NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Techno-Economic Modeling

Tribal Energy Webinar Series

Tony Jimenez, Senior Engineer
NREL

Jun 24, 2020

Presentation Overview

Techno-Economic Modeling (TEM) Overview (For renewable energy [RE] projects in particular)

Models and Data Resources:

- Models
- Resource Data
- Cost Data

Example Analysis Using System Advisor Model (SAM)

NREL Image Library # 08058

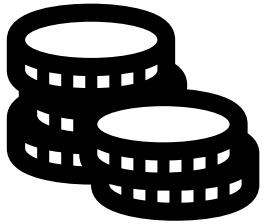
Techno-Economic Modeling (TEM) Overview

Models and Sources of Information

Example Analysis

Techno-Economic Modeling: What is it and Why do it?

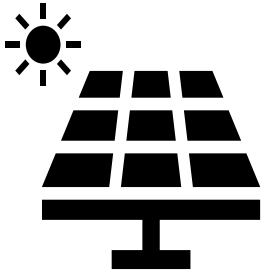
What is it? Process to estimating the technical and economic performance of a proposed (or envisioned) energy project.



- What is the performance?
- What are the economics?
- What are the practical considerations relevant to executing the project?

TEM mostly focuses on the first two items

Why do it? Inform decision making



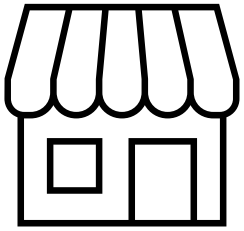
Techno-Economic Modeling: Simple Example (1 of 2)

Scenario: You are considering a PV project for your store, Woodlands Market, located north of Redding, CA.

- Location: Lat: N 40.79, Long: W122.32
- Average Monthly Consumption: 80,000 kWh
- Roof Area (flat roof): 12,000 sq. ft.

Questions

- What size PV system do is needed so that annual production roughly matches annual consumption?
- What size system will fit on the roof?
- What is the estimated capital cost?



Techno-Economic Modeling: Simple Example (2 of 2)

Consumption
- 80,000 kWh/mo = 960,000 kWh/year = 2,630 kWh/day = 110 kW

Solar resource:
- 4.75-5.00 kWh/m2/day (On a horizontal surface) (Source: Solar Atlas)
- Assume 4.8 kWh/m2/day

PV Production (per kW_{dc} of PV capacity) (Average)
- Average daily production (ignoring tilt & losses): 4.8 kWh/day/kW_{dc}

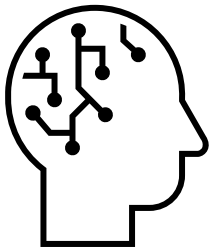
Capacity needed for production to (roughly) equal consumption
- 2,630 kWh/day divided by 4.8 kWh/day/kW_{dc} ➔ 550 kW_{dc}

Space Analysis
- Rule of thumb: 10 $watts_{dc}$ (0.01 kW_{dc}) per square foot of roof space
- Rule of thumb: can use 2/3 of roof area
- Capacity that roof can accommodate: 12,000 sq. ft. x 0.01 kw_{dc}/sq. ft. x 2/3 ➔~ 80 kW_{dc}

Capital Costs
- Small non-residential (average) (up to 100 kW_{dc}): \$3,000/kW_{dc}
- Large residential: (> 100 kW_{dc}): \$2,400/kW_{dc}
- Estimated capital cost for 550 kW_{dc} system: 550 kW_{dc} x \$2,400/kW_{dc} ➔ ~\$1,300,000
- Estimated capital cost for 80 kW_{dc} system: 80 kW_{dc} x \$3,000/kW_{dc} ➔ ~\$240,000

Techno-Economic Modeling: Why Use a TEM Tool?

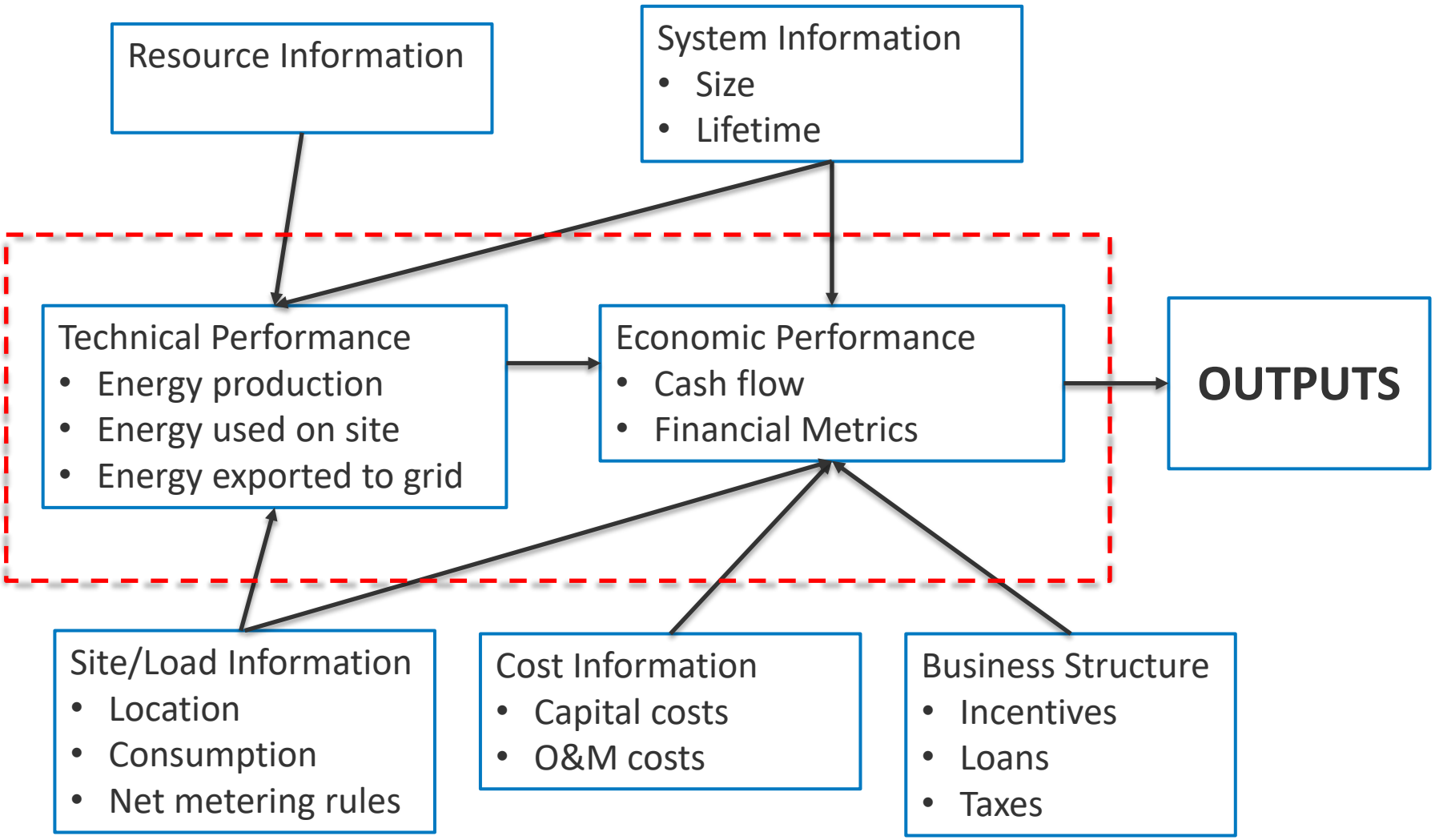
- TEM tools do the tedious math required if you want to go beyond a back of the envelope analysis
  - Hourly simulation
  - Detailed economics
  - Greater precision
- Many TEM tools allow for sensitivity analysis
- Some TEM tools do optimization (help size components such as the battery bank and PV array)
- TEM tools may have links to (or defaults for) resource data, cost data, tariff data.



TE Modeling Process: Common Questions

Performance	Fac. Scale	Util. Scale
How much energy will the system produce?	x	x
How does the production compare to my load?	x	
Seasonal and diurnal variations in the energy production	x	x
System degradation over time	x	x
Lifetime	x	x
Economics		
Will the system result in net savings?	x	
Will the system yield a reasonable profit?		x
Practical Considerations		
How much space will the system require?	x	x
How much effort is required to execute the project?	x	x

TE Modeling Process: Analysis Flow



Techno-Economic Modeling (TEM) Overview

Models and Sources of Information

Example Analysis

Models: A Sampling of What's Out There

Model	Free?	Source	Optimize?
PVWatts Photovoltaics only https://pvwatts.nrel.gov/	Yes	NREL	No
System Advisor Model Multiple technologies https://sam.nrel.gov/	Yes	NREL	No
RETScreen Multiple technologies www.retscreen.net	*Partial	Natural Resources Canada	No
REopt Lite PV, wind, battery[1] Publicly available version of NREL REopt model https://reopt.nrel.gov/tool	Yes	NREL	Yes
HOMER Multiple technologies https://www.homerenergy.com/	No	Homer Energy	Yes

* Free "viewer" version available

1. More technologies to be added

Resources: Resource Data

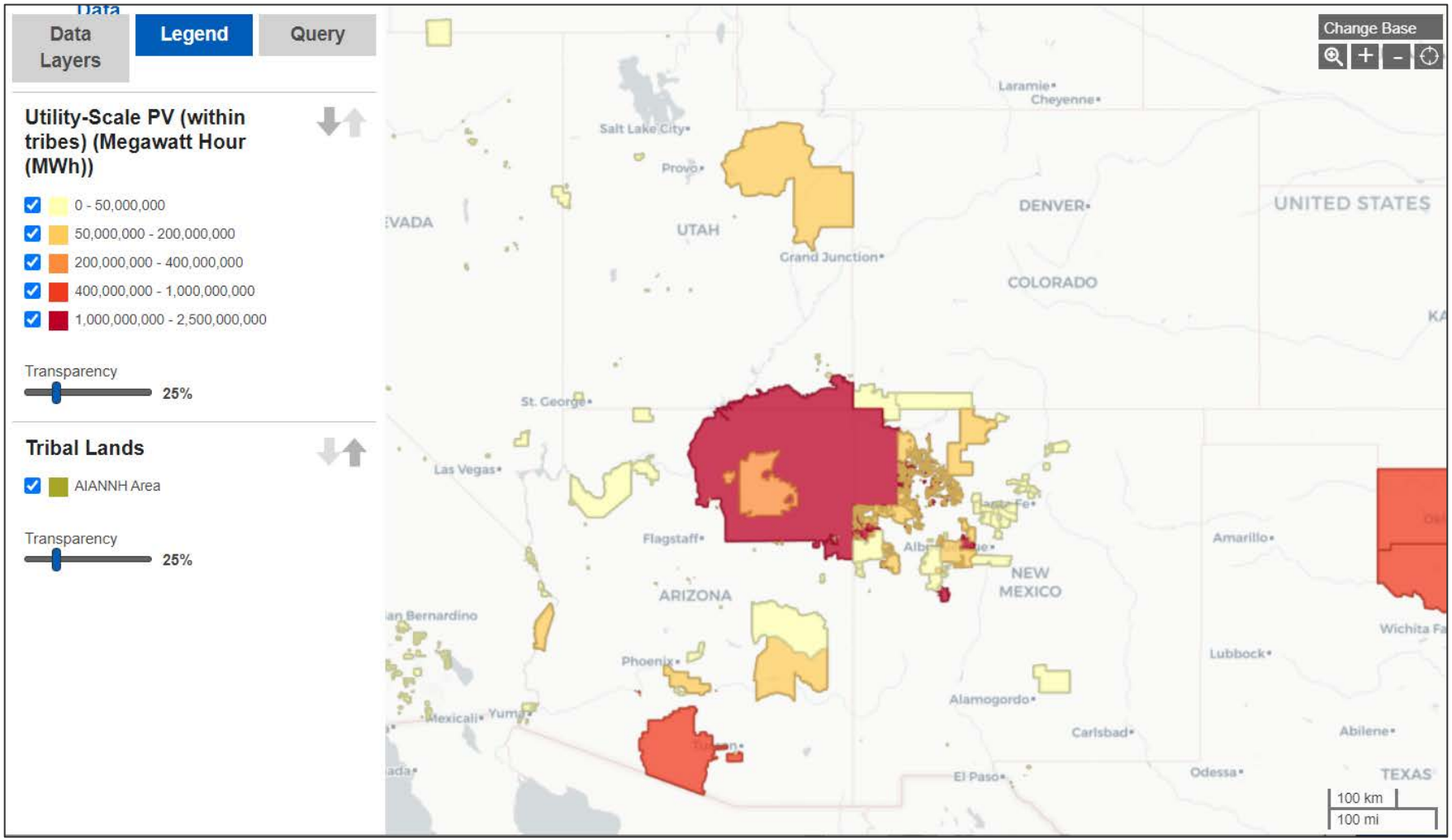
NREL offers a suite of RE resource information at https://www.nrel.gov/gis/data-tools.html . The resources are divided into three categories:

- Maps,
- Data Sets
- Data Visualization & Geospatial Tools

Starting Points

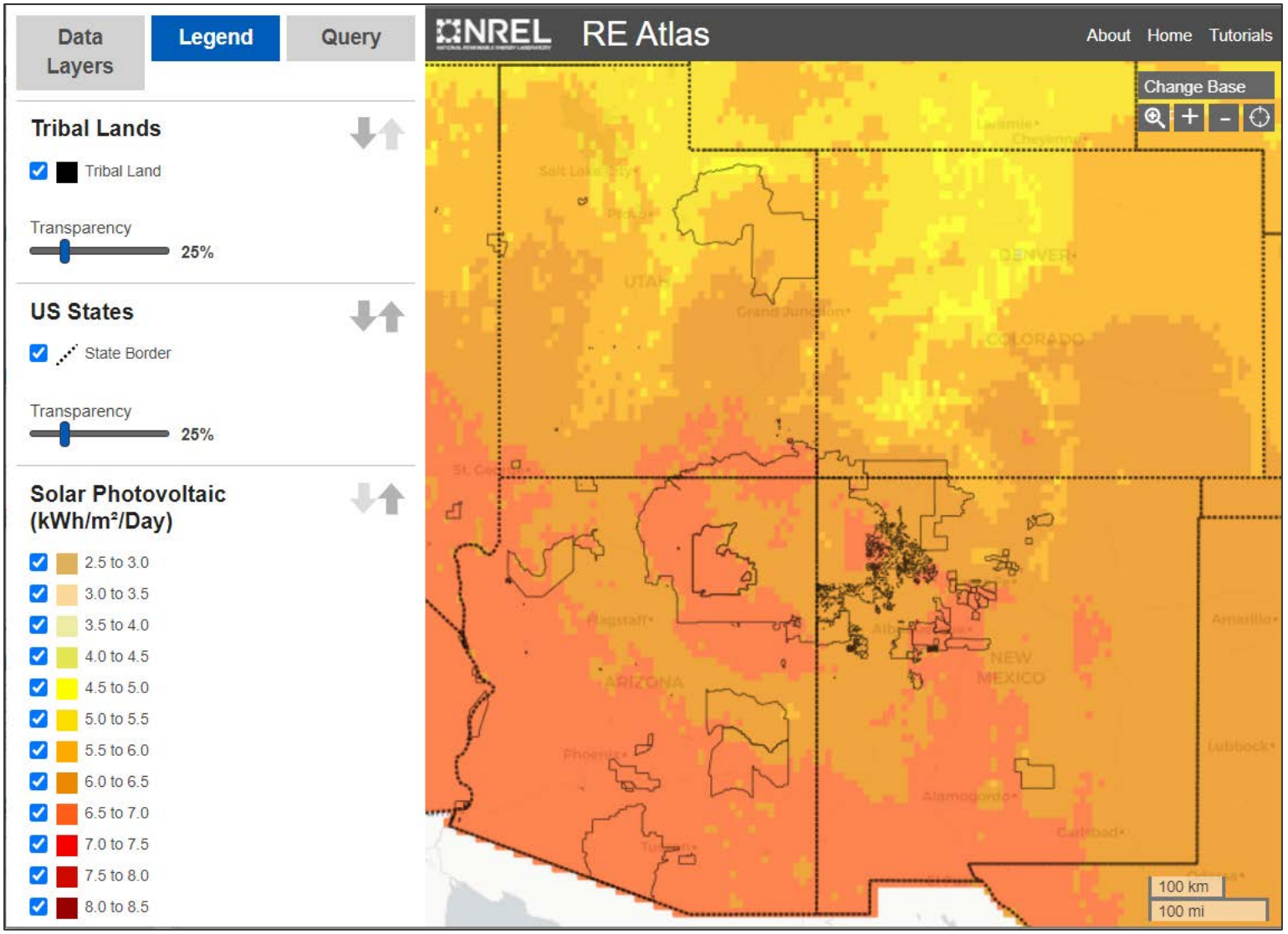
- Tribal Energy Atlas: https://maps.nrel.gov/tribal-energy-atlas
- Renewable Energy Atlas: https://maps.nrel.gov/re-atlas
- Wind Prospector: https://maps.nrel.gov/wind-prospector

Resource Data: Tribal Energy Atlas



Screenshot of Tribal Energy Atlas

Resource Data: Renewable Energy Atlas



Screenshot of Renewable Energy Atlas

Resources: Cost Data

Lazard's Levelized Cost of Energy Analysis v13.0; Lazard, Nov 2019
https://www.lazard.com/perspective/lcoe2019

Lazard's Levelized Cost of Storage Analysis v5.0; Lazard, Nov 2019
https://www.lazard.com/perspective/lcoe2019

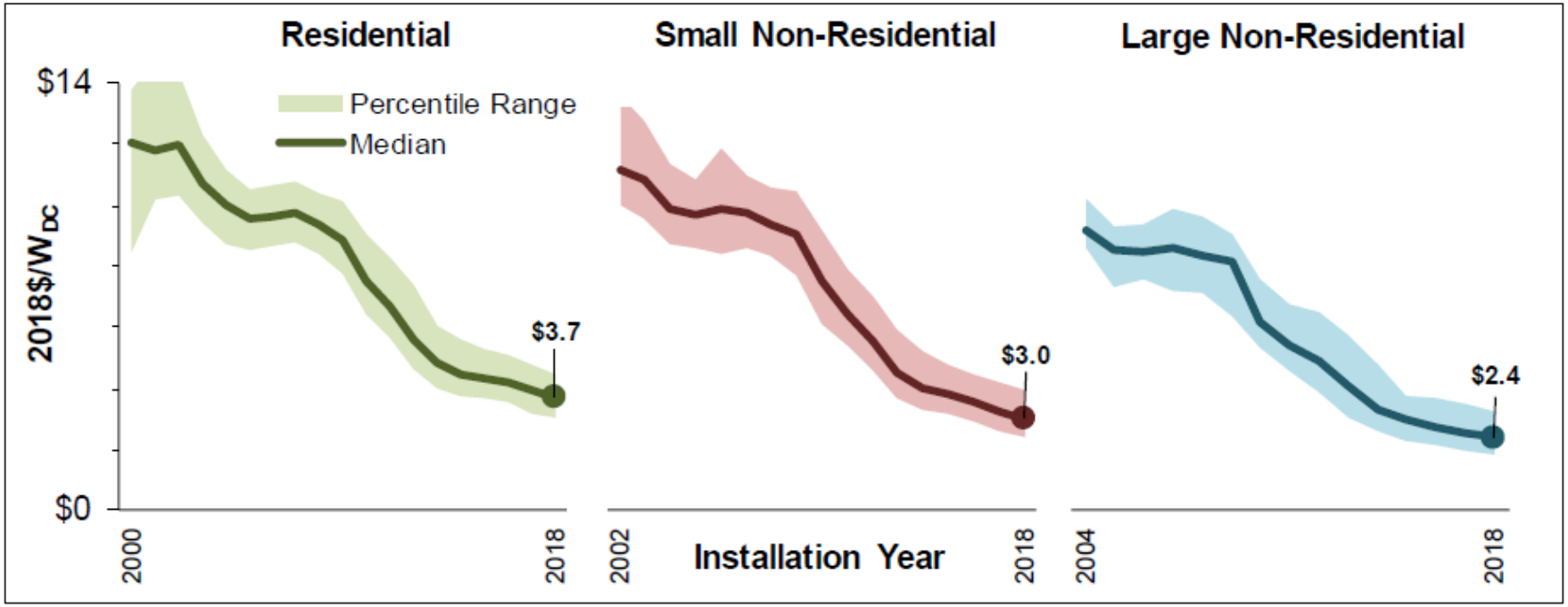
Tracking the Sun - 2019 Edition; DOE/LBL, Oct 2019
https://emp.lbl.gov/tracking-the-sun

Utility Scale Solar - 2019 Edition; DOE/LBL, Dec 2019
https://emp.lbl.gov/utility-scale-solar

2018 Wind Technologies Market Report; DOE/LBL, Aug 2019
https://emp.lbl.gov/wind-technologies-market-report

2018 Distributed Wind Market Report; DOE/PNNL, Aug 2019
https://www.energy.gov/eere/wind/downloads/2018-distributed-wind-market-report

Market (PV) – Cost Trends (non-utility)



Notes: Percentile Range represents the band between the 20th and 80th percentile values in each year.

Source: Tracking the Sun - 2019 Edition https://emp.lbl.gov/tracking-the-sun

Techno-Economic Modeling (TEM) Overview

Models and Sources of Information

Example Analysis

Techno-Economic Modeling: More Complex Example Using SAM

Same scenario as before with a more detailed analysis using SAM.

Analyze the 80 kW_{dc} rooftop system.

NREL Image Library # 06430

Analysis Facts & Assumptions (1 of 3)

Item	Value	Note/Source
Project location	North of Redding, CA	
Latitude	40.79°	
Longitude	-122.32°	
Annual Consumption (kWh)	960,000	Average load = ~110 kW
Roof area (sq. ft.)	12,000 sq. ft.	
Cost of grid electricity ($/kWh)	$0.10/kWh	Energy charge portion of the bill

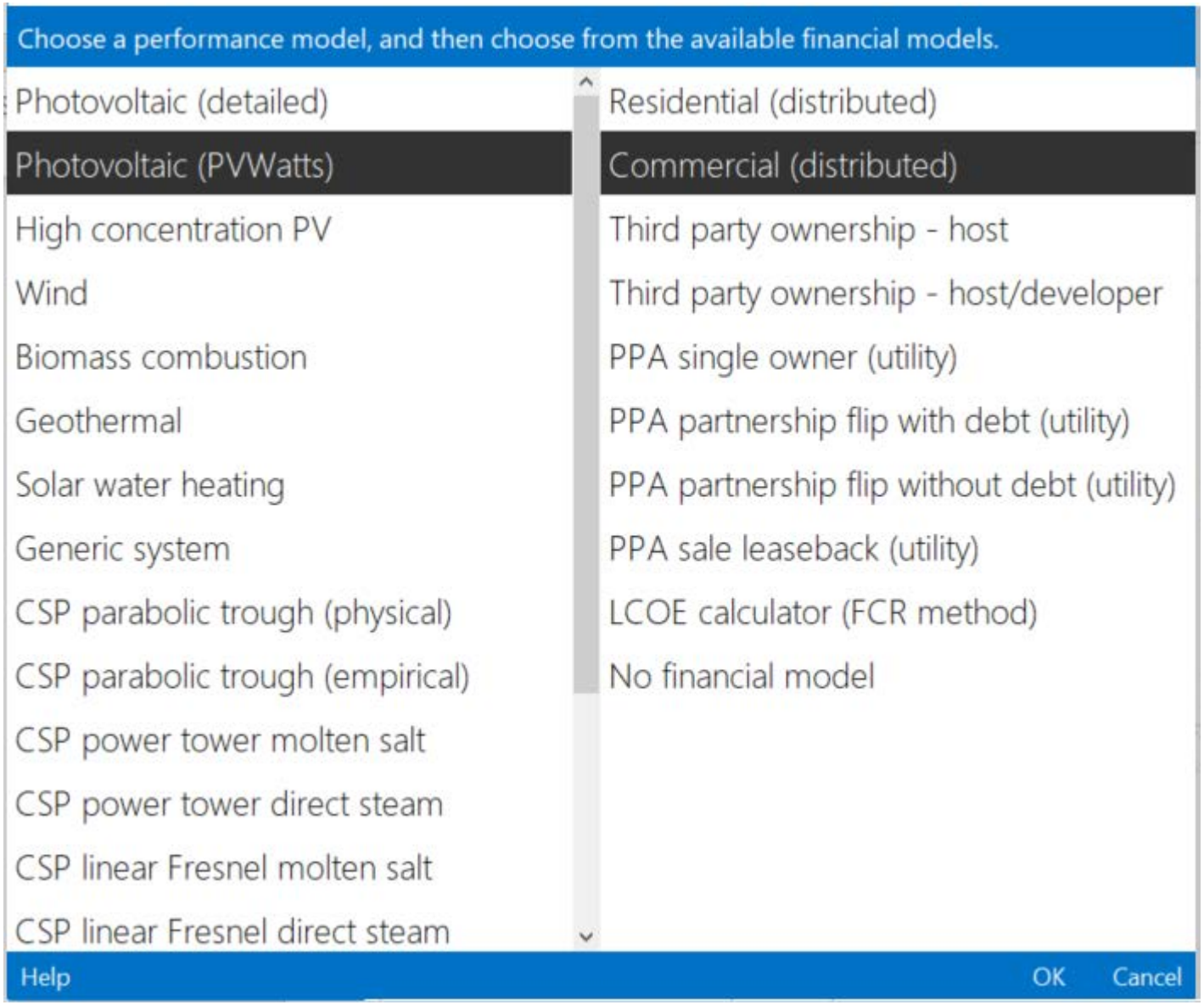
Analysis Facts & Assumptions (2 of 3)

Item	Value	Note/Source
System Lifetime (years)	30 years	Typical value
System Size (kW_{dc})	80 kW_{dc}	
Inverter Loading Ratio	1.2	Within the range of typical values
Racking type	Fixed tilt	
Array orientation	180° (due south)	(Flat) roof mounted
Array tilt	10°	(Flat) roof mounted
Annual degradation	0.5%/year	SAM default
Array Losses	14.08%	SAM default
Inverter losses	4.0%	SAM default

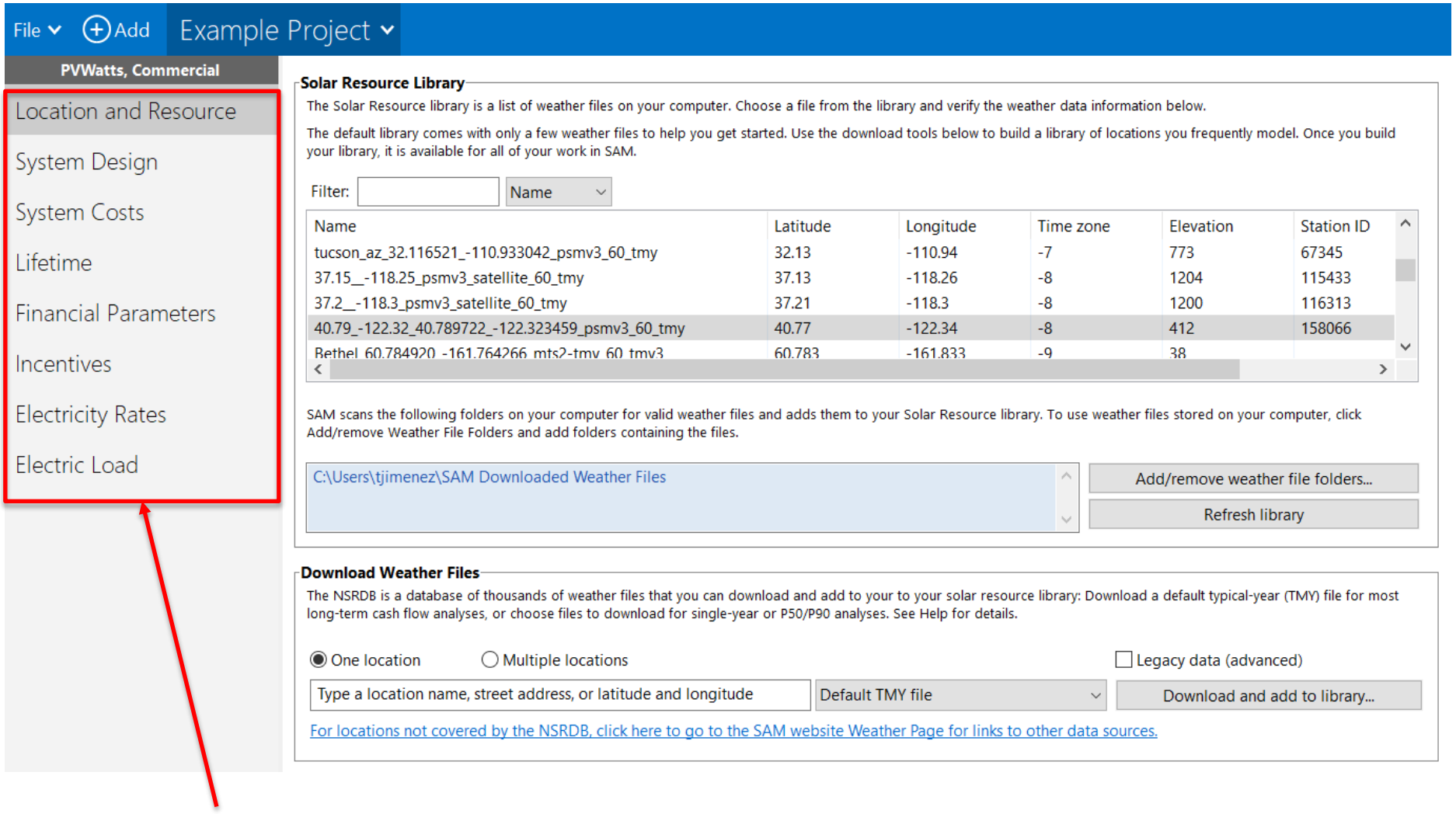
Analysis Facts & Assumptions (3 of 3)

Item	Value	Note/Source
Unit system capital cost ($/kW)	$2,700/kW	*Tracking the Sun*, Small Commercial with assumed cost reductions since 2018.
Operation & Maintenance ($/kW)	$20/kW	Estimate Escalates with inflation
Business model	Tribe owns	
Insurance (% of capital cost)	0%	Rolled into O&M
Inflation	2%	Used to escalate the price of utility power
Tribal Discount Rate (real)	4%	
% Equity	25%	
% Debt	75%	
Interest rate on debt	5%	Assumes some concessional financing
Loan Term (years)	20	
Federal Tax Rate (%)	0%	Tribally owned system
State Tax Rate (%)	0%	Tribally owned system

SAM: Models


Choose a performance model, and then choose from the available financial models.
Photovoltaic (detailed)
Photovoltaic (PVWatts)
High concentration PV
Wind
Biomass combustion
Geothermal
Solar water heating
Generic system
CSP parabolic trough (physical)
CSP parabolic trough (empirical)
CSP power tower molten salt
CSP power tower direct steam
CSP linear Fresnel molten salt
CSP linear Fresnel direct steam
Residential (distributed)
Commercial (distributed)
Third party ownership - host
Third party ownership - host/developer
PPA single owner (utility)
PPA partnership flip with debt (utility)
PPA partnership flip without debt (utility)
PPA sale leaseback (utility)
LCOE calculator (FCR method)
No financial model
Help
OK
Cancel

SAM: Location & Resource



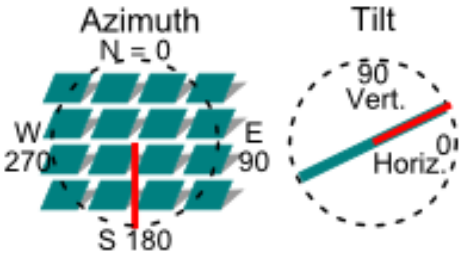
In SAM, you will step through these windows to create your project

SAM: System Design

System Parameters

System nameplate size	80	kWdc
Module type	Standard	
DC to AC ratio	1.2	
Rated inverter size	66.67	kWac
Inverter efficiency	96	%

Orientation



Array type	Fixed open rack	
Tilt	10	degrees
Azimuth	180	degrees
Ground coverage ratio	0.4	

Losses

SAM: System Costs

Direct Capital Costs

Module	1	units	80.0	kWdc/unit	80.0	kWdc	2.70	$/Wdc	$ 216,000.00
Inverter	1	units	66.7	kWac/unit	66.7	kWac	0.00	$/Wdc	$ 0.00
					Battery pack 0.0	kWh	300.00	$/kWh dc	
					Battery power 0.0	kW	600.00	$/kW dc	$ 0.00

	$		$/Wdc		
Balance of system equipment	0.00		0.00		$ 0.00
Installation labor	0.00	+	0.00	=	$ 0.00
Installer margin and overhead	0.00		0.00		$ 0.00
				Subtotal	$ 216,000.00

Contingency

Contingency	0	% of subtotal	$ 0.00
		Total direct cost	$ 216,000.00

Indirect Capital Costs

	% of direct cost		$/Wdc		$		
Permitting and environmental studies	0		0.00		0.00		$ 0.00
Engineering and developer overhead	0	+	0.00	+	0.00	=	$ 0.00
Grid interconnection	0		0.00		0.00		$ 0.00

Land Costs

SAM: Lifetime

System Performance Degradation

Degradation rate Value sched 0.5 %/year

Applies to the system's total annual AC output.

In Value mode, the degradation rate applies to the system's total annual kWh output for the previous year starting in Year 2. In Schedule mode, each year's rate applies to the Year 1 value. See Help for details.

Battery single year analysis

In this mode, one year of degradation of the battery is modeled, which may not accurately represent battery performance in subsequent years. To consider multiyear degradation, including battery replacement costs, please change to the "Photovoltaic (detailed)" model and select "PV simulation over analysis period".

SAM: Financial Parameters

Project Term Debt

Debt percent	75 %	Net capital cost	$ 216,000.00	The weighted average cost of capital (WACC) is displayed for reference. SAM does not use the value for calculations.
Loan term	20 years	Debt	$ 162,000.00	
Loan rate	5 %/year	WACC	5.27 %	For a project with no debt, set the debt percent to zero.

Analysis Parameters

Analysis period	30 years	Inflation rate	2 %/year
		Real discount rate	4 %/year
		Nominal discount rate	6.08 %/year

Project Tax and Insurance Rates

Federal income tax rate	0 %/year	Assessed percentage	100 % of installed cost
State income tax rate	0 %/year	Assessed value	$ 216,000.00
Sales tax	0 % of total direct cost	Annual decline	0 %/year
Insurance rate (annual)	0 % of installed cost	Property tax rate	0 %/year

Salvage Value

Net salvage value	0 % of installed cost	End of analysis period value	$ 0

Depreciation

Federal	State

SAM: Incentives

DSIRE Incentives Database

Go to website...

The online Database of State Incentives for Renewables and Efficiency (DSIRE) contains detailed information for specific incentives in U.S. locations.

Tax Credits

Investment Tax Credit (ITC)

	Amount ($)	Reduces Depreciation Basis: Federal	Reduces Depreciation Basis: State
Federal	0.00	☑	☑
State	0.00	☐	☐

	Percentage (%)	Maximum ($)		
Federal	0	1e+38	☑	☑
State	0	1e+38	☐	☐

Production Tax Credit (PTC)

		Amount ($/kWh)	Term (years)	Escalation (%/yr)
Federal	Value / Sched	0	10	0.00
State	Value / Sched	0	10	0.00

Inflation does not apply to the PTC amount. In Schedule mode, use nominal (current) dollar values. See Help for details.

Direct Cash Incentives

Investment Based Incentive (IBI)

	Amount ($)	Taxable Incentive: Federal	Taxable Incentive: State	Reduces Depreciation and ITC Bases: Federal	Reduces Depreciation and ITC Bases: State
Federal	0.00	☑	☑	☐	☐
State	0.00	☑	☑	☐	☐
Utility	0.00	☑	☑	☐	☐
Other	0.00	☑	☑	☐	☐

SAM: Electricity Rates

OpenEI U.S. Utility Rate Database

Download rate structures for electric utility companies included in the OpenEI Utility Rate Database. After downloading a rate structure, compare the inputs below with a copy of the rate sheet to verify that the information is correct.

Search for rates...

Go to Open EI Utility Rate Database website

Save / Load Rate Data

Save rate to file... | Load rate from file... | C:/Users/jfreeman/Desktop/res.csv

Metering and Billing

- ○ Net energy metering
- ○ Net energy metering with $ credits
- ◉ Net billing
- ○ Net billing with carryover to next month
- ○ Buy all / sell all

Sell rate for kWh credits remaining at end of year 0 $/kWh

☐ Use hourly (subhourly) sell rates instead of TOU sell rates

Hourly (subhourly) sell rates Edit data... $/kWh

Fixed Charge

Fixed monthly charge 30 $

Minimum Charges

Monthly minimum charge 0 $

Annual minimum charge 0 $

Annual Escalation

Electricity bill escalation rate 0 %/yr

In Value mode, enter a rate in real terms because SAM applies both escalation and inflation to the total first-year electricity bill to calculate the annual electricity bill in later years. In Schedule mode, enter rates in nominal terms because inflation does not apply. See Help for details.

SAM: Electric Load

Electric Load Data

Energy usage: Edit data... kW

Scaling factor (optional): 1

☑ Normalize supplied load profile to monthly utility bill data

Monthly energy usage: Edit values... kWh

View load data...

Monthly Load Summary

	Energy (kWh)	Peak (kW)
Jan	60,000.00	150.34
Feb	60,000.00	164.03
Mar	80,000.00	237.45
Apr	80,000.00	293.84
May	80,000.00	298.22
Jun	100,000.00	268.03
Jul	100,000.00	226.93
Aug	100,000.00	253.98
Sep	80,000.00	243.50
Oct	80,000.00	280.17
Nov	80,000.00	215.99
Dec	60,000.00	156.19
Annual	960,000.00	298.22

Annual Adjustment

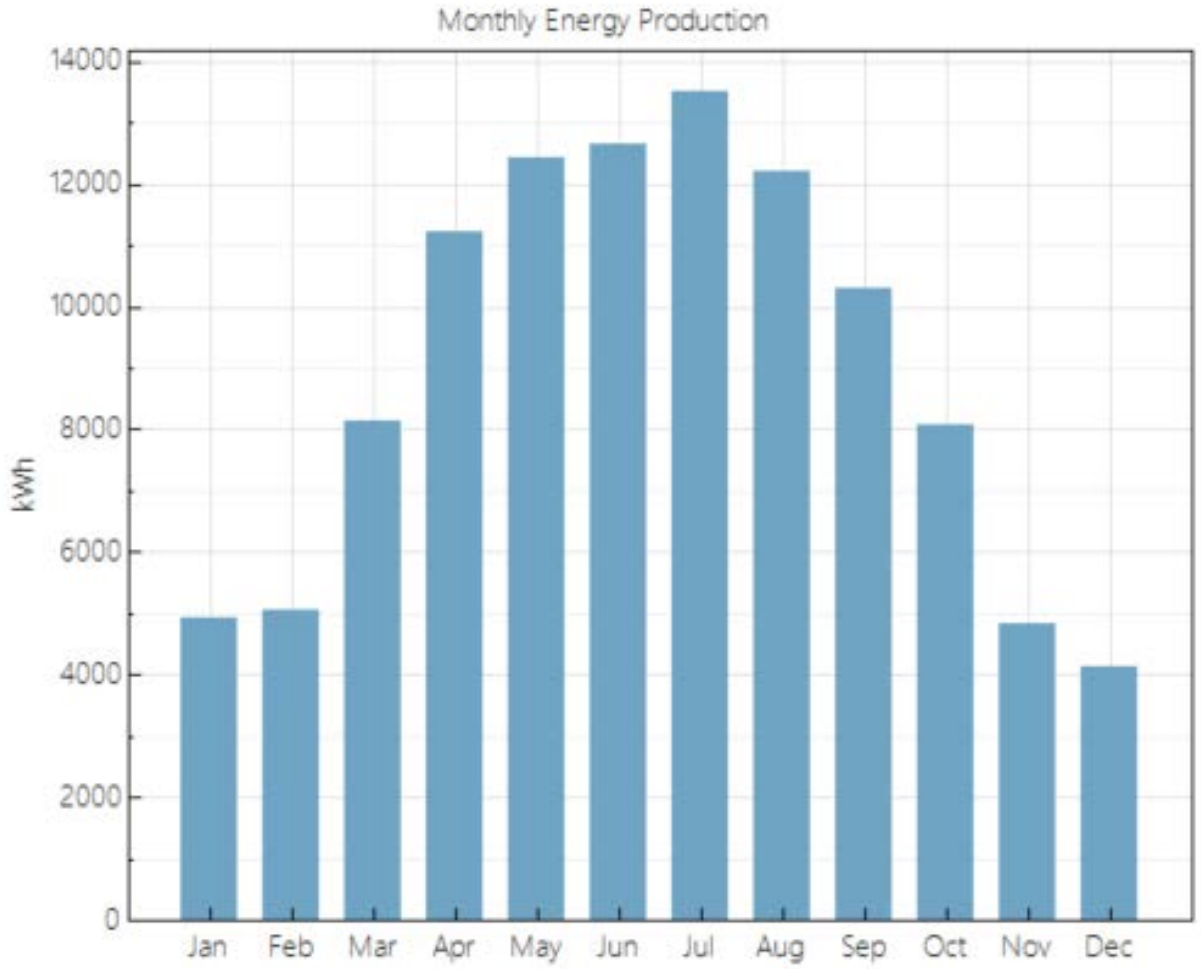
Load growth rate (Value / Sched): 0 %/yr

In Value mode, the growth rate applies to the previous year's annual kWh load starting in Year 2. In Schedule mode, each year's rate applies to the Year 1 kWh value. See Help for details.

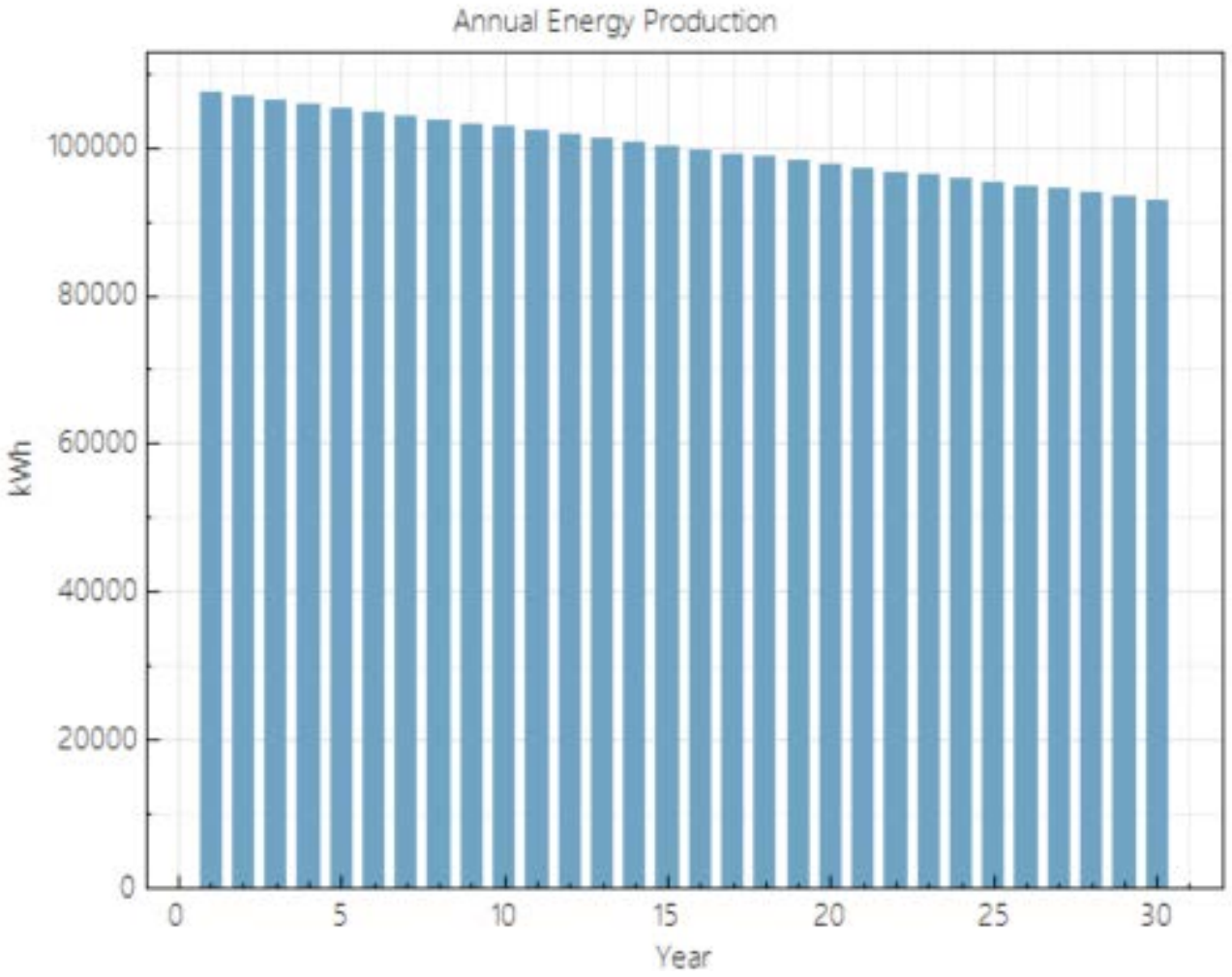
SAM: Results

Metric	Value
Annual energy (year 1)	107,503 kWh
Capacity factor (year 1)	15.3%
Energy yield (year 1)	1,344 kWh/kW
Levelized COE (nominal)	16.44 ¢/kWh
Levelized COE (real)	13.06 ¢/kWh
Electricity bill without system (year 1)	$96,360
Electricity bill with system (year 1)	$85,610
Net savings with system (year 1)	$10,750
Net present value	$-57,181
Simple payback period	20.5 years
Discounted payback period	NaN
Net capital cost	$216,000
Equity	$54,000
Debt	$162,000

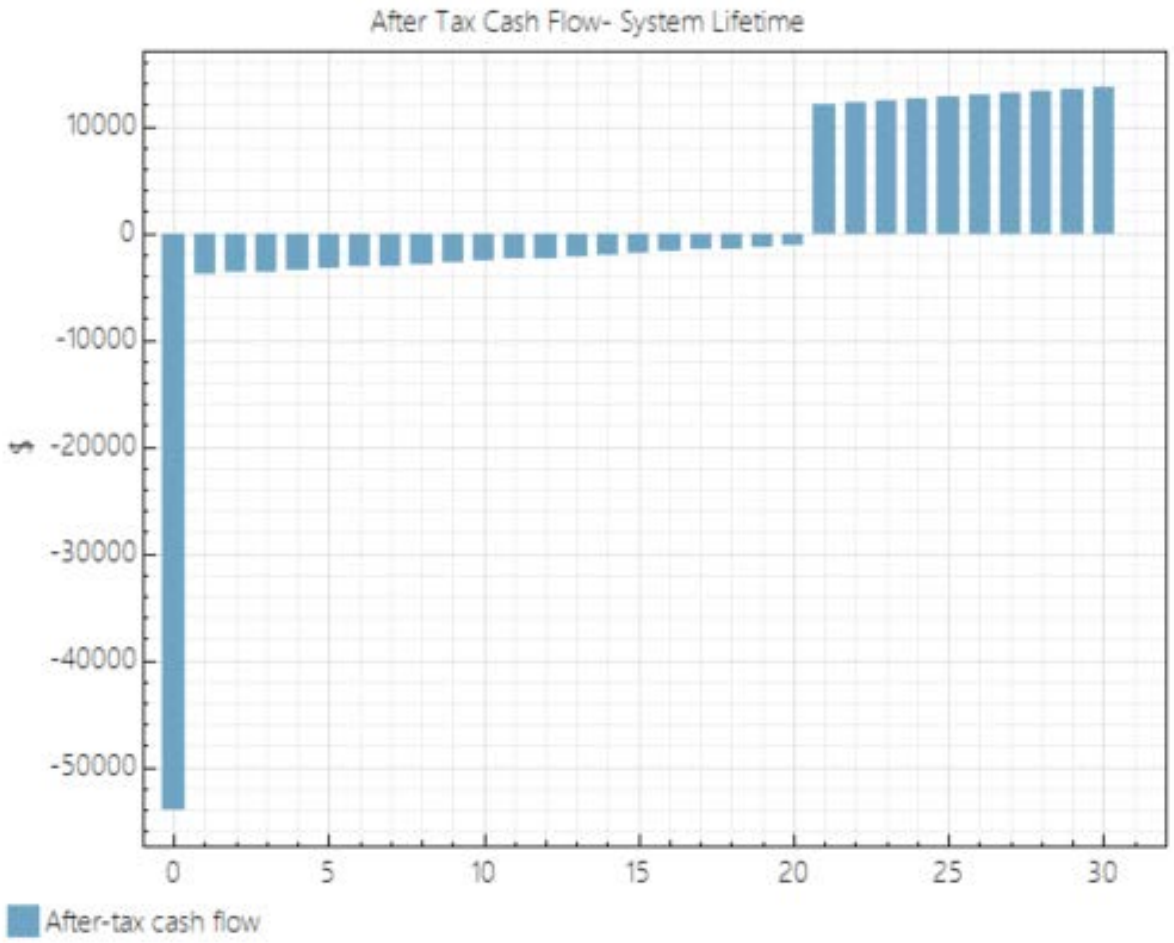
SAM: Results


Monthly Energy Production
kWh
14000
12000
10000
8000
6000
4000
2000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

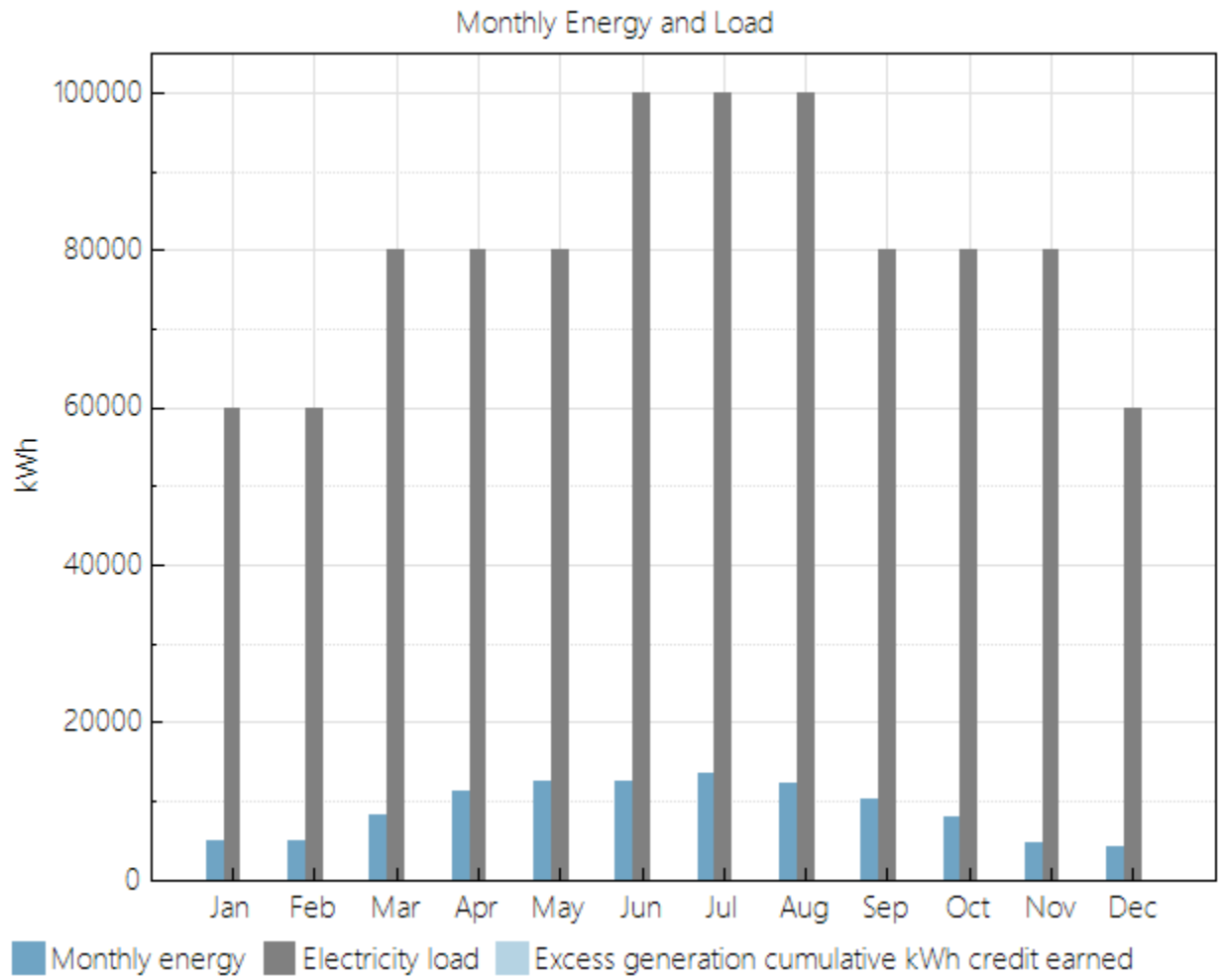
SAM: Results


Annual Energy Production
kWh
100000
80000
60000
40000
20000
0
0
5
10
15
20
25
30
Year

SAM: Results


After Tax Cash Flow- System Lifetime
10000
0
-10000
-20000
-30000
-40000
-50000
$
0
5
10
15
20
25
30
After-tax cash flow

SAM: Results


Monthly Energy and Load
100000
80000
60000
40000
20000
0
kWh
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Monthly energy
Electricity load
Excess generation cumulative kWh credit earned

Presentation Recap

Techno-Economic Modeling (TEM) is the process of estimating the technical and economic performance of a proposed or envisioned project. It is done to inform decision making.

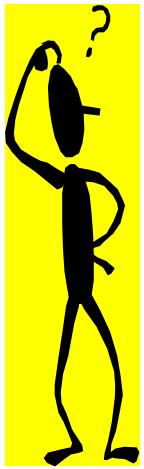
TEM tools are very helpful if you want to go beyond a back of the envelope analysis.

TEM is more than simply running a TEM tool. TEM results need to be leavened with sound judgement and common sense. Also GIGO (Garbage In = Garbage Out)

In TEM it is common to start with a high-level analysis and then iterate with successively more detailed analysis efforts.

Often, the most time-consuming part of the analysis is gathering the needed analysis inputs.

Sources exist that can provide needed renewable energy (RE) resource and RE technology cost information required to conduct TEM.



www.nrel.gov

Tony Jimenez

tony.jimenez@nrel.gov

work: 303-275-4849

NREL
NATIONAL RENEWABLE ENERGY LABORATORY