5th Asia Pacific Conference on Industrial Engineering and Operations Management
Tokyo, Japan, September 10-12, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AP05.20240137
Published: September 10, 2024

Techno-economic Analysis of Modularizing Standalone PV Solar Systems to Power Onshore Wells in Saudi Arabia

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Abstract

Onshore Wells is one of the key enablers in maintaining and unlocking Oil & Gas production potential. Constructing Water, Oil, and Gas Onshore Wells includes a scope of supplying power to the equipment at the Wellhead area. As the number of new wells is expected to increase to accommodate the global demand for Oil & Gas, the power consumption is anticipated to increase to accommodate the power supply of these new wells. In Saudi Arabia, electrifying Onshore Wells is done currently by constructing Over Head Power Lines (OHPL) from the nearest tap-off point to the Wellhead area. OHPL network has congested the area and harms the environment by adding greenhouse emissions. In this paper, powering Onshore Wells by Standalone Solar PV system was techno-economically analyzed. A fixed Standalone Solar PV system of 24, 41, 171 kWp capacities was sized to meet the loads of Water, Oil, and Gas Onshore Wells, respectively. Depending on the distance from the tap-off point to the Wellhead area, the economic feasibility of adopting a Solar PV system can be determined.

Keywords
Onshore Wells, Oil & Gas Wells, Renewable Energy, Standalone Solar PV, Techno-economic Analysis.

Introduction
Over the years constructing Water, Oil, and Gas wells has been considered the main factor of enabling the Kingdom to maintain and unlock production potential. Wells are classified into two different categories: Onshore Wells and Offshore Wells. In Saudi Arabia, around 10,000 new wells are expected to be drilled from 2023 to 2030 and 80% of these new wells are onshore wells (Rystad Energy 2024). Therefore, seeking a techno-economically feasible alternative to a grid power supply is considered an essential area of study. Each well adds around 96.25 MWh/year of energy consumption, which emissions around 69.9 Ton of CO^2 yearly according to Saudi Aramco Best Practices published in 2020. The energy consumption was calculated depending on the average well power consumption per year. Onshore Wells is currently electrified by Over Head Power Lines (OHPL), which require construction efforts to erect poles, right of way (ROW), and a transformer from the nearest available tap of point to the wellhead area. OHPL network congested the area and its operation harms the environment since it produces greenhouse gasses (GHG) emissions.

Onshore Wells are scattered around the Kingdom, however, most of the Wells are constructed in the Eastern province. For the aim of this study, Onshore Wells under consideration are wells in the Eastern province which were divided into two areas: North and South of Dhahran.

Akikur et al. (2013) presented a comparative case study that included project examples of powering rural areas with a standalone Solar Photovoltaic (PV) System and concluded that solar energy is a cost-competitive technology for rural locations and the most environmentally friendly technology since it does not produce greenhouse gases (GHG) emissions, nor sound pollution while operating. Powering the newly constructed wells with carbon-free renewable energy offers an opportunity that help reduce the carbon footprint of the Oil & Gas industry. In this paper, a techno-economic analysis to power Onshore Wells by Standalone Solar Photovoltaic Systems in Saudi Arabia was conducted. Providing a Modular fixed solution matching the loads of each Well type in comparison with the current implemented power supply.

1.1 Objectives

The primary objectives of this paper are as follows:
Technically analyze the supply of solar energy to onshore wells.
Size a modular Standalone PV Solar System according to the obtained load data from Onshore Wells.
Economically evaluate the supply of power to the onshore wells by solar energy.

2. Literature Review

Oil & Gas industry plays a major role in providing energy to meet the global increasing demand and it will continue to do so for decades, however, this industry is a significant consumer of energy and highly contributes to GHG emissions, whether it is consuming or producing. In fact, Oil & Gas production is predicted to consume more energy progressively. Thus, it is key to utilize renewables to save hydrocarbon resources, reduce Oil & Gas industry GHG emissions, and improve the public image of the industry. One of the main renewable technologies that can be utilized of Solar PV technology (Saadawi 2019). Saudi Arabia has an abundance of Solar potential as it is in the middle of the so-called "sunbelt". Currently, Saudi Arabia is ranked sixth worldwide for solar energy potential (AlGhamdi 2020). The Average daily total Global Horizontal Irradiance (GHI) of the Kingdom varies from 5.6 kWh/m2 to 6.6 kWh/m2, as shown in Figure 1.

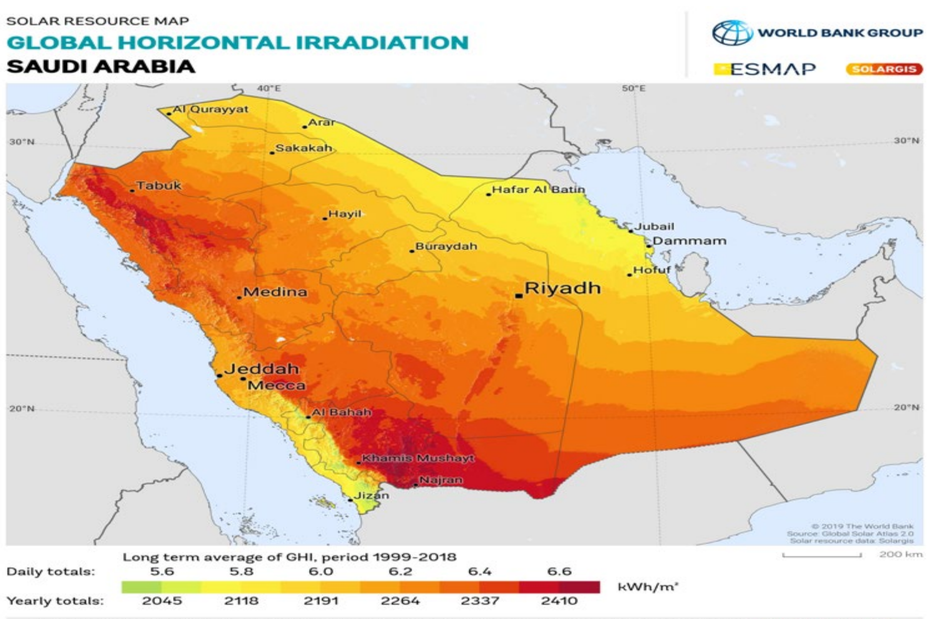


Figure 1. GHI of Saudi Arabia

An assessment of solar radiation resources in Saudi Arabia performed by E. Zell et al. (2015), shows that in the Eastern area of the Kingdom, the average daily total GHI is 5.874 kWh/m2. Moreover, one of the great meteorological data of the Kingdom is the average duration of sunshine hours having a value of 8.8 h/day, ranging from 7.4 to 9.4 h/day

(Almasoud and Gandayah 2014). The most common method to harness solar energy is Solar PV technology, where it converts solar radiation into electricity (Kumar et al. 2021). It is a reliable technology and considered an ideal solution for off-grid power supply because of its modular nature compared to other renewables, along with the many successful implementations that have been noticed worldwide (Waqas et al. 2018).

Solar PV systems can be divided into grid-connected systems or standalone systems (off-grid), where the former is often utilized in urban areas and the latter is mostly installed in rural areas (Akikur et al. 2013). Standalone Solar PV system components include PV Modules, Charge controller, Storage system (i. e. Battery), and Inverter (for AC loads) (Waqas et al. 2018). The process begins by capturing sunlight through tilted PV modules after that produced electricity by PV cells is regulated by the charge controller and the excess electricity generated is stored in a storage medium for backup situations, then an inverter will serve the process by converting the DC electricity to AC. Figure 2 below shows a schematic diagram of a typical Standalone Solar PV system.

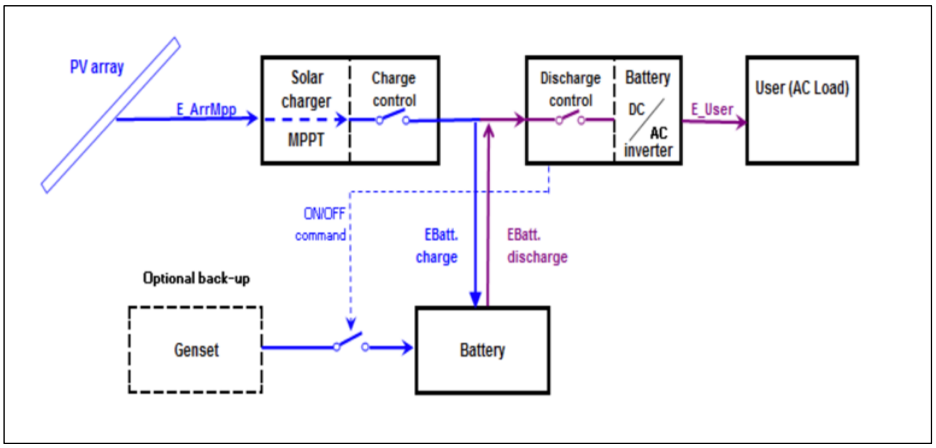


Figure 2. Schematic diagram of a standalone solar PV system

3. Methodology and Data Collection

3.1 Solar Energy Resource Review

Since the area considered for this study is the Eastern Province, North of Dhahran was selected as shown in Figure-3. The selected area has lower GHI compared to the South of Dhahran area as shown in Figure 1. Therefore, the Solar PV system that is suitable for a load in the North of Dhahran area will be suitable as well for a load in the South of Dhahran area.

Figure 3. Selected point location

3.2 Load & Solar data

A fundamental step in designing a standalone solar PV system is calculating the daily energy demand to size the system accordingly (Waqas et al. 2018). In order to assess providing a Modular standalone solar PV system technically, load data of Oil, Gas, and Water wells were obtained to find each type of well daily energy demand. The maximum load of each equipment according to its duty designation was considered as shown in Tables 1, 2, and 3 from Appendix-A which illustrate the Oil, Gas, and Water wellhead loads respectively. Equipment duty designation was classified into, continuous, intermittent, and standby, having the following factors 1, 0.3, and 0.1 respectively. Solar panel data sheets used in this study were obtained from currently available panels in the market.

3.3 Technical Analysis

PVsyst software was utilized to design standalone solar PV systems of each well type that will serve the purpose for technically analyzing the power supply. A total of three (3) simulations were done to analyze and provide fixed modular design for each well type.

3.4 Economical Evaluation

Levelized Cost of Energy (LCOE) is the metric method that will be used to economically compare between standalone Solar PV system and OHPL. As shown in equation one (1), LCOE is calculated by dividing the Net Present Value (NPV) over the total energy consumption (EC). NPV shall include all costs associated with each system over the lifetime of intended operation.

$$LCOE = \frac{NPV}{EC} \tag{1}$$

4 Standalone Solar PV Systems Design by PVsyst

PVsyst is a simulation software that facilitate designing a PV system configuration, which enables calculating amount of energy generated by the user configured system. With the increasing demand in Solar PV systems installations, designers, and installers, require a reliable tool to anticipate produced energy, and system performance under real conditions (Irwan et al. 2015). PVsyst has a rich database that allows users to select from a variety of PV Modules, and Batteries of different manufacturers, its geographical database provides precise meteorological information about an area selected (Morshed et al. 2015). Following steps have been performed to simulate each well type power consumption to accurately size the PV system.

4.1 Geographical location and Solar Data

From PVsyst interactive a point with coordinates 28.29 °N 48.37 °E shown in Figure-3, which is located within an area considered one of the lowest GHI value. Figure-4 shows the Monthly Meteo values of the selected location.

Monthly Meteo Values

Source Meteonorm 8.0 (1998-2002), Sat=100%

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	3.57	4.29	4.73	5.78	6.34	7.04	6.73	6.32	5.77	4.62	3.70	3.23	5.18	kWh/m²/day
Horizontal diffuse	1.54	2.18	2.75	3.19	3.48	3.63	3.33	3.23	2.51	2.24	1.72	1.50	2.61	kWh/m²/day
Extraterrestrial	6.23	7.53	8.97	10.32	11.10	11.37	11.23	10.63	9.50	8.03	6.58	5.83	8.95	kWh/m²/day
Clearness Index	0.574	0.569	0.527	0.560	0.571	0.619	0.599	0.594	0.607	0.576	0.562	0.554	0.579	ratio
Ambient Temper.	12.9	15.5	21.0	26.4	33.3	37.1	39.3	38.7	34.6	29.2	20.0	14.6	26.9	°C
Wind Velocity	3.4	3.8	4.0	4.1	4.2	5.2	4.8	4.1	3.7	3.3	3.3	3.4	3.9	m/s

Figure 4. Monthly meteo values

4.2 Solar Module Orientation

Fixed tilted plane has been chosen as the field structure with a tilt of 27° and a plane orientation azimuth 0°as shown in Figure-5. The optimization is performed with respect to a yearly irradiation yield and the loss with respect to it is 0°.

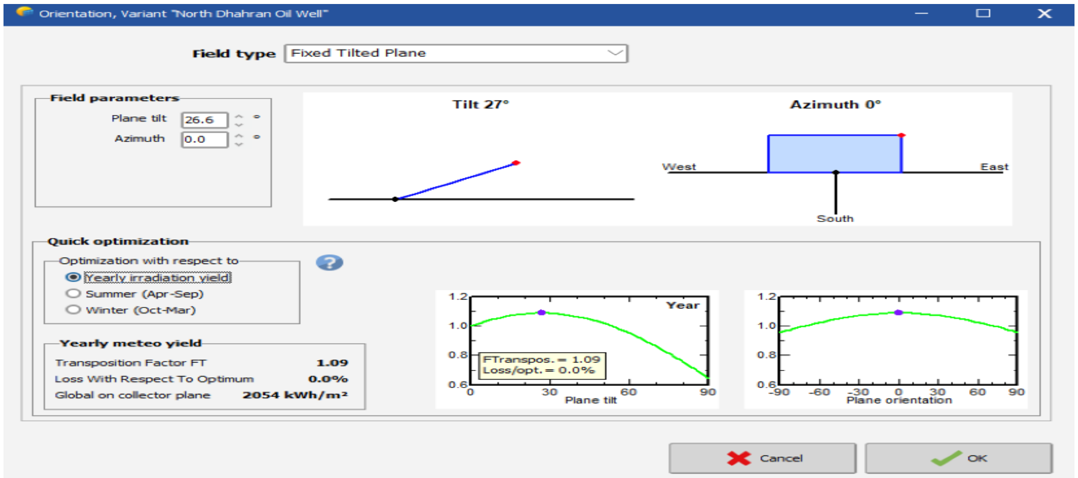
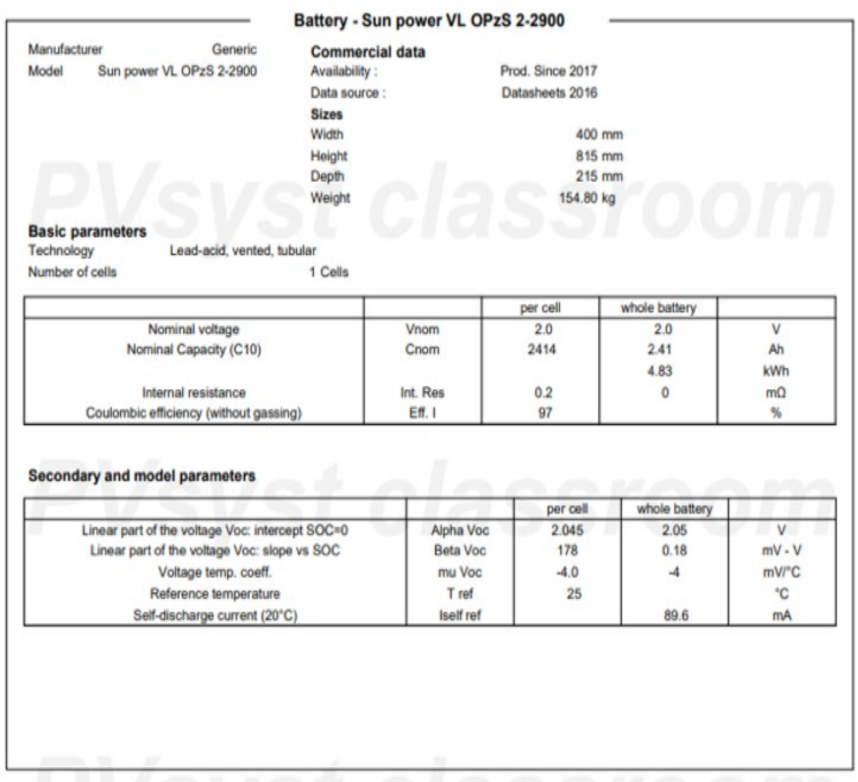


Figure 5. Module and plane Orientation

4.3 Load and System Components

Load was defined in PVsyst as the load profile shown in Table 1 from Appendix-A. System components, such as PV Module, Battery, and MPPT controller were chosen from PVsyst data base and adjusted according to vendor datasheets. Figures-6 and 7 show the selected components details for the Battery and PV Module respectively. Based on the selected components and parameters defined, such as days of autonomy (5 days according to Saudi Aramco standards), loss of load probability, and battery voltage. The system sizing is completed, and simulations were performed iteratively to ensure the system yields no missing energy.



Battery - Sun power VL OPzS 2-2900

Manufacturer Generic
Model Sun power VL OPzS 2-2900

Commercial data
Availability : Prod. Since 2017
Data source : Datasheets 2016

Sizes
Width 400 mm
Height 815 mm
Depth 215 mm
Weight 154.80 kg

Basic parameters
Technology Lead-acid, vented, tubular
Number of cells 1 Cells

		per cell	whole battery	
Nominal voltage	Vnom	2.0	2.0	V
Nominal Capacity (C10)	Cnom	2414	2.41	Ah
			4.83	kWh
Internal resistance	Int. Res	0.2	0	mΩ
Coulombic efficiency (without gassing)	Eff. I	97		%

Secondary and model parameters

		per cell	whole battery	
Linear part of the voltage Voc: intercept SOC=0	Alpha Voc	2.045	2.05	V
Linear part of the voltage Voc: slope vs SOC	Beta Voc	178	0.18	mV - V
Voltage temp. coeff.	mu Voc	-4.0	-4	mV/°C
Reference temperature	T ref	25		°C
Self-discharge current (20°C)	Iself ref		89.6	mA

Figure 6. Battery specification

Manufacturer	Generic	**Commercial data**	
Model	Mono 440 Wp Twin 144 half-cells	Availability :	Prod. Since 2020
		Data source :	Typical
Pnom STC power (manufacturer)	450 Wp	Technology	Si-mono
Module size (W x L)	1.048 x 2.108 m²	Rough module area (Amodule)	2.21 m²
Number of cells	2 x 72	Sensitive area (cells) (Acells)	1.99 m²
Specifications for the model (manufacturer or measurement data)			
Reference temperature (TRef)	25 °C	Reference irradiance (GRef)	1000 W/m²
Open circuit voltage (Voc)	49.1 V	Short-circuit current (Isc)	11.60 A
Max. power point voltage (Vmpp)	41.1 V	Max. power point current (Impp)	10.96 A
=> maximum power (Pmpp)	450.5 W	Isc temperature coefficient (muIsc)	5.8 mA/°C

Figure 7. PV module specification.

5. Results and Discussion

5.1 Simulation and Results

After defining required parameters, PVsyst performs the simulation and generate the results for the user. Figure-8 below shows yearly fundamental outcomes in terms of energy delivered by the system. It can be noticed that energy supplied meets the energy demand. Normalized productions in kWh/kWp/day such as collection losses, system losses, and useful energy is shown in Figure-9. Performance ratio (PR) that indicates the ratio of actual yield to target yield along with the solar fraction. Figure-10 shows the rate of energy supplied to energy demand.

	GlobHor kWh/m²	GlobEff kWh/m²	E_Avail kWh	EUnused kWh	E_Miss kWh	E_User kWh	E_Load kWh	SolFrac ratio
January	110.8	151.0	4202	32.6	0.000	3720	3720	1.000
February	120.1	145.1	3984	385.5	0.000	3360	3360	1.000
March	146.7	158.4	4239	288.7	0.000	3720	3720	1.000
April	173.4	173.5	4536	686.1	0.000	3600	3600	1.000
May	196.5	183.3	4642	646.2	0.000	3720	3720	1.000
June	211.2	190.6	4724	853.3	0.000	3600	3600	1.000
July	208.5	190.5	4683	672.3	0.000	3720	3720	1.000
August	195.8	190.5	4678	672.8	0.000	3720	3720	1.000
September	173.1	185.7	4638	763.2	0.000	3600	3600	1.000
October	143.4	168.5	4336	388.8	0.000	3720	3720	1.000
November	111.0	144.6	3895	68.1	0.000	3600	3600	1.000
December	100.1	137.1	3801	67.3	0.000	3720	3720	1.000
Year	1890.5	2018.8	52357	5525.0	0.000	43800	43800	1.000

Legends

GlobHor	Global horizontal irradiation	E_User	Energy supplied to the user
GlobEff	Effective Global, corr. for IAM and shadings	E_Load	Energy need of the user (Load)
E_Avail	Available Solar Energy	SolFrac	Solar fraction (EUsed / ELoad)
EUnused	Unused energy (battery full)		
E_Miss	Missing energy		

Figure 8. The energy output of the System.

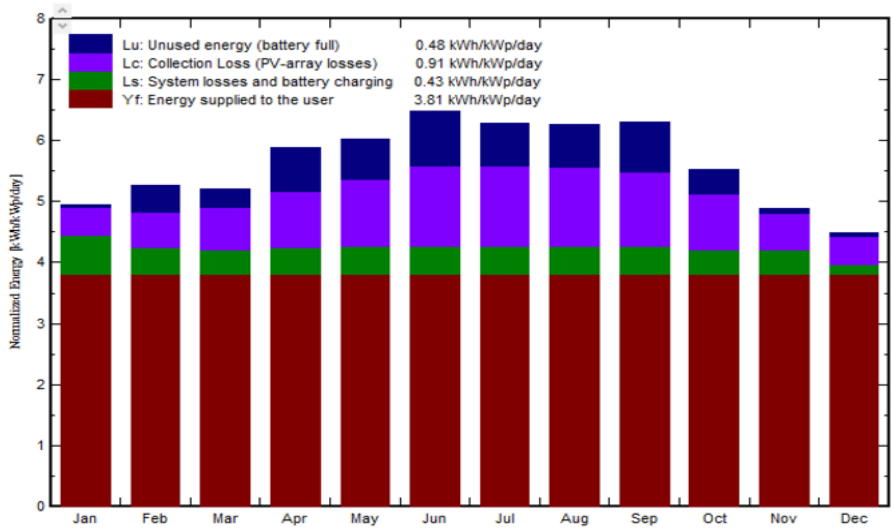


Figure 9. Normalized productions.

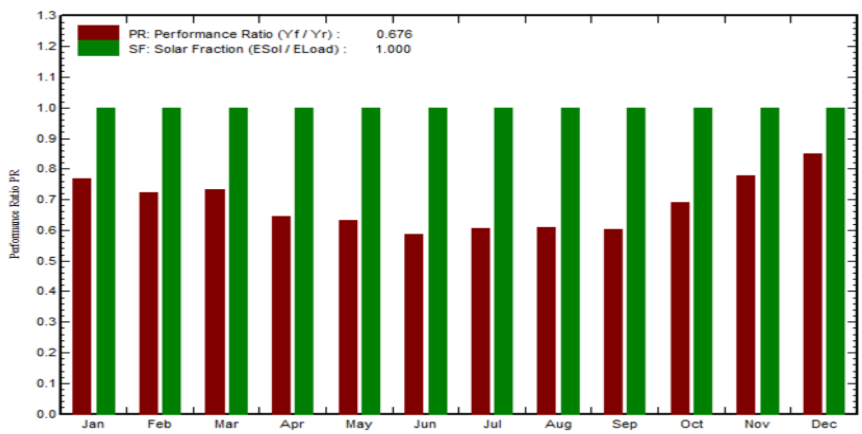


Figure 10. Performance ratio and solar fraction.

5.2 Standalone Solar PV Systems Output

After performing the technical analysis through PVsyst simulations, outputs of the parameters of the main system are summarized below in Table 4. Inverters were added since PVsyst does not account for inverters in the simulation. The inverter capacity used for calculations was 5400W as obtained from the vendor.PVsyst runs simulations for standalone PV systems for one year only. To cover for the remaining years, degradation and dusting factors of 1.25, and 1.1 were used respectively according to the vendor.

(Table 1., Table 2., & Table 3. Are in APPENDIX -A)

Table 1. Systems Details

Stan-alone Solar PV System	System Capacity (kWp)	No. PV Modules (Parallel/Series)	No. Batteries (Parallel/Series)	No. Inverters	Delivered Energy (MWh)
Gas Well	171	380 (95/4)	576 (24/24)	5	183.96
Oil Well	41	98 (14/7)	144 (6/24)	1	43.8
Water Well	24	54 (18/3)	96 (4/24)	1	26.28

5.3 Economic Evaluation

After receiving quotations for PV systems from local vendors for the needed system capacities 3, 5, and 21kW for Water, Oil, and Gas well, the prices were analyzed as shown in Table 5. The PV system was divided into four components, PV modules, Batteries, Electronics, and Passive Cooling Shelter. Each component price includes all associated materials. The final cost including installation and startup of each Well Standalone Solar PV system was calculated, as shown in table 6. The current method of power supply has four cost components, OHPL Construction, Terminal Pole, Electricity Bill, and Social Cost of Carbon (SCC) of $51/Ton of CO_2 (Social Cost of Carbon 2021). Therefore, the economic evaluation of the installation of OHPL is directly related to the well location with respect to the nearest tap-off point. Long OHPL distances yield higher construction costs and eventually higher LCOE costs. LCOE's of each well Standalone PV system were calculated using equation (1), as shown in Table 6 & Table 7., considering battery replacement every five years (according to Saudi Aramco standard). By applying equation 2, the economic feasibility can be determined for adopting a PV system instead of OHPL

$$\frac{LCOE\ of\ \ OHPL}{LCOE\ of\ PV\ system} \quad (2)$$

Table 2. Standalone Solar PV System Components Prices

PV Module (SAR/PV Module)	Battery (SAR/Battery)	Electronics (SAR/kW)	Passive Cooling Shelter (SAR/150 battery)
3,234	7,015	102,980	470,000

If the value is greater than 1, then its economically feasible to consider the PV system. For instance, if we consider an example where the LCOE for an Oil well powered by OHPL is 4.9 SAR/kWh then using equation-2 the factor will be 1.02. Thus, in this case installing a Standalone PV system is considered Economically feasible.

Table 3. Standalone PV Systems Costs

Well Type	PV	Batteries	Electronics	Passive Cooling Shelter	Total Cost (SAR)
Gas Well	1,229,026	4,041,005	2,265,575	1,880,000	9,415,606
Oil Well	316,959	1,010,251	514,903	470,000	2,312,114
Water Well	174,651	673,500	308,942	470,000	1,627,094

Table 7. LCOE of Standalone PV Systems

Standalone PV System	NPV (SAR)	Energy Delivered (kWh)	LCOE (SAR/kWh)
Gas Well	17,006,459	3,679,200.00	4.622
Oil Well	4,209,827	876,000	4.806
Water Well	2,892,236	525,600	5.503

5. Conclusion

The off-grid Standalone Solar PV Systems has been proven as a reliable source of power to electrify Onshore wells. Fixed standalone solar PV systems were modularized to meet loads of each well type with 3, 5, and 21 kW for water, oil, and gas wells, respectively. Also, LCOE was calculated for PV system for each type of well with 4.6, 4.8, and 5.5 SAR/kWh for gas, oil, and water well, respectively. A key factor before installing such system is the distance between the wellhead location from the nearest tap off point. Therefore, LCOE shall be considered in order to compare between OHPL and PV system to determine the most economical feasible electrical source for the Onshore Wells.

6. Recommendations

Below items have been defined as proposed recommendations to enhance the installation of the solar PV system for onshore Wells:

- Oil and gas companies shall fix modular design that can be suitable for each type of well.
- Optimize well loads, especially the gas well loads which will help to lower the system capacity and enhance its economic feasibility.
- Governments shall motivate renewable energy companies which will help to lower the capital cost of the PV systems.
- Governments shall mandate assessing the environmental impact in addition to the economic feasibility before constructing new OHPL.

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Biographies

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Appendix-A

Table 1. Load information and Daily Energy Demand of an Oil Well

Load Description	**Duty Designation(usage)**	**Power Consumption (kW)**
Eelectrical mounting rack (EMR)lighting	Continous	0.29
Smart well ccompletion (SWC) shelter lighting	Continous	0.12
Remote terminal unit (RTU)	Continous	0.20
Flow computer	Continous	0.13
PDHMS	Continous	0.10
Switchrack receptacle	Stand by	0.02
SWC motor	Intermittent	0.34
SWC panel	Continous	0.10
Choke valve	Intermittent	0.51
Emergency shutdown (ESD) panel	Continous	0.85
Cathodic protection (CP) transformer	Continous	1.70
CCTV	Continous	0.08
Total power consumption (kW)		4.43
Total power consumption + 10% spare (kW)		5
Daily energy demand (kWh/day)		120

Table 2. Load information and Daily Energy Demand of a Gas Well

Load Description	Duty Designation(usage)	Power Consumption (kW)
Choke valve	Continous	0.24
Corrosion inhibitor pump-a	Continous	0.75
Corrosion inhibitor pump-b	Stand by	0.07
Wellhead shutdown (WSD) motor-a	Continous	1.12
WSD motor-b	Stand by	0.11
Air blower	Intermittent	1.12
AC unit/HVAC	Continous	2.46
Battery charger/rectifier	Continous	5.79
ESD/RTU utility power	Continous	3.21
ESD/RTU utility power	Stand by	0.14
WSD panel lighting	Intermittent	0.01
Corrosion inhibitor intruments	Continous	0.19

Heat tracing	Continous	1.02
Control shelter receptacle	Stand by	0.02
Choke valve receptacle	Stand by	0.02
Lighting control panel	Intermittent	0.04
Control shelter indoor lighting	Continous	0.07
Control shelter door lighting	Intermittent	0.03
Skid task lighting	Intermittent	0.17
Skid flood lighting	Intermittent	0.09
Area lighting (off skid)	Intermittent	0.64
CP transformer	Continous	1.49
Total power consumption (kW)		18.77
Total power consumption + 10% spare (kW)		21
Daily energy demand (kWh/day)		504

Table3. Load information and Daily Energy Demand of a Water Well

Load Description	Duty Designation(usage)	Power Consumption (kW)
EMR lighting	Continous	0.29
RTU	Continous	0.20
Swithrack receptacle	Stand by	0.02
Choke valve	Intermittent	0.51
CP transformer	Continous	1.70
Total power consumption (kW)		2.71
Total power consumption + 10% spare (kW)		3
Daily energy demand (kWh/day)		72