

Energy Balance – Return on Energy (ROE) Period Evaluation of a PV Power Plant

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ABSTRACT: The economics of return on investment (ROI) of a Solar PV Power plant is evaluated to arrive at a financial investment decision on such power generation projects. In the present scenario in India, where the investments on Solar are encouraged by government through many policies, the return on investment period is about 3.5 to 5.5 years from the date of commissioning of a typical 1MW ground mounted PV power plant. But most of the input material which goes into building a PV Power plant are manufactured in large factories, where the power consumed is generated from fossil-fuel based power plants. Here an attempt is made to evaluate the overall energy balance of such a typical PV Power plant & to arrive at the period of time required for the net power generation to become positive.

KEYWORDS: Specific Energy Consumption (SEC), Solar PV Power Plant, PV Module installation, Energy Balance and ROI of Solar PV power plants.

NOTATIONS:

1. SEC: Specific Energy Consumption.
2. ROI: Return on Investment
3. PV Module: Solar Photo Voltaic Module

I. INTRODUCTION

A Solar Power plant generates electrical energy by using solar power as the input energy, which is available for free. The Solar PV Panels convert the solar energy to DC Electrical Power. Then a Solar Inverter is used to convert it to more usable AC Electrical Power. Then the Transformer & switch gear panels are used to step-up the power so generated to grid voltage level. The evacuation system, right from Inverter, controls the output voltage & frequency to ensure synchronisation with the grid power.

The major parts of a solar Power plant can be listed as:

1. Solar PV Panels / Modules.
2. Module mounting structures.
3. Inverter
4. Power evacuation system
5. Plant infrastructure.

II. STEPS FOLLOWED FOR EVALUATION

1. Design a typical Solar PV Power plant of size about 1MWp, with specific & realistic design parameters.
2. Make the Layout of the PV Plant.
3. Make the Electrical SLD (Single Line Diagram) of the plant.
4. Make the complete BOM of the plant.
5. Derive the annual & life cycle power generation of the plant using NREL data.
6. Arrive at the plant investment cost at present market rates.
7. Evaluate the financial return on investment period for the plant.
8. Evaluate the total energy input for building the plant.
9. Evaluate the return on energy period for the plant.



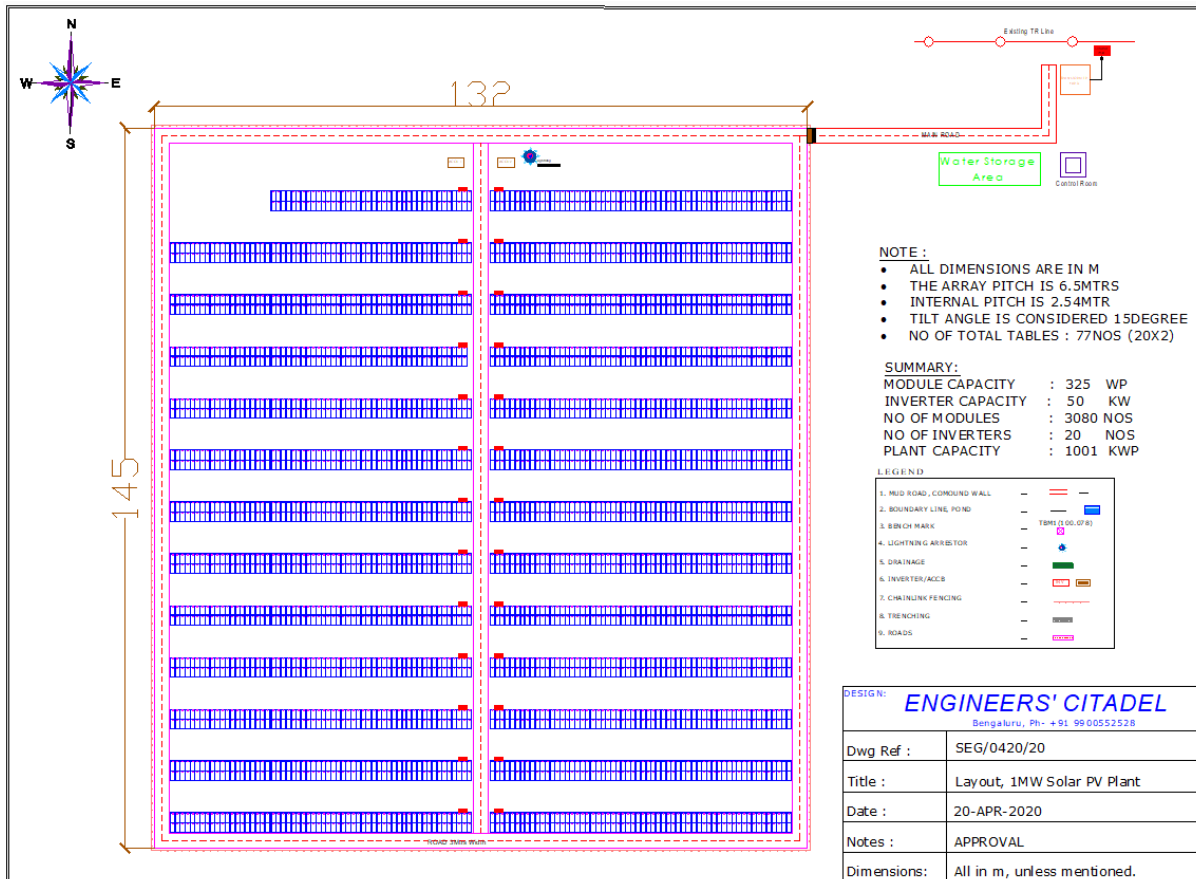
Step-1: Design of a typical Solar PV Power plant

Design basis:

Site: Near Bengaluru, Karnataka, India.
 Location: Lat 12.95°N. Lon 77.55°E
 Mounting: Ground mounted.
 Module tilt: Fixed tilt of 15° South.
 PV Module: 325Wp, Standard Poly-crystalline Modules.
 Inverter: String Inverter of 50 kWp.
 Table configuration of MMS: 40 modules per table.
 Minimum ground clearance: 600mm

Step-2: Layout of the plant:

A levelled land of about 145m X 132m is considered to position the plant as per below layout.





Step-4: Plant BOM

Complete Bill of Materials (BOM) of the plant is evaluated:

BOM-1MWp				
PRJ :	1MWpProject			27-04-2020
CAP:	1000kWpGridConnectedSolarPVPowerPlant(GroundMount)			R0
Sl.No.	Description	Specification	UOM	QTY
1 DCSYSTEM				
1.1	325WpSolarPVModules(Polycrystalline)	325Wp-PolycrystallinePVModule	Nos.	3080
1.2	MC4Connectors-Male	UVResistiveMC4Connectorsfor 4 mm2	Nos.	170
1.3	MC4Connectors-Female	UVResistiveMC4Connectorsfor 4 mm2	Nos.	170
1.4	MC3Connectors-Male	UVResistiveMC3Connectorsfor4 mm2	Nos.	165
1.5	MC3Connectors-Female	UV Resistive MC3 Connectors for 4 mm2	Nos.	165
1.6	Module mounting structure	MS + HDG structure, fixed tilt type, with short pile foundations, 40 MMS table.	Nos.	77
2 INVERTER				
2.1	StringInverter	50kWpgridtiedSolarInverter	Nos.	20
3 Cables&Conduits				
3.1	1Cx4Sq.mmCu.stringcables	Solargrade,UVresistant1.1kV,CablesconfirmingtoIS1554,	Mtrs.	10000
3.2	4Cx50Sq.mmCu.ACCables(fromINVTolisolators)	FlexibleMultistrandCu.Copper1.1kV,cablesconfirmingt oIS1554,temperaturerange-40to+90C,Multistrands cable	Mtrs.	650
3.4	3.5Cx185Sq.mmAr.AI.ACCables(fromIsolatorstoACCB)	1.1kVLTXLPE,3.5Cx185Sq.mmAl.ArmouredCable -fromISOLATORStoACCBPANELS.	Mtrs.	451
3.5	3.5Cx300Sq.mmAr.AI.ACCables(fromACCBtoTransformers)	1.1kVLTXLPE,3.5Cx300Sq.mmAl.ArmouredCable -fromACCBtoTransformers	Mtrs.	575
3.6	HTCables-(fromTransformerstoHTPanel)	11kVLTXLPE,3Cx300Sq.mmAl.ArmouredCable- fromTRANSFORMERtoHTPanel.	Mtrs.	30
3.7	HTCables-(fromHTPaneltoMeteringCubical)	11kVLTXLPE,3x300Sq.mmAl.ArmouredCable- fromtransformerHTsidetoMVandDPStructure	Mtrs.	30
3.8	Conduits	Doublewallcorrugated,BlackColourHDPEConduit	Mtrs.	30
3.9	Conduits	32mmInternalDia	Mtrs.	865
3.9	FlexibleConduits	32mmInternalDia	Mtrs.	40
4 ISOLATORS				
4.1	ISOLATORS	AsperSLD	No.	1
4.2	ISOLATORSwithfastenersIP65Outdoortype	ASPerISOLATORSSpecificationSheet	No.	1
5 ACDB				
5.1	ACDB	AsperSLD	No.	2
5.2	ACDBwithfastenersIP65Outdoortype	ASPerACDBSpecificationSheet	No.	2
5.3	LTKioskwithMetering	ReferSLD	No.	2

5.4	InverterTransformer	ASPertransformerSpecificationSheet	No.	1
5.5	MVPanel	ASPertransformerSpecificationSheet	No.	1
5.6	HTMeteringCubicalPanel	ASPertransformerSpecificationSheet	No.	1
5.7	DPstructurewithIsolator&LA	ReferSLD	No.	1
5	EARTHING			
5.1	EarthingKit	AsperIS3043specifications,ChemicalEarthing	Nos.	25
5.2	EarthingKit	AsperIS3043specifications,ConventionalEarthing	Nos.	1
5.2	EarthStripwithnecessaryclamping,earthNut&bolts	25x6EarthStripasperIS3043	Mtrs.	800
5.3	Earthingchamber	350mmx450mm	Set	25
5.4	LightningArrestor	ESELRMODEL-FLASHL1 , Radius of protection=107m (MountingHeight=5m)	Set	1
6	MonitoringSystem			
6.1	MonitoringSystem		No.	1
6.2	Datalogger		No.	1
6.3	IrradianceSensor		No.	1
6.4	ModuleTemperatureSensor		No.	1
6.5	MonitoringCable	RS485	Mtrs.	450
7	Accessories			
7.1	Cabletie100mmlong	UVstabilizednylonflexiblecabletiewithpawlandteetharrangement	Pac ket	5
7.2	Cabletie200mmlong		Pac ket	5
7.3	Cabletie300mmlong		Pac ket	5
7.4	Cabletie400mmlong		Pac ket	10
7.5	4Cx50.Sq.mmCu.RingtypelugswithFasteners	Cu.lugwithinsulationSuitablefor4Cx50Sqmm	Sets	180
7.6	3.5Cx185Sq.mmAlRingtypelugswithFasteners	Al.lugwithinsulationSuitablefor3.5Cx185Sqmm	Sets	70
7.7	95Sq.mmAlRingtypelugswithFasteners	Al.lugwithinsulationSuitablefor95Sqmm	Sets	25
7.8	3.5Cx300Sq.mmRingtypelugswithFasteners	Al.lugwithinsulationSuitablefor3.5Cx300Sqmm	Sets	30
7.9	150Sq.mmRingtypelugswithFasteners	Al.lugwithinsulationSuitablefor150Sqmm	Sets	15
7.1	3Cx300Sq.mmRingtypelugswithFasteners	Al.lugwithinsulationSuitablefor3Cx300Sqmm	Sets	8
7.1	InsulationTape	Red	Nos.	15
7.1	InsulationTape	Blue	Nos.	4
7.1	InsulationTape	Yellow	Nos.	4
7.1	InsulationTape	Black	Nos.	15
7.1	DangerBoardwithbacksidegumforfixing	220x150x2mmforoutdooruse	Nos.	6
7.1	Labelsidentification	Asperlabellingdrawing	Set	1



6				
7.1	Ziplockcover8"x12"	8"x12"	Nos.	6
7				
8	INFRA			
8.1	Road	3m wide road	Mtr s.	719
8.2	Fence	Chain-link fence of 2m high	Mtr s.	554
8.3	Drain trench for storm water	Earthen drain till plant boundary.	Mtr s.	554
8.4	Module cleaning system pipe lines	1" HDPE pipe with pumping system	Mtr s.	300
8.5	Control & monitoring room	4mX4m room with office facilities	SQ M	16
8.6	Perimeter lights	Street lights at every ~ 100m pitch along fence	No	10

**Step-5: Plant power output
(Using NREL data)**

To evaluate the power generation of the plant for the life period of 25 years using NREL data, following losses are considered:

1. Soiling loss = 2%
2. Shading loss = 3%
3. Mismatch loss = 2%
4. Wiring loss = 2%
5. Connection loss = 0.5%
6. Light induced degradation = 1.5%
7. Name plate rating = 1%
8. Availability = 3%
- 9. Average estimated system losses = 14.08 %**

Location and Station Identification		Month	Solar Radiation (kWh / m ² / day)	AC Energy (kWh)
Requested Location	Bangalore, India	January	6.69	150,114
Weather Data Source	Lat, Lon: 12.95, 77.55 3.4 mi	February	7.09	141,557
Latitude	12.95° N	March	7.13	152,954
Longitude	77.55° E	April	6.68	139,733
PV System Specifications (Residential)		May	6.06	135,428
DC System Size	1000 kW	June	5.30	119,935
Module Type	Standard	July	4.85	115,142
Array Type	Fixed (open rack)	August	4.89	114,141
Array Tilt	15°	September	5.72	127,608
Array Azimuth	180°	October	5.51	125,544
System Losses	14.08%	November	5.88	130,833
Inverter Efficiency	96%	December	5.84	134,945
DC to AC Size Ratio	1	Annual	5.97	1,587,934



POWER GENERATION SUMMARY						
PROJECT : 1MWp, ground mounted Solar Power plant.						
SITE : Bengaluru, India.						
DATA SOURCE : NREL						
PV MODULE : Crystalline, standard PV module.						
INVERTER : String Inverter.						
No	Site	Module (Wp)	Number of modules (no)	DC Capacity (Wp)	Inverter (kW X No)	Average annual generation (kWh)
1	Ground Mount	325	3080	1001000	String, 50kW, 20 Nos	1587934
NOTE :						
1 The power generated is evacuated to the 11kV line near the plant.						
2 Prediction basis: NREL Data.						

Step-6: Plant investment cost

BUDGETORY CAPEX DETAILS						
No	Item	UOM	Qty	Unit rate (INR)	Tot Cost (INR)	
1	PV Modules	Wp	1001000	20	20020000	
2	Inverters	Wp	1001000	5	5005000	
3	Mounting structure	Wp	1001000	4	4004000	
4	Junction boxes	No	4	10000	40000	
5	DC & AC Cable	Wp	1001000	0.6	600600	
6	Earthing & LA	Wp	1001000	0.25	250250	
7	ACDB	NO	1	30000	30000	
8	Transformer & switch yard	No	1	100000	100000	
9	Transmission line	m	100	1000	100000	
10	Plant infra works (CR, fence, road, lighting, SWD, MCS)	Wp	1001000	1	1001000	
11	Installation services	Wp	1001000	1	3003000	
12	Overhead & others	%	10%	1	3415385	
				TOTAL	37569235	
NOTE :						
1 The budgetary cost is considered as per prevailing market rates.						
2 The interconnection is considered within campus.						
3 A transmission line of about 100m is considered.						

Step-7: Financial investment rate of return

Plant performance:

PR & CUF			
1	Installed DC capacity	kW	1001.00
2	Yield at PV generation meter as plant output	kWh	1587934.00
3	Average Solar irradiation (Global Irradiation on module plane)	kWh/m2/day	5.97
4	Effective Module area installed	m2	5951.95
5	Module efficiency (standard module, from module data sheet)	%	15.20%
6	Number of days per year considered for PR calculation	no	365.00
7	PR (Performance ratio)	%	80.55%
8	CUF (capacity Utilisation factor)	%	18.11%
NOTE :			
1	PR = (Yield) / (Irradiance X Module area X Module efficiency)		
2	CUF = (Yield) / (365 X 24 X DC capacity of plant)		



Return on investment:

The return on investment is evaluated as per prevailing tariff for the power availability for industrial use in the state of Karnataka, India. An annual generation degradation of 0.5% & O&M cost of 1% is considered in the calculation. Other consideration are as per the table below.

Return on investment:

REVENUE DETAILS											
1	Plant capacity:				1001000					Wp	
2	Project cost:				37569235					INR	
3	Minimum annual generation first year				1587934					kWh	
4	Annual degradation				0.50%					%	
5	PPA export Tariff				0.00					INR/Unit	
6	O&M & other charges				1.0%					%	
7	Escalation of O&M & other charges				3%					%	
8	Self consumption				100%					%	
9	Av. Import tariff				7.00					INR/Unit	
10	Annual increase of import tariff				0.00%					%	
11	Wheeling charges				1.2					INR/Unit	
12	REC				0					INR/Unit	
Year	Generation	Net export	Export	Import tariff	Self consumption	Revenue	Wheeling	O&M Expenses	Net income	Balance of Capex	
0										3,75,69,235	
1	1587934.00	0.00	0.00	7.00	11115538.00	0.00	1905520.80	375692.35	8834324.85	2,87,34,910	
2	1579994.33	0.00	0.00	7.00	11059960.31	0.00	1895993.20	386963.12	8777003.99	1,99,57,906	
3	1572094.36	0.00	0.00	7.00	11004660.51	0.00	1886513.23	398572.01	8719575.26	1,12,38,331	
4	1564233.89	0.00	0.00	7.00	10949637.21	0.00	1877080.66	410529.17	8662027.37	25,76,304	
5	1556412.72	0.00	0.00	7.00	10894889.02	0.00	1867695.26	422845.05	8604348.71	(60,28,045)	
6	1548630.65	0.00	0.00	7.00	10840414.57	0.00	1858356.78	435530.40	8546527.39	(1,45,74,573)	
7	1540887.50	0.00	0.00	7.00	10786212.50	0.00	1849065.00	448596.31	8488551.19	(2,30,63,124)	
8	1533183.06	0.00	0.00	7.00	10732281.44	0.00	1839819.68	462054.20	8430407.56	(3,14,93,531)	
9	1525517.15	0.00	0.00	7.00	10678620.03	0.00	1830620.58	475915.83	8372083.63	(3,98,65,615)	
10	1517889.56	0.00	0.00	7.00	10625226.93	0.00	1821467.47	490193.30	8313566.15	(4,81,79,181)	
11	1510300.11	0.00	0.00	7.00	10572100.80	0.00	1812360.14	504899.10	8254841.56	(5,64,34,023)	
12	1502748.61	0.00	0.00	7.00	10519240.29	0.00	1803298.34	520046.08	8195895.88	(6,46,29,919)	
13	1495234.87	0.00	0.00	7.00	10466644.09	0.00	1794281.84	535647.46	8136714.79	(7,27,66,633)	
14	1487758.70	0.00	0.00	7.00	10414310.87	0.00	1785310.44	551716.88	8077283.55	(8,08,43,917)	
15	1480319.90	0.00	0.00	7.00	10362239.32	0.00	1776383.88	568268.39	8017587.05	(8,88,61,504)	
16	1472918.30	0.00	0.00	7.00	10310428.12	0.00	1767501.96	585316.44	7957609.72	(9,68,19,114)	
17	1465553.71	0.00	0.00	7.00	10258875.98	0.00	1758664.45	602875.93	7897335.59	(10,47,16,449)	
18	1458225.94	0.00	0.00	7.00	10207581.60	0.00	1749871.13	620962.21	7836748.26	(11,25,53,198)	
19	1450934.81	0.00	0.00	7.00	10156543.69	0.00	1741121.78	639591.08	7775830.84	(12,03,29,028)	
20	1443680.14	0.00	0.00	7.00	10105760.97	0.00	1732416.17	658778.81	7714566.00	(12,80,43,594)	
21	1436461.74	0.00	0.00	7.00	10055232.17	0.00	1723754.09	678542.17	7652935.91	(13,56,96,530)	
22	1429279.43	0.00	0.00	7.00	10004956.01	0.00	1715135.32	698898.44	7590922.25	(14,32,87,452)	
23	1422133.03	0.00	0.00	7.00	9954931.23	0.00	1706559.64	719865.39	7528506.20	(15,08,15,959)	
24	1415022.37	0.00	0.00	7.00	9905156.57	0.00	1698026.84	741461.35	7465668.38	(15,82,81,627)	
25	1407947.26	0.00	0.00	7.00	9855630.79	0.00	1689536.71	763705.19	7402388.89	(16,56,84,016)	
Note:											
1	Interest on debt fund not considered.									Average ROI	21.64 %
2	AD benefits not considered.										4.62 Years



Step-8: Plant Energy Input

All input materials as per the final BOM are converted to their equivalent weights as per table below. Assuming all cables are of Aluminium, the materials considered are Steel, Aluminium, Plastic, Glass & Cement.

BOQ - 1MWp - Material content							
PRJ:	1MWp Project						
CAP:	1000kWp Grid Connected Solar PV Power Plant (Ground Mount)						
Sl.No.	Description	Qty	Steel	Aluminium	Plastic	Glass	Cement
1.1	Solar PV Modules (Polycrystalline)	3080		11088.00	2310.00	46200.00	
1.2	MC4 Connectors - Male	170		3.40	0.60		
1.3	MC4 Connectors - Female	170		3.40	0.60		
1.4	MC3 Connectors - Male	165		3.30	0.58		
1.5	MC3 Connectors - Female	165		3.30	0.58		
1.6	MMS Structure (MS+HDG)	78	34000.00				39697.16
2.1	Inverter & steel mounting frame	20	471.30	200.00	200.00	36.00	
3.1	1C x 4 Sq.mm Cu.string cables	10000		108.00	10.80		
3.2	4C x 50 Sq.mm Cu . AC Cables	650		351.00	35.10		
3.4	3.5C x 185 Sq.mm Ar.Al. AC Cable	451		788.46	78.85		
3.5	3.5C x 300 Sq.mm Ar.Al. AC Cable	575		1630.13	163.01		
3.6	HT Cables	30		85.05	8.51		
3.7	HT Cables	30		85.05	8.51		
3.8	Conduites, 1" Dia	30			6.36		
3.9	Conduits, 1.5" Dia	865			244.57		
3.9	Flexible Conduits, 1.5" Dia	40			11.31		
4.1	ISOLATORS	1					
4.2	ISOLATORS with fastners IP65	1					
5.1	ACDB	2	47.13	20.00	20.00		
5.2	ACDB with fastners IP65	2	20.00		-		
5.3	LT Kiosk with Metering	2	74.26	20.00	20.00		
5.4	Inverter Transformer	1	2000.00	500.00	-		
5.5	MV Panel	1	46.17	10.00	10.00		
5.6	HT Metering Cubical Panel	1	46.17	10.00	10.00		
5.7	DP structure with Isolator and LA	1	80.00		-		
5.1	Earthing Kit	25	100.00				
5.2	Earthing Kit	1	10.00				
5.2	Earth Strip -25X6 flat	800	942.00				
5.3	Earthing chamber, 350 x450	25	247.28				
5.4	Ligthing Arrestor (Mtg Ht 5m)	1	25.00				
6.1	Monitoring System	1		5.00	2.50		
6.2	Datalogger	1		15.00			
6.3	Irradiance Sensor	1		1.00			
6.4	Module Temperatur Sensor	1		1.00			
6.5	Monitoring Cable	450		15.00	2.00		
7.1	Cable tie 100 mm long	5			0.08		
7.2	Cable tie 200 mm long	5			0.08		
7.3	Cable tie 300 mm long	5			0.08		
7.4	Cable tie 400 mm long	10			0.15		
7.5	4C x50.Sq.mm Cu. Ring type lugs	180		3.60			
7.6	3.5C x185Sq.mm Al Ring type lug	70		1.40			
7.7	95Sq.mm Al Ring type lugs	25		0.50			
7.8	3.5C x 300 Sq.mm Ring type lugs	30		0.60			
7.9	150 Sq.mm Ring type lugs	15		0.30			
7.10	3C x 300 Sq.mm Ring type lugs	8		0.16			
7.11	Insulation Tape	15			0.38		
7.12	Insulation Tape	4			0.10		
7.13	Insulation Tape	4			0.10		
7.14	Insulation Tape	15			0.38		
7.15	Danger Board	6	1.00				
7.16	Labels identification	1			1.00		
7.17	Zip lock cover 8"x12"	6			1.00		
8.1	Road, 3m wide	719					
8.2	Fence, 2m high	554	2216.00				
8.3	Drain trench for storm water	554					
8.4	Module cleaning pipe lines, 1"HDPE	300			63.62		
8.5	Control & monitoring room	16					9600.00
8.6	Perimeter lights, 4m high	10	360.00				424.12
TOTAL MATERIAL WT in kg			40686.31	14952.65	3210.82	46236.00	49721.28



The total energy required for manufacture of unit quantity of material is Specific Energy Consumption (SEC). The SEC of all input materials used in the solar power plant is evaluated.

The energy is mainly classified as High-Grade Energy & Low-Grade Energy. A form of energy is called High grade energy as per the ease of its conversion to other forms of energy. And Low-grade energy is that which is difficult to convert to other forms of energy.

Thus, electrical energy is a High-grade energy, as it is easy to convert almost all of it into other energy forms such as thermal energy (say by using an electrical heater). Whereas, it is not possible to convert thermal energy completely into electrical energy (typical efficiencies of thermal power plants are around 30 percent), hence thermal energy is a Low-grade energy. Naturally, high-grade energy sources are more expensive compared to low-grade energy sources. Here to evaluate SEC, the conversion efficiency of Low-grade energy to High grade energy is taken at 40%. Accordingly, the SEC for all elements is arrived at as equivalent of High-Grade Energy.

SEC			
No	Material	UOM	SEC
1	PV Cell manufacture	kWh/Wp	7.20E-01
2	PV Module manufacture	kWh/Wp	3.06E+00
	Total PV Module		3.78E+00
4	Raw cast steel	kWh/ton	1.39E+04
5	Forming / Machining / Press	kWh/ton	90.00
6	Welding	kWh/ton	2.00
7	HDG	kWh/ton	1.11E+02
8	Total Steel	kWh/ton	1.41E+04
9	Glass - raw process	kWh/ton	6.94E+03
10	Finishing process	kWh/ton	1.736E+03
11	Total Glass	kWh/ton	8.68E+03
12	Raw cast Aluminium	kWh/ton	2.500E+04
13	Aluminium extrusion	kWh/ton	2.500E+04
14	Total Aluminium	kWh/ton	5.000E+04
15	Raw cement manufacture	kWh/ton	1.395E+03
16	Concrete mixing	kWh/ton	1.395E+03
17	Total Cement	kWh/ton	2.789E+03
18	Raw PVC / Polymer	kWh/ton	2.906E+03
19	Pipe extrusion & processing	kWh/ton	2.906E+03
20	Total PVC / PP	kWh/ton	5.811E+03
21	Energy towards installation services	kWh/MW	1.392E+05
22	Energy towards transportations	kWh/MW	6.380E+03
23	Total Services	kWh/MW	1.456E+05

The Specific energy consumptions are derived from the following references:

Reference:	
1	For Steel, Aluminium, Cement, Polymer & Glass : Energy efficiency document Developed specifically for Designated Consumers notified under Perform Achieve and Trade (PAT) Program for National Mission for Energy Efficiency (NMEEE). Published by Bureau of Energy Efficiency Ministry of Power, Government of India.
2	For Hot Dip Galvanisation (HDG) process : Open Access Journal of Power Technologies 97 (5) (2017) 349–358, " Energy efficiency of a hot-dip galvanizing plant", by Jacek Szymczyka, Aldona Kluczekb, Institute of Heat Engineering, Warsaw.
3	For PV Cell & PV Modules : "Crystalline Silicon Photovoltaic Module Manufacturing" by NREL (National Renewable Energy Laboratory of the U.S. Department of Energy) Technical Report NREL/TP-6A20-72134 Revised February 2020, by Michael Woodhouse, Brittany Smith, Ashwin Ramdas, and Robert Margolis.
4	Energy towards installation services : Assuming the site is remote & site construction is taken to be supported by use of 20kVA DG set. Construction time is taken as 100 days from start, DG to work for 10 hours per day, diesel consumption of 4.8 Lit / hr, diesel; energy equivalent at 11.6 kWh/kg of diesel, L-grade to H-grade energy conversion efficiency of 40% : $100 \times 10 \times 4.8 \times 11.6 / 0.4 = 139200$ kWh.
5	Transportation related energy consumption : On average total transportation is conservatively taken at 2000 km of travel by a vehicle. Corresponding diesel consumption at about 7.5 km/l, diesel energy equivalent at 11.6 kWh/kg, Diesel density at 0.825 kg/l, L-grade to H-grade energy conversion efficiency of 40% : $2000 / 7.5 \times 0.825 \times 11.6 / 0.4 = 6380$ kWh.



Total material content & the corresponding input energy for the plant:

The energy consumption of the plant of 1MW capacity:					
No	Item	UOM	Qty	SEC (kWh/ton) OR (kWh/Wp)	Energy (kWh)
1	Steel	ton	40.69	14092.01	573351.87
2	Aluminium	ton	14.95	50000.04	747632.89
3	Plastic	ton	3.21	5811.12	18658.47
4	Glass	ton	46.24	8680.56	401354.49
5	Cement	ton	49.72	2789.34	138689.33
6	PV Module	Wp	1000000.00	3.78	3782039.49
7	Installation	MW	1	145580.00	145580.00
TOTAL ENERGY INPUT					5807306.53

STEP-9: Evaluate the Return on Energy (ROE) period for the plant.

ENERGY BALANCE DETAILS				
1	Plant installed capacity:	1001000.00	Wp	
2	PV plant input energy :	5807306.53	kWh	
3	Minimum annual generation: (First year)	1587934.00	kWh	
4	Annual degradation of generation:	0.50%	%	
5	Energy consumed for O&M annually:	1.00%	%	
6	Escalation of energy consumption during O&M annually:	1.00%	%	
Year	Generation (kWh)	O&M Energy consumption (kWh)	Net energy generation (kWh)	Balance of Energy Input (kWh)
0				58,07,307
1	1587934.00	15879.34	1572054.66	42,35,252
2	1579994.33	16038.13	1563956.20	26,71,296
3	1572094.36	16198.51	1555895.84	11,15,400
4	1564233.89	16360.50	1547873.39	(4,32,474)
5	1556412.72	16524.10	1539888.61	(19,72,362)
6	1548630.65	16689.35	1531941.31	(35,04,303)
7	1540887.50	16856.24	1524031.26	(50,28,335)
8	1533183.06	17024.80	1516158.26	(65,44,493)
9	1525517.15	17195.05	1508322.10	(80,52,815)
10	1517889.56	17367.00	1500522.56	(95,53,338)
11	1510300.11	17540.67	1492759.44	(1,10,46,097)
12	1502748.61	17716.08	1485032.54	(1,25,31,130)
13	1495234.87	17893.24	1477341.63	(1,40,08,471)
14	1487758.70	18072.17	1469686.53	(1,54,78,158)
15	1480319.90	18252.89	1462067.01	(1,69,40,225)
16	1472918.30	18435.42	1454482.88	(1,83,94,708)
17	1465553.71	18619.77	1446933.94	(1,98,41,642)
18	1458225.94	18805.97	1439419.97	(2,12,81,062)
19	1450934.81	18994.03	1431940.78	(2,27,13,002)
20	1443680.14	19183.97	1424496.17	(2,41,37,499)
21	1436461.74	19375.81	1417085.93	(2,55,54,584)
22	1429279.43	19569.57	1409709.86	(2,69,64,294)
23	1422133.03	19765.27	1402367.77	(2,83,66,662)
24	1415022.37	19962.92	1395059.45	(2,97,61,722)
25	1407947.26	20162.55	1387784.71	(3,11,49,506)
Average ROI			25.46	%
			3.93	Years

III. ANALYSIS OF RESULTS & REMARKS

The energy input for building the Solar PV power plant is accounted for all physical materials which goes into the plant & tangible service inputs. But still few energy consumptions for plant building may not be accurately accounted for. So even on a conservative view point, the energy return period would not be beyond 4.5 years from the plant commissioning.

The energy balance & return period shall be given due importance, as the financial returns depends on few major input materials, which are available in abundance, like Silicon, land & sunlight.

So, the plant design shall be focussed to reduce input materials which are manufactured using energy from fossil fuel. The design should target minimum use of steel, cement, land, cables, etc. Also, large evacuation sub-station, switch yards and long transmission lines made exclusively for solar power plant is not recommended as it would affect energy return considerably.

IV. CONCLUSION

The financial return on investment (ROI) period for a typical 1MW sized solar Power plant is about 4.62 years from the plant commissioning. The return period on the energy input (ROE) for building the plant is about 3.93 years (4.50 years with allowance for unaccounted energy inputs). This is under the conditions of standard assumptions as indicated in the above calculations.

Smaller PV Plants in distributed locations, which do not require a dedicated evacuation system, are better on ROE terms. This also implies the use of PV Powerplants as roof-top systems & consumption of generated power locally, as the most efficient application of this technology on energy terms.

V. ACKNOWLEDGEMENT

The plant design is done as per standard industrial practices by Mr. Prasanna Mathad & Mr. Mallikarjun Sajji of M/s Daksh Energy Solutions, Bengaluru.

REFERENCES

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2. Investors Manual for Energy Efficiency by Confederation of Indian Industry, (CII), Energy Management Cell and IREDA.
3. Crystalline Silicon Photovoltaic Module Manufacturing" by NREL (National Renewable Energy Laboratory of the U.S. Department of Energy) Technical Report NREL/TP-6A20-72134.