Chapter 07

ECONOMIC ANALYSIS

7.1. Cost Estimation

The estimation of costs was carried out using midterm (2010) and long term (2020) cost projections developed by Sargent & Lundy LLC Consulting Group, Chicago, Illinois in 2003 for NREL.

The estimation of Tanamalwila 50 MW central receiver type power plant for 2010 midterm cost projections is given below [4]. It is taken as case 01.

Description	Per Unit Cost In USD	Size	Costs (USD)
Structures and Improvements	3.9 $\$/m^2$ field	1,021,094 m^2	3,982,266.60
Heliostat Field	134 $\$/m^2$ field	1,021,094 m^2	136,826,596.00
Receiver	30.631 $\$/m^2$	686.88 m^2	21,039.82
Tower and Piping	8.7 $\$/m^2$ field	1,021,094 m^2	8,883,517.80
Thermal Storage	41 $/kWht	2,222,730 kWt	91,131,930.00
Steam Generator	8 $/kWt	138,920 kWt	1,111,360.00
Electric Power	306 $/kWe	50,000 kWe	15,300,000.00
Balance of Plant	367 $/kWe	50,000 kWe	18,350,000.00
Total Direct Installation Cost			**275,606,710.22**

Table 7.1: Midterm Cost Estimations of Tanamalwila 50 MW Power Tower

The estimation of Tanamalwila 50 MW central receiver type power plant for 2020 long term cost projections is given below [4]. It is taken as case 02.

Description	**Per Unit Cost In USD**	**Size**	**Costs (USD)**
Structures and Improvements	2.7 $\$/m^2$ field	1,021,094 m^2	2,756,953.80
Heliostat Field	117 $\$/m^2$ field	1,021,094 m^2	119,467,998.00
Receiver	23.834 $\$/m^2$	686.88 m^2	16,371.10
Tower and Piping	9.1 $\$/m^2$ field	1,021,094 m^2	9,291,955.40
Thermal Storage	40 $/kWht	2,222,730 kWt	88,909,200.00
Steam Generator	7 $/kWt	138,920 kWt	972,440.00
Electric Power	231 $/kWe	50,000 kWe	11,550,000.00
Balance of Plant	169 $/kWe	50,000 kWe	8,450,000.00
Total Direct Installation Cost			**241,414,918.30**

Table 7.2: Long term Cost Estimations of Tanamalwila 50 MW Power Tower

The balance-of-plant costs include general balance-of-plant equipment, condenser and cooling tower system, water treatment system, fire protection, piping, compressed air systems, closed cooling water system, instrumentation, electrical equipment, and cranes and hoists.

It can be seen the highest cost of the plant is the cost of heliostats field of 41.66% of the total cost. The other highest cost component is the thermal storage cost which amounts to 31% of the total cost.

The percentages of estimated costs components for case 02 (long term) are given below as a pie chart.

Power Tower Costs in Percentages

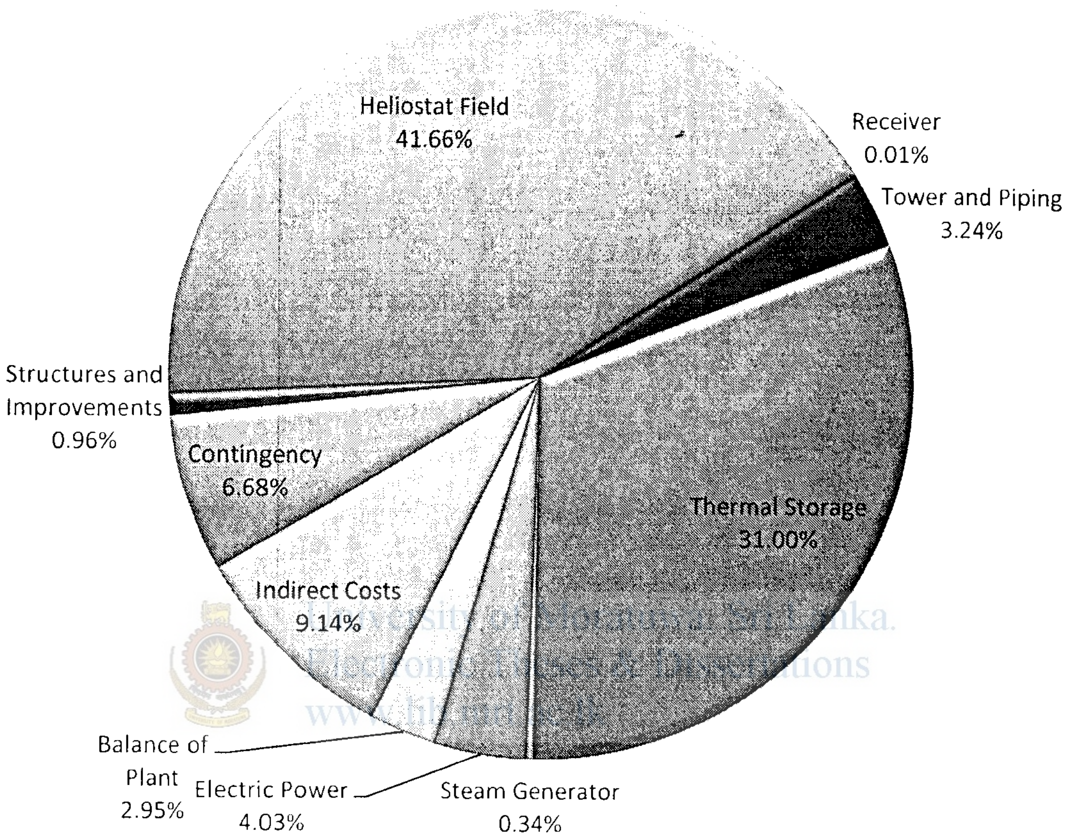

Figure 7.1: Power tower costs in percentages for long term estimation

7.2. Estimation of Annual Energy Output

The capacity factor is the ratio of the system's predicted electrical output in the first year of operation to the output had the system operated at its nameplate capacity [12],

$$CF = \frac{E_{OutputYear1}}{P_{SystemCapacity}}.8760 \qquad 7.01$$

Where,

CF Capacity factor.

$E_{OutputYear1}$ The total annual electric generation in the first year of operation,

$P_{SystemCapacity}$ The system's rated capacity expressed in kilowatts

8760 Number of hours in a year

It is assumed that the capacity factor equals to 50%. Accordingly the total annual electric generation in the first year of operation is 219 GWh.

7.3. Evaluation of Economic Feasibility

Economic evaluation was carried out by a spread sheet program which is developed to perform economic evaluations for solar thermal power plants which is available at NREL website. The input parameters used to evaluate case 01 and case 02 are given in table 7.3. The analysis was carried out in US dollar terms.

Input Parameters for Economic Evaluation	**Case 01**	**Case 02**
General		
Analysis Period	30 yrs	30 yrs
Inflation Rate	2.50%	2.50%
Real Discount Rate	4.00%	4.00%
Taxes and Insurance		
State Tax	7.5%	7.5%
Sales Tax	0%	0%
Insurance	0.50%	0.50%
Loan		
Loan (Debt) Percent	40.00%	40.00%
Loan Term	20 yrs	20 yrs
Loan Rate	4.00%	4.00%

Power Purchase Agreement		
PPA Escalation	1.0%	1.0%
Constraining Assumptions		
Minimum Required IRR	15.00%	15.00%
Costs		
Capital (Direct) Cost	$275,606,710.22	$241,414,918.30
Contingency	10.00%	10.00%
Total Capital (Direct) Cost	$303,167,381.24	$265,556,410.13
Engineering, Procurement & Construction	15.00%	15.00%
Project, Land, Other	10.00%	10.00%
Total Indirect Cost	$75,791,845.31	$66,389,102.53
Total Installed Cost	**$378,959,226.55**	**$331,945,512.66**
Variable O&M ($/MWh)	$8.00	$6.00
Variable O&M Real Escalation	1%	1%
Performance Based Incentives (PBI)		
Carbon Credit cost saving[1]	0.03 $/kWh	0.03 $/kWh
Energy Production		
First Year Annual Output (kWh)	219,000,000	219,000,000

Table 7.3: Input Parameters for Economic Evaluation

[1] Emission factor for coal was taken as 0.963 kg/kWh and Carbon price as 32 USD per metric ton.

Following assumptions were made while the economic evaluation was carried out.

- It is assumed that the project is carried out by an IPP.
- It was assumed that the project will be a BOI approved project so that 15 year tax exemptions could be obtained. Therefore 30% tax that should be applied for rest of the 15 year was applied for full period of 30 years reducing it to 7.5% as spread sheet model accepts only a single tax rate for the whole period.
- It was assumed that a soft loan having 4% loan rate and a loan period of 20 years could be obtained from Global Environment Fund (GEF) or from World Bank as they are already providing soft loans for solar thermal projects.
- It was assumed that minimum required IRR is 8% as it is the typical value for such projects.
- It was assumed a power purchase agreement can be made with Ceylon Electricity Board with an escalation rate of 1% per year.
- It was assumed capacity factor of 50% for the evaluation.
- It was assumed the project could obtain the benefit of carbon credit program and the Carbon price as 0.03 $/kWh which is the current price for such projects.

The final results of the economic evaluation are given in the table 7.4.

Final Results of Economic Evaluation	**Case 01**	**Case 02**
Real LCOE (USD cents/kWh)	10.15	8.55
Nominal LCOE (USD cents/kWh)	13.58	11.44
First Year PPA (USD cents/kWh)	12.25	10.32
Installation cost per kW (USD)	7,579.2	6,638.9

Table 7.4: Final Results of Economic Evaluation

Accordingly if the above assumptions are correct the project becomes an economically viable project.

The after tax net equity cash flow for case 02 is given below for 30 year analysis period.

Year	After Tax Net Equity Cash Flow	Year	After Tax Net Equity Cash Flow
0	(199,167,307.60)	16	17,432,581.54
1	14,865,342.78	17	17,594,952.22
2	15,040,921.65	18	17,755,608.29
3	15,216,215.76	19	17,914,420.52
4	15,391,154.61	20	18,071,254.47
5	15,565,664.66	21	27,996,023.13
6	15,739,669.28	22	28,177,785.90
7	15,913,088.58	23	28,358,306.74
8	16,085,839.32	24	28,537,475.58
9	16,257,834.80	25	28,715,178.06
10	16,428,984.71	26	28,891,295.41
11	16,599,195.00	27	29,065,704.25
12	16,768,367.76	28	29,238,276.47
13	16,936,401.05	29	29,408,879.07
14	17,103,188.78	30	29,577,373.93
15	17,268,620.57		

Table 7.5: After Tax Net Equity Cash Flow in USD

7.4. Sensitivity Analysis

Considering above two analyses as base cases, a sensitivity analysis is done. All the LCOE values are in USD cents per kWh.

The variation of LCOE against different capacity factors is given below.

Capacity Factor (CF)	Total Annual Electric Generation	Case 01		Case 02	
		Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
0.3	131,400,000.00	18.05	24.15	15.47	20.70
0.4	175,200,000.00	13.11	17.54	11.14	14.91
0.5	219,000,000.00	10.15	13.58	8.55	11.44
0.6	262,800,000.00	8.17	10.93	6.82	9.12
0.7	306,600,000.00	6.76	9.04	5.58	7.47
0.8	350,400,000.00	5.70	7.62	4.65	6.22

Table 7.6: LCOE vs. Capacity Factor

The variation of LCOE against different real discount rates is given below.

Real Discount Rate	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
3.5%	10.10	13.62	8.51	11.47
4%	10.15	13.58	8.55	11.44
6%	10.33	13.42	8.71	11.30
8%	10.50	13.28	8.85	11.19
10%	10.65	13.17	8.98	11.09

Table 7.7: LCOE vs. Real Discount Rate

The variation of LCOE against minimum required IRR is given below.

Minimum Required IRR	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
4%	7.05	9.43	5.85	7.83
6%	8.54	11.43	7.15	9.57
8%	10.15	13.58	8.55	11.44
10%	11.83	15.83	10.02	13.40
15%	16.27	21.77	13.90	18.59

Table 7.8: LCOE vs. Minimum Required IRR

The variation of LCOE against the availability of Carbon Credit Facility is given below.

Availability of Carbon Credit	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
0.030 USD per kWh	10.15	13.58	8.55	11.44
0.015 USD per kWh	11.39	15.24	9.79	13.10
Without carbon credit	12.63	16.90	11.03	14.76

Table 7.9: LCOE vs. Availability of Carbon Credit

The variation of LCOE against the loan term is given below.

Loan Term (Years)	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
10	10.71	14.33	9.04	12.10
15	10.40	13.92	8.77	11.74
20	10.15	13.58	8.55	11.44

Table 7.10: LCOE vs. Loan Term

The LCOE if the BOI state is not given.

Availability of BOI State	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
With BOI State	10.15	13.58	8.55	11.44
Without BOI State	13.28	17.76	11.29	15.11

Table 7.11: LCOE vs. Availability of BOI state

The variation of LCOE against PPA escalation rate is given below.

PPA Escalation Rate	Case 01		Case 02	
	Real LCOE	Nominal LCOE	Real LCOE	Nominal LCOE
1%	10.15	13.58	8.55	11.44
2%	10.23	13.69	8.62	11.53
3%	10.32	13.81	8.70	11.63

Table 7.12: LCOE vs. PPA escalation rate

It can be observed that the LCOE is more sensitive to capacity factor and minimum required IRR compared to other parameters. And the tax exemption for 15 years, which is received if the BOI state is given, has a considerable impact on the LCOE.