Renewable Energy Systems (12210588)

4. Financial and economic analysis of PV Grid-Tied and autonomous system

Fathi Anayah, PhD

Lecture 4

http://solarprofessional.com/articles/finance-economics/reducing-residential-pv-system-pii-costs

Reduce your electricity bill

- The power generated by your PV system reduces the power you need to buy
- **Example**: if you use **400** kWh of power each month and your system generates **100** kWh, you only pay for the **300** kWh that you have used from the electricity grid
- If you use less power than the system generates, the system generated back into the grid, and this is **credited** to your account

http://newscenter.lbl.gov/news-releases/2010/04/21/net-metered-photovoltaics/

Policy of grid connection

Electricity delivered to the grid can be compensated in several ways:

1. **Net metering**: is where the entity that owns the RE power source receives compensation from the utility for its net outflow of power
   - **E.g.**, if the PV system feeds **500** kWh into the grid and **100** kWh were used from the grid, a compensation of **400** kWh would be received

2. **Feed-in tarrif**: where the producer is paid for every kWh delivered to the grid by a special tariff based on a contract with distribution company or other power authority
   - **E.g.**, you pay $**0.50** for each kWh from the grid for and sell every kWh to the grid by $**0.55**

3

Roof-mounted residential solar PV systems (Winter 2015)

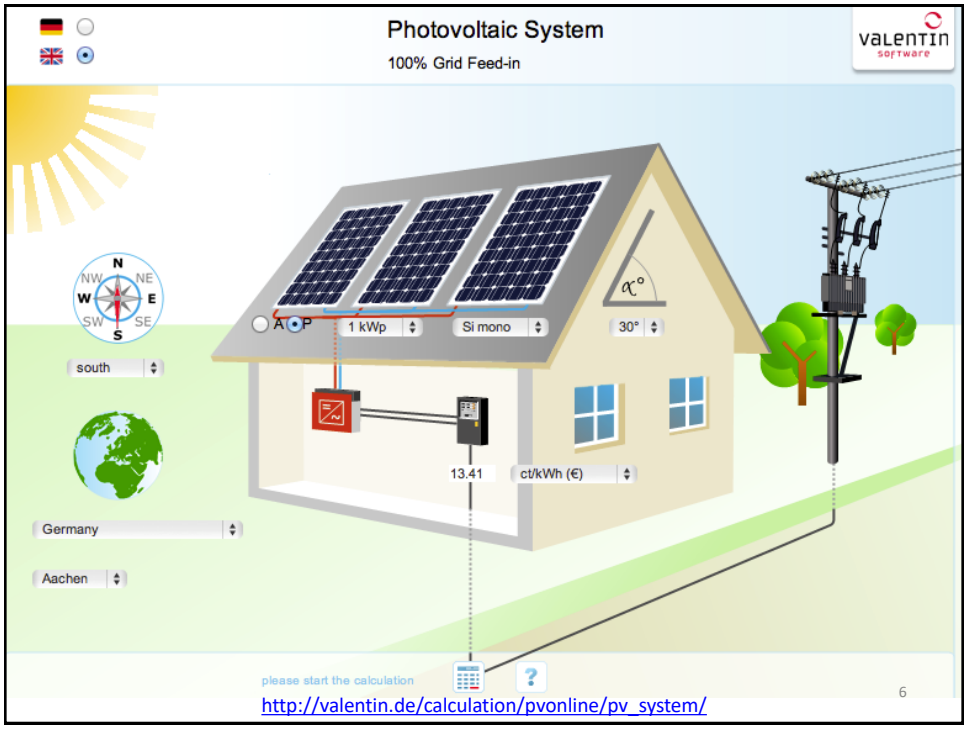
Direct Grid-Tie (net metering)					
System Size	**3.4 kW**	**5.0 kW**	**6.7 kW**	**9.0 kW**	**12.3 kW**
Approx Shade Free Area Required	282 sq. ft.	423 sq. ft.	565 sq. ft.	753 sq. ft.	1,036 sq. ft.
Estimated monthly energy output (kWh)*					
Monthly Average	353 kWh	529 kWh	706 kWh	941 kWh	1,294 kWh
Major System Components					
Inverter	SolarEdge 3000	SolarEdge 5000	SolarEdge 6000	SolarEdge 7600	SolarEdge 11400
Modules	(12) 280 Watt	(18) 280 Watt	(24) 280 Watt	(32) 280 Watt	(44) 280 Watt
Estimated Total Installed Cost					
Installed Price	**$14,859**	**$19,080**	**$23,909**	**$29,980**	**$38,563**
Financial Incentives & Cost Offsets					
Federal 30% ITC	$4,458	$5,724	$7,173	$8,994	$11,569
Net Cost After Investment Tax Credit	**$10,401**	**$13,356**	**$16,736**	**$20,986**	**$26,994**
Estimated Total Utility Savings & SREC Income over 25 years②	$25,418	$38,127	$50,836	$67,781	$93,199
Net Monthly Investment with Key Financing①	**$120.47 for 5 yrs.**	**$142.09 for 5 yrs.**	**$204.22 for 5 yrs.**	**$102.31 for 7 yrs.**	**$118.31 for 7 yrs.**
Environmental Impact	166,046 lbs CO2	249,069 lbs CO2	332,092 lbs CO2	442,789 lbs CO2	608,835 lbs CO2

http://www.dovetailsolar.com/getattachment/Solar-Electric/Pricing-for-Solar-Electric-Systems/Winter-2015-SOLAR-PV-Residential-Price-Sheet-2-16-2015af.pdf

Renewable energy. Enduring value. DOVETAIL Solar and Wind

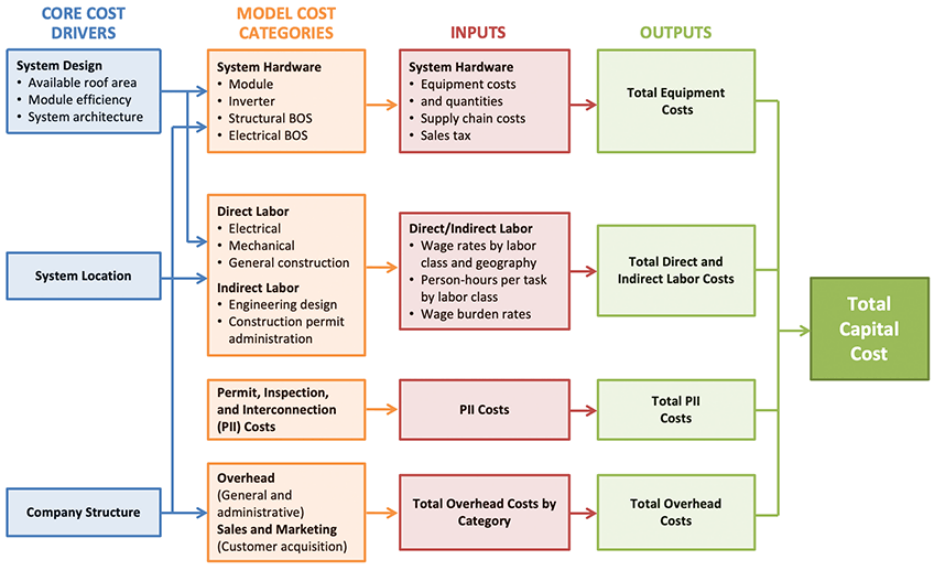
Ground-mounted residential solar PV systems (Winter 2015)

Ground Mounted, Direct Grid-Tie (net metering)				
System Size	**3.1 kW**	**4.1 kW**	**6.1 kW**	**9.2 kW**
Approx Shade Free Area Required	400 sq. ft.	800 sq. ft.	1,200 sq. ft.	1,800 sq. ft.
Estimated monthly energy output (kWh)*				
Monthly Average	295 kWh	400 kWh	595 kWh	900 kWh
Major System Components				
Modules	(12) US made 255 Watt	(16) US made 255 Watt	(24) US made 255 Watt	(36) US made 255 Watt
Estimated Total Installed Cost				
Installed Price	$18,750	$24,300	$32,900	$43,750
Financial Incentives & Cost Offsets				
Federal 30% ITC	$5,625	$7,290	$9,870	$13,125
Net Cost With Tax Credit	**$13,125**	**$17,010**	**$23,030**	**$30,625**
Net Monthly Investment with Key Financing①	**$179.88 for 5 yrs.**	**$230.35 for 5 yrs.**	**$188.67 for 7 yrs.**	**$233.87 for 7 yrs.**
Conservative Utility Savings & SREC Income over 25 years②	$20,372	$27,624	$41,090	$62,153
Environmental Impact	138,842 lbs CO2	188,261 lbs CO2	280,038 lbs CO2	423,587 lbs CO2



http://valentin.de/calculation/pvonline/pv_system/

Cost modeling methodology for residential PV systems



https://www.nrel.gov/analysis/solar-installed-system-cost.html

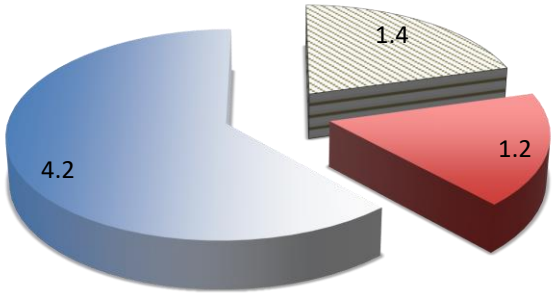
7

PV Balance of System (BOS) costs

Average installed cost for residential PV systems

Unit: $/Wdc

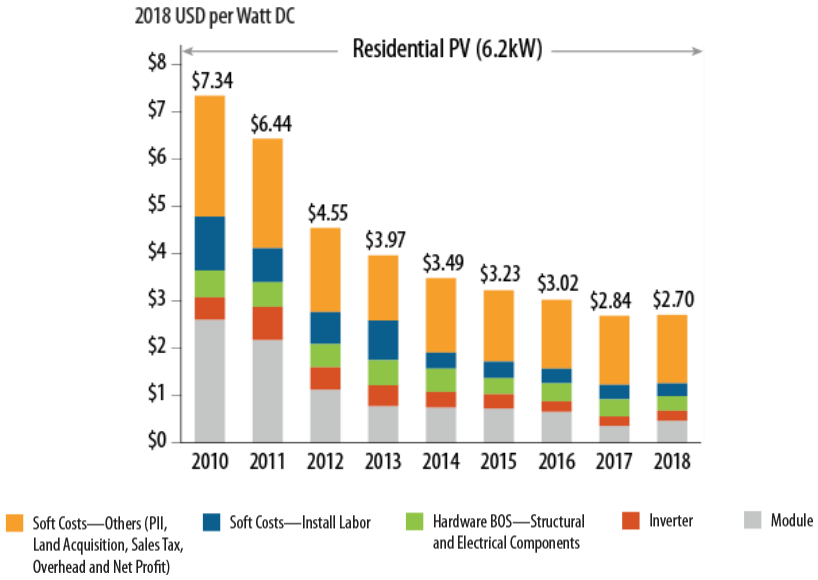
Total: $6.8 / Wdc



BOS: includes mounting and soft cost (permitting, labor, management, etc.)

8

Solar installed system cost analysis for residential rooftop



https://www.nrel.gov/analysis/solar-installed-system-cost.html

9

Example: Cost of electricity from PVs

- Suppose you install a **2 kW** array in Tulkarm that costs **$7/Wdc**, STC (Standard Test Conditions rating)
- If you borrow the money at **6%** interest on a **30-year** loan (on CRF basis), let's find the **cost of electricity** generated
- The system is installed on a south-facing roof with a tilt of **45°** and we assume a de-rating factor of **0.75**
- Assume that the average annual insolation is **5.5** kWh/m^2/day

10

Solution

- The average annual solar insolation is 5.5 kWh/m^2/day is equivalent to that having the sun shining for 5.5 hrs/day
- The system would generate

  Power = 2 kW × 0.75 × 5.5 hrs/day × 365 days/yr

  = 3,011 kWh/yr
- The system costs 2kW × $7/Wdc = $14,000
- The Capital Recovery Factor (CRF) is

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

where i is the interest rate and
n is the number of annuities received

CRF: is the ratio of a constant annuity to the present value of receiving that annuity for a given length of time.

For i = 0.06 and n = 30 yrs, CRF = 0.07265/yr

11

Solution

- The annual cost of the loan is

  $14,000 × 0.07265/yr = 1,017 $/yr
- The total cost over the 30-yr = 1,017 × 30 = $30,513
- Combine the $/yr and the kW/yr to get the cost of electricity to be

$/kWh = ($1,017 /yr) / (3,011 kWh/yr)

= $ 0.338 / kWh

Compound Interest Formula

$$A = P\left(1 + \frac{r}{n}\right)^{nt}$$

The total cost over the 30-yr = A = $80,409

where
P = principal amount (the initial amount you borrow or deposit)
r = annual rate of interest (as a decimal)
t = number of years the amount is deposited or borrowed for
n = number of times the interest is compounded per year
A = amount of money accumulated after n years, including interest

12

PV economic basics

- Solar PV cells convert sunlight directly into electricity
- They are sold on a $/Wp basis or $/power Wp **is the power in Watts for peak sun hours**. The equivalent number of hours per day, with solar irradiance equaling 1,000 W/m^2, that gives the same energy received from sunrise to sundown
- To convert power to energy simply multiply by the amount of time that the cell is illuminated – W × hr = 1.0 W-hr
- Electricity (energy) is normally billed in $/kW-hr

13

PV economic terms

- kW = kilowatt = 1,000 Watts

  MW = Megawatt = 1,000,000 Watts

  kW-h/ year or month or day
- Amount of power predicted to be produced from a 1 kW solar panel in the desired location
- Payback = minimum time it takes to recover investment costs

14

Economic of a solar electric home

- A Palestinian consumer ~ **15,000** kWh per year
- A well-designed consumer needs **4** kW to **5** kW of PV to provide for its energy needs averaged throughout the year
- It depends on the location (solar flux) and energy use
- Because calculations are based on /Wp basis, you do not need to worry about efficiency

How much for a solar electric house?

- The price tag for the complete installed system including all labor and management costs of 2010 is between **$5/Wp** to **$10/Wp**
- For a **4 kW** system
  - 4,000 Wp × $5/Wp = $20,000
  - 4,000 Wp × $10/Wp = $40,000

15

Financing PV systems

- For this consumer a PV system can be folded into the mortgage – long term low interest loan
- For retrofits of existing consumer PV system can be economic with:
  - Financial assistance through grants, subsidies, or other incentives
  - High costs of electricity in your area
  - Green power purchase agreements
  - Off-grid applications

16

Economic example 1/3

- 4000 Watt PV system @ 40° fixed tilt of efficiency 0.70
- $20,000 initial cost
- Assume 5.5 kWh/m^2/day
- Find power/day?

4000 Watt (4 kW) system power is
Power = 4 kW × 0.70 × 5.5 hr/day = 15.4 kWh/day (ac)

- if you borrow the money at 6% interest on a 25-year loan (on CRF basis), let's find $/kWh?

The annual cost of the loan = $20,000 × 0.07823
= $1,565/yr
Total cost = $39,113
Annual power = 15.4 kWh/day × 365 day/yr = 5,621 kWh/yr
$/kWh = ($1565/yr) / (5,621 kWh/yr) = $ 0.278 /kWh

17

Economic example 2/3

- 4000 Watt PV system @ 40° fixed tilt
- $20,000 initial cost
- Assume 5.5 kWh/m^2/day
- Find power/day?

4000 Watt (4 kW) system is about 23.5 m^2 area
✓ 23.5 × 5.5 = 129.25 kWh/day (dc)

- Module efficiency = 17%

✓ 129.25 kWh/day × 0.17 = 21.97 kWh/day (dc)

18

Cont. Economic example 2/3

- Derate factor = 77%

✓ Derate factor takes into account inefficiencies in the DC/AC conversion and internal module components

✓ 21.97 kWh/day × 0.77 = 16.92 kWh/day (ac)

✓ Output power = ~17 kWh/day

✓ Output power = 16.92 kWh/day × 365 day/yr
= 6,176 kWh/yr

- Over 20 years @ 6% interest rate, CRF(6%,20yr) = ? Ann. cost?

✓ CRF = 0.08718, so annual cost of loan = $1,744 /yr

- Based on loan calculations, cost of energy ($/kWh) = ?

✓ $/kWh = ($1,744 /yr) / (6,176 kWh/yr) = $0.282 / kWh

19

Economic example 3/3

- Pay $20,000, save $1800/year

✓ 16.92 kWh/day × $0.15/kWh × 365 day/yr
= $926 / yr

✓ 2.7% return

- Over 20 years @ 6% interest rate

✓ Cost of energy = $0.282 / kWh

✓ Compared to $0.15 / kWh

✓ Expensive!

20

http://solarprofessional.com/articles/finance-economics/reducing-residential-pv-system-pii-costs