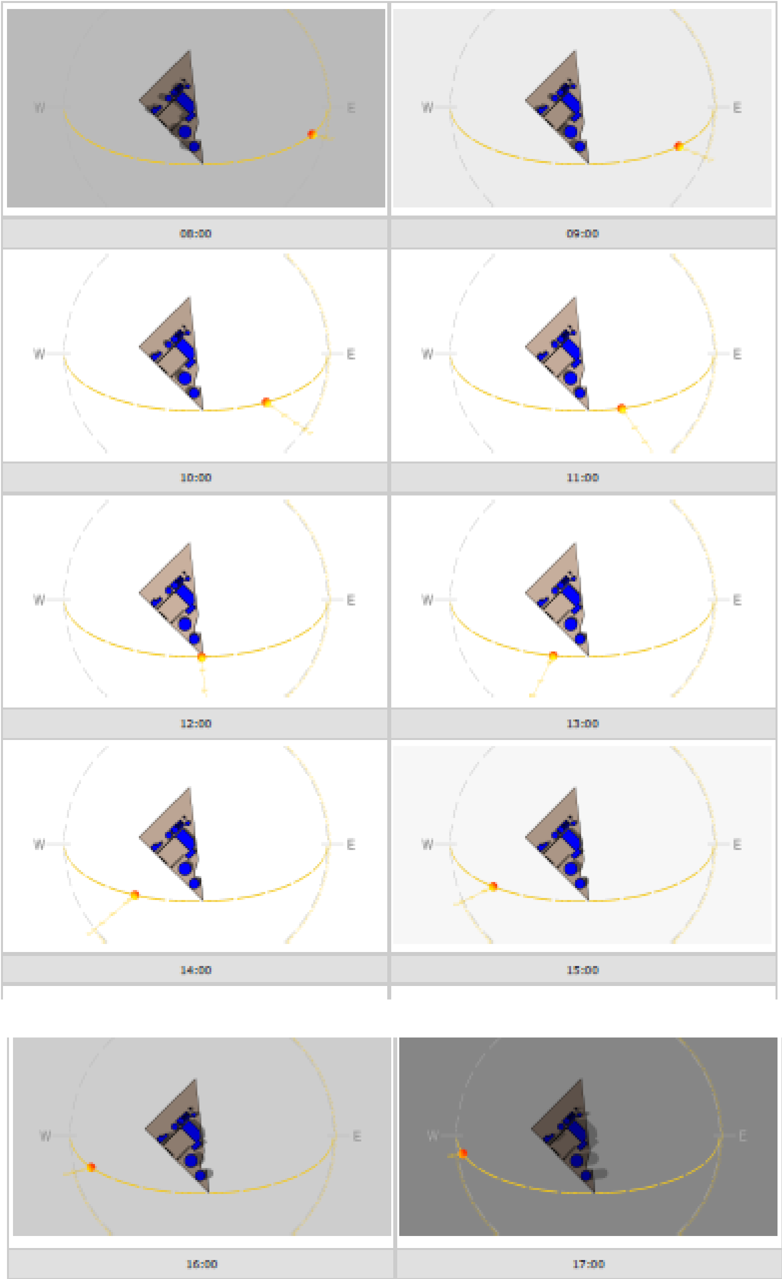


16:00

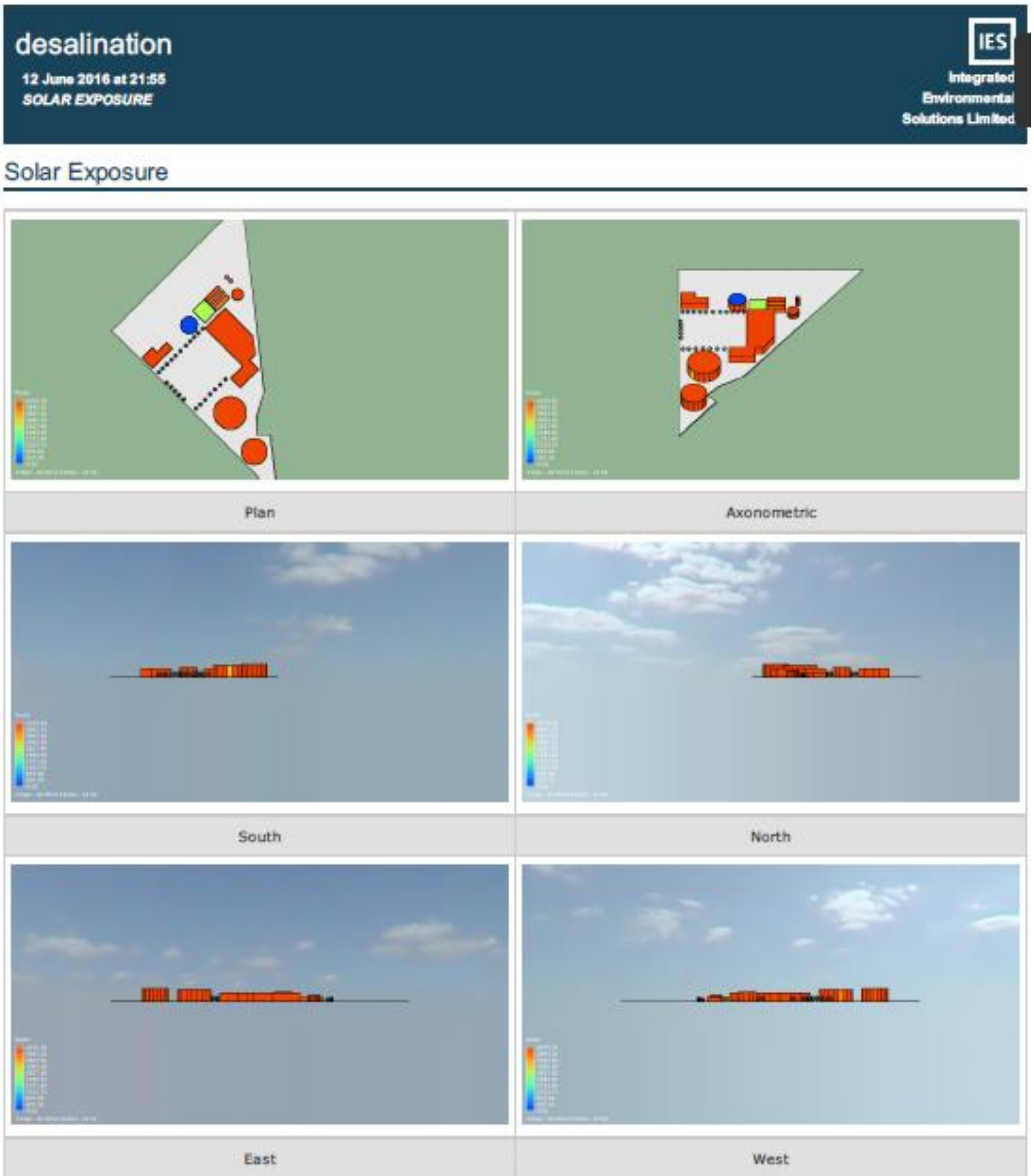


17:00

Solar shading: equinox



EXPOSURE REPORT –IES VE



SOLAR PANEL DATA

www.jinkosolar.com

JinKO Solar

Building Your Trust in Solar

(4BB)

JKM320P-72

305-320 Watt

POLY CRYSTALLINE MODULE

Positive power tolerance of 0/+3%

ISO9001:2008-ISO14001:2004-OHSAS18001 certified factory.

IEC61215-IEC61730 certified products.

KEY FEATURES

4 Busbar Solar Cell:
4 busbar solar cell adopts new technology to improve the efficiency of modules , offers a better aesthetic appearance, making it perfect for rooftop installation.

High Efficiency:
High module conversion efficiency (up to 16.49%), through innovative manufacturing technology.

Low-light Performance:
Advanced glass and solar cell surface texturing allow for excellent performance in low-light environments.

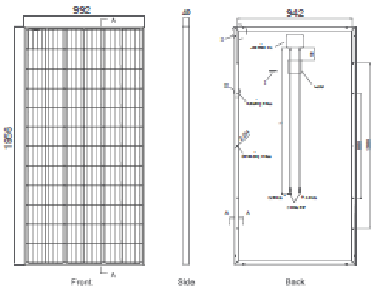
Severe Weather Resilience:
Certified to withstand: wind load (2400 Pascal) and snow load (5400 Pascal).

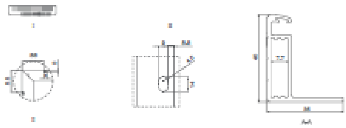
Durability against extreme environmental conditions:
High salt mist and ammonia resistance certified by TUV NORD.

LINEAR PERFORMANCE WARRANTY

10 Year Product Warranty • 25 Year Linear Power Warranty

Engineering Drawings





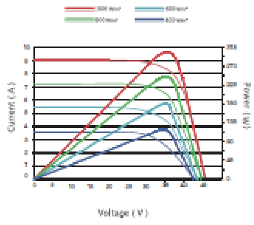
Packaging Configuration

(Two boxes =One pallet)

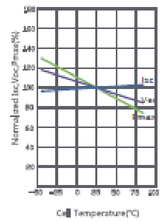
25pcs/ box, 50pcs/pallet, 600 pcs/40'HQ Container

Electrical Performance & Temperature Dependence

Current-Voltage & Power-Voltage Curves (305W)



Temperature Dependence of Isc,Voc,Pmax



Mechanical Characteristics

Cell Type	Poly-crystalline 156×156mm (6 inch)
No.of cells	72 (6×12)
Dimensions	1956×992×40mm (77.01×39.05×1.57 inch)
Weight	26.5 kg (58.4 lbs.)
Front Glass	4.0mm, High Transmission, Low Iron, Tempered Glass
Frame	Anodized Aluminium Alloy
Junction Box	IP67 Rated
Output Cables	TÜV 1×4.0mm², Length: 900mm or Customized Length

SPECIFICATIONS

Module Type	JKM305P		JKM310P		JKM315P		JKM320P	
	STC	NOCT	STC	NOCT	STC	NOCT	STC	NOCT
Maximum Power (Pmax)	305Wp	225Wp	310Wp	230Wp	315Wp	233Wp	320Wp	237Wp
Maximum Power Voltage (Vmp)	36.8V	34.0V	37.0V	34.4V	37.2V	34.7V	37.4V	34.7V
Maximum Power Current (Imp)	8.30A	6.62A	8.38A	6.68A	8.48A	6.71A	8.56A	6.83A
Open-circuit Voltage (Voc)	45.6V	42.4V	45.9V	42.7V	46.2V	42.8V	46.4V	43.0V
Short-circuit Current (Isc)	8.91A	7.21A	8.96A	7.26A	9.01A	7.28A	9.05A	7.35A
Module Efficiency STC (%)	15.72%		15.98%		16.23%		16.49%	
Operating Temperature(℃)	-40℃~+85℃							
Maximum system voltage	1000VDC (IEC)							
Maximum series fuse rating	15A							
Power tolerance	0~+3%							
Temperature coefficients of Pmax	-0.41%/℃							
Temperature coefficients of Voc	-0.31%/℃							
Temperature coefficients of Isc	0.06%/℃							
Nominal operating cell temperature (NOCT)	45±2℃							

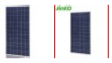
STC: Irradiance 1000W/m² Cell Temperature 25°C AM=1.5

NOCT: Irradiance 800W/m² Ambient Temperature 20°C AM=1.5 Wind Speed 1m/s

* Power measurement tolerance: ± 3%

The company reserves the final right for explanation on any of the information presented hereby. EN-MKT-320P_v1.0_rev2015

Home / **Jinko 320W JKM320P-72 Poly Silver Frame Solar Panel**



Jinko 320W JKM320P-72 Poly Silver Frame Solar Panel

USD **$256.00**

Add to Cart   Wishlist Count (0)

Previous

SKU:SP07P672320S

Availability: Out of st

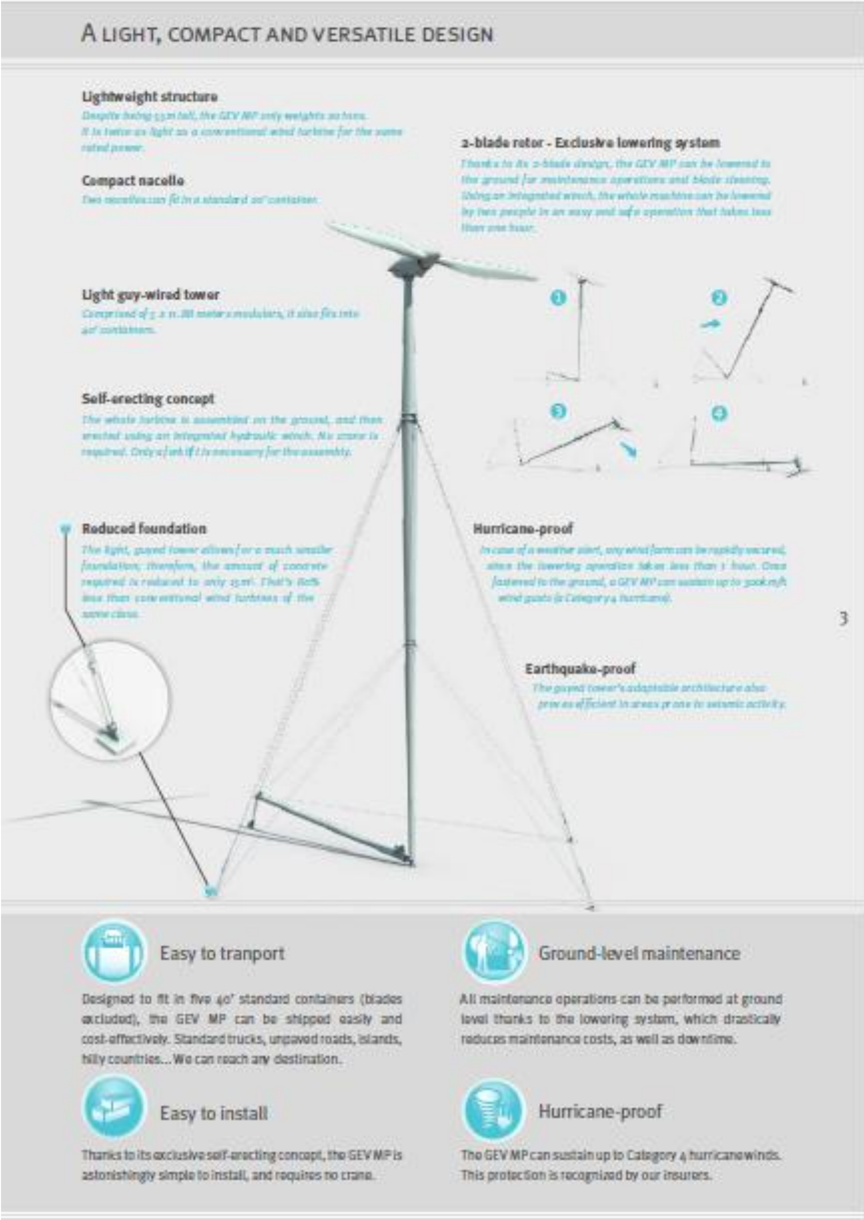
Sign up for price alert

Email to a Friend

0 Review

Jinko JKM320P-72-3
Silver Frame Solar P
Cells,High Quality.
218

WIND TURBINE DATA



A LIGHT, COMPACT AND VERSATILE DESIGN

Lightweight structure

Despite being 55m tall, the GEV MP only weights 20 tons. It is twice as light as a conventional wind turbine for the same rated power.

Compact nacelle

Two nacelles can fit in a standard 20' container.

2-blade rotor - Exclusive lowering system

Thanks to its 2-blade design, the GEV MP can be lowered to the ground for maintenance operations and blade cleaning. Using an integrated winch, the whole machine can be lowered by two people in an easy and safe operation that takes less than one hour.

Light guy-wired tower

Comprised of 5 x 11.88 meters modules, it also fits into 40' containers.

Self-erecting concept

The whole turbine is assembled on the ground, and then erected using an integrated hydraulic winch. No crane is required. Only a forklift is necessary for the assembly.

Reduced foundation

The light, guyed tower allows for a much smaller foundation; therefore, the amount of concrete required is reduced to only 15m³. That's 80% less than conventional wind turbines of the same class.

Hurricane-proof

In case of a weather alert, any wind farm can be rapidly secured, since the lowering operation takes less than 1 hour. Once fastened to the ground, a GEV MP can sustain up to 300km/h wind gusts (a Category 4 hurricane).

Earthquake-proof

The guyed tower's adaptable architecture also proves efficient in areas prone to seismic activity.

3

Easy to tranport

Designed to fit in five 40' standard containers (blades excluded), the GEV MP can be shipped easily and cost-effectively. Standard trucks, unpaved roads, islands, hilly countries... We can reach any destination.

Ground-level maintenance

All maintenance operations can be performed at ground level thanks to the lowering system, which drastically reduces maintenance costs, as well as downtime.

Easy to install

Thanks to its exclusive self-erecting concept, the GEV MP is astonishingly simple to install, and requires no crane.

Hurricane-proof

The GEV MP can sustain up to Category 4 hurricane winds. This protection is recognized by our insurers.

GEV MP C - Technical description

TURBINE CONCEPT
- 2-blade down wind rotor, two-speed generator
- Teetering hub with rubber/metal dampening
- Hydraulic pitch control

• Cut in wind speed	3.5 m/s
• Cut out wind speed	25 m/s
• Output Voltage & Frequency (3-phase)	400 V - 50 Hz or 460 V - 60 Hz
• Class (as per IEC 61400-1): 1999	**From class II to class IV**
• Hub height	55/60 m (180/197')
• Rotor diameter	32 m (105')
• Rotation speed *(50 & 60 Hz)*	31 to 46 rpm
• Max. wind speed *(average 10 mn)*	
Operating position	30 - 42.5 m/s
Lowered position	85 m/s

EXTREME CONDITION PROTECTION

• Corrosion	Galvanized tower + option marine anti-corrosion protection (C5)
• Generator tightness/insulation	IP55 / Class F
• Hurricane resistance	Lowering system
• Earthquake resistance	Flexible architecture (guyed tower) Multi-pole, shock-absorbent anchors
• Lightning protection	Fully-integrated lightning protection (IEC-61400-24) Lightning arrester on nacelle (IEC 62305/61643-12)
• Operating limits	Standard : -5ºC to +40ºC (+23ºF to +104ºF) Polar : -20ºC to +35ºC (+4ºF to +95ºF)
• Survival	Standard : -10ºC to +50ºC (+14ºF to +122ºF) Polar : -40ºC to +40ºC (-40ºF to +104ºF)

PERFORMANCE DETAILS

• Gearbox	2-stage planetary gearbox
• Generator	2-speed, asynchronous, squirrel cage generator - rated power : 275 kW
• Grid connection	Power factor compensation Electrical cabinet including transformer at tower base
• Emergency and parking brake	Aerodynamic and disc on high speed shaft
• Yaw	Hydraulic active yaw, automatic cable untwisting

MAST

• Type	Guyed : Tubular or Lattice
• Sections	5 x 11.88m (5x39')
• Material	Galvanized steel
• Installation	Self-erection via hydraulic winch
• Anchors	Boreholes with steel rods cast in concrete

BLADES

• Material	Twisted vinylester reinforced with fiber glass

CONTROL COMMAND SYSTEM

• Automation control	Industrial automation Siemens through Profibus + Ethernet
• UPS (voltage outage)	56 Ah
• Remote supervision	V-SCADA™ / through RTC, radio, internet...

WEIGHT - DIMENSIONS (CLASS III)

• Nacelle with rotor	9 t (17196 lb)
• Wind turbine mast	15 t (26455 lb)
• Total packed volume	5x40' containers + blades (1 load)

MANUFACTURERS

• Blades	ACO (VERGNET)
• Blade design	AERODYN
• Gearbox	BONFIGLIOLI
• Generator	ABB

POWER CURVE

Wind speed (m/s) d=1.225kg/m^3	Power curve (kW) 32m blades
2,5	0
3,0	0
3,5	0
4,0	3
4,5	10
5,0	18
5,5	27
6,0	36
6,5	47
7,0	58
7,5	78
8,0	98
8,5	119
9,0	141
9,5	164
10,0	189
10,5	215
11,0	243
11,5	262
12	275
Up to 25	275

PRODUCTION ESTIMATES

Hub height wind speed (m/s)	Annual gross production (MWh/year)
4	164
4,5	246
5	342
5,5	449
6	560
6,5	674
7	785
7,5	893
8	994
8,5	1089
9	1176

BATTERY DATA

TAILOR-MADE SYTEM POWER OUTPUT FROM KW TO MW

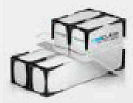
CellCube - The modular solution for every application.

Flexible, modular and individually applicable - that is CellCube, the redox flow energy storage system based on vanadium. The modules of the individual CellCube families can be combined simply and quickly, depending on the requirement. This is the basis for a flexible, tailor-made implementation and a wide range of power output from the kilowatt range to the megawatt range.

Available power and storage capacity

	Power output (kW)	Storage capacity (kWh)				
CellCube FB 10	10	40	70	100	130	
CellCube FB 20	20	40	70	100	130	
CellCube FB 30	30	40	70	100	130	
CellCube FB 200	200		400	800	1600	

CellCube - combination examples

	**FB 10-100** 10 kW, 100 kWh		**2x FB 10-100** 20 kW, 200 kWh
	**FB 200-400** 200 kW, 400 kWh		**FB 200-800** 200 kW, 800 kWh
	**FB 400-1600** 400 kW, 1600 kWh		**FB 400-800** 400 kW, 800 kWh

A solution for every requirement *

Power (kW)	1 h	2 h	3 h	4 h	5 h	6 h	8 h	10 h
10	FB 10-40	FB 10-40	FB 10-40	FB 10-70	FB 10-70	FB 10-100	FB 10-100	FB 10-130
20	FB 20-40	FB 20-70	FB 20-70	FB 20-100	FB 20-130	FB 200-400	FB 200-400	FB 200-400
30	FB 30-40	FB 20-70	FB 30-100	FB 30-130	FB 200-400	FB 200-400	FB 200-400	FB 200-800
100	FB 200-400	FB 200-400	FB 10-40	FB 200-800	FB 200-800	FB 200-800	FB 200-1600	FB 200-1600
150	FB 200-400	FB 200-400	FB 200-800	FB 200-800	FB 200-1600	FB 200-1600	FB 200-1600	
200	FB 200-400	FB 200-800	FB 200-800	FB 200-1600	FB 200-1600	FB 200-1600		

* The optimal combination of power and energy capacity are specified in each case (other combinations or oversizing are also possible)

CELLCUBE

Technical data.

Perfomance and energy	CellCube FB 10/20/30 kW	CellCube FB 200 kW
Nominal charge output	10/20/30 kW	200 kW
Nominal discharge output	10/20/30 kW	200 kW
Capacity of the energy storage system	40/70/100/130 kWh	400/800/1600 kWh
Battery and system voltage		
Output voltage option	- 48 VDC; 120 VAC; 230 VAC (1-phase); 400 VAC (3-phase)	400 VAC
Duration of connection/ Reaction time	grid-independent: < 20 ms, remote converter: < 3 ms	
Control system		
Control via external interfaces	serial, TCP/IP, bus systems	
Monitoring		
Condition detection via remote monitoring by e-mail	State of charge (SOC), available energy, charge/ discharge power output, and more	
Efficiency		
Charge/ discharge cycle DC	up to 80 %	up to 80 %
Multi-stage management reduces power losses	3 independent, switchable circuits with energy-efficient pump control system	4 independent, switchable circuits with energy-efficient pump control system
Self-discharge		
Self-discharge in standby**	< 150 W	< 200 W
Self-discharge in tank	negligible (< 1 % per year)	negligible (< 1 % per year)
Size and weight		
Dimensions L x W x H	4,660 x 2,200 x 2,420 mm (15 x 7 x 8 ft)	6,060 x 2,440 x 5,800 mm* (20 x 8 x 19 ft)
Weight (empty condition)	3,8 - 4,5 t	20 t
Gross weight (filled condition)	7 - 14 t	60 t
Climatic operating conditions		
Climatic control	-40°C to +50°C (monthly average temperature)	
	The inside temperature is controlled between 20°C and 30°C by an intelligent temperature management system. Suitable insulation (for heating and cooling) allows deployment in any climate.	

* Base unit. ** Subject to change.

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