the Learning Network on Sustainable energy systems

The Learning Network on Sustainable energy systems is funded by the European-ACP-EU Edulink II

Implemented by the ACP Group of States Secretariat

Funded by the EU

Economic and Environmental Evaluation of Renewable Energy Systems

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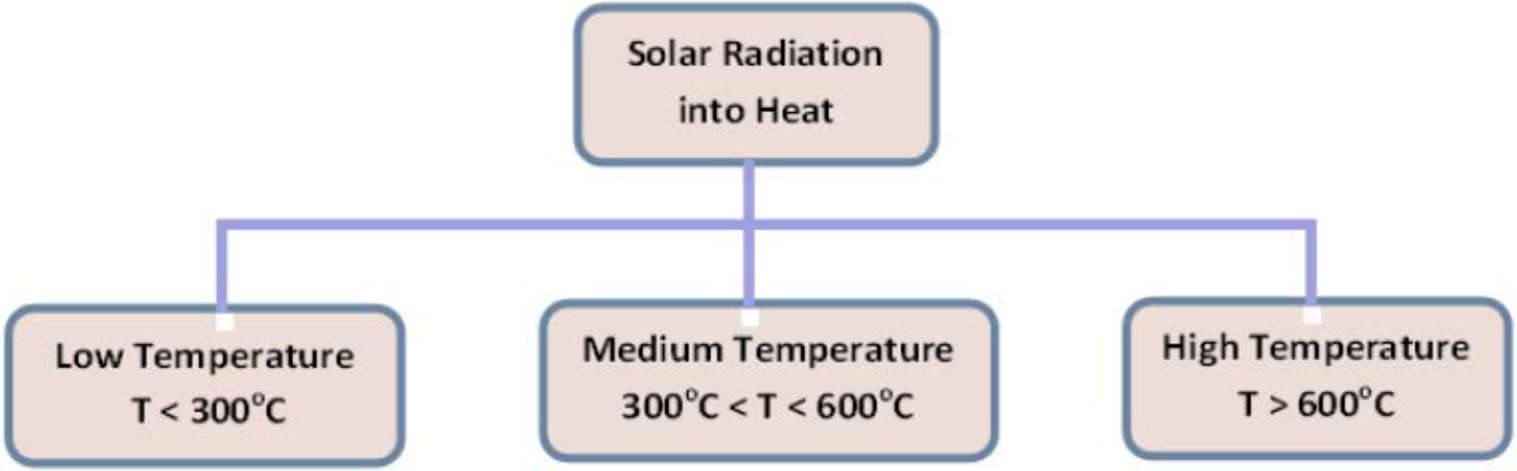
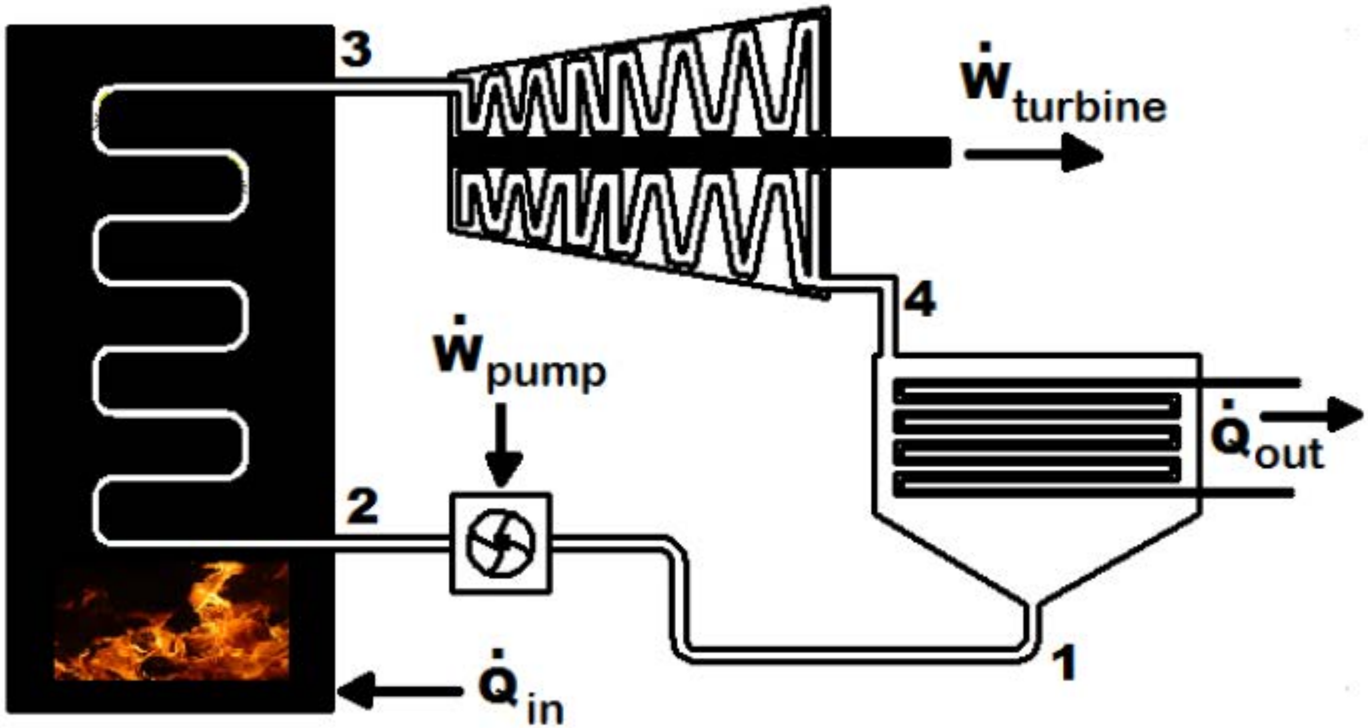
1. INTRODUCTION

- research to evaluate the feasibility of low temperature solar thermal energy conversion system based on the organic Rankine cycle (ORC) as a viable means of generating clean and environmentally sustainable electricity.

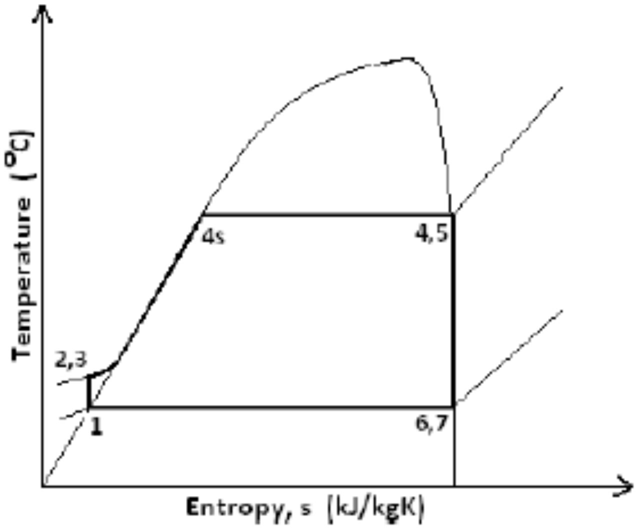
- study conducted at University of KwaZulu-Natal (UKZN), Durban, South Africa.

- Findings presented in two sections:
  - economic analysis and;
  - environmental analysis.
  - social analysis not considered at this stage

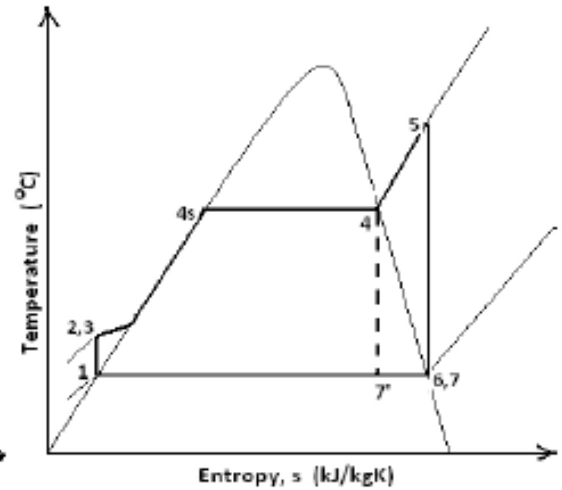




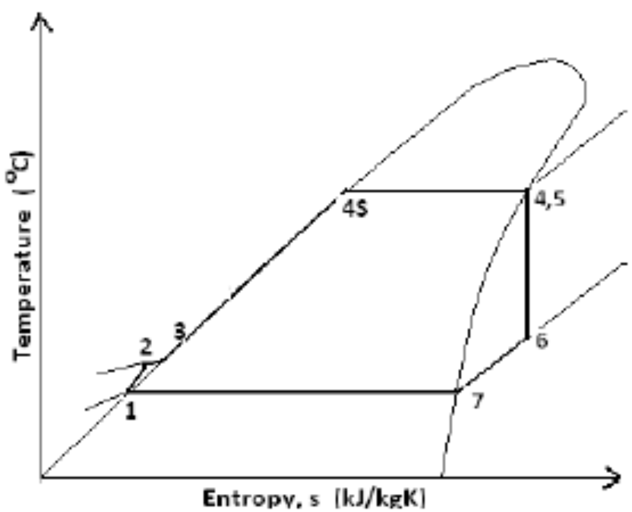
- ***Economic and Environmental Evaluation of Renewable Energy Systems***
- *Shadreck Situmbeko/ University of Botswana*



(a) Isentropic T-S Expansion



(b) Negative T-S Expansion



(c) Positive T-S Expansion

2. METHODOLOGY : Economic Analysis

- **Benefit-Cost Ratio (BCR):** directly compares benefits and costs. To calculate the BCR, divide total discounted benefits by discounted costs.

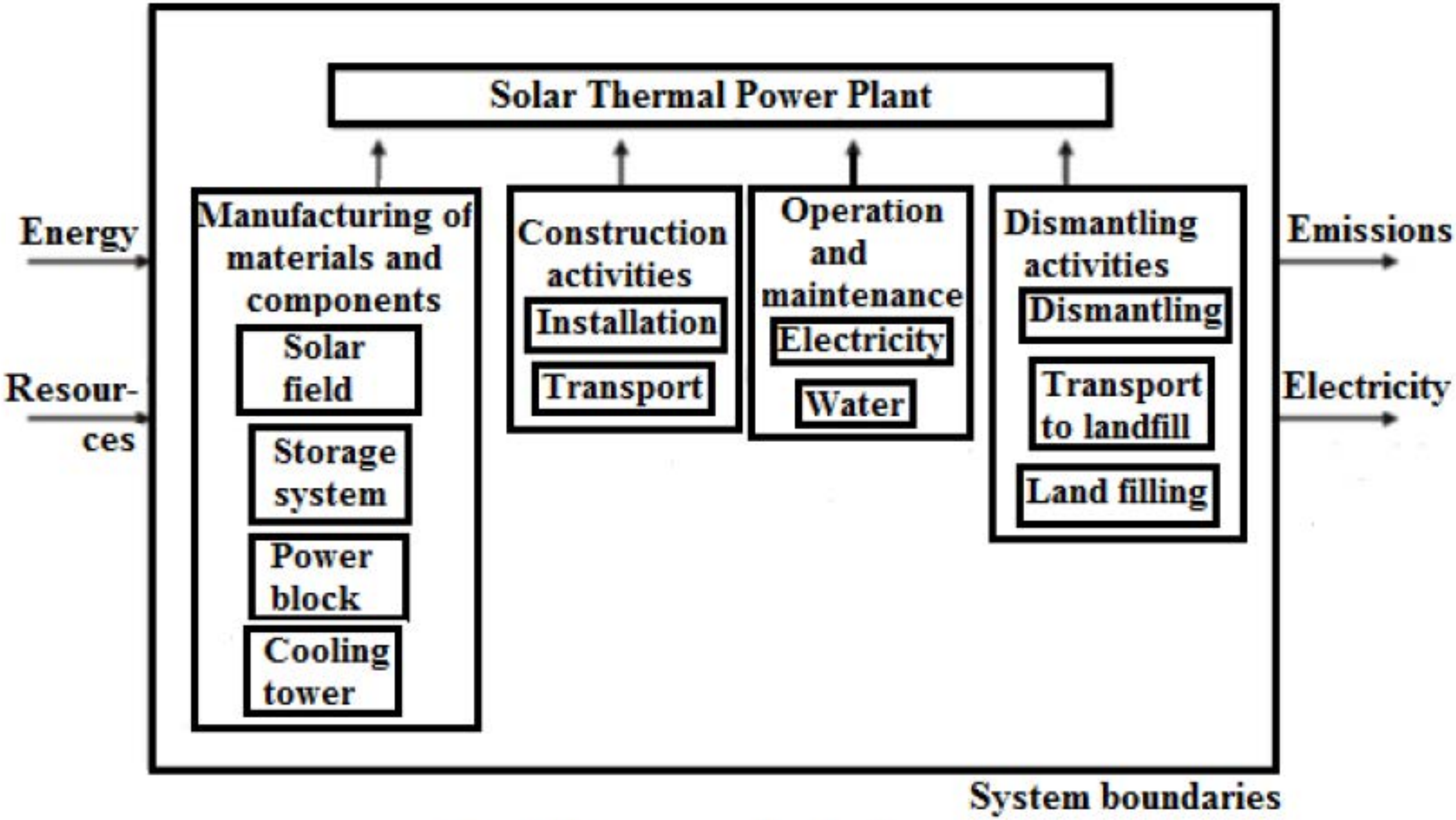
- **Return on Investment (ROI):** compares the net benefit (total discounted benefits minus total discounted costs) to costs. To calculate the ROI, first calculate the net benefits and then divide the net benefits by the costs; expressed as a percentage.

- **Net Present Value (NPV):** reflects the net benefits of a project in 'dollar' terms. To calculate the NPV, subtract the total discounted costs from the total discounted benefits.

- **Energy Pay Back Period (EPBP):** is a measure of how long a plant needs to run to compensate the energy consumed during the manufacturing, operation and decommissioning of the power plant .

- **Energy Intensity:** is the energy consumed by the plant during the manufacturing, operation and decommissioning of the power plant per unit of electricity produced over the life time.

2. METHODOLOGY : Environmental Analysis



[Figure 1] *Life cycle of a solar thermal power plant*

- **Carbon Pay Back Period (CPBP)**: is a measure of how long a CO_2 mitigating process needs to run to compensate the CO_2 emitted to the atmosphere during the life cycle stage.

- **Carbon intensity**: is the carbon emission associated with the manufacturing, operation and decommissioning of the power plant per unit of electricity produced over the life time.

2. METHODOLOGY : Social Analysis

- This is not considered in this study.

- Most researchers on this topic base its analyses on the energy model set of indicators and these are poverty and equity; where

  - energy poverty is measured in terms of ‘access to use of modern and clean energy’ and

  - equity in terms of ‘access to useful energy’.

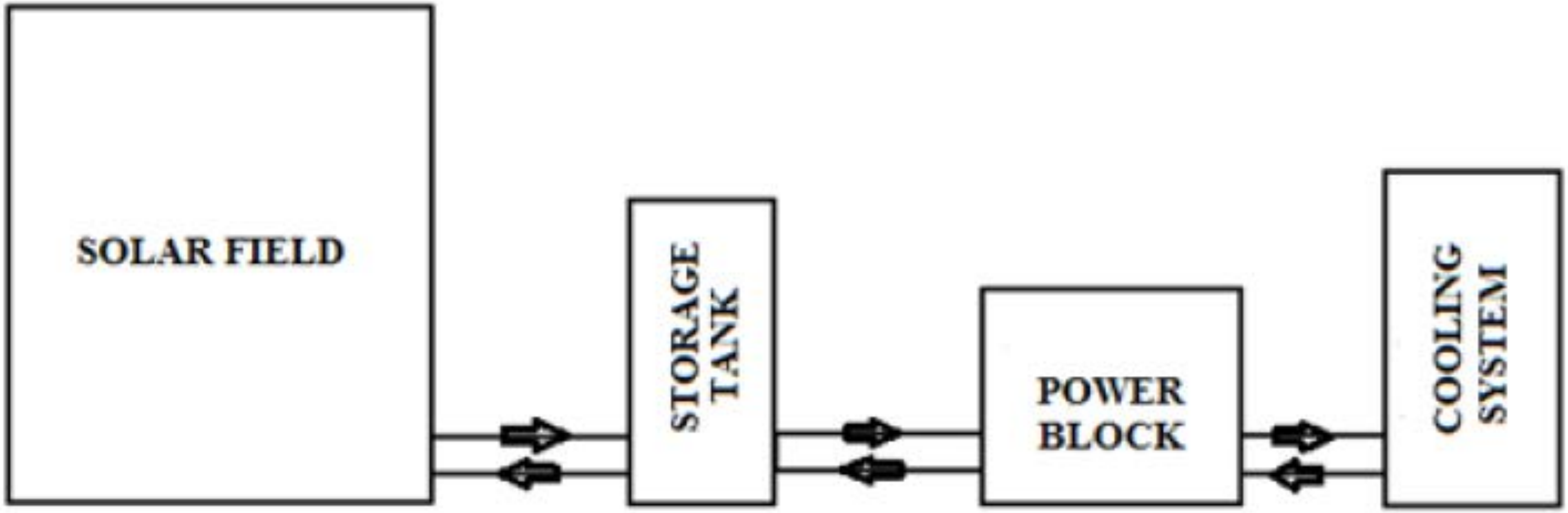
3. CASE STUDY : Description

10 kW SOLAR THERMAL POWER PLANT

The 10kW plant to be installed in a community/village to be identified will basically consist of a solar field, pumps and field piping, storage tank, a complete ORC plant developed by the University on a similar model of the IT10 supplied by Infinity Turbines of USA, and a cooling tower.

A schematic representation of the concept plant is shown in figure 2.

Table 1 shows a breakdown of costs for the power plant.



[Figure 2] *schematic representation of the final concept plant*


INFINITY

Component	Unit Price [ZAR]	Quantity	Sub-Total [ZAR]
Land		50 m x 30 m	50 000
Solar Collectors	7 000	180	630 000
Cooling Tower		01	20 000
Pumps		03	5 000
Storage		01	20 000
Field Piping		PVC/Rubber Hose/PERT	5 000
Frame Structure		30x30x4 mm Galvanised Steel	100 000
ORC Unit		01	300 000
Working Fluid: R134a		58kg	4 000
Labour			100 000
		Total	ZAR 1 234 000

- The price of electricity would normally be determined during the bidding process. For this analysis however tariffs obtained from the eThekwini Single-Phase Tariffs will be used; that is R1.3146/kWh [4].

3. CASE STUDY : Calculations

- Notes regarding data used to perform analyses:
- Power Cost Calculations: price of electricity = 131.46 c/kWh; increase in price per year = 15%; discounted rate = 5% [2]
- R134a is very attractive as a refrigerant because it has zero ozone depleting potential as well as a low direct global warming potential (GWP). [3]
- 10 kW ORC Plant: 181 kg (un-crated); without proper data we assume the unit consists 90% steel and associated alloys; 2.5% copper; 2.5% aluminium and associated alloys; 2.5% rubber hoses; and 2.5% other metals.
- Power generated and emissions avoided: emissions avoided (Eskom average Emission Factor 1.015 kg CO2-eqt/kWh) times power generated from plant per annum (30000kWh/annum) equals 30450 kg CO_2-eqt/annum. [4]
- Pump power estimated at 1% of produced power [5]: emissions = 304.5 kg CO2/annum; power = 300 kWh/annum.

3. CASE STUDY : Results

The results of the NPV calculations are shown in table 2 and the results of the environmental analyses of the plant are captured in table 3 respectively:

[Table 2] *NPV computations*

Year	Year	System Cost [ZAR]	Annual Cash Flow [ZAR]	NPV of Annual Cash Flow [ZAR]	Cumulative NPV [ZAR]
0	2015	-1 234 000	0.00	0.00	-1 234 000.00
1	2016		39438.00	37560.00	-1 196 440.00
2	2017		45353.70	41137.14	-1 155 302.86
3	2018		52156.76	45054.97	-1 110 247.89
4	2019		59980.27	49345.92	-1 060 901.98
5	2020		68977.31	54045.53	-1 006 856.45
6	2021		79323.90	59192.72	-947 663.73
7	2022		91222.49	64830.12	-882 833.61
8	2023		104905.86	71004.42	-811 829.19
9	2024		120641.74	77766.74	-734 062.45
10	2025		138738.01	85173.10	-648 889.35

3. CASE STUDY : Results

The results of the NPV calculations are shown in table 2 and the results of the environmental analyses of the plant are captured in table 3 respectively:

[Table 2] *NPV computations*

Year	Year	System Cost [ZAR]	Annual Cash Flow [ZAR]	NPV of Annual Cash Flow [ZAR]	Cumulative NPV [ZAR]
11	2026		159548.71	93284.82	-555 604.52
12	2027		183481.01	102169.09	-453 435.43
13	2028		211003.16	111899.48	-341 535.95
14	2029		242653.64	122556.58	-218 979.37
15	2030		279051.68	134228.63	-84 750.74
16	2031		320909.44	147012.31	62 261.57
17	2032		369045.85	161013.48	223 275.05
18	2033		424402.73	176348.10	399 623.15
19	2034		488063.14	193143.16	592 766.31
20	2035		561272.61	211537.74	804 304.05

• [Table 3] Environmental Analysis

Component	Description	Mass (kg)	Embedded Energy Index (MJ/kg)	Embedded Energy Content (MJ)	Embedded Carbon Emissions Index ($kgCO_2eq/kg$)	Embedded Carbon Emissions Content ($kgCO_2eq$)
IT10	Steel	162.9	24.4	3974.76	1.77	290
	Copper	4.525	50	226.25	2.77	12.5
	Aluminium	4.525	155	701.375	8.14	36.8
	Rubber hose	4.525	101.7	460.1925	3.18	14.4
	Others	4.525	-		4.4	19.9
Sub-Total				5362.5775		373.6

Component	Description	Mass (kg)	Embedded Energy Index (MJ/kg)	Embedded Energy Content (MJ)	Embedded Carbon Emissions Index ($kgCO_2eq/kg$)	Embedded Carbon Emissions Content ($kgCO_2eq$)
Solar Field	Galvanised steel 30x30x4 mm	3768	24.4	91939.2	1.77	6670
	0.5mm Galvanised steel casing	2200	24.4	53680	1.77	3894
	4mm Solar Glass	5720	15	85800	0.85	4862
	40mm Insulation	1400	45	63000	1.86	2604
	15mm Copper pipes	3263	50	163150	2.77	9038
	0.5mm Copper absorber	2500	50	125000	2.77	6925
	Rubber hose	60	101.7	6102	3.18	190
	Black paint	50 (546.48 m^2)	68 (/m^2)	37160.64	3	150
	Other		-			ignore
Sub-Total				625831.84		34333

Component	Description	Mass (kg)	Embedded Energy Index (MJ/kg)	Embedded Energy Content (MJ)	Embedded Carbon Emissions Index ($kgCO_2eq/kg$)	Embedded Carbon Emissions Content ($kgCO_2eq$)
Storage	Insulated & vented Tank					
	pumping energy – covered under operational energy and emissions					
Sub-Total						ignore
Cooling	mainly consists of pumping energy – covered under operational energy and emissions					
Sub-Total						ignore
Construction & Installation	Concrete (hard surface for equipment)	$2m^3$ (4800 kg)	0.95	4560	$263/m^3$	526
	Transport	100 km	-		0.26/km	26
Sub-Total				4560		552
TOTAL				635754.418		35258.6

From table 2:

- Return on Investment (ROI): = $804304.05/1234000$ = 0.652

- Net Present Value (NPV): = ZAR 804 304.05

From table 3:

- Total embedded energy = 635754.418 MJ or 176598.45 kWh

From table 2:

- Return on Investment (ROI): = $804304.05/1234000$ = 0.652

- Net Present Value (NPV): = ZAR 804 304.05

- Life Cycle CO_2 emissions (g of CO_2) = 35 258 690 g

Economic and Environmental Evaluation of Renewable Energy

- Energy Pay Back Period (EPBP):
- EPBP=Energy consumed by power plant (kWh)/Energy produced by power plant per year (kWh) = 176598.45/29700 =5.95 years

- Energy Intensity:
- Energy Intensity = Total Input Energy (kWh)/Life Time Electricity Production (kWh) = 176598.45/594000 = 0.2973

- Carbon Pay Back Period (CPBP):
- CPBP=$Life\ Cycle\ CO_2\ emission/Gross\ CO_2\ emission\ avoided\ per\ year\ x\ 365 = 35258.6/(30450-304)\ x\ 365 = 426.9\ days$

- Carbon intensity:
- $CO_2\ Intensity = Life\ Cycle\ CO_2\ emissions\ (g\ of\ CO_2)/Life\ time\ electricity\ generation\ (kWh) = 35258.6*1000/594000 = 59.36\ g/kWh$

Conclusion and Recommendation

- It is evident from the NPV value of ZAR 804 304.05 that under the current scenario the 10 kW Low Temperature Solar Thermal Concept Power Plant is an attractive investment option, economically.

- The energy payback period (EPBP) was obtained as 5.95 years; this is considered comparable with other similar technologies. A typical solar power system is reported to payback after about four years, a photovoltaic system between one-and-half and three-and-half years, while a small wind turbine could take between fifteen to fifty years [6],[7]. Carbon payback period (CPBP) on the other hand was computed as 426.9 days (1.17 years); this figure too is comparable with what has been obtained by other researchers such as 2.21 years obtained for a solar water heater by Marimuthu C. and Kirubakaran V. [8], and carbon payback periods (excluding transport) obtained as 6.0, 2.2, and 1.9 years respectively for PV system, solar thermal-individual and solar thermal-community by Croxford Ben and Scott Kat [9].

Conclusion and Recommendation

- The results obtained here are considered partial or conservative because the scrap and recycling values of the materials or components following decommissioning has not been taken into account; this would reduce the embodied energy and emissions.

- The implications of these analyses do indicate that the low temperature solar thermal concept plant has potential to be a net clean energy producer both cost effectively and environmentally beneficially.

Thank you