CHAPTER 6

CARBON CREDIT AND LIFECYCLE COST
ANALYSIS OF PHOTOVOLTAIC THERMAL
SYSTEMS
6.1 CARBON CREDIT ANALYSIS OF SCPVT ARRAY

Whenever we generate electricity by solar energy that means we are saving the emission of carbons rather than it produced with conventional energy resources like coal. This saving of carbon is known as carbon credit. It is a managerial approach and used to control pollution by providing economic incentives for achieving reductions in the emission of pollutants.

A credit gives the right to owner that he can emit one ton of carbon dioxide. Any country can produce the greenhouse gases, according to the quotas set by international treaties such as the Kyoto Protocol. At present there are two exchanges for sold and bought carbon credits: the European Climate Exchange and the Chicago Climate Exchange. According to Committee on Climate Change in (2009), China was the seller and European and Japanese companies were the major buyers of the carbon credits. After the evaluation of overall thermal gain and overall exergy gain, the carbon credit analysis has been computed.
on the basis of overall thermal energy and overall exergy gain. The annual overall thermal
gain and annual overall exergy gain are shown in Figure 6.1.

6.1.1 On the Basis of Overall Thermal Gain

Let us consider that a unit cost of electricity is ₹ 7.3 as per tariff order dated July
2014 of Delhi, India. From above discussion the overall thermal power produced per annum
\(P_{Th}\) is 12869 kWh.
The annual cost of energy produced \(C_{E,Th}\) = \(P_{Th} \times 7.3\)
\[= 12869 \times 7.3 = ₹ 0.93943 \text{ lakhs /annum.}\]

20% losses are considered due to poor domestic appliances and 40% losses are, due
to transmission and distribution, which are common in Indian conditions then:

The transmitted power for unit power consumption of consumer \(P_T\) = \(\frac{1}{1-0.2} = 1.25 \text{units}\)
The power that has to be generated in the power plant \(P_{G,PP}\) = \(\frac{1.25}{1-0.4} = 2.08 \text{units}\)

The intensity of generating electricity from coal is equivalent to average carbon
dioxide, which is approximately 0.982 kg of CO\(_2\)/kWh a source [Watt et al. (1998), Nawaj
and Tiwari (2006)].
The emitted carbon dioxide (CO\(_2\)) when unit power is consumed \(E_{CO2}\) = 0.982x \(P_{G,PP}\) kg
\[= 0.982 \times 2.08 \quad = 2.04 \text{ kg}\]

\text{Reduction in carbon dioxide emission (ER}_{CO2}) = \text{Annual overall thermal energy x E}_{CO2}
\[= \frac{12869 \times 2.04}{1000} \quad \text{ton}\]
\[= 26.25 \text{ ton CO}_2\text{e}\]

Currently, according to European Commission (2014), if the carbon dioxide emission
reduction being traded @ € 30/ton CO\(_2\)e,.
The carbon emission reduction by single channel glazed PVT array = \(ER_{CO2} \times \text{cost of CO}_2\text{e}\)
\[= 26.25 \times 30\€ \quad (1\€= ₹69.36) \quad = ₹ 0.54621 \text{ lakhs}\]

The total financial gain = annual financial gain from overall thermal energy produced
+ annual financial gain from carbon trading
= (0.93943 + 0.54621) lakhs
= ₹ 1.486 lakhs

Total 26.25 tons CO\textsubscript{2}e mitigated from SCGPVT array and ₹ 1.486 lakhs earned from annual carbon emission reduction which is 88% more than an un-optimize system as shown in Figure 6.2, on the basis of overall thermal energy.

![Figure 6.2: Total financial gain from overall thermal and overall exergy gain of PVT array](image)

6.1.2 On the Basis of Overall Exergy Gain

Similarly the overall exergy power produced per annum (P\textsubscript{Ex}) is 3394 kWh.

The annual cost of energy produced (C\textsubscript{E,Ex}) = P\textsubscript{Ex} x 7.3 = 3394 x 7.3
= ₹ 0.24776 lakhs /annum.

Then the transmitted power for unit power consumption of consumer (P\textsubscript{T}) = \frac{1}{T-0.2} = 1.25 units

The power that has to be generated in the power plant (P\textsubscript{G,PP}) = \frac{1.25}{T-0.4} = 2.08 units

The intensity of generating electricity from coal is equivalent to average carbon dioxide, which is approximately 0.982 kg of CO\textsubscript{2}/kWh a source.

The emitted carbon dioxide (CO\textsubscript{2}) when unit power is consumed (E\textsubscript{CO2}) = 0.982 x P\textsubscript{G,PP} kg
Reduction in carbon dioxide emission (ER\textsubscript{CO2}) = Annual overall thermal energy x \textsubscript{ECO2} \[ \frac{3394 \times 2.04}{1000} \text{ ton} \]

= 6.924 ton CO\textsubscript{2}e

Currently, according to European Commission, if the carbon dioxide emission reduction being traded @ € 30/ton CO\textsubscript{2}e.

The carbon emission reduction by single channel glazed PVT array = ER\textsubscript{CO2} x cost of CO\textsubscript{2}e

= 6.924 x 30€ (1€ = ₹69.36)

= ₹ 0.14407 lakhs

The total financial gain = annual financial gain from overall thermal energy produced + annual financial gain from carbon trading

= (0.24776 + 0.14407) lakhs

= ₹ 0.39183 lakhs

Total 6.92 tons CO\textsubscript{2}e mitigated from SCGPVT array and ₹ 0.39183 lakhs earned from annual carbon emission reduction which is 69.6% more than a un-optimize system as shown in Figure 6.2, on the basis of overall exergy gain.

### 6.2 CARBON ANALYSIS OF DCSPVT MODULE

Carbon credit analysis of the proposed hybrid module has been done for Srinagar, India climatic conditions will be called as case-I and obtained results have been compared with single channel semi transparent photovoltaic thermal (SCSPVT) hybrid module and will be called as case-II. After the evaluation of overall thermal gain and overall exergy gain, the carbon credit analysis has been computed on the basis of overall thermal energy and overall exergy gain. The annual overall thermal gain and annual overall exergy gain are shown in Figure 6.3.
Figure 6.3: Annual overall exergy and annual overall thermal gain for case-I and case-II

6.2.1 On the Basis of Overall Thermal Gain

Let us consider that a unit cost of electricity is ₹ 7.3 as per tariff order dated July 2014 of Delhi, India. From above discussion the overall thermal power produced per annum ($P_{Th}$) is 915 kWh.

The annual cost of energy produced ($C_{E, Th}$) = $P_{Th} \times 7.3$

$$= 915 \times 7.3 = ₹ 6680/- per annum.$$  

20% losses are considered due to poor domestic appliances and 40% losses are, due to transmission and distribution, which are common in Indian conditions then:

The transmitted power for unit power consumption of consumer ($P_T$) = \[ \frac{1}{1-0.2} = 1.25\,units \]

The power that has to be generated in the power plant ($P_{G,PP}$) = \[ \frac{1.25}{1-0.4} = 2.08\,units \]

The intensity of generating electricity from coal is equivalent to average carbon dioxide, which is approximately 0.982 kg of CO$_2$/kWh a source [Watt et al. (1998), Nawaj and Tiwari (2006)].

The emitted carbon dioxide (CO$_2$) when unit power is consumed ($E_{CO2}$) = 0.982 x $P_{G,PP}$ kg

$$= 0.982 \times 2.08$$

$$= 2.04 \, kg$$
Reduction in carbon dioxide emission \( (\text{ER}_{\text{CO}_2}) \) = Annual overall thermal energy \( \times \text{E}_{\text{CO}_2} \)

\[
\frac{915 \times 2.04}{1000} \text{ton} = 1.87 \text{ ton CO}_2\text{e}
\]

Currently, according to European Commission (2014), if the carbon dioxide emission reduction being traded @ € 30/ton CO\(_2\)e.,

The carbon emission reduction by DCSPVT array = \( \text{ER}_{\text{CO}_2} \times \text{cost of CO}_2\text{e} \)

\[
= 1.87 \times 30€ \quad (1€ = ₹69.36)
\]

\[
= ₹ 3891/- \text{ per annum}
\]

The total financial gain = annual financial gain from overall thermal energy produced + annual financial gain from carbon trading

\[
= (₹ 6680 + ₹3891)
\]

\[
= ₹ 10771/- \text{ per annum}
\]

Total 1.87 ton CO\(_2\)e mitigated from DCSPVT module and ₹ 10771 earned from annual carbon emission reduction, which is 48.77\% more than case-II as shown in Figure 6.4, on the basis of overall thermal energy.

**6.2.2 On the Basis of Overall Exergy Gain**

Similarly the overall exergy power produced per annum \( (P_{\text{Ex}}) \) is 151 kWh.

The annual cost of energy produced \( (C_{\text{E,Ex}}) = P_{\text{Ex}} \times 7.3 = 151 \times 7.3 \)

\[
= ₹ 1102/- \text{ per annum.}
\]

Then the transmitted power for unit power consumption of consumer \( (P_T) = \)

\[
= \frac{1}{1-0.2} = 1.25 \text{ units}
\]

The power that has to be generated in the power plant \( (P_{G,PP}) = \frac{1.25}{1-0.4} = 2.08 \text{ units} \)

The intensity of generating electricity from coal is equivalent to average carbon dioxide, which is approximately 0.982 kg of CO\(_2\)/kWh a source.

The emitted carbon dioxide \( (\text{CO}_2) \) when unit power is consumed \( (\text{E}_{\text{CO}_2}) = 0.982x P_{G,PP} \text{ kg} \)

\[
= 2.04 \text{ kg}
\]
Reduction carbon dioxide emission (ER\text{CO}_2) = \text{Annual overall thermal energy} \times E_{\text{CO}_2}
\begin{align*}
&= \frac{151 \times 2.04}{1000} \text{ton} \\
&= 0.308 \text{ ton CO}_2\text{e}
\end{align*}

Currently, according to European Commission, if the carbon dioxide emission reduction being traded @ € 30/ton CO\text{2}e,.
The carbon emission reduction by DCSPVT array = ER_{\text{CO}_2} \times \text{cost of CO}_2\text{e}
\begin{align*}
&= 0.308 \times 30€ (1€= ₹69.36) \\
&= ₹ 640/- \text{ per annum}
\end{align*}

Figure 6.4: Total financial gain due to overall thermal gain and overall exergy gain for case-I and case-II

The total financial gain = annual financial gain from overall thermal energy produced + annual financial gain from carbon trading
\begin{align*}
&= (₹1102 + ₹640) \\
&= ₹ 1743/- \text{ per annum}
\end{align*}

Total 0.308 tons CO\text{2}e mitigated from DCSPVT module and ₹ 1743/- earned from annual carbon emission reduction, which is 49.61\% more than case-II as shown in Figure 6.4, on the basis of overall exergy gain.
6.3 LIFECYCLE COST ANALYSIS OF DCSPVT MODULE

As discussed earlier that, photovoltaic thermal module is considered as one of the most promising renewable energy resource which has the potential to fulfill the energy demand of the whole world. Now a days, the world is depending upon the fossil fuels for energy generations. However, the obligation to reduce CO₂ and other gas emissions in order to maintain the standard of Kyoto agreements, the whole world focusing on non-polluting renewable energy sources.

Now a days, there is rapid design and development of PV cells because they are predicted to become a major renewable energy source. The embodied energy payback plays a crucial role for renewable technologies as their use makes no sense if the energy used in their manufacturing is more than they can save in their lifetime. The embodied energy payback period should always be one of the main criteria used for comparing the feasibility of one renewable technology against another.

In this section, energy and life cycle cost analysis of DCSPVT module discussed in the previous chapter has been evaluated. The study will be helpful to closely relate the actual life cycle cost in conjunction with the performance of a given module. The module has been analyzed based upon overall thermal energy and overall exergy output for the climatic conditions of Srinagar, India.

6.3.1 Methodology

The life cycle energy analysis is carried out to quantify the energy in use and generation of energy through DCSPVT module. The analysis has been done in two ways, namely energy matrices and embodied energy. The evaluation of electrical and thermal energy have been obtained following the same methodology described in previous chapters. The monthly thermal and electrical energy have been calculated by multiplying the daily energy to number of clear days in a month. The overall thermal energy output is obtained by using Equation 1.13, where the useful thermal energy gain from the DCSPVT module is added to electrical gain. The electrical gain being high grade energy therefore, it is first converted into equivalent thermal energy output by dividing it by a factor 0.38 for coal quality of India, which is called as "electric power generation efficiency conversion factor of conventional power plant". The overall exergy output is obtained by using Equation 1.15., where the useful thermal energy gain is converted to equivalent high grade energy by
multiplying it with the Carnot efficiency and added to the electrical gain of the module. The daily average solar intensity \((I_{SL})\) of each month has been multiplied by the number of clear days in a month; the average monthly solar intensity is averaged to get the annual average solar intensity.

6.3.2 Embodied Energy

The embodied energy is a new idea for environmental assessment. The purpose of this concept is used life cycle energy calculations of PVT modules. It is defined as: “the amount of energy required by all of the actions associated with a fabrication process, including the relative proportions consumed in all actions upstream to the acquisition of natural resources and the share of energy used in making equipments and in other supporting functions i.e. direct energy plus indirect energy”, Treloar (1994). Thus the purpose of any embodied energy analysis is to enumerate the amount of energy used to produce a material or component. This involves the evaluation of the overall energy consumption required to extract the raw material, fabricate a product or components, installation and maintain the component element whichever is being assessed. The embodied energy analysis of the present DCSPVT module discussed, the total energy required for individual components with their manufacturing energy needs to be evaluated. The required quantity for making a DCSPVT and SCSPVT module is assumed and the breakup of embodied energy needs to fabricate each component of DCSPVT and SCSPVT module have been tabulated in Table 6.1 and Table 6.2 respectively. The PV module is a high energy intensive component of the DCSPVT and SCSPVT module. It is important to note that the energy density for manufacturing of the opaque PV module, semi-transparent PV module and SCT is considered same due to same energy density involved in the manufacturing process.

6.3.3 Energy Matrices

The performance of a DCSPVT module is computed using three basic metrics namely; energy payback time (EPBT), the energy production factor (EPF) and the life cycle conversion efficiency (LCCE). The methodology and formulae for evaluation of these matrices will be given in the subsequent sections.

6.3.3.1 Energy Payback Time (EPBT)

The EPBT depends on the energy consumed to produce the materials used for fabrication of the module and its components (embodied energy) and annual energy output
obtained from the module. The assessment of embodied energy of various components of a DCSPVT module, the energy densities of different materials are required. EPBT is the time required to recover the energy consumed to prepare the materials and fabrication of a module.

It is the ratio of the total energy spent ($E_{\text{Con}}$) in the manufacturing of DCSPVT module and installation of the module to the total energy out ($E_{\text{Out}}$).

$$\text{EPBT (Years)} = \frac{E_{\text{Con}} (\text{kWh})}{E_{\text{Out}} (\text{kWh/years})}$$  \hspace{1cm} (6.1)

**Table 6.1: Breakup of Embodied Energy of Different Components of DCSPVT Module (Barnwal and Tiwari, 2008, Tiwari et al., 2009).**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Component</th>
<th>Assumed Quantity</th>
<th>Energy density (kWh/kg)</th>
<th>Total embodied energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MS support structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Steel angle</td>
<td>10 kg</td>
<td>8.89</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td>(ii) Screw</td>
<td>0.15 kg</td>
<td>8.89</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>(iii) Nut and bolt</td>
<td>0.5 kg</td>
<td>8.89</td>
<td>4.45</td>
</tr>
<tr>
<td>2.</td>
<td>PVC Sheet</td>
<td>1.70 kg</td>
<td>25.64</td>
<td>43.59</td>
</tr>
<tr>
<td>3.</td>
<td>Paint</td>
<td>0.35 kg</td>
<td>25.11</td>
<td>8.79</td>
</tr>
<tr>
<td>4.</td>
<td>DC Fan</td>
<td>Two</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Aluminum</td>
<td>0.78 kg</td>
<td>55.28</td>
<td>43.12</td>
</tr>
<tr>
<td></td>
<td>(ii) Iron</td>
<td>0.44 kg</td>
<td>8.89</td>
<td>3.91</td>
</tr>
<tr>
<td></td>
<td>(iii) Plastic</td>
<td>0.24 kg</td>
<td>19.44</td>
<td>4.67</td>
</tr>
<tr>
<td></td>
<td>(iv) Copper wire</td>
<td>0.10 kg</td>
<td>19.61</td>
<td>1.96</td>
</tr>
<tr>
<td>5.</td>
<td>PV module (Semitransparent)</td>
<td>0.605 m$^2$</td>
<td>980 kW h / m$^2$</td>
<td>592.9</td>
</tr>
<tr>
<td>6.</td>
<td>Glass (Upper duct)</td>
<td>5.15 kg</td>
<td>8.72</td>
<td>44.93</td>
</tr>
<tr>
<td>7.</td>
<td>Blackened Plate</td>
<td>1.70 kg</td>
<td>25.64</td>
<td>43.59</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>882.14</td>
</tr>
</tbody>
</table>

**6.3.3.2 Energy Production Factor (EPF)**

The overall energy performance of the DCSPVT module can be evaluated by comparing the total energy consumed to the total energy output. The ratio of energy consumed and energy output is referred as the energy production factor. It is used to predict
the overall performance of the system. The energy production factor is a function of time because both $E_{\text{Out}}$ and $E_{\text{Con}}$ are time dependent and can be defined in two ways.

**Table 6.2: Breakup of Embodied Energy of Different Components of SCSPVT Module**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Component</th>
<th>Assumed Quantity</th>
<th>Energy density (kWh/kg)</th>
<th>Total embodied energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>MS support structure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Steel angle</td>
<td>10 kg</td>
<td>8.89</td>
<td>88.9</td>
</tr>
<tr>
<td></td>
<td>(ii) Screw</td>
<td>0.15 kg</td>
<td>8.89</td>
<td>1.33</td>
</tr>
<tr>
<td></td>
<td>(iii) Nut and bolt</td>
<td>0.5 kg</td>
<td>8.89</td>
<td>4.45</td>
</tr>
<tr>
<td>2.</td>
<td>PVC Sheet</td>
<td>1.70 kg</td>
<td>25.64</td>
<td>43.59</td>
</tr>
<tr>
<td>3.</td>
<td>Paint</td>
<td>0.35 kg</td>
<td>25.11</td>
<td>8.79</td>
</tr>
<tr>
<td>4.</td>
<td>DC Fan</td>
<td>One</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(i) Aluminum</td>
<td>0.39 kg</td>
<td>55.28</td>
<td>21.56</td>
</tr>
<tr>
<td></td>
<td>(ii) Iron</td>
<td>0.22 kg</td>
<td>8.89</td>
<td>1.96</td>
</tr>
<tr>
<td></td>
<td>(iii) Plastic</td>
<td>0.12 kg</td>
<td>19.44</td>
<td>2.33</td>
</tr>
<tr>
<td></td>
<td>(iv) Copper wire</td>
<td>0.05 kg</td>
<td>19.61</td>
<td>0.98</td>
</tr>
<tr>
<td>5.</td>
<td>PV module (Semitransparent)</td>
<td>0.605 m$^2$</td>
<td>980 kW h/m$^2$</td>
<td>592.9</td>
</tr>
<tr>
<td>6.</td>
<td>Blackened Plate</td>
<td>1.70 kg</td>
<td>25.64</td>
<td>43.59</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td>810.38</td>
</tr>
</tbody>
</table>

(i) **On annual basis**

$$\chi_a = \frac{E_{\text{Con}}}{E_{\text{Out}}} \quad \text{or} \quad \chi_a = \frac{1}{EPBT} \quad (6.2)$$

If $\chi_a \rightarrow 1$, for $EPBT = 1$ the system is worthwhile otherwise it is not worth from an energy point of view.

(ii) **On lifetime basis**

$$\chi_L = \frac{E_{\text{Out}} \times T}{E_{\text{Con}}} \quad (6.2a)$$

### 6.3.3.3 Life Cycle Conversion Efficiency (LCCE)

This is the net energy productivity of the system with respect to the solar input (Radiation, $E_{\text{sol}}$) over the lifetime of the system ($T$, years) given by
\[ \phi(t) = \frac{E_{Out} \times T - E_{Con}}{E_{Sol} \times T} \] (6.3)

**6.3.4 Annualized Uniform Cost (AUC)**

An effective economic analysis can be done with the knowledge of cost analysis, which can be done by the aid of cash flow diagrams. The product of net present value (NPV) and capital recovery factor (CRF) is defined as the annualized uniform cost, (Tiwari, 2002). Capital recovery factor is a compound-interest factor or future value factor which is used to calculate future value (S) from present value (V_p).

\[
\text{AUC} = \text{Net present value (NPV)} \times \text{Capital recovery factor (CRF)} \quad (6.4)
\]

and

\[
CRF = \frac{i(i+1)^n}{(i+1)^n - 1} \quad (6.5)
\]

Where, n = number of years and i = interest rate per year.

Let V_p is present value and C_{OM,1}, C_{OM,2}, C_{OM,3},...... C_{OM,n} is per year operation and maintenance cost and C_{FR,10}, C_{FR,20},..... is wood and fan replacement cost in every ten years. S represents the salvage value. The conventional line diagram for life cycle cost of DCSPVT module has been shown in Figures 6.5. The net present value for conventional cash flow diagram [Rajoria al. 2015] can be evaluated as,

\[
NPV = V_p + C_{OM} \times \left[ \frac{(1+i)^n - 1}{i(1+i)^n} \right] + C_{FR,10} \times \left[ \frac{1}{(1+i)^{10}} \right] + C_{FR,20} \times \left[ \frac{1}{(1+i)^{20}} \right] + \ldots \ldots \ldots - S \times \left[ \frac{1}{(1+i)^n} \right]
\]

(6.6)
6.3.5 Results and Discussion

The life cycle and annualized uniform cost analysis has been done on DCSPVT and SCSPVT module, will be called as case-I and case-II respectively. The detailed modeling of the proposed module has been given in chapter 5. The study has been performed for Set A to D type weather conditions of Srinagar, India. The analysis has been done on the basis of overall exergy gain and overall thermal gain as evaluated in chapter 5 for Srinagar, India. The Equation 6.1, 6.2 and 6.2a are used for evaluating the energy payback time (EPBT) and energy production factor (EPF) respectively in terms of overall exergy and overall thermal energy for case-I and case-II. EPBT and EPF on an annual basis is given in Table 6.3. It has been observed that the energy payback time for case-I is less as compared to the case-II, which is 0.96, 5.84 years and 1.29, 8.02 years on the basis of overall thermal and exergy gain respectively. The energy production factor for case-I and case-II is 1.04, 0.17 and 0.77, 0.12 on the basis of annual thermal and exergy gain respectively.

<table>
<thead>
<tr>
<th>S. No.</th>
<th>On the basis of</th>
<th>Energy (kWh)</th>
<th>Energy payback time (EPBT)</th>
<th>Energy production factor (EPF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Overall thermal gain</td>
<td>915</td>
<td>0.96</td>
<td>1.04</td>
</tr>
<tr>
<td></td>
<td>Overall exergy gain</td>
<td>151</td>
<td>5.84</td>
<td>0.17</td>
</tr>
</tbody>
</table>

The Equations 6.3 and 6.4 have been used for evaluation of life cycle conversion efficiency (LCCE) and annualized uniform cost (AUC). The evaluation of energy matrices has been done on the basis of overall exergy and overall energy. The net present value (NPV) has been computed by the Equation 6.6. The LCCE and EPF have been evaluated for the life (n) as 20, 25 and 30 years on an annual overall thermal and the exergy basis for case-I and case-II and given in Table 6.6. The maximum EPF has been observed for 30 years, which is 31.2 and 5.1 on energy and exergy basis respectively. The input solar intensity for Srinagar is 1736.8 kWh / m². The highest LCCE of case-I for 30 years has been observed, which is 0.85 and 0.12 on energy and exergy basis respectively as shown in Table 6.4.
### Table 6.4: EPF and LCCE on Annual Overall Thermal Energy and Exergy Basis for Case-I and Case-II.

<table>
<thead>
<tr>
<th>Life (T) Year</th>
<th>Energy Production Factor (EPF)</th>
<th>Life Cycle Conversion Efficiency (LCCF)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Energy</td>
<td>Exergy</td>
</tr>
<tr>
<td></td>
<td>Case-I</td>
<td>Case-II</td>
</tr>
<tr>
<td>20</td>
<td>20.8</td>
<td>15.6</td>
</tr>
<tr>
<td></td>
<td>0.83</td>
<td>0.56</td>
</tr>
<tr>
<td>25</td>
<td>26.0</td>
<td>19.5</td>
</tr>
<tr>
<td></td>
<td>0.84</td>
<td>0.57</td>
</tr>
<tr>
<td>30</td>
<td>31.2</td>
<td>23.4</td>
</tr>
<tr>
<td></td>
<td>0.85</td>
<td>0.58</td>
</tr>
</tbody>
</table>

### Table 6.5: Capital cost ($P$, Salvage value ($S$) and Maintenance cost ($M$) of DCSPVT module (Rajoria et al., 2016)

<table>
<thead>
<tr>
<th>Components</th>
<th>Assumed Quantity</th>
<th>DCSPVT module Rs.</th>
<th>Salvage value of different components ($S$) at the inflation rate of 4% value of scrap for Iron @Rs. 15/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel support structure @ Rs. 50/kg</td>
<td>10 kg</td>
<td>500</td>
<td>After 20 years Iron scrap @ Rs. 33/kg After 25 years Iron scrap @ Rs. 40/kg After 30 years Iron scrap @ Rs. 49/kg</td>
</tr>
<tr>
<td>Semitransparent PV module @Rs 15500/75 Wp</td>
<td>01</td>
<td>15500</td>
<td>330 400 490</td>
</tr>
<tr>
<td>DC fan</td>
<td>02 Nos.</td>
<td>9600</td>
<td>504 504 504</td>
</tr>
<tr>
<td>Paints @ Rs 80/kg</td>
<td>0.35 kg</td>
<td>28</td>
<td>- - -</td>
</tr>
<tr>
<td>Fabrication Charges</td>
<td>-</td>
<td>1500</td>
<td>- - -</td>
</tr>
<tr>
<td>Capital cost (Rs.)</td>
<td>-</td>
<td>27128</td>
<td>1334 1334 1334</td>
</tr>
</tbody>
</table>

Operation and maintenance cost = Rs 500/- per year.
DC fan replacement cost and paints = Rs 600/- in every 10 year.

### Table 6.6: Variation on Annualized Uniform Cost for Various Interest Rates and Lifetime of DCSPVT Module (Case-I)

<table>
<thead>
<tr>
<th>Life (Years)</th>
<th>$i = 0.08$</th>
<th>$i = 0.10$</th>
<th>$i = 0.12$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annualized Uniform Cost (Rs. /kWh)</td>
<td>Annualized Uniform Cost (Rs. /kWh)</td>
<td>Annualized Uniform Cost (Rs. /kWh)</td>
</tr>
<tr>
<td>Exergy</td>
<td>Energy</td>
<td>Exergy</td>
<td>Energy</td>
</tr>
<tr>
<td>20</td>
<td>21.97</td>
<td>3.63</td>
<td>25.00</td>
</tr>
<tr>
<td>25</td>
<td>20.52</td>
<td>3.39</td>
<td>23.48</td>
</tr>
<tr>
<td>30</td>
<td>19.73</td>
<td>3.26</td>
<td>22.80</td>
</tr>
</tbody>
</table>
The capital cost ($P_S$) and the salvage value ($S$) of DCSPVT module is given in Table 6.5 and a variation on annualized uniform cost for various interest rates is given in Table 6.6. The capital cost ($P_S$) and the salvage value ($S$) of SCSPVT module is given in Table 6.7 and a variation on annualized uniform cost for various interest rates is given in Table 6.8.

**TABLE 6.7: CAPITAL COST ($P_S$), SALVAGE VALUE ($S$) AND MAINTENANCE COST ($M_S$) OF SCSPVT MODULE (RAJORIA ET AL. 2016)**

<table>
<thead>
<tr>
<th>Components</th>
<th>Assumed Quantity</th>
<th>DCSPVT module Rs.</th>
<th>Salvage value of different components ($S$) at the inflation rate of 4% value of scrap for Iron @Rs. 15/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel support structure @ Rs. 50/kg</td>
<td>10 kg</td>
<td>500</td>
<td>After 20 years Iron scrap @ Rs. 33/kg After 25 years Iron scrap @ Rs. 40/kg After 30 years Iron scrap @ Rs. 49/kg</td>
</tr>
<tr>
<td>Semitransparent PV module @Rs 15500/75 Wp</td>
<td>01</td>
<td>15500</td>
<td>500 500 500</td>
</tr>
<tr>
<td>DC fan</td>
<td>01 Nos.</td>
<td>4800</td>
<td>252 252 252</td>
</tr>
<tr>
<td>Paints @ Rs 80/kg</td>
<td>0.35 kg</td>
<td>28</td>
<td>- - -</td>
</tr>
<tr>
<td>Fabrication Charges</td>
<td>-</td>
<td>1500</td>
<td>- - -</td>
</tr>
<tr>
<td>Capital cost (Rs.)</td>
<td>-</td>
<td>22328</td>
<td>1082 1082 1082</td>
</tr>
</tbody>
</table>

Operation and maintenance cost = Rs 500/- per year.
DC fan replacement cost and paints = Rs 600/- in every 10 years.

**TABLE 6.8: VARIATION ON ANNUALIZED UNIFORM COST FOR VARIOUS INTEREST RATES AND LIFETIME OF SCSPVT MODULE (CASE-II)**

<table>
<thead>
<tr>
<th>Life (Years)</th>
<th>$i = 0.08$</th>
<th>$i = 0.10$</th>
<th>$i = 0.12$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Annualized Uniform Cost  (Rs. / kWh)</td>
<td>Annualized Uniform Cost  (Rs. / kWh)</td>
<td>Annualized Uniform Cost  (Rs. / kWh)</td>
</tr>
<tr>
<td></td>
<td>Exergy Energy</td>
<td>Exergy Energy</td>
<td>Exergy Energy</td>
</tr>
<tr>
<td>20</td>
<td>27.68 4.45</td>
<td>31.11 5.01</td>
<td>34.68 5.59</td>
</tr>
<tr>
<td>25</td>
<td>25.88 4.17</td>
<td>29.56 4.76</td>
<td>33.35 5.37</td>
</tr>
<tr>
<td>30</td>
<td>24.92 4.01</td>
<td>29.70 4.78</td>
<td>32.65 5.26</td>
</tr>
</tbody>
</table>

The annualized uniform cost (Rs. / kWh) for a different life span for case-I and case-II is given in Table 6.6 and 6.8. The interest rate varying with 8%, 10% and 12%. The lifetime of the module is considered as 20, 25 and 30 years. It is inferred that, the annualized
uniform cost for case-I is Rs. 19.73 /kWh and Rs. 3.26 /kWh, while it is Rs. 24.92 /kWh and Rs. 4.01 /kWh for case-II on the basis of overall exergy and thermal gain respectively for 30 years. From the above study, It is noted that annualized cost (Rs. / kWh) is an indicative of the cost of energy incurred in the module and hence, it can be observed that a module which is having lowest value is a better module. From above discussion, it is concluded that the annualized uniform cost for case-I is less as compared to the case-II. Hence the performance of DCSPVT module is a better one as compared to a SCSPVT module in all aspects of analysis.

6.4 SUMMARY

- For New Delhi climatic condition, the annual CO₂ mitigation from SCPVT array is 26.25 tons and 6.92 tons on the basis of overall thermal energy and exergy respectively.
- The annual CO₂ mitigation from DCSPVT module is 1.87 tons and 0.31 tons on the basis of overall thermal energy and exergy respectively.
- The energy payback time is 0.96, 5.84 years and 1.29, 8.02 years for case-I and case-II on the basis of overall thermal and exergy gain respectively. It has been observed that the energy payback time is less of case-I as compared to case-II.
- It is inferred that, the annualized uniform cost for case-I is Rs. 19.73 /kWh and Rs. 3.26 /kWh, while it is Rs. 24.92 /kWh and Rs. 4.01 /kWh for case -II on the basis of overall exergy and thermal gain respectively for 30 years.