# ECE 333 – GREEN ELECTRIC ENERGY

# 15. *PV* ECONOMICS

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# *PV* SYSTEM ECONOMICS


 

# *PV* SYSTEM ECONOMICS

- Now that we know how to approximate the power and the energy delivered by a grid–connected *PV* system, the next step is to explore its economics
- The key inputs into an economic analysis of a *PV* system are the investment costs and the expected annual energy production under a set of *reasonable* and *justifiable* assumptions

  

# *PV* SYSTEM ECONOMICS

- Key considerations in the performance of a detailed economic analysis include
  - electricity prices
  - debt terms and discount rates
  - incentives, such as *ITC* and rebates
  - tax benefits
  - costs or residual values at system retirement
  - the *O&M* costs

# TOPICAL OUTLINE

- Total *PV* system cost estimation
- *LCOE* determination of a *PV* system
- The *PV* system tax incentive impacts on the *LCOE*
- The *PV* system tax benefits and rebate program impacts
- *Power purchase agreement* (*PPA*) issues

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The *PV* system for a Boulder house is designed to generate roughly 4,000 *kWh* annually
- The key cost components are

| *component* | *costs ($)* |
|---|---|
| *PVs* | 4.20/*W* (*DC*) |
| *inverter* | 1.20/*W* (*DC*) |
| *tracker* | $400 + 100/m^2$ |
| *installation* | 3,800 |

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- We assume the *PV*s have a 12 % efficiency and the inverter efficiency is 75 %
- We use the solar insolation tables in *Appendix G* to obtain the average daily insolation for a fixed array
- We compare the costs of a fixed array with a $-15°$ tilt angle with those of an array with a *single – axis* tracker

  

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The solar insolation tables in *Appendix G* indicate the average daily insolation in Boulder for a fixed array to be 5.4 $kWh/m^2 - d$
- We interpret the insolation as 5.4 $h/d$ of 1 *sun*
- We compute

$$P_{DC,stc} = \frac{4,000}{(0.75)(5.4)(365)} = 2.71 \; kW_p$$

  

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The costs of the *PV*s and the inverters are

$$costs\ of\ PVs = 4.20 \times 2{,}710 = \$\ 11{,}365$$

$$costs\ of\ inverters = 1.20 \times 2{,}710 = \$\ 3{,}247$$

- Given the 12 % efficiency of the *PV*s, the array area required is

$$area = \frac{P_{DC,stc}}{\left(1\ kW/m^2\right)\eta} = \frac{2.71}{1 \times 0.12} = 22.6\ m^2$$

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- We next consider the average daily insolation in Boulder with a *single–axis* tracker of $7.2\ kWh/m^2 - d,$ i.e., $7.2\ h/d$ *of full sun* – as given in *Appendix G*
- We compute

$$p_{DC,stc} = \frac{4,000}{(0.75)(7.2)(365)} = 2.03\, kW_p$$

- The costs of the *PV*s and the inverters are

  

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

$$costs\ of\ PVs = 4.20 \times 2,030 = \$\,8,524$$

$$costs\ of\ inverters = 1.20 \times 2,030 = \$\,2,436$$

- Thus the area for the system is

$$area = \frac{P_{DC,stc}}{\left(1\ kW/m^2\right)\eta} = \frac{2.03}{1 \times 0.12} = 16.9\ m^2$$

- The tracker costs are

$$costs\ of\ trackers = 400 + 16.9 \times 100 = \$\,2,090$$

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

| *element* | *fixed tilt array* | *single–axis tracker* |
|---|---|---|
| *PVs* | $ 11,365 | $ 8,524 |
| *inverter* | $ 3,247 | $ 2,436 |
| *tracker* | – | $ 2,090 |
| *installation* | $ 3,800 | $ 3,800 |
| *total* | $ 18,412 | $ 16,850 |

# EXAMPLE: BOULDER HOUSE *PV* SYSTEM

- The trackers increase the average daily insolation received at the *PV* panels and decrease the area required for the system
- While the trackers add *$* 2,090 to the fixed costs of the *PV* system, the *PV* system investment costs with the trackers are nevertheless markedly lower than those of the fixed panels

  

# REVIEW OF THE *c.r.f.*

- The *capital recovery factor* is the scheme we use to determine the financing costs of a *PV* project
- A loan of $P$ at interest rate $i$ may be recovered over $n$ years through fixed annual payments of

*interest rate*

*c.r.f.*

$$A = P \; \frac{i}{1-(\beta)^{n}}$$

$$\beta \triangleq \frac{1}{1+i}$$

  

# EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

- We illustrate the determination of the *LCOE* with a *PV* system example with the following features:
  - installation costs: *\$ 7 million*
  - annual *O&M* costs: $\$\ 35{,}000$
  - annual land lease fee: $\$\ 40{,}000$
  - annual energy production: 4 *GWh*
  - $9\ \%,\ 20-year$ loan
- The *c.r.f.* is computed to be

# EXAMPLE: *LCOE* FOR THE *PV* SYSTEMS

$$c.r.f.\left(9\,\%,\ 20\,y\right) = \frac{\left(0.09\right)\left(1\ +\ 0.09\right)^{20}}{\left(1+0.09\right)^{20} - 1} = 0.1095\ y^{-1}$$

- The *c.r.f.* results in the annual amortized fixed costs of

$$7{,}000{,}000\ \times\ 0.1095 = \ \$\,766{,}500$$

- Then we can evaluate the *LCOE* using

$$\frac{766{,}500\ +\ 35{,}000\ +\ 40{,}000}{4{,}000{,}000} = 0.21\,\frac{\$}{kWh}$$

  

# FINANCIAL INCENTIVES FOR SOLAR

- A significant factor that we ignored in the cost calculation in the previous examples is the impacts of the financial and tax incentives
- Many solar installations are eligible for federal and state tax incentives for the purchase and implementation of *PV* systems

  

# FEDERAL BUSINESS ENERGY INVESTMENT TAX CREDIT (*ITC*)

| | |
|---|---|
| State: | Federal |
| Incentive Type: | Corporate Tax Credit |
| Administrator: | U.S. Internal Revenue Service |
| Expiration Date: | Varies by technology, see below |
| Eligible Renewable/Other Technologies: | Solar Water Heat, Solar Space Heat, Geothermal Electric, Solar Thermal Electric, Solar Thermal Process Heat, Solar Photovoltaics, Wind (All), Geothermal Heat Pumps, Municipal Solid Waste, Combined Heat & Power, Fuel Cells using Non-Renewable Fuels, Tidal, Wind (Small), Geothermal Direct-Use, Fuel Cells using Renewable Fuels, Microturbines |
| Applicable Sectors: | Commercial, Industrial, Investor-Owned Utility, Cooperative Utilities, Agricultural |
| Incentive Amount: | 30% for solar, fuel cells, small wind*<br>10% for geothermal, microturbines and CHP |
| Maximum Incentive: | Fuel cells: $1,500 per 0.5 kW<br>Microturbines: $200 per kW<br>Small wind turbines placed in service 10/4/08 - 12/31/08: $4,000<br>Small wind turbines placed in service after 12/31/08: no limit<br>All other eligible technologies: no limit |

**Source: http://programs.dsireusa.org/system/program/detail/658**

  

# TAX INCENTIVES FOR SOLAR

- The *ITC* originally enacted in the *Energy Policy Act* of 2005 for solar has been renewed numerous times and is currently set at 30 % of the initial investment
- The *ITC* supports electricity generated by solar systems on residential and commercial properties

  

# EXAMPLE: TAX INCENTIVES FOR SOLAR

- We illustrate the *ITC* impacts on the *LCOE* in the previous *PV* system example
- With the *ITC* , the initial investment tax savings amount to $0.3 \times 7{,}000{,}000 = \$\,2{,}100{,}000$
- The resulting *annual amortized fixed costs* become

$$(1-0.3) \times 7{,}000{,}000 \times 0.1095 = \$\,536{,}550$$

  

# EXAMPLE: TAX INCENTIVES FOR SOLAR

- Then we can evaluate the *LCOE* using

$$\frac{536,550 + 35,000 + 40,000}{4,000,000} = 0.15 \frac{\$}{kWh}$$

- We observe that the introduction of the *ITC* lowers the *LCOE* by 6 $¢/kWh$

- This reduction corresponds to a 27 % decrease in the *LCOE*

# TAX BENEFITS FOR SOLAR

- The use of a home loan to finance the installation of a *PV* system has an important impact on the *PV* electricity price in light of the income tax benefits, which depend on the homeowner *marginal tax bracket* (*MTB*)

# TAX BENEFIT FOR SOLAR

- For a loan over several years, almost all of the first year payments constitute the interest due, with a very small repayment of the loan principal, while the opposite allocation occurs towards the end of the loan life
- In the first year, interest is owed on the entire amount of the loan and the tax benefits are

$$i \times loan \times MTB$$

# EXAMPLE: TAX BENEFIT FOR SOLAR

- Consider a $30-year$ $4.5\%$ loan to install a residential $3.36-kW_p$ $PV$ system in Chicago, with the annual energy of $4{,}942\ kWh$

- The $c.r.f.$ for the loan is

$$\frac{(0.045)(1+0.045)^{30}}{(1+0.045)^{30}-1} = 0.06139\ y^{-1}$$

 

# EXAMPLE: TAX BENEFIT FOR SOLAR

- The residential *PV* system costs *$* 19,186 and the annual loan payment is

$$19{,}186 \times 0.06139 = \$1{,}178$$

- Thus the cost of *PV* electricity in the first year is

$$\frac{1{,}178}{4{,}932} = 0.239 \frac{\$}{kWh}$$

- During the first year, the owner pays the annual interest on the *$* 19,186 loan in the amount of

  

# EXAMPLE: TAX BENEFIT FOR SOLAR

$$\textit{first year interest} = 19{,}186 \times 0.045 = \$\,863$$

- We assume the homeowner is in the 25 % *MTB*

  and determine the first year tax savings to be

$$863 \times 0.25 = \$\,216$$

which make the effective cost of *PV* electricity

$$\frac{1{,}178 - 216}{4{,}932} = 0.192 \frac{\$}{kWh}$$

  

# REBATES

- Many states and certain jurisdictions have introduced rebate programs to promote investments in solar systems
- A rebate reduces the total investment required by, in effect, returning some of the costs of the *PV* system installation to the investor:

$$\textit{reduced costs} = \textit{original costs} - \textit{rebate}$$

# *ILLINOIS* SOLAR AND WIND ENERGY REBATE PROGRAM

| | |
|---|---|
| Budget: | $2.5 million |
| Start Date: | 12/16/1997 |
| Expiration Date: | 10/10/2014 (current applications) |
| Eligible Renewable/Other Technologies: | Solar Water Heat, Solar Photovoltaics, Wind (All), Solar Pool Heating, Wind (Small) |
| Applicable Sectors: | Commercial, Industrial, Local Government, Nonprofit, Residential, Schools, State Government, Federal Government |
| Incentive Amount: | Residential PV: $1.50/watt or 25% of project costs<br>Commercial PV: $1.25/watt or 25% of project costs<br>Nonprofits and Public Sector PV: $2.50/watt or 40% of project costs<br>Residential and Commercial Wind (SWCC certified): $1.75/watt or 30% of project costs<br>Nonprofits and Public Sector Wind (SWCC certified): $2.60/watt or 40% of project costs<br>Wind energy systems that are not SWCC certified: $1.00/watt<br>Residential and Commercial Solar Thermal: 30% of eligible project costs<br>Nonprofits and Public Sector Solar Thermal: 40% of eligible project costs |
| Maximum Incentive: | Residential: $10,000<br>Commercial: $20,000<br>Nonprofits and Public Sector: $30,000 |
| Eligible System Size: | PV systems: Rated design capacity of at least 1 kW;<br>Solar thermal systems: Designed to produce at least 0.5 therms or 50,000 Btus per day or contain at least 60 sq. ft. of collectors<br>Wind: Name-plate capacity 1-100 kW |

**Source: http://programs.dsireusa.org/system/program/detail/585**

# EXAMPLE: REBATES

- For instance, if the total investment costs in the previous example are reduced by the 25 % rebate under the *Illinois* solar and wind energy program, we can determine the reduced annual payment

$$19{,}186 \times (1 - 0.25) \times 0.06139 = \$ 883$$

- Then the first year interest reduces to

  

# EXAMPLE: REBATES

$$19,186 \times (1 - 0.25) \times 0.045 = \$648$$

- Therefore the first year tax savings are given by

$$648 \times 0.25 = \$162$$

- Consequently the cost of *PV* electricity in the first year reduces to

$$\frac{883 - 162}{4,932} = 0.146 \frac{\$}{kWh}$$

  

# POWER PURCHASE AGREEMENTS

- In the broadest terms, a *power purchase agreement* (*PPA*) is a contract between two parties – a *seller* who generates electricity and a *buyer* who purcha-ses the electricity
- The *PPA* defines all the terms for the purchase/ sale of electricity between these parties, such as:
  - the start date of the project commercial operation;
  - the schedule for delivery of electricity;

 

# POWER PURCHASE AGREEMENT

- penalties for under delivery;
- payment terms; and
- termination

- A *PPA* defines the revenue and credit quality of a generation project and constitutes thus a key instrument of project finance
- There are many forms of *PPA* in use today and they vary according to the needs of the buyer, the seller, and the financing counterparties

# POWER PURCHASE AGREEMENT

- **While the *PPA*s signed with utilities serve to finance utility–scale renewable energy resource installations under, typically, long–term, fixed–price energy, the use of the *PPA* vehicle to implement distributed generation projects to supply residential, commercial and municipal and state governments is a more recent application**
- **Under the *PPA* structure, project developers find a way to use federal tax credits to supply renewable**

# POWER PURCHASE AGREEMENT

energy without involving any up–front investment on the part of the buyer

- The owner provides the space to the seller to install the system and purchases energy from the system at a negotiated price for the contract term
- Typically, the ownership of the project passes to the customer at the end of the tax credit payments
- More recently, research centers and campuses make use of *PPAs* to install larger *PV* systems

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

http://www.fs.illinois.edu/services/utilities-energy/production/solar-farm

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The University of Illinois set a goal in the 2010 *Climate Action Plan* that specifies that 5 % of the campus electricity to be supplied from renewable energy resources by 2015
- To meet this goal, University of Illinois is dedica– ting 20.5 *acres* ( 82,961 $m^2$ ) of campus land in the South Farms area to install a solar farm

  

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The University of Illinois set a goal in the 2015 *Climate Action Plan* that specifies that 12.5 *GWh* of electricity is provided by solar installations on campus property by 2020
- To meet this goal, University of Illinois is dedica–ting 20.5 acres ( 82,961 $m^2$ ) of campus land in the South Farms area to install a solar farm

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- In order to take advantage of the tax incentives, University of Illinois signed a 10–*year PPA* with the developer *Phoenix Solar Inc.* to design, build, operate and maintain the solar farm for the first 10 *years* of its life, at which point the solar farm becomes the property of the University

  

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The solar farm is connected directly to the University's electrical distribution system
- The annual energy production from the solar farm is estimated at 7.86 *GWh*, roughly 2 % of the 2012 electricity usage of 432.45 *GWh* for the campus
- University of Illinois has agreed to buy all the energy from the solar farm during the first 10 *years*

  

# EXAMPLE: THE UNIVERSITY ILLINOIS *PV* PROJECT

- We provide an approximation of this solar farm production based on representative data along the lines typically performed for *PV* systems
- We do not have information on the company's tax situation and therefore we use a reasonable debt financing situation of a 5–%, 10–*year* loan for the solar farm

 

# EXAMPLE: THE UNIVERSITY ILLINOIS *PV* PROJECT

- *Phoenix Solar Inc.* **design is for the *PV* system to generate roughly 7.86 *GWh* annually**
- **The average daily insolation received by a fixed panel is 5.2 $kWh/m^2 - d$ – i.e., 5.2 $h/d$ of 1–*sun***
- **We assume a value of $\chi' = 0.8$, so that**

$$p_{DC,stc} = \frac{7,860,000}{(0.8)(5.2)(365)} = 5,180\, kW_p$$

  

# EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The key cost components are

| *component* | *costs* (*$*) |
|---|---|
| *PV module* | $1.20/W\,(DC)$ |
| *PCU* | $0.30/W\,(DC)$ |
| *other equipment* | $0.60/W\,(DC)$ |

- The total fixed costs of the solar farm are

$$(1.20+0.30+0.60)(5{,}180{,}000) \; = \; \$10.8 \; million$$

  

# EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- *Phoenix Solar Inc.* leases the land at $1 \ \$/m^2 - y$ with annual costs of

$$costs_{land} = 1 \times 82{,}961 = \$\ 82{,}961$$

- We assume the annual solar farm *O&M* costs are $10 \ \$/MWh$ so the total annual *O&M* costs are

$$costs_{O\&M} = 0.01 \times 7{,}860{,}000 = \$\ 78{,}600$$

  

# EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- If the developer of the solar project uses a debt instrument with a 5–% interest 10–*year* term

$$c.r.f.(5\%,\ 10y) = \frac{(0.05)(1+0.05)^{10}}{(1+0.05)^{10}-1} = 0.129\ y^{-1}$$

- Under the 2015 *ITC*, the initial savings obtained are

$$10,800,000 \times 0.3 = \$\ 3,240,000$$

# EXAMPLE: THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- The annual amortized fixed costs are then

$$10,800,000 \times (1 - 0.3) \times 0.129 \ = \ \$\, 975,240$$

- Consequently, the *LCOE* is determined to be

$$\frac{975,240 \ + \ 82,961 \ + \ 78,600}{7,860,000} \ = \ 0.145 \, \frac{\$}{kWh}$$

# THE UNIVERSITY OF ILLINOIS *PV* PROJECT

- **Indeed, the University of Illinois pays about *$ 15 million* to *Phoenix Solar Inc.* for the first 10 *years* of operation and takes over ownership thereafter**
- **Once the University of Illinois becomes the owner and operator of the solar farm, all the variable costs are born by the University**

  

# IMPLICATIONS OF THE *ITC*

- The residential and commercial solar *ITC* has helped annual solar installation grow by over 1,600% since 2006
- In 2015 the *ITC* was extended for another eight years, providing market certainty for the solar industry

  