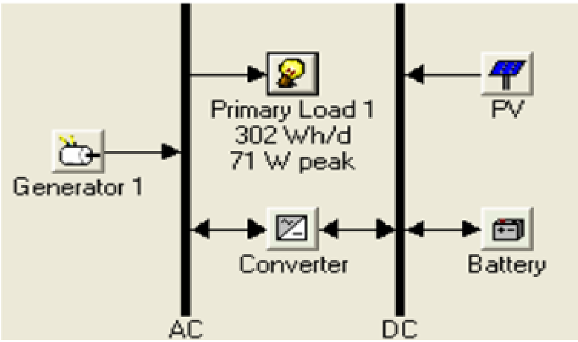
Micro-power System Modeling using HOMER - Tutorial



Charles Kim

Howard University

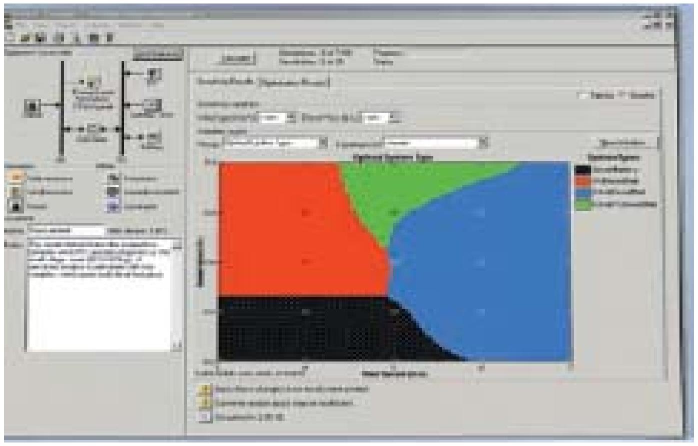
www.mwftr.com

HOMER

- **Homer (Hybrid Optimization Model for Electric Renewables)**

NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

HOMER
The Micropower Optimization Model

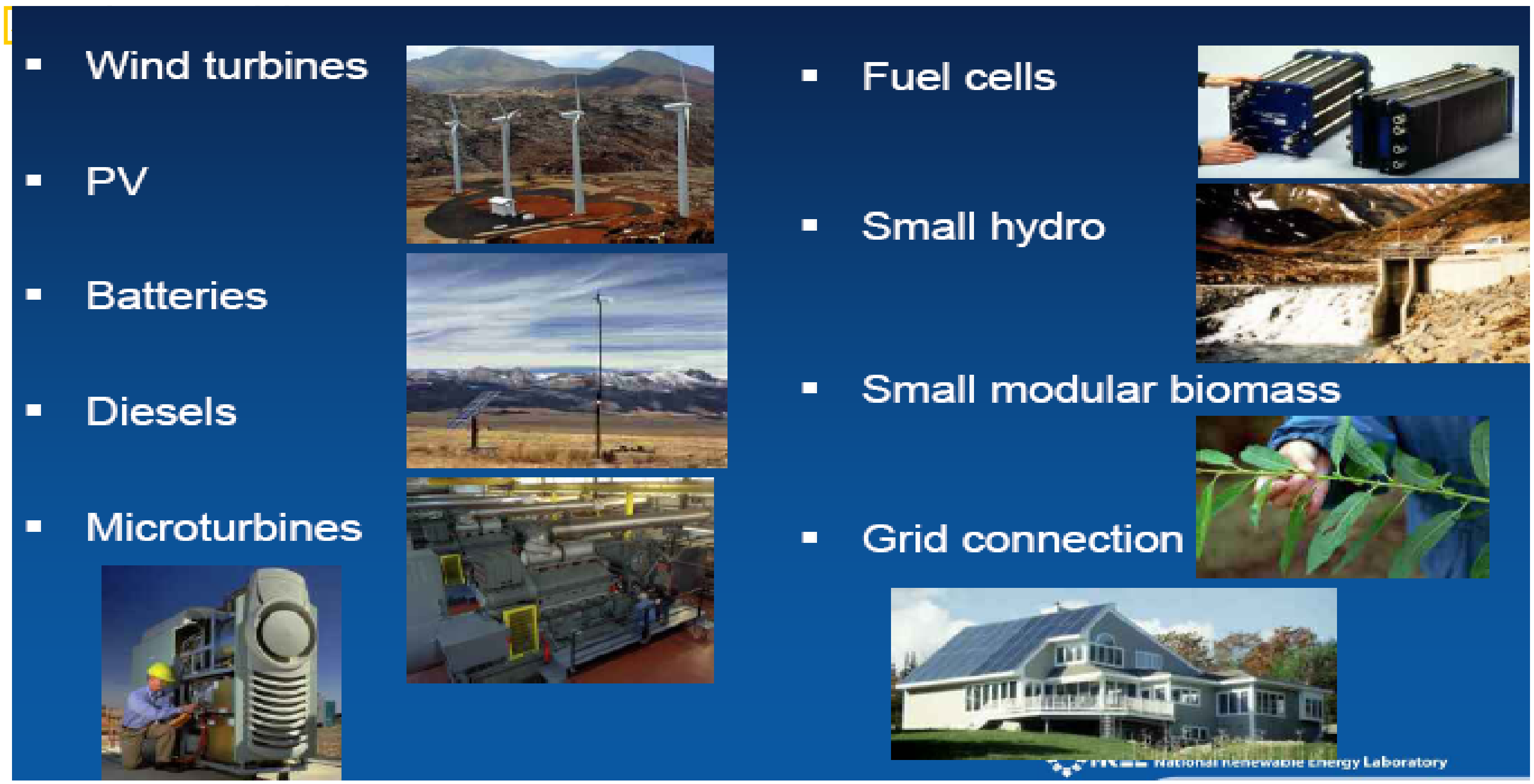


HOMER models micropower systems with single or multiple power sources:

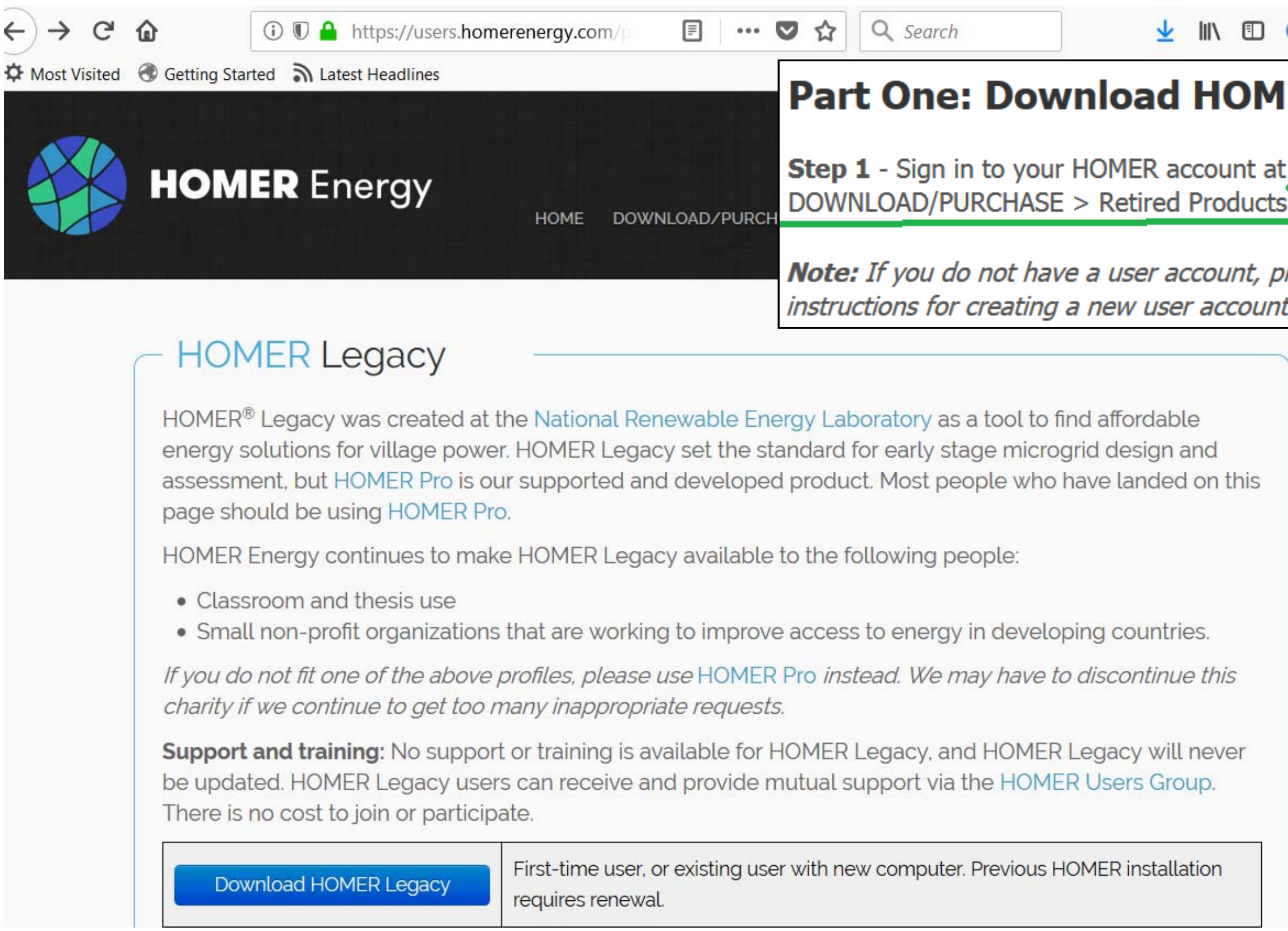
Photovoltaics
Wind turbines
Biomass power
Run-of-river hydro
Diesel and other reciprocating engines
Cogeneration
Microturbines
Batteries
Grid
Fuel cells
Electrolyzers

Homer – a tool

- A tool for designing micropower systems
  - Village power systems
  - Stand-alone applications and Hybrid Systems



“HOMER Legacy” software



https://users.homerenergy.com/

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HOMER Energy

HOME DOWNLOAD/PURCH

HOMER Legacy

HOMER® Legacy was created at the National Renewable Energy Laboratory as a tool to find affordable energy solutions for village power. HOMER Legacy set the standard for early stage microgrid design and assessment, but HOMER Pro is our supported and developed product. Most people who have landed on this page should be using HOMER Pro.

HOMER Energy continues to make HOMER Legacy available to the following people:

- Classroom and thesis use
- Small non-profit organizations that are working to improve access to energy in developing countries.

If you do not fit one of the above profiles, please use HOMER Pro *instead. We may have to discontinue this charity if we continue to get too many inappropriate requests.*

Support and training: No support or training is available for HOMER Legacy, and HOMER Legacy will never be updated. HOMER Legacy users can receive and provide mutual support via the HOMER Users Group. There is no cost to join or participate.

Download HOMER Legacy	First-time user, or existing user with new computer. Previous HOMER installation requires renewal.

Part One: Download HOMER Legacy

Step 1 - Sign in to your HOMER account at users.homerenergy.com, navigate to DOWNLOAD/PURCHASE > Retired Products > HOMER Legacy.

Note: *If you do not have a user account, please refer to instructions for creating a new user account.*

Homer - capabilities

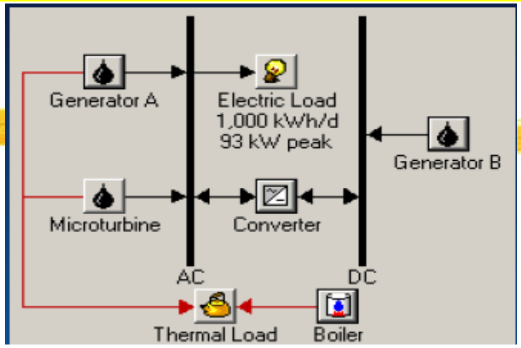
- Finds combination components that can service a load at the lowest cost with answering the following questions:
  - Should I buy a wind turbine, PV array, or both?
  - Will my design meet growing demand?
  - How big should my battery bank be?
  - What if the fuel price changes?
  - How should I operate my system?
  - And many others…

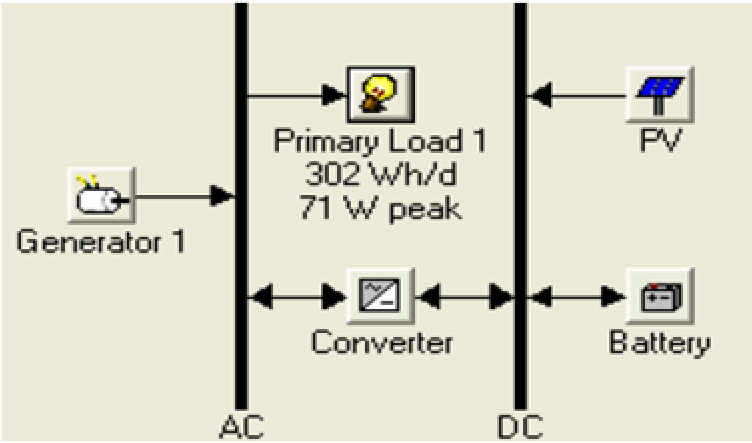
Homer - Features

- Simulation–Estimate the cost and determine the feasibility of a system design over the 8760 hours in a year
- Optimization–Simulate each system configuration and display list of systems sorted by net present cost (NPC)
  - Life-Cycle Cost:
    - Initial cost – purchases and installation
    - Cost of owning and O&M and replacement
  - NPC: Life-cycle cost expressed as a lump sum in "today's dollars"
- Sensitivity Analysis–Perform an optimization for each sensitivity variable

Features

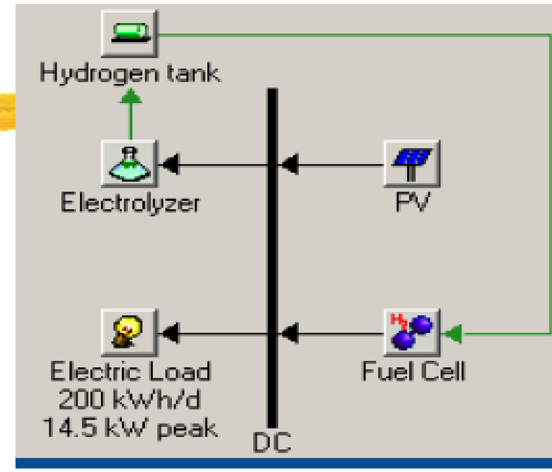
- Homer can accept max 3 generators
  - Fossil Fuels
  - Biofuels
  - Cogeneration
- Renewable Technologies
  - Solar PV
  - Wind
  - Biomass and biofuels
  - Hydro

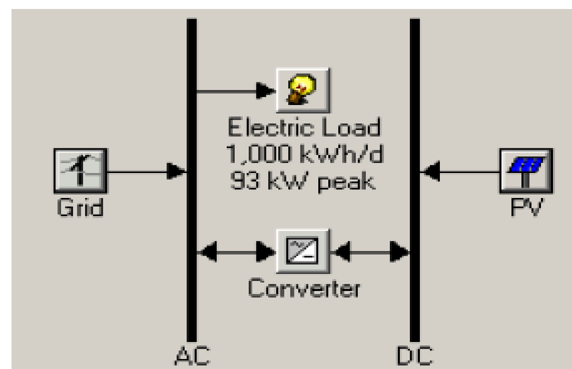




Features

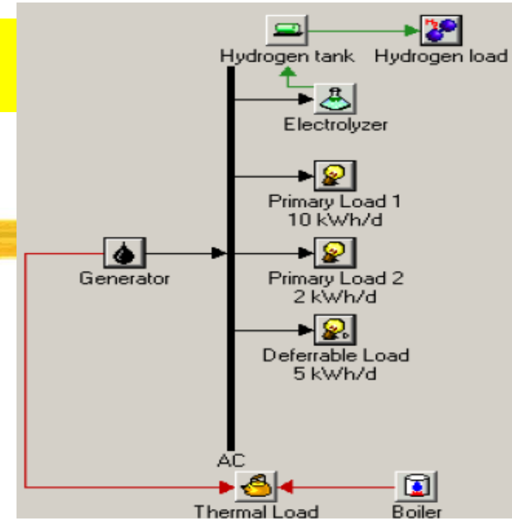
- Emerging Technologies
  - Fuel Cells
  - Microturbines
  - Small Modular biomass
- Grid Connected System
  - Rate Schedule, Net metering, and Demand Charges
- Grid Extension
  - Breakeven grid extension distance: minimum distance between system and grid that is economically feasible

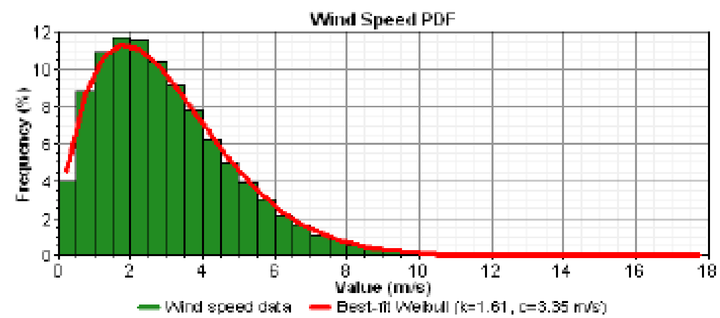


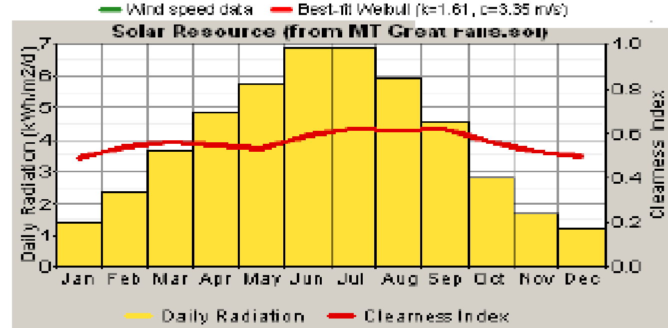


Features

- ⌘ Loads
  - Electrical
  - Thermal
  - Hydrogen
- ⌘ Resources
  - Wind speed (m/s)
  - Solar radiation (kWh/m^2/day)
  - Stream Flow (L/s)
  - Fuel price ($/L)





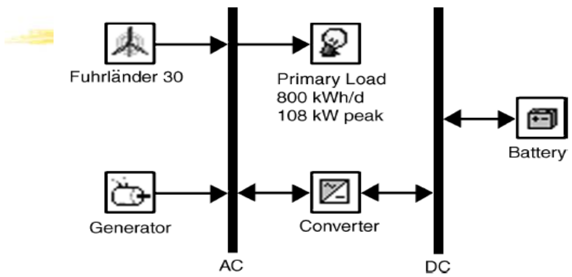


Optimization

- Best possible system configuration that satisfies the user-specified constraints at the **lowest total NPC (net present cost).**
- Decide on the mix of components that the system should contain, the **size** or **quantity** of each component,
- Ranks the feasible ones according to total net present cost

Optimization Example

- Configuration and 140 (5x1x7x4=140) search spaces



	FL30 (Quantity)	Gen (kW)	Batteries (Quantity)	Converter (kW)
1	0	135.00	0	0.00
2	1		16	30.00
3	2		32	60.00
4	3		48	120.00
5	4		64	
6			96	
7			128	
8				

- **Overall** Optimization results

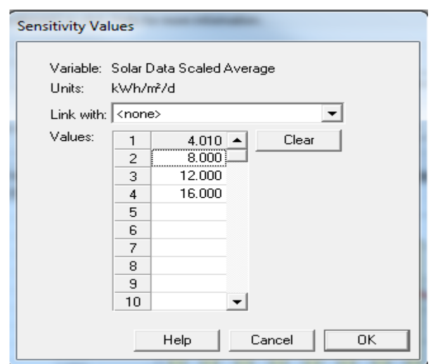
FL30	Gen (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Diesel (L)	Gen (hrs)
1	135	64	30	$ 216,500	$ 849,905	0.273	75,107	4,528
2	135	64	30	$ 346,500	$ 854,660	0.274	54,434	3,350
1	135	48	30	$ 200,500	$ 855,733	0.275	78,061	4,910
2	135	48	30	$ 330,500	$ 856,335	0.275	57,654	3,685

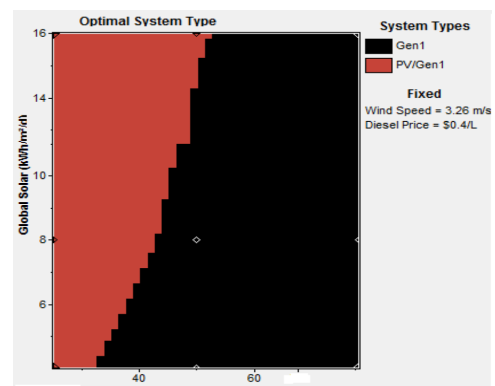
- **Categorized** optimization result

FL30	Gen (kW)	Batt.	Conv. (kW)	Initial Capital	Total NPC	COE ($/kWh)	Diesel (L)	Gen (hrs)
1	135	64	30	$ 216,500	$ 849,905	0.273	75,107	4,528
	135	64	30	$ 86,500	$ 885,175	0.284	101,290	5,528
	135			$ 0	$ 996,273	0.320	132,357	8,760
1	135			$ 130,000	$ 1,130,637	0.363	127,679	8,740

Sensitivity Analysis

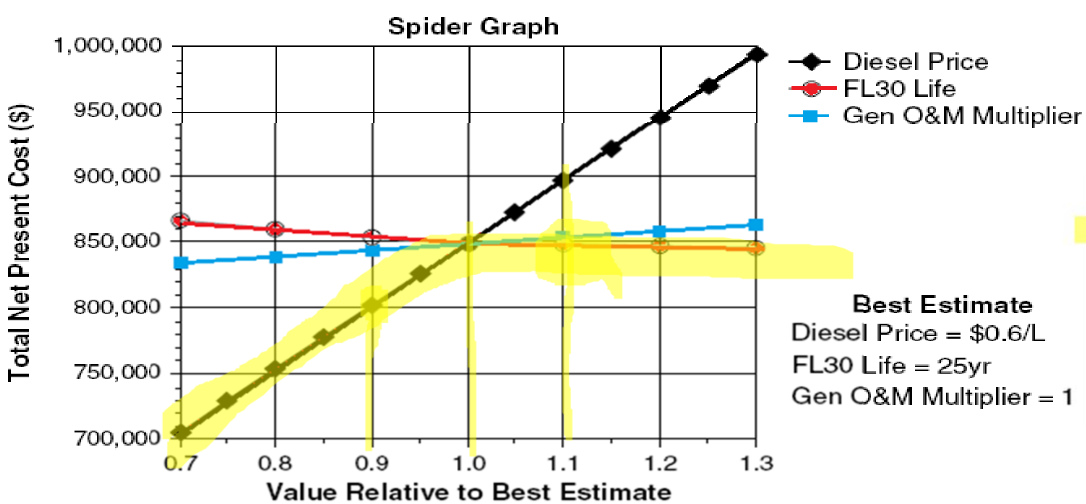
- Optimization: best configuration under a particular set of input assumptions
- Sensitivity Analysis: Multiple optimizations each using a **different set of input assumptions**
- "How sensitive the outputs are to changes in the inputs" – results in various tabular and graphic formats
- User enters a range of values for a single input variable:
  - Grid power price
  - Fuel price,
  - Interest rate
  - Lifetime of PV array
  - Solar Radiation
  - Wind Speed





Why Sensitivity Analysis? Uncertainty!

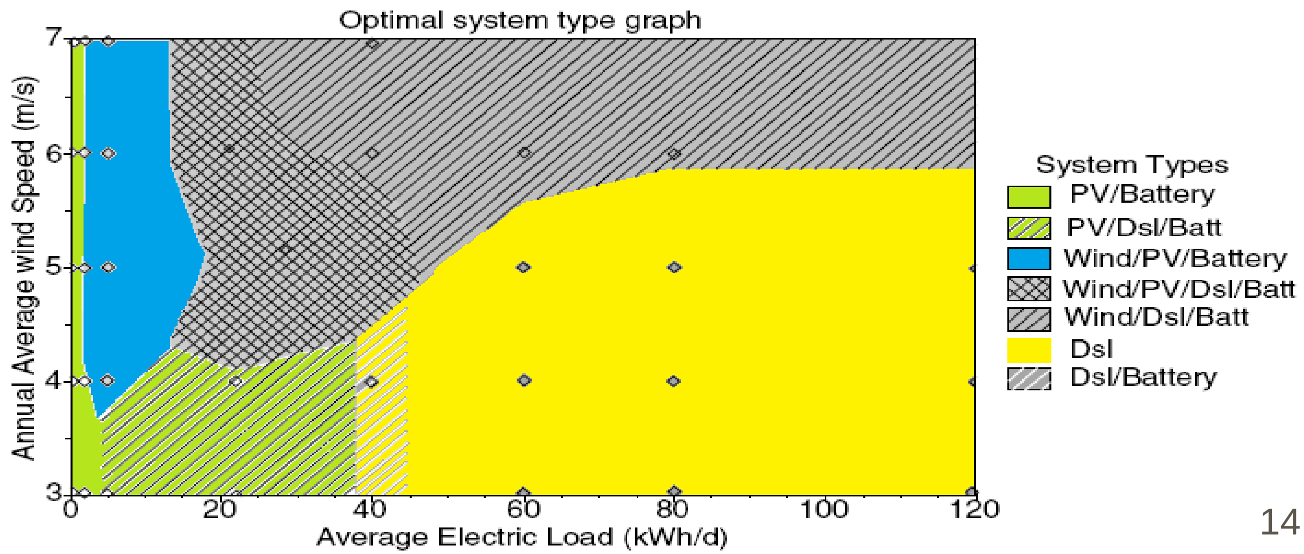
- When unsure of a particular variable, enter several values covering the likely range and see how the results vary across the range.
- Diesel Generator – Wind Configuration: Uncertainty in diesel fuel price with $0.6 per liter in the planning stage and 30 year generator lifetime
- Example: **<u>Spider Graph</u>** **<u>Tabular Format</u>**



Diesel ($/L)	FL30	Gen (kW)	Batt.	Conv. (kW)	Total NPC
0.420		135	48	30	$ 688,679
0.450		135	48	30	$ 721,987
0.480	1	135	64	30	$ 753,695
0.510	1	135	64	30	$ 777,748
0.540	1	135	64	30	$ 801,800
0.570	1	135	64	30	$ 825,852
0.600	1	135	64	30	$ 849,905
0.630	2	135	64	30	$ 872,093
0.660	2	135	64	30	$ 889,525
0.690	2	135	64	30	$ 906,957
0.720	2	135	64	30	$ 924,389

Sensitivity Analysis on Hourly Data Sets

- Sensitivity analysis on hourly data sets such as primary electric load, solar/wind resource
- 8760 values that have a certain average value with scaling variables
- Example: Graphical Illustration
  - Hourly primary load data with an annual average of 22 kWh/day with average wind speed of 4 m/s
  - Primary load scaling variables of 20, 40, ---, 120kWh/day & 3, 4, ---, 7 m/s wind speeds.



Resources Modeling

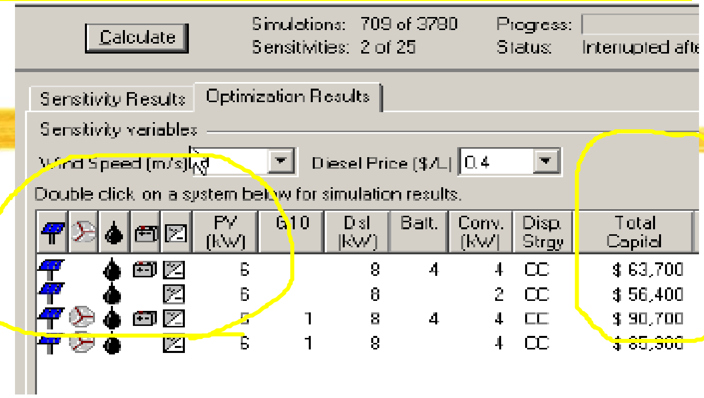
- **Solar Resources**: average global solar radiation on horizontal surface (kWh/m^2 or kWh/m^2-day) **or** monthly average clearness index (atmosphere vs. earth surface). Inputs – solar radiation values and the latitude and the longitude. Output – 8760 hour data set
- **Wind Resources**: Hourly or 12 monthly average wind speeds. Anemometer height. Wind turbine hub height. Elevation of the site.
- **Hydro Resources**: Run-of-river hydro turbine. Hourly (or monthly average) stream flow data.
- **Biomass Resources**: wood waste, agricultural residue, animal waste, energy crops. Liquid or gaseous fuel.
- **Fuel**: density, lower heating value, carbon content, sulfur content. Price and consumption limits

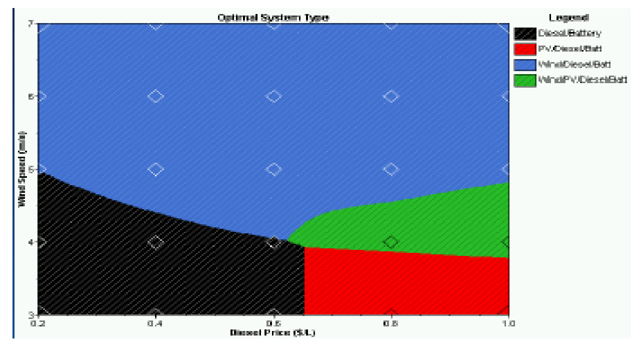
Component Modeling– See **Appendix** for details

- HOMER models 10 types of part that generates, delivers, converts, or stores energy
  - 3 intermittent renewable resources:
    - PV modules (dc)
    - wind turbines (dc or ac)
    - run-of-river hydro turbines (dc or ac)
  - 3 dispatchable energy sources: [control them as needed]
    - Generators
    - the grid
    - boilers
  - 2 energy converters:
    - Converters (dc ←→ ac)
    - Electrolyzers (ac,dc → electrolysis → Hydrogen)
  - 2 types of energy storage:
    - batteries (dc)
    - hydrogen storage tanks

How to build a HOMER project

- 1. Collect Information
  - Electric demand (load)
  - Energy resources
- 2. Define Options (Gen, Grid, etc)
- 3. Enter Load Data
- 4. Enter Resource Data
- 5. Enter Component Sizes and Costs
- 6. Enter Sensitivity Variable Values
- 7. Calculate Results
- 8. Examine Results

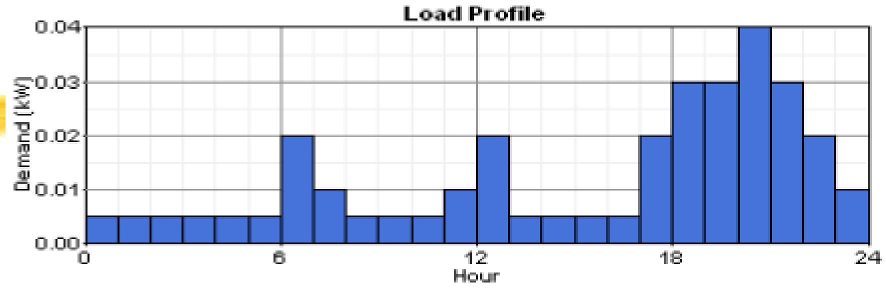


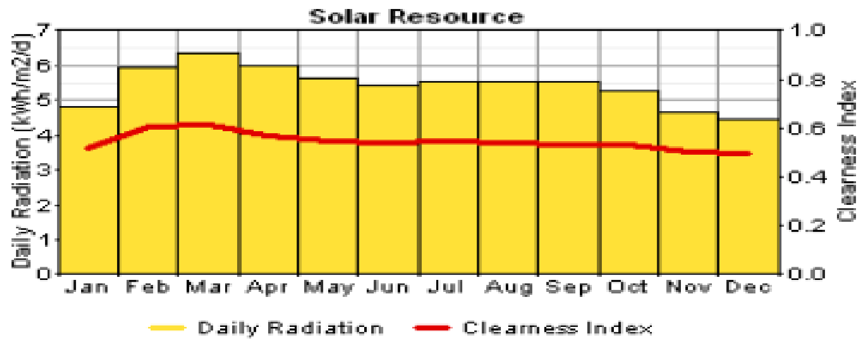


- Caveat: <u>HOMER is only a model. HOMER does not provide "the right answer" to questions.</u> It does help you <u>consider important factors, and evaluate and compare options.</u>

Example Case – Micro Grid in Sri Lanka

- Load profile:
  - base load of 5W, small peaks of 20 W, peak load of 40W; total daily average load = 350 Wh
  - Sensitivity analysis range: [0.3kW/h, 16kWh/d]
- Solar Resource
  - 7.30 Latitude & 81.30 longitude
  - NASA Surface Meteorology and Solar Energy Web: average solar radiation = 5.43 kWh/m²/d.
- Diesel Fuel Price
  - $0.4/L – $0.7/L
  - Sensitivity analysis range: [$0.3, 0.8] with increment of $0.1/L

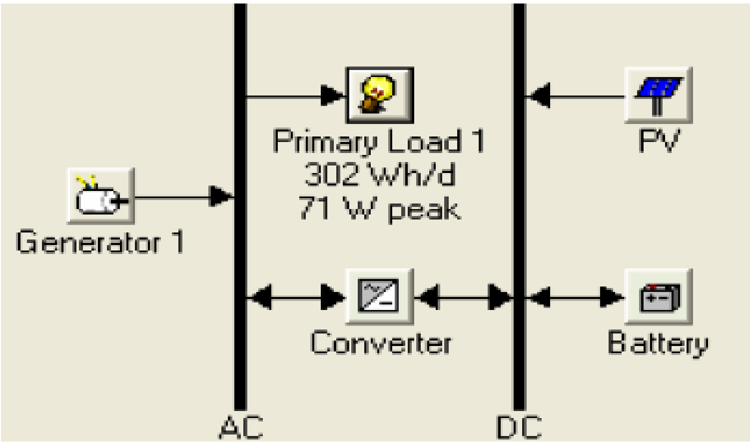




- **Economics:**
  - Real annual interest rate at 6%
- **Reliability Constraints**
  - 0% annual capacity shortage Sensitivity Analysis range: [0,5 – 5]%

Example Case – Micro Grid in Sri Lanka

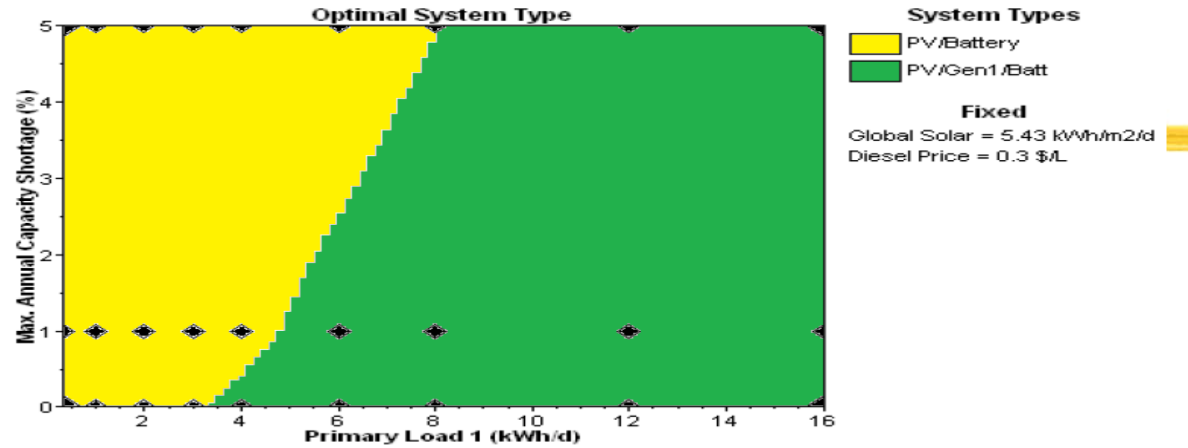
- PV: de-rating factor at 90%
- Battery:T-105 or L-16
- Converters: efficiency at 90% for inversion and 85% for rectification
- Generator: not allowed to operate at less than 30% capacity



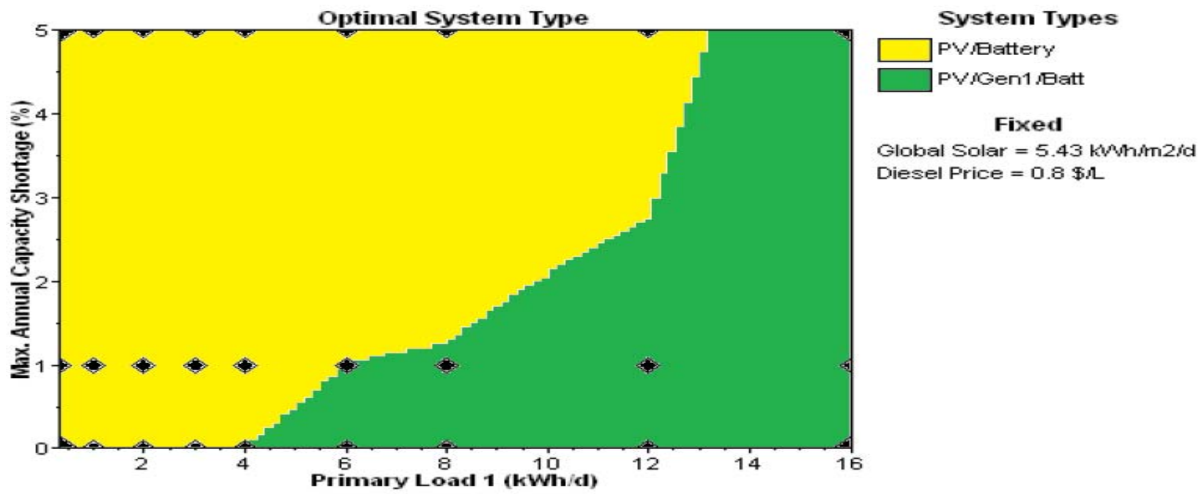
Component	Size	Capital Cost ($)	Replacement Cost	O&M Cost ($)	Lifetime
PV Panels	0.05 – 5.0 kW	$7,500/kW	$7,500/kW	0.00	20 years
Trojan T-105 Batteries	225 Ah / 6 volt (bank size: 1 – 54 batteries)	$75/battery	$75/battery	$2.00/year	845 kWh of throughput per battery
Converter	0.1 – 4.0 kW	$1,000/kW	$1,000/kW	$100/year	15 years
Generator	4.25 kW	$2,550	$2,550	$0.15/hour	5000 hours

Analysis Result

⌘Diesel price $0.3/L



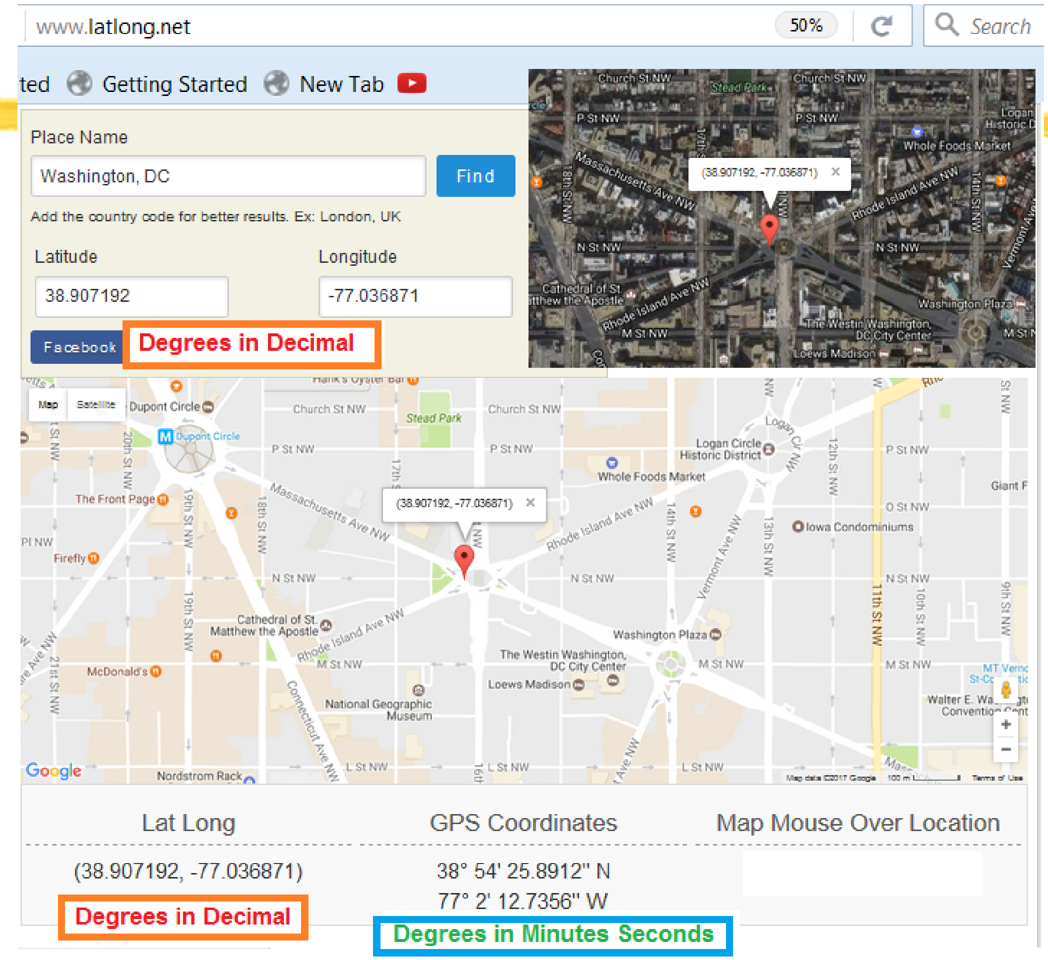
⌘Diesel Price $0.8/L



Find the Site [Location]

- **Latitude and Longitude**

- Your dorm room
- Your home
- Your favorite place



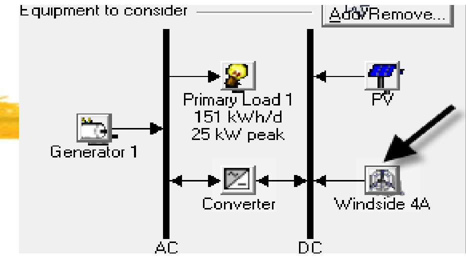
Monthly Wind Speed: Search Web

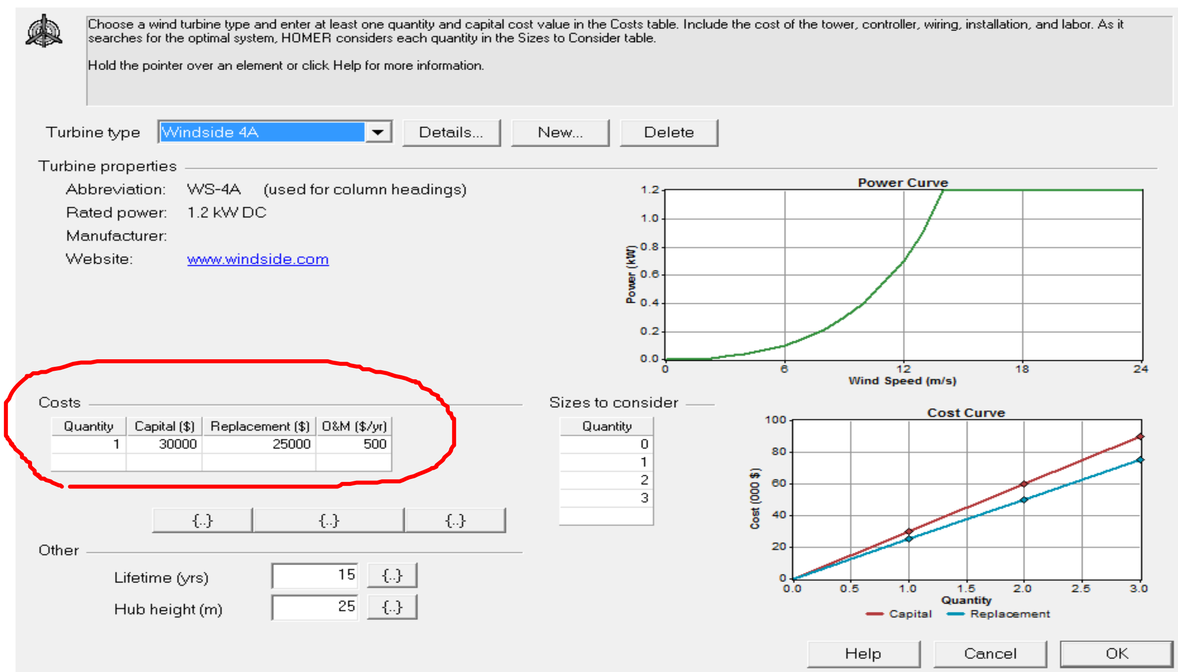
one example website: https://www.weather-and-climate.com

Sources for Wind Data

Equipment

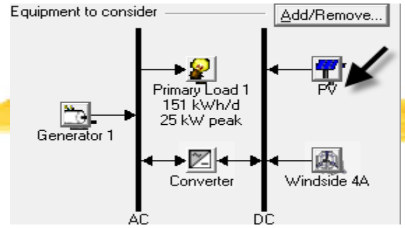
- Wind Turbine
  - From the drop down list click through the wind turbines and look at the power curve. Try to find a Wind Turbine that would best maximize Average Wind Speed (m/s) :3.27



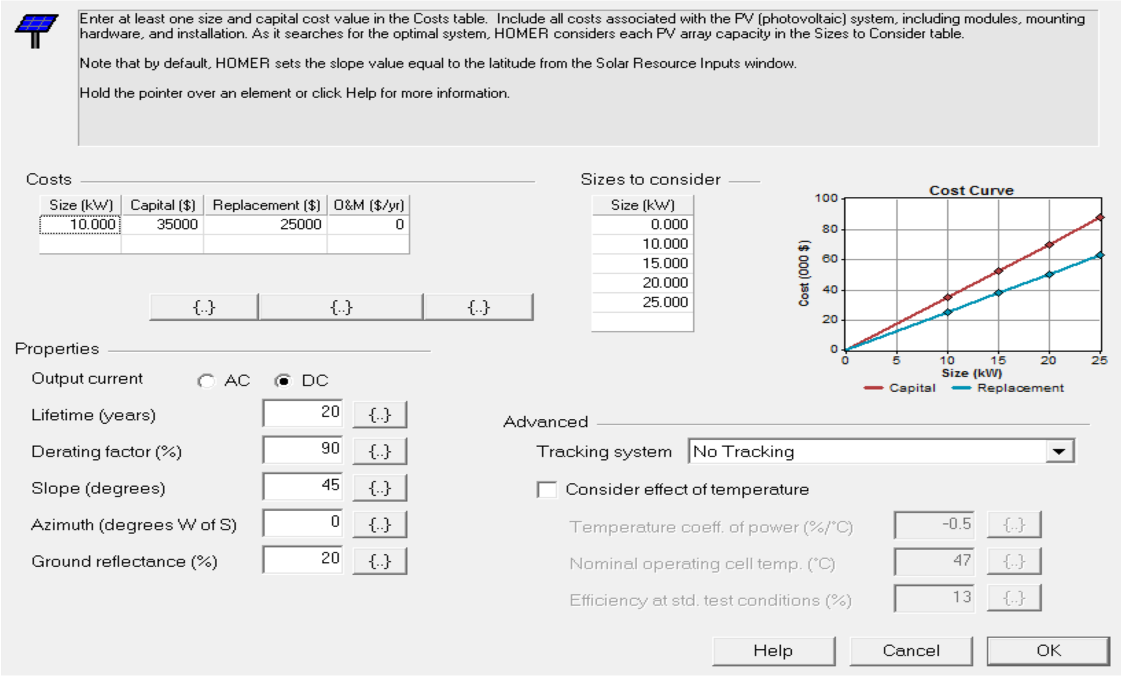


Equipment

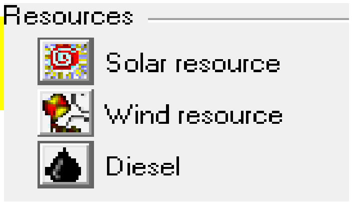
- PV



- Lifetime, De-rating factor, slope, No-tracking

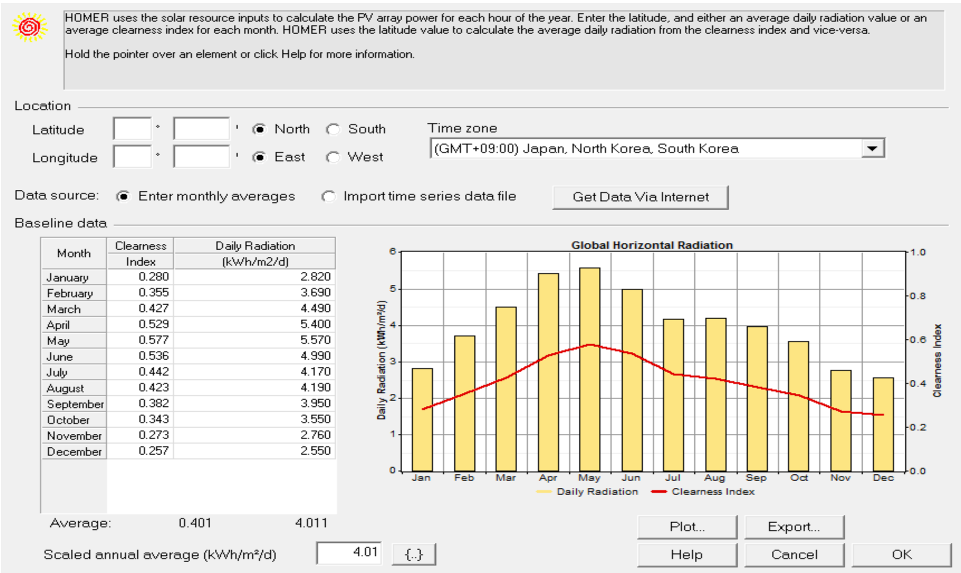


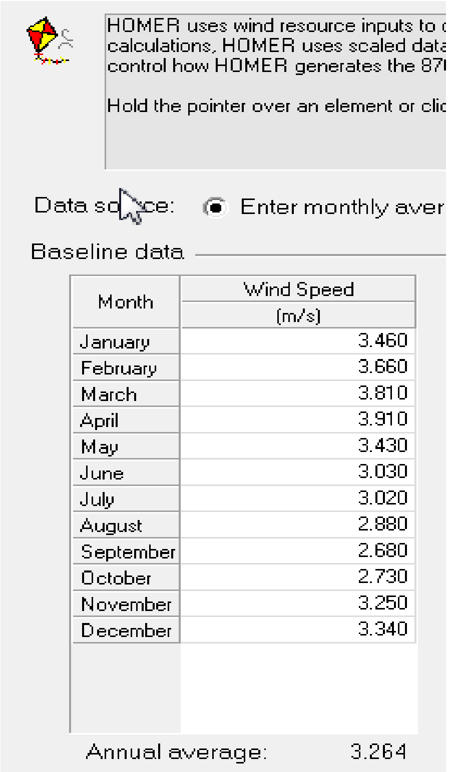
Resource Information



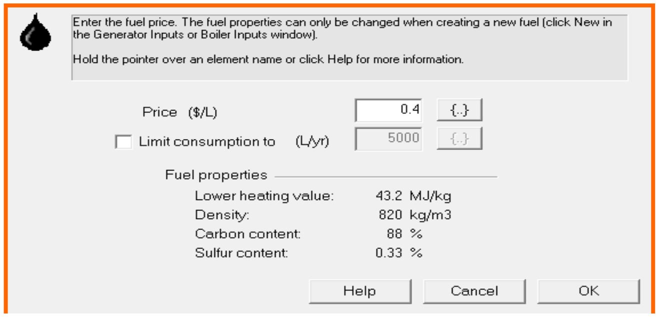
- Select Solar Resources, Wind Resources, and Diesel
- Type in Solar Radiation

Type in Wind Speed



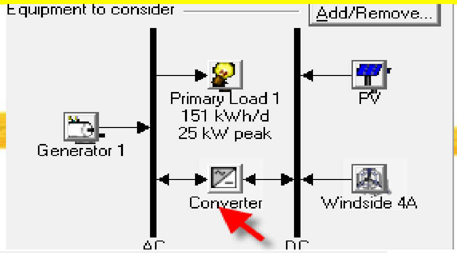


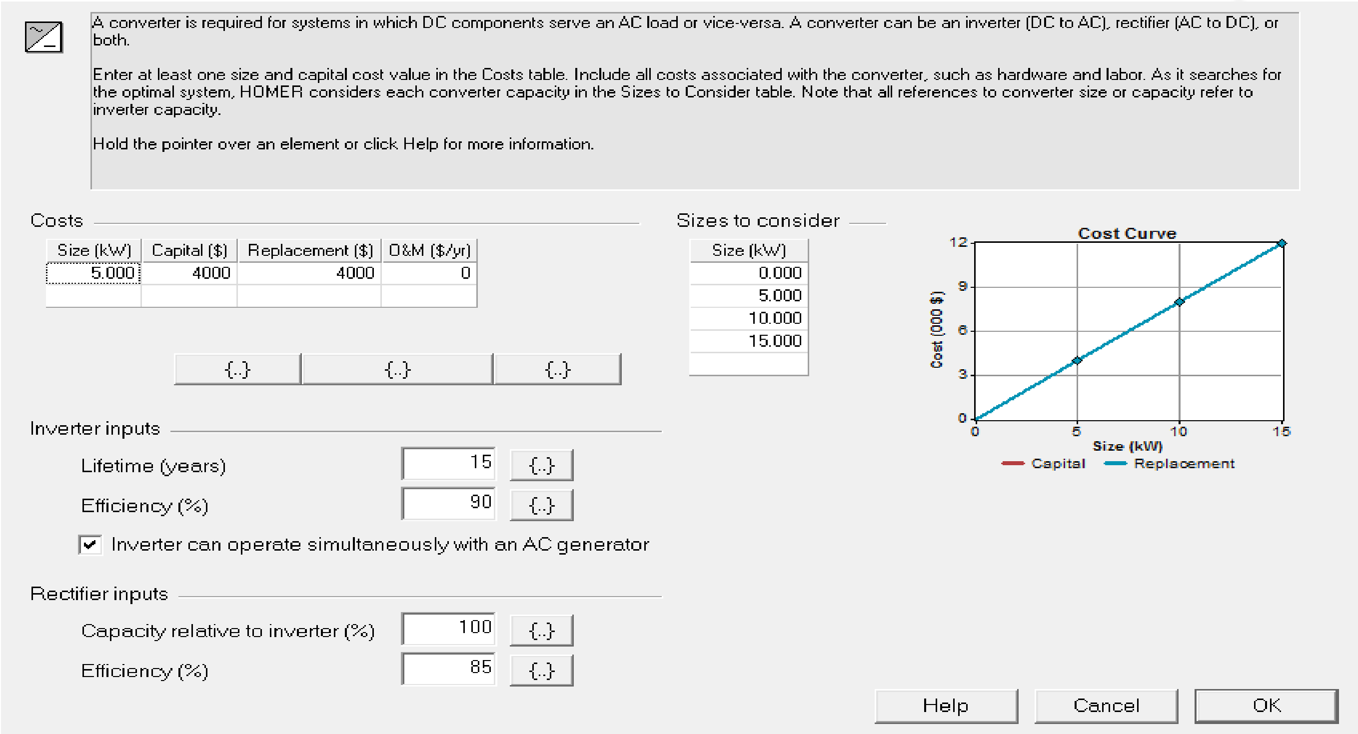
- Diesel Fuel Price



Equipment

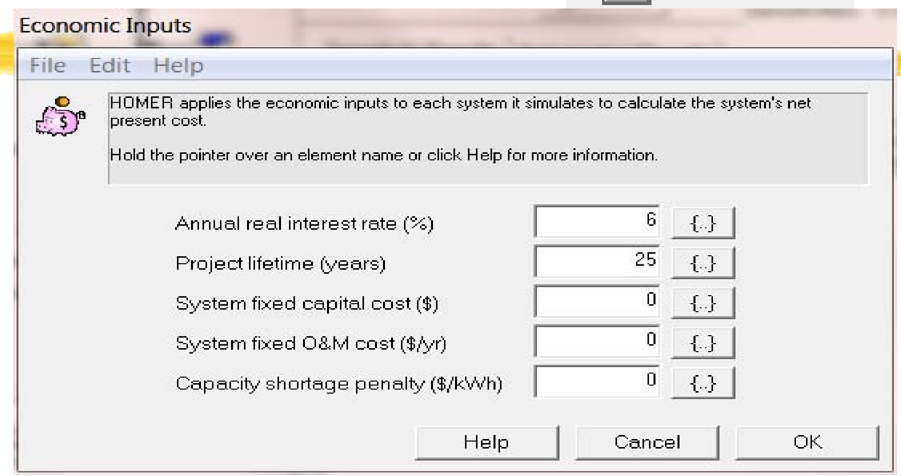
- Converter
- 5kW $4,000

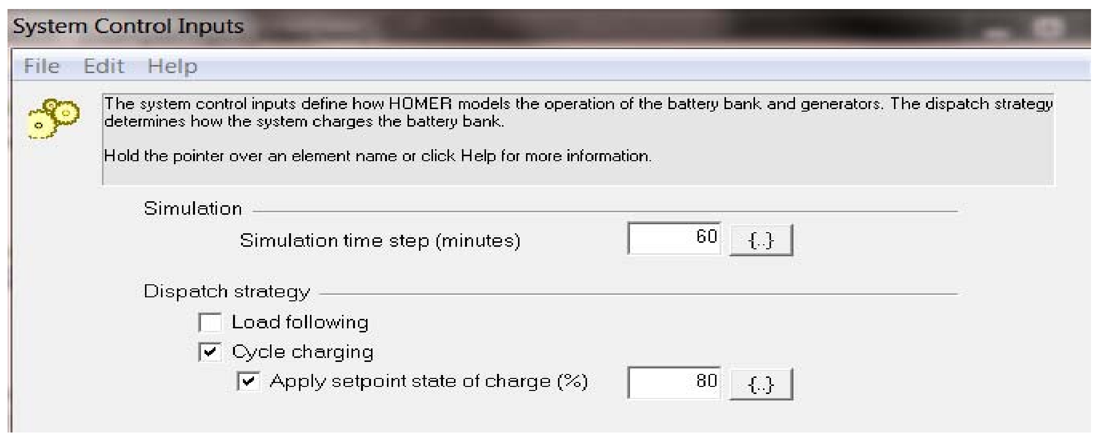




Other Information

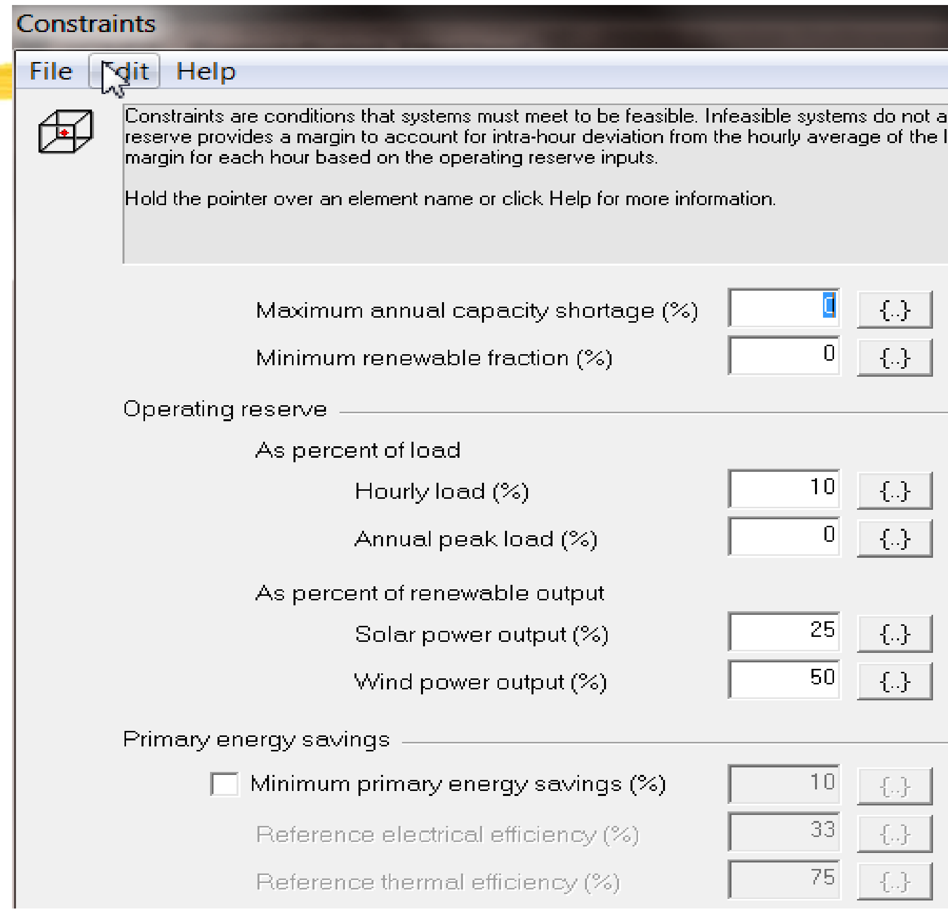
- ⌘Economics
  - Real interest 6 %
  - Lifetime 25 years
- ⌘System Control
  - Cycle-charging





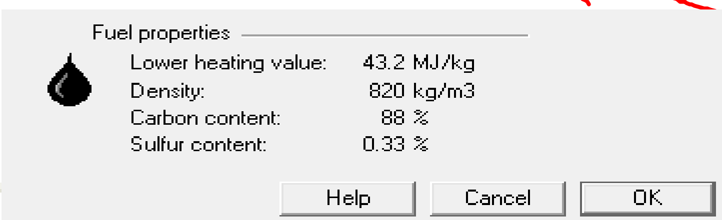
Other Information

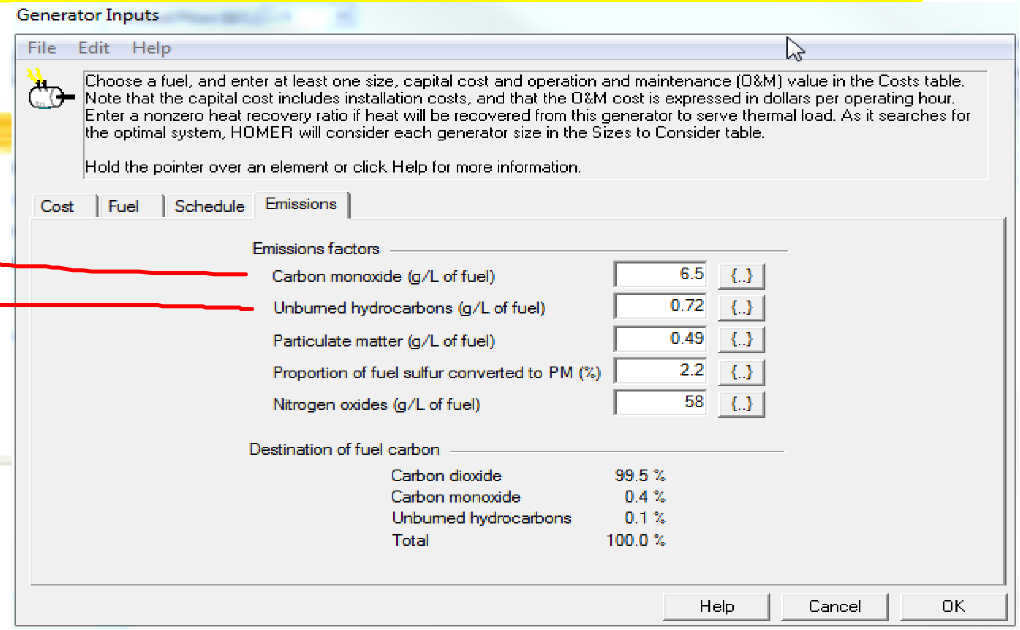
- Constraints
  - Operating reserve 10%
  - Capacity shortage 0%



Emission Calculation in HOMER

- Carbon content of fuel
- If CO_2 is only interest
  - Set 0 to CO





10080 - Emission calculation

Posted by on 15 December 2010 03:49 PM

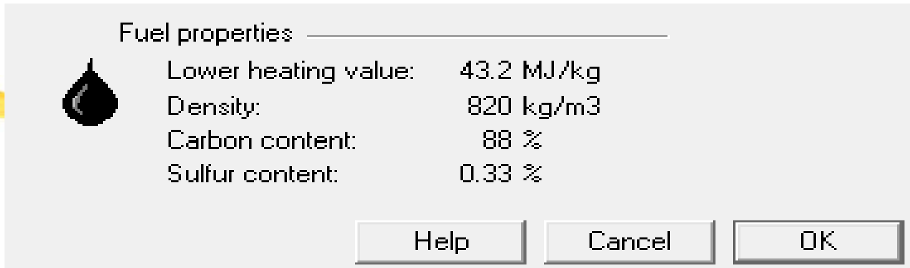
How does HOMER calculate emission, especially carbon dioxide?

If the system you are modeling consumes fuel, HOMER calculates the total annual carbon input by multiplying the fuel consumption by the carbon content of the fuel. It assumes that all that carbon gets emitted as either unburned hydrocarbons, CO, or CO2. You enter the emissions factors for unburned hydrocarbons and CO, so HOMER can calculate how much of the total carbon gets emitted in those two forms. The rest gets emitted as CO2.

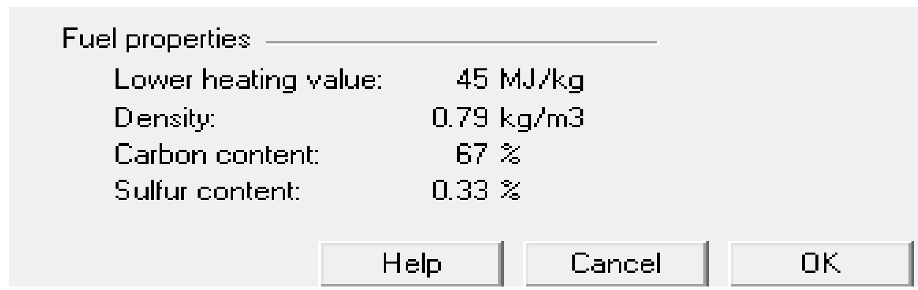
Typically only a tiny fraction of the carbon gets emitted as hydrocarbon and CO, so nearly all of it gets emitted as CO2. If you are interested only in CO2, you should set the UHC and CO emissions factors to zero. Note that 3.67 g of CO2 contains 1 g of carbon. So ignoring UHC and CO emissions, the system will emit 3.67 g of CO2 for every g of carbon in the consumed fuel.

Fuel Carbon Content

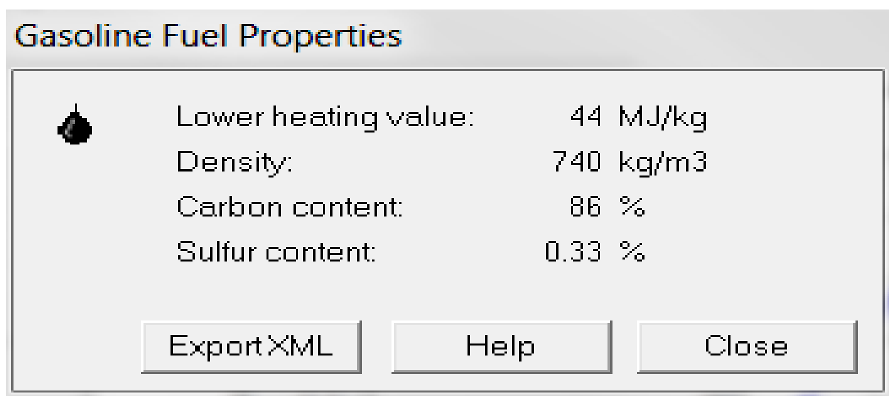
⌘Diesel



⌘Natural Gas



⌘Gasoline



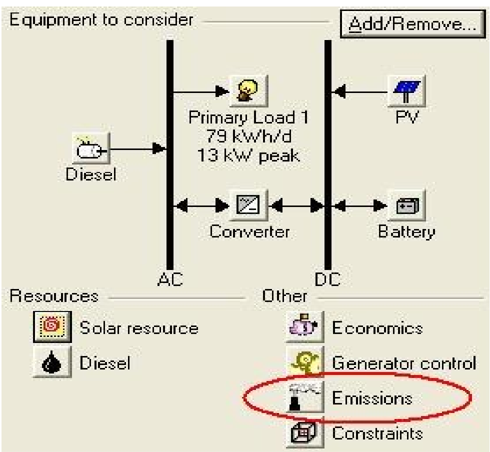
Carbon Tax or Penalty

10397 - HOMER and Carbon

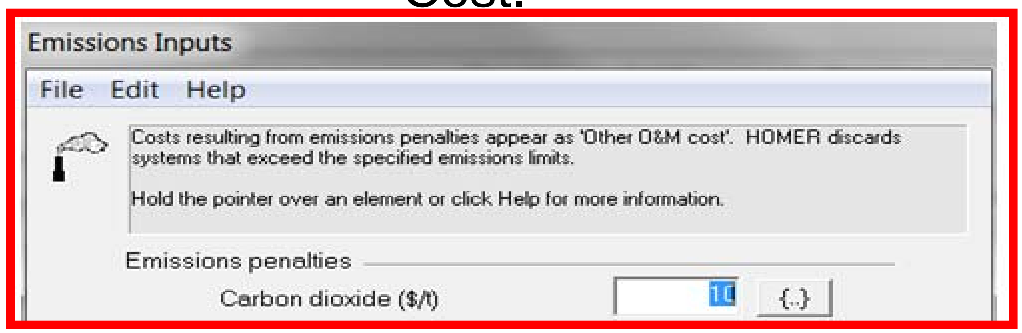
Posted by on 04 January 2011 11:50 AM

The best way to use HOMER and Carbon? Two scenarios suppose you are carbon capped would you just put in a fuel cap. If you are carbon taxed would you just add cost to fuel.

You can limit or penalize emissions if you click the Emissions button just below the schematic:



- ⌘ Carbon penalty will appear as ”Other” O&M Cost.



To cap carbon dioxide emissions, click the CO_2 checkbox in the lower half of the Emissions window and enter the maximum allowable emissions in kg/yr. To apply a carbon tax enter the penalty in $/tonne in the top half of the window. Just be sure to enter it in terms of $/tonne of CO_2, not per tonne of carbon.

You can limit fuel consumption if you click on the fuel button below the schematic. That would have the same effect as limiting emissions, but you would have to calculate the amount of fuel corresponding to your emission cap. It's easier to just enter the emission cap. Same with the carbon tax – you could calculate the equivalent cost per litre of fuel and increase the fuel price accordingly, but it's easier to just enter the emission penalty.

Example

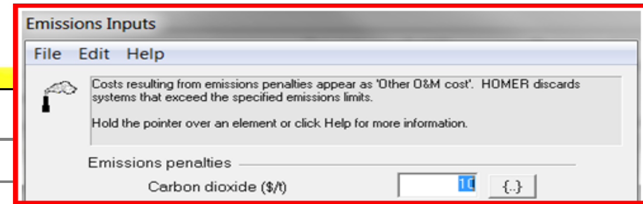
- 3 Generators only to meet a load
  - Diesel generator – Carbon 88% of 820 kg per 1000 L
  - Gasoline generator – Carbon 86% of 740 kg per 1000L
  - Natural Gas generator – Carbon 67% of 0.79kg per 1 m^3
- Total fuel consumption for each
  - Diesel – 10,996 L
  - Gasoline – 1,762 L
  - Natural Gas – 2,613 m^3
- Carbon Content
  - Diesel: 820 * 10.996 * 0.88 = 7974 kg/yr
  - Gasoline: 740 * 1.762 * 0.86 = 1,121 kg/yr
  - Natural Gas: 0.79 * 2,613 * 0.67 = 1,383 kg/yr
  - Total = 10,478 kg/yr
- Total CO_2
  - 10,478 kg * 3.67 = 38.454 kg CO_2/year
- Added O&M Cost per year with $2 per ton of CO_2
  - $2*38.454 = $76.9/yr

Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	38,097
Carbon monoxide	99.9
Unburned hydocarbons	11.1
Particulate matter	7.53
Sulfur dioxide	79.9
Nitrogen oxides	892

System Report - Example

Project Period = 25 years



Net Present Costs

Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generator 1	2,000	14,307	22,294,186	112,453	-217	22,422,726
Generator 2	2,000	7,693	6,151,354	33,794	-457	6,194,385
Generator 3	4,000	8,125	7,649,564	33,470	-12	7,695,147
Other	0	0	974	0	0	974
System	8,000	30,126	36,096,072	179,718	-687	36,313,236

36,095,104 for no carbon penalty

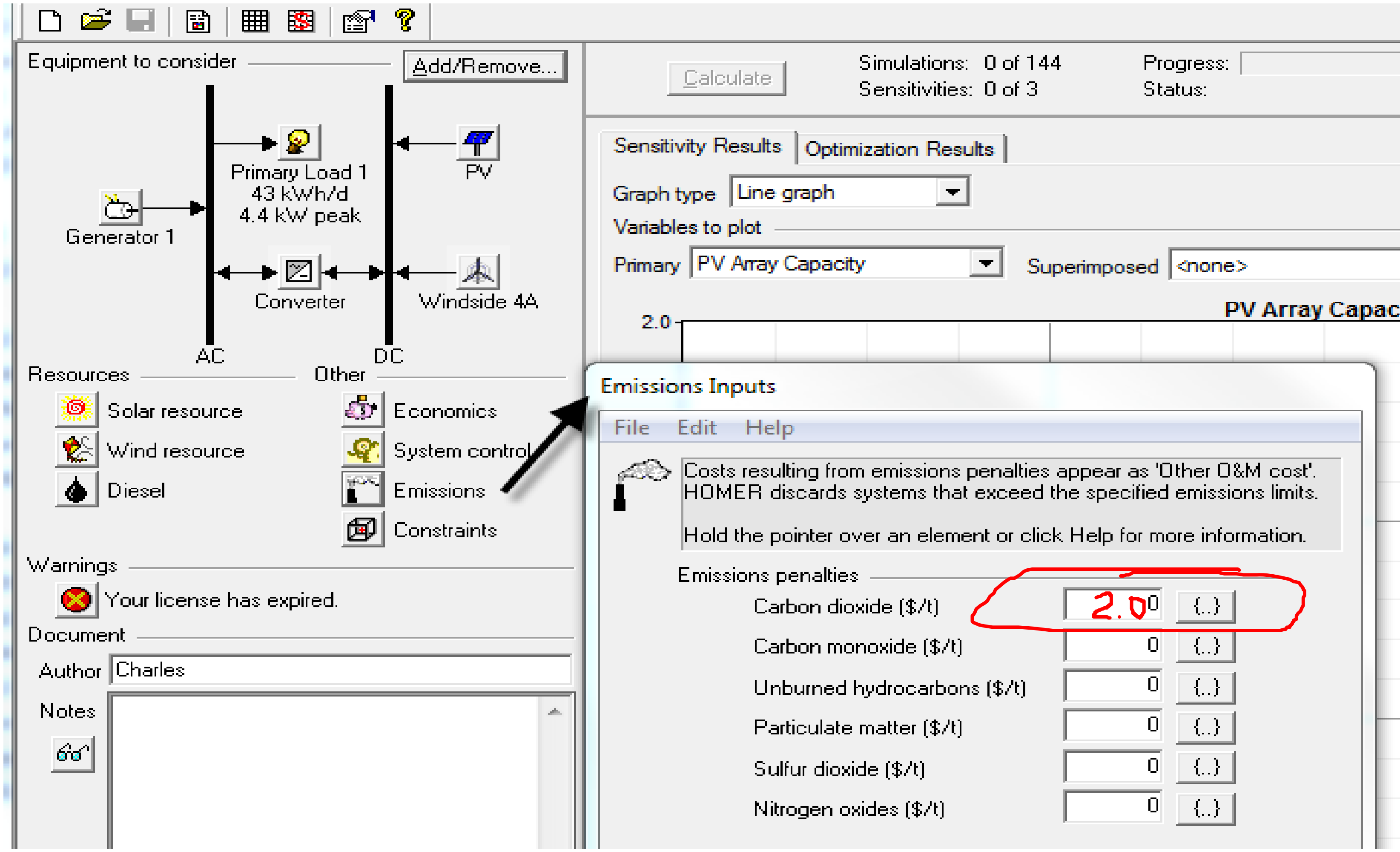
Annualized Costs

Component	Capital ($/yr)	Replacement ($/yr)	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
Generator 1	156	1,119	1,744,001	8,797	-17	1,754,056
Generator 2	156	602	481,200	2,644	-36	484,566
Generator 3	313	636	598,400	2,618	-1	601,966
Other	0	0	76	0	0	76
System	626	2,357	2,823,677	14,059	-54	2,840,665

Changed O&M with $2 per ton of CO_2 penalty, for the 38 ton emission per year. $2x38 = $76/year

2,823,602 for no carbon penalty

Emission Input – Emission Penalty



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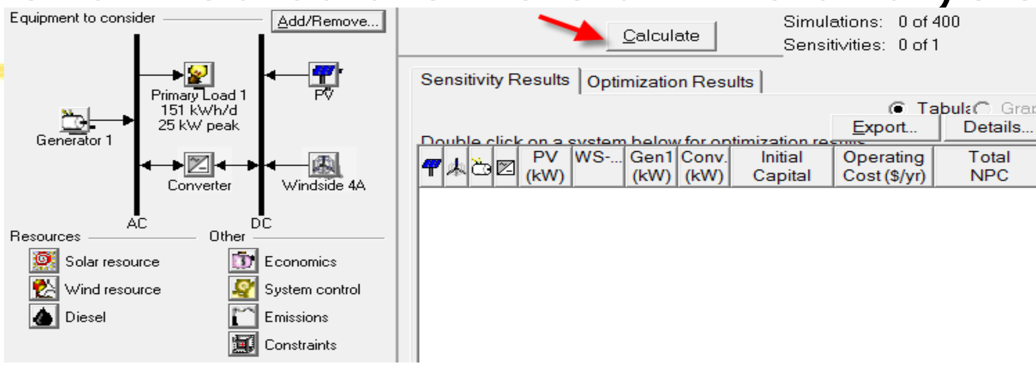
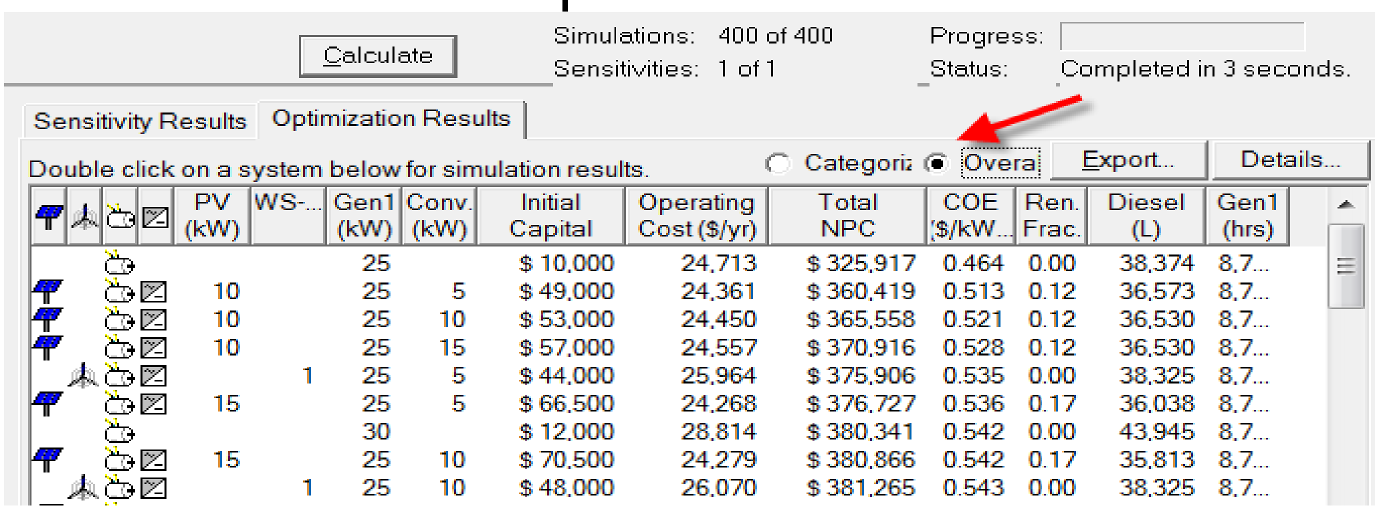
Analysis of the System

⌘ 1. Click “Calculate” to start the analysis

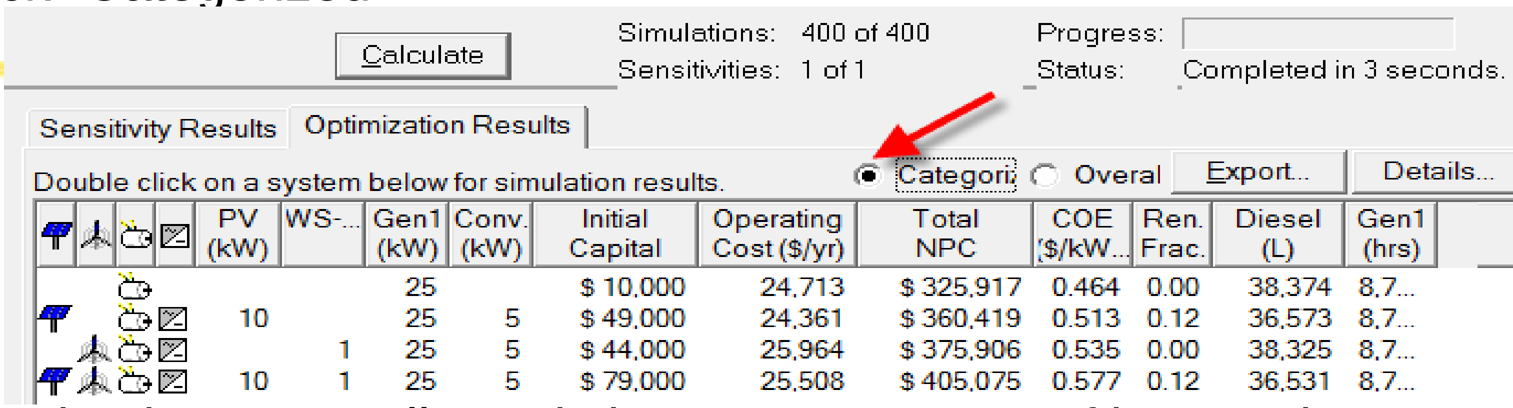


⌘ Click Overall: view all possible combinations



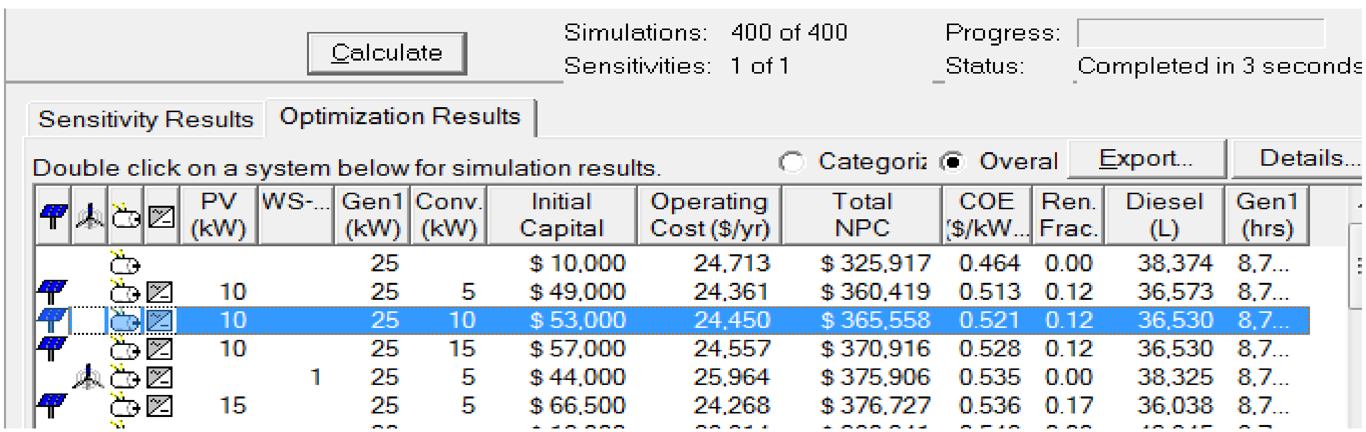
Analysis of the System

- Click “Categorized”



	PV (kW)	WS-...	Gen1 (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Diesel (L)	Gen1 (hrs)
			25		$ 10,000	24,713	$ 325,917	0.464	0.00	38,374	8,7...
	10		25	5	$ 49,000	24,361	$ 360,419	0.513	0.12	36,573	8,7...
		1	25	5	$ 44,000	25,964	$ 375,906	0.535	0.00	38,325	8,7...
	10	1	25	5	$ 79,000	25,508	$ 405,075	0.577	0.12	36,531	8,7...

- Now back to “Overall”, and choose any system of interest by clicking/ double clicking



	PV (kW)	WS-...	Gen1 (kW)	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kW...	Ren. Frac.	Diesel (L)	Gen1 (hrs)
			25		$ 10,000	24,713	$ 325,917	0.464	0.00	38,374	8,7...
	10		25	5	$ 49,000	24,361	$ 360,419	0.513	0.12	36,573	8,7...
	10		25	10	$ 53,000	24,450	$ 365,558	0.521	0.12	36,530	8,7...
	10		25	15	$ 57,000	24,557	$ 370,916	0.528	0.12	36,530	8,7...
		1	25	5	$ 44,000	25,964	$ 375,906	0.535	0.00	38,325	8,7...
	15		25	5	$ 66,500	24,268	$ 376,727	0.536	0.17	36,038	8,7...

Analysis

⌘ Simulation Results

Simulation Results

System Architecture: 10 kW PV; 25 kW Generator 1; 10 kW Inverter; 10 kW Rectifier

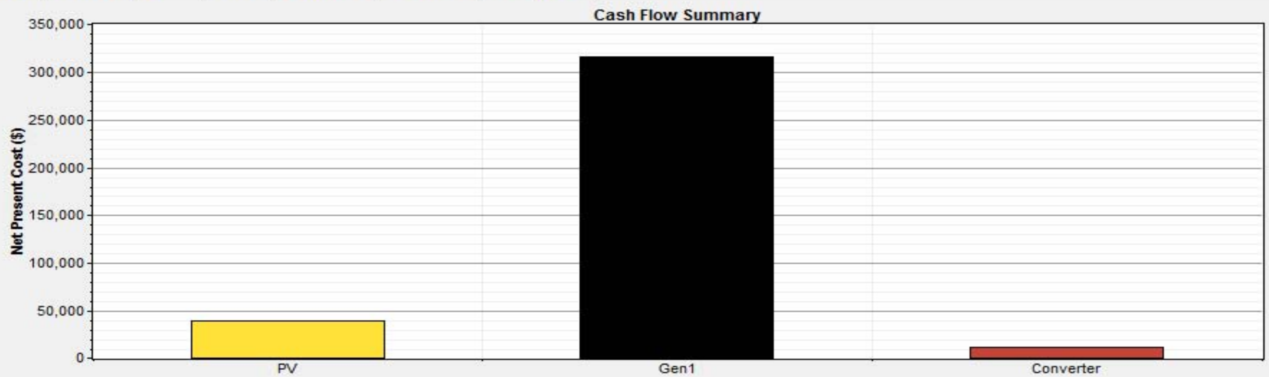
Total NPC: $ 365,558
Levelized COE: $ 0.521/kWh
Operating Cost: $ 24,450/yr

Cost Summary | Cash Flow | Electrical | PV | Gen1 | Converter | Emissions | Hourly Data

Cost type:
- Net present
- Annualized
- Reverse sign

Categorize:
- By component
- By cost type
- Show details

Compare...



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	35,000	7,795	0	0	-4,369	38,426
Generator 1	10,000	64,532	55,953	186,790	-860	316,415
Converter	8,000	3,338	0	0	-621	10,717
System	53,000	75,665	55,953	186,790	-5,850	365,558

XML Report | HTML Report | Help | Close

PV Output

Simulation Results

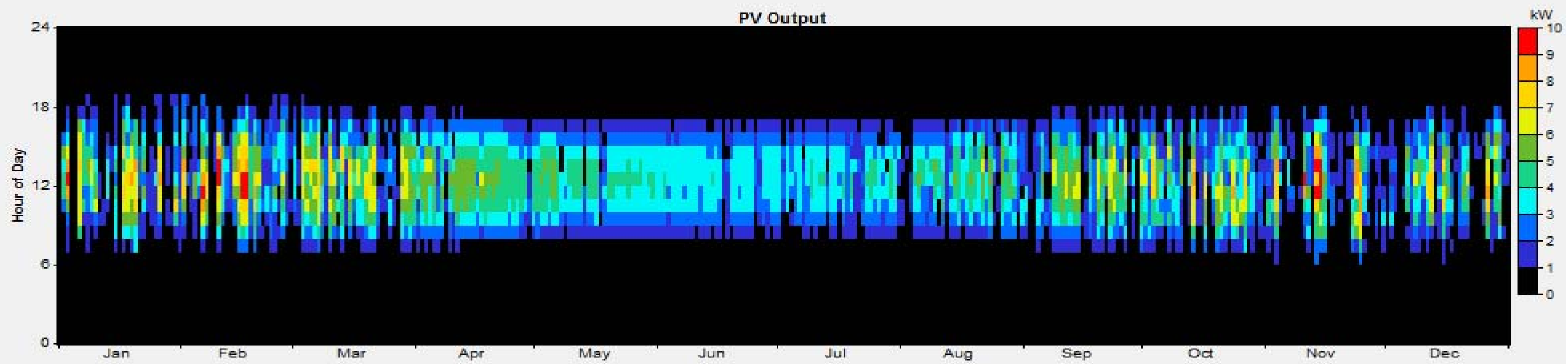
System Architecture: 10 kW PV, 25 kW Generator 1, 10 kW Inverter, 10 kW Rectifier

Total NPC: $ 365,558
Levelized COE: $ 0.521/kWh
Operating Cost: $ 24,450/yr

Cost Summary | Cash Flow | Electrical | PV | Gen1 | Converter | Emissions | Hourly Data

Quantity	Value	Units
Rated capacity	10.0	kW
Mean output	1.13	kW
Mean output	27.2	kWh/d
Capacity factor	11.3	%
Total production	9,911	kWh/yr

Quantity	Value	Units
Minimum output	0.00	kW
Maximum output	9.94	kW
PV penetration	18.0	%
Hours of operation	4,380	hr/yr
Levelized cost	0.303	$/kWh



XML Report | HTML Report | Help | Close

Electrical Output

Simulation Results

System Architecture: 10 kW PV | 25 kW Generator 1 | 10 kW Inverter | 10 kW Rectifier

Total NPC: $ 365,558
Levelized COE: $ 0.521/kWh
Operating Cost: $ 24,450/yr

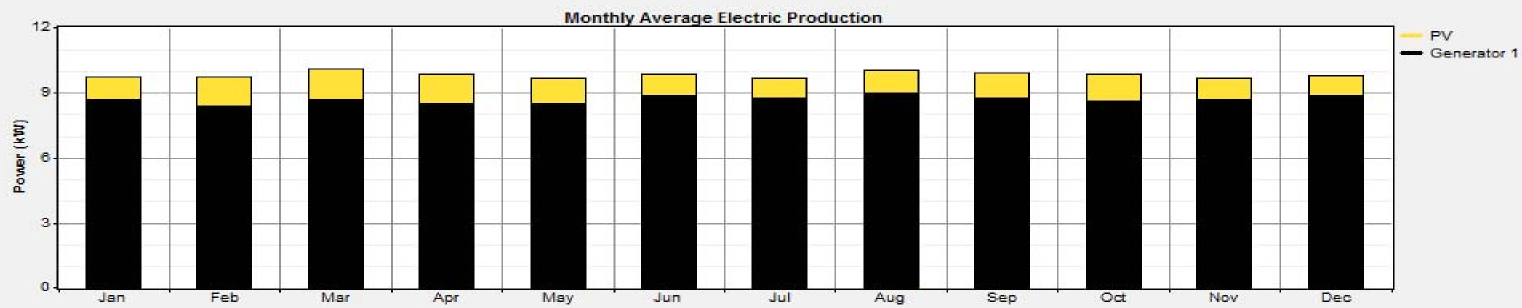
Cost Summary | Cash Flow | Electrical | PV | Gen1 | Converter | Emissions | Hourly Data

Production	kWh/yr	%
PV array	9,911	12
Generator 1	76,087	88
Total	85,998	100

Consumption	kWh/yr	%
AC primary load	54,933	100
Total	54,933	100

Quantity	kWh/yr	%
Excess electricity	30,254	35.2
Unmet electric load	0.000535	0.0
Capacity shortage	0.442	0.0

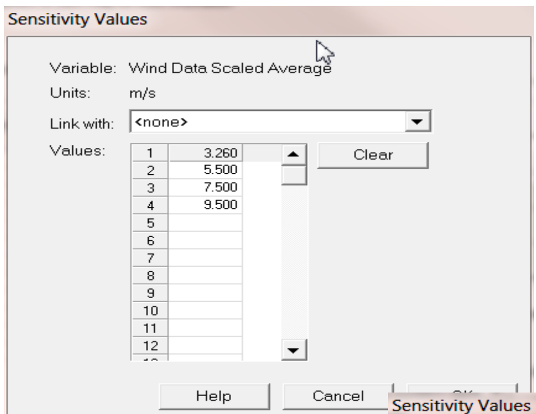
Quantity	Value
Renewable fraction	0.115



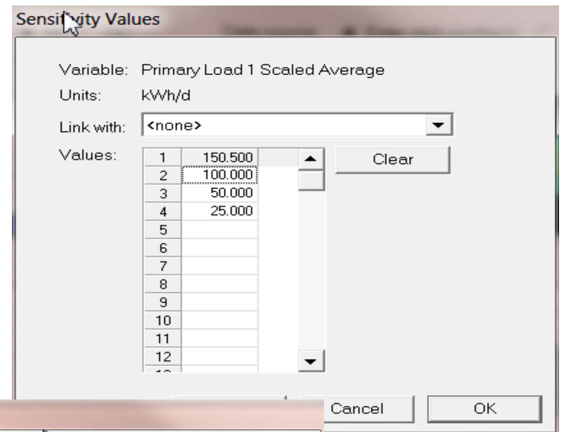
XML Report | HTML Report | Help | Close

Sensitivity Analysis

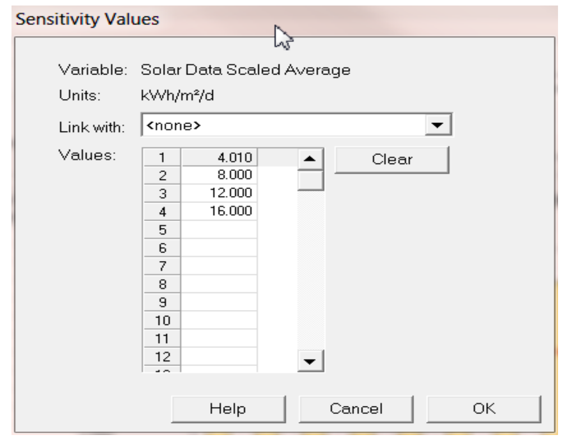
- Click Wind resource
- Click “Edit Sensitivity Values” >> **Do so for Load, Solar, and Diesel**
- Wind Resources



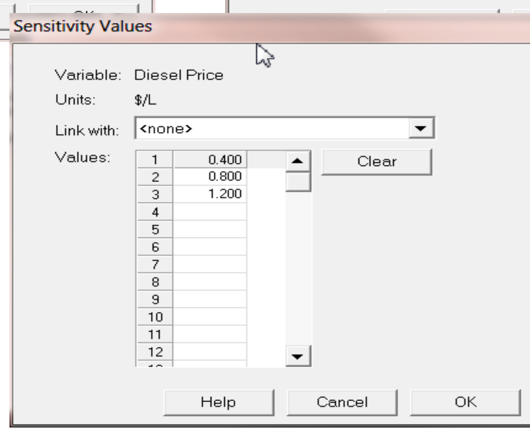
Primary Load



Solar Resources

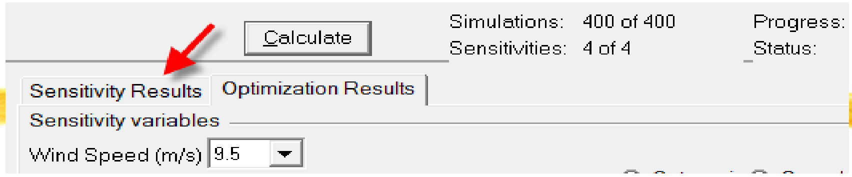


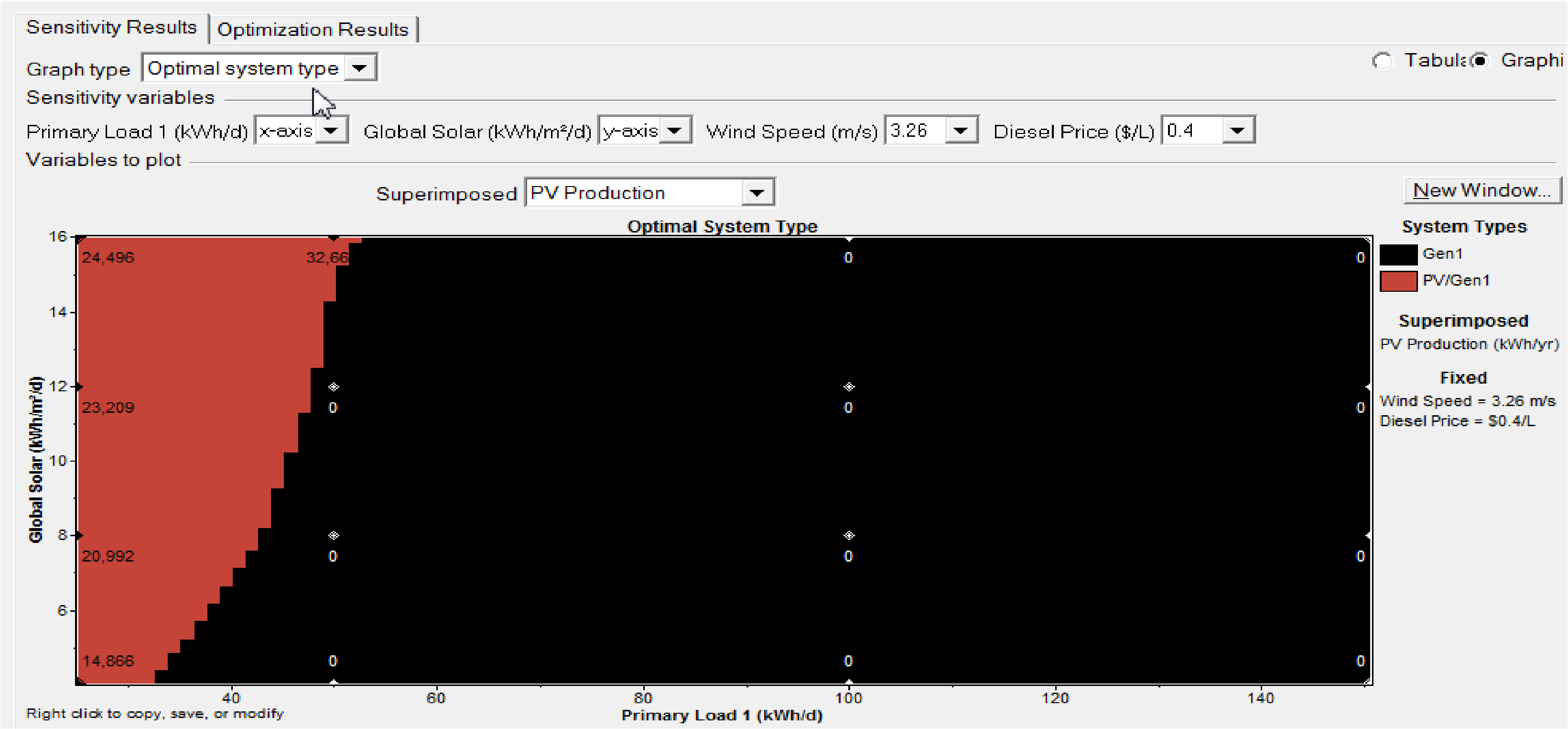
- Diesel Fuel



Sensitivity Analysis

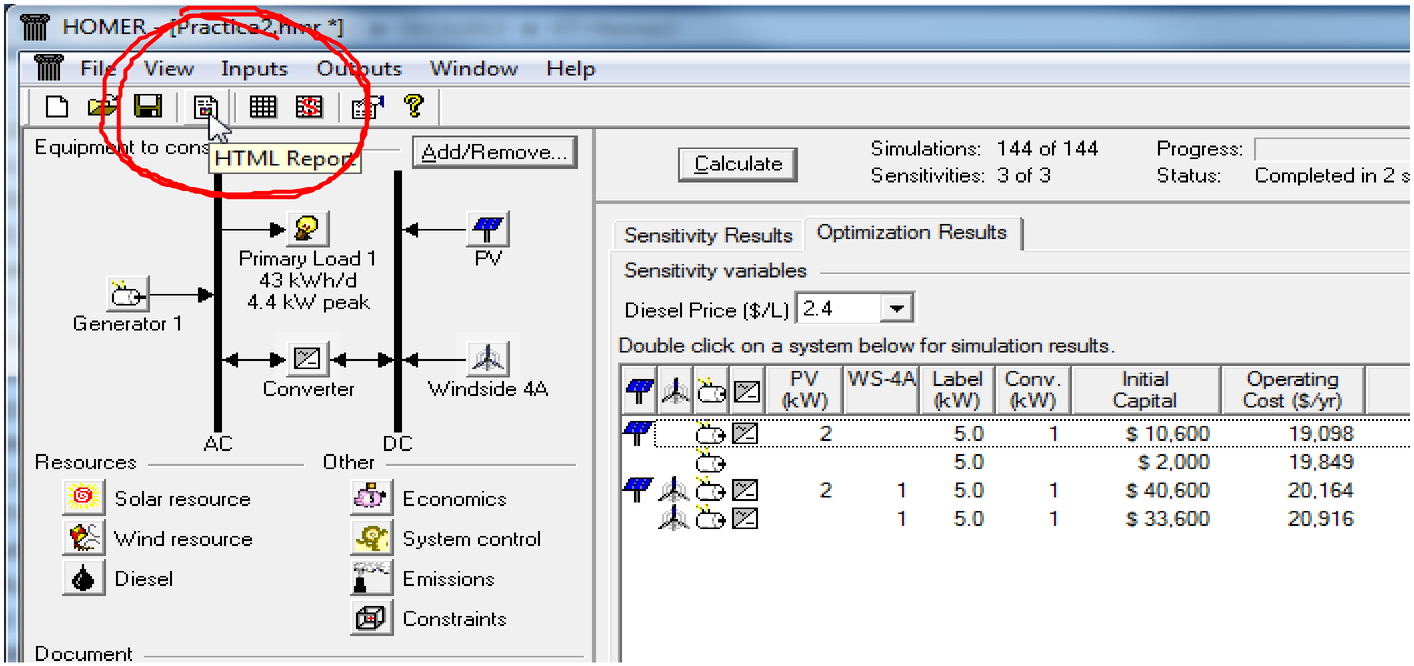
- Save and Calculate
- New we see the tab for "Sensitivity Results"





Input Summary Report

- HOMER Produces An Input Summary Report:
  - Click HTML Input Summary from the File menu, or click the toolbar button:
  - HOMER will create an HTML-format report summarizing all the relevant inputs, and display it in a browser. From the browser, you can save or print the report, or copy it to the clipboard so that you can paste it into a word processor or spreadsheet program.



Input summary Report - Example

Practice2.hmr - Mozilla Firefox

File Edit View History Bookmarks Tools Help

Practice2.hmr

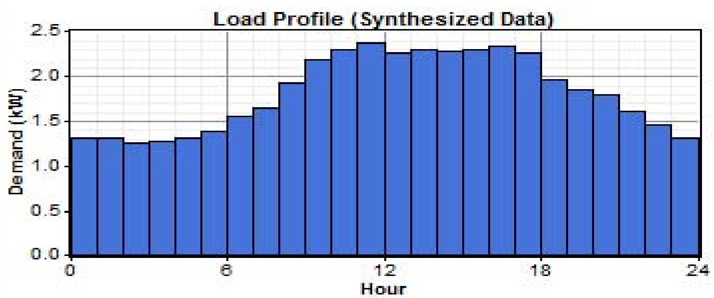
file:///C:/Users/ckim/AppData/Local/Temp/Practice2.htm

HOMER Input Summary

File name:	Practice2.hmr
File version:	2.68 beta
Author:	Charles

AC Load: Primary Load 1

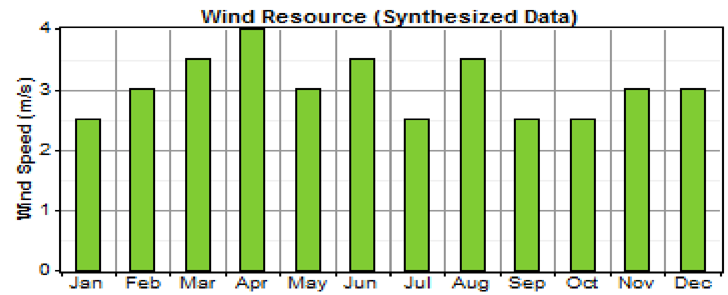
Data source:	Synthetic
Daily noise:	15%
Hourly noise:	20%
Scaled annual average:	43.4 kWh/d
Scaled peak load:	4.36 kW
Load factor:	0.414



PV

Size (kW)	Capital ($)	Replacement ($)	O&M ($/yr)
2.000	7,000	7,000	0

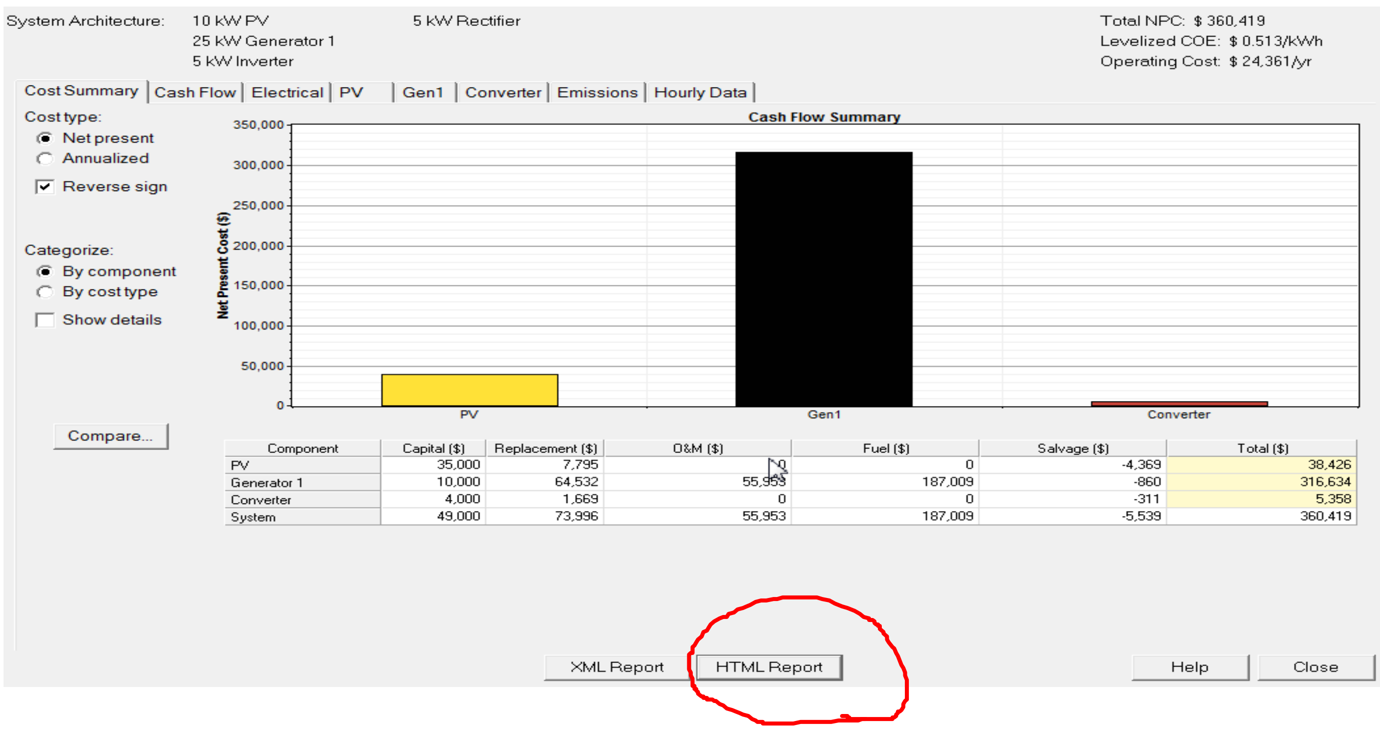
Sizes to consider:	0, 2, 4, 6 kW
Lifetime:	20 yr
Derating factor:	80%
Tracking system:	No Tracking
Slope:	0 deg
Azimuth:	0 deg
Ground reflectance:	20%



Weibull k:	2.00
Autocorrelation factor:	0.850
Diurnal pattern strength:	0.250
Hour of peak wind speed:	15
Scaled annual average:	3.04 m/s
Anemometer height:	10 m
Altitude:	0 m
Wind shear profile:	Logarithmic
Surface roughness length:	0.01 m

Simulation Result - System Report

- HOMER Produces A Report Summarizing The Simulation Results
  - Just click the HTML Report button in the Simulation Results window:



Example System Report

System Report - Practice2.hmr

Sensitivity case

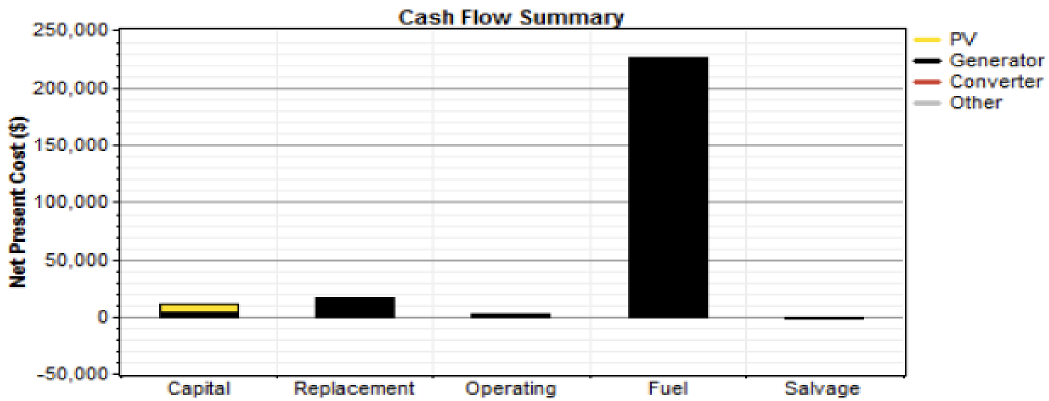
Diesel Price: 2.4 $/L

System architecture

PV Array	2 kW
Generator 1	5 kW
Inverter	1 kW
Rectifier	1 kW

Cost summary

Total net present cost	$ 254,738
Levelized cost of energy	$ 1.258/kWh
Operating cost	$ 19,098/yr



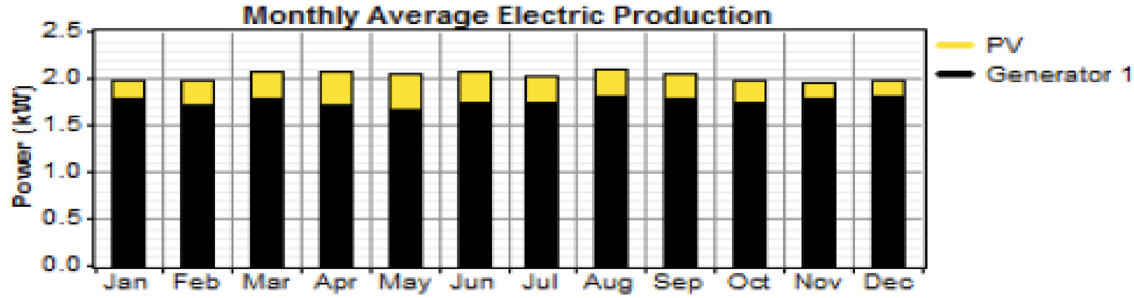
Net Present Costs

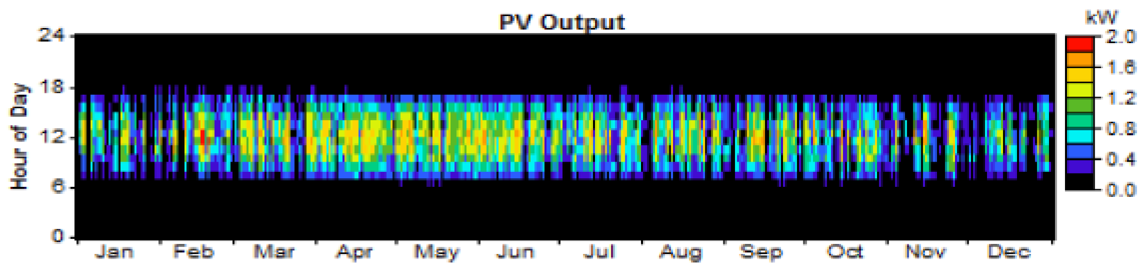
Component	Capital	Replacement	O&M	Fuel	Salvage	Total
	($)	($)	($)	($)	($)	($)
PV	7,000	2,183	0	0	-1,223	7,959
Generator 1	2,000	14,340	2,238	225,506	-191	243,893
Converter	1,600	668	0	0	-124	2,143
Other	0	0	742	0	0	742
System	10,600	17,191	2,980	225,506	-1,539	254,738

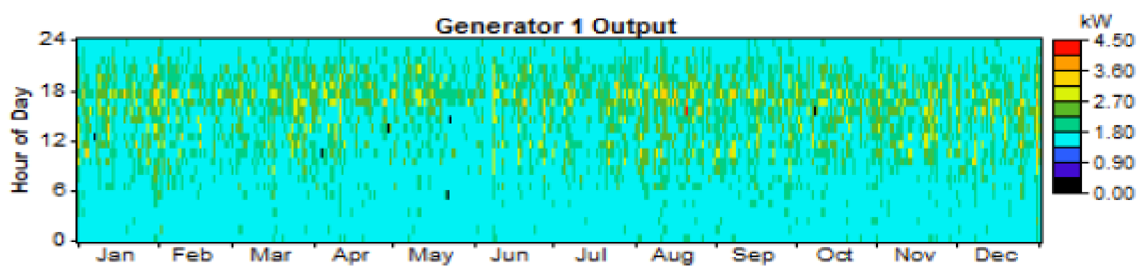
Electrical

Component	Production	Fraction
	(kWh/yr)	
PV array	2,341	13%
Generator 1	15,396	87%
Total	17,737	100%

System Report



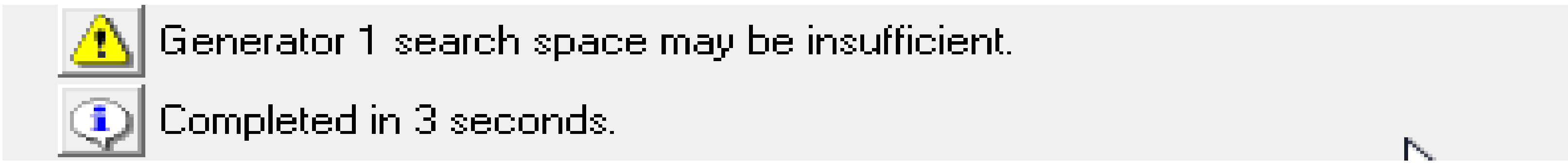




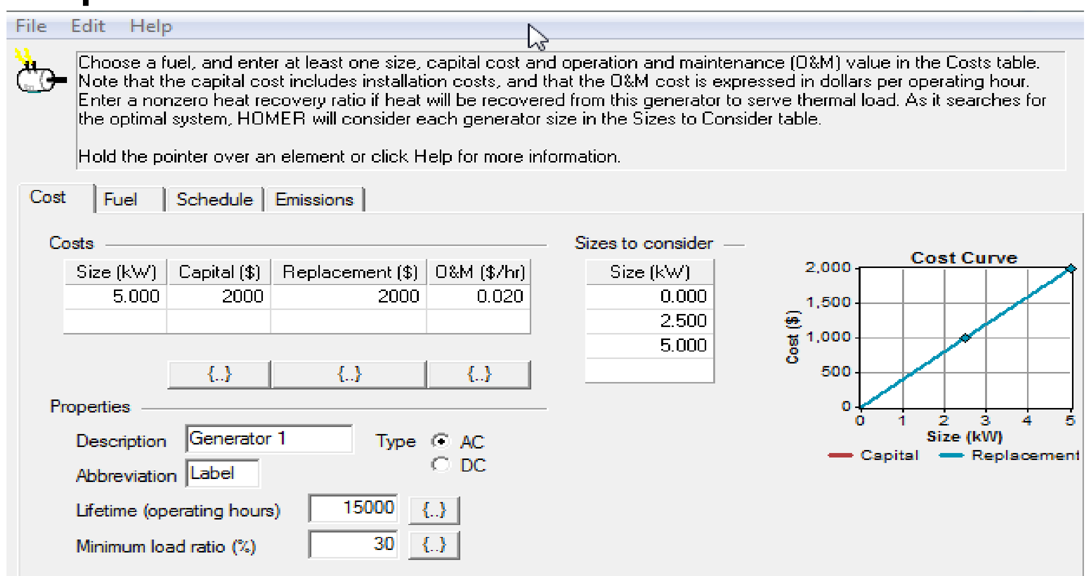
Emissions

Pollutant	Emissions (kg/yr)
Carbon dioxide	19,356
Carbon monoxide	47.8
Unburned hydocarbons	5.29
Particulate matter	3.6
Sulfur dioxide	38.9
Nitrogen oxides	426

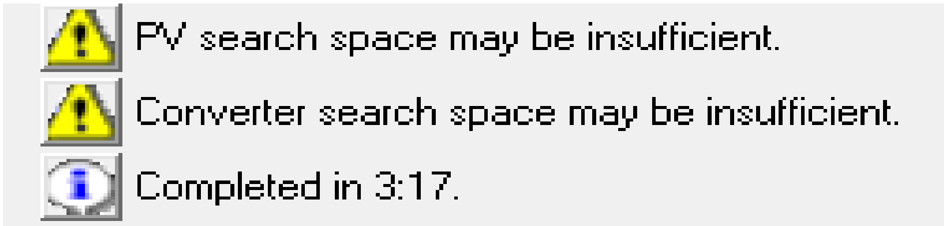
This message?



⌘ HOMER displays a message suggesting that we add more generator quantities to the sizes to consider.



Other messages to appear



- Those messages mean that:
  - you need to expand your search space to be sure you have found the cheapest system configuration.
  - If the total net present cost varied with the PV size in this way, and you simulated 10, 20, 30, and 40 kW sizes, HOMER would notice that the optimal number of turbines is 40 kW, but since that was as far as you let it look, it would give you the "search space may be insufficient" warning because 50 kW may be better yet.
  - It doesn't know that until you let it try 50kW and 60kW.
  - If you expanded the search space, HOMER would no longer give you that warning, since the price started to go up so you have probably identified the true least-cost point.

APPENDIX Physical Modeling - Components

- HOMER models 10 types of part that generates, delivers, converts, or stores energy
  - 3 intermittent renewable resources:
    - PV modules (dc)
    - wind turbines (dc or ac)
    - run-of-river hydro turbines (dc or ac)
  - 3 dispatchable energy sources: [control them as needed]
    - Generators
    - the grid
    - boilers
  - 2 energy converters:
    - Converters (dc ←→ ac)
    - Electrolyzers (ac,dc → electrolysis → Hydrogen)
  - 2 types of energy storage:
    - batteries (dc)
    - hydrogen storage tanks

Physical Modeling - load

- Load: a demand for electric or thermal energy
- 3 types of loads
  - **Primary load**: electric demand that must be served according to a particular schedule
    - When a customer switches on, the system must supply electricity
    - kW for each hour of the load
    - Lights, radio, TV, appliances, computers,
  - **Deferrable load**: electric demand that can be served at any time within a certain time span
    - Tank – drain concept
    - Water pumps, ice makers, battery-charging station
  - **Thermal load**: demand for heat
    - Supply from boiler or waste heat recovered from a generator
    - Resistive heating using excess electricity

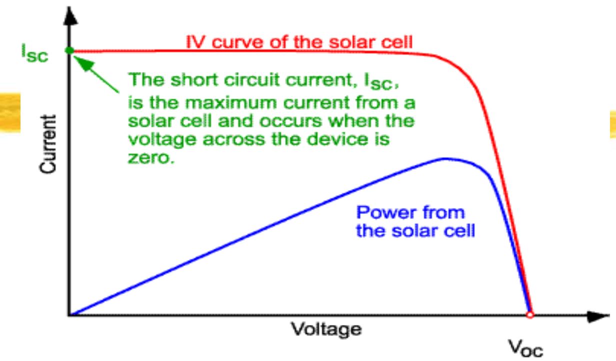
Physical Modeling - Resources

- **Solar Resources**: average global solar radiation on horizontal surface (kWh/m^2 or kWh/m^2-day) **or** monthly average clearness index (atmosphere vs. earth surface). Inputs – solar radiation values and the latitude and the longitude. Output – 8760 hour data set
- **Wind Resources**: Hourly or 12 monthly average wind speeds. Anemometer height. Wind turbine hub height. Elevation of the site.
- **Hydro Resources**: Run-of-river hydro turbine. Hourly (or monthly average) stream flow data.
- **Biomass Resources**: wood waste, agricultural residue, animal waste, energy crops. Liquid or gaseous fuel.
- **Fuel**: density, lower heating value, carbon content, sulfur content. Price and consumption limits

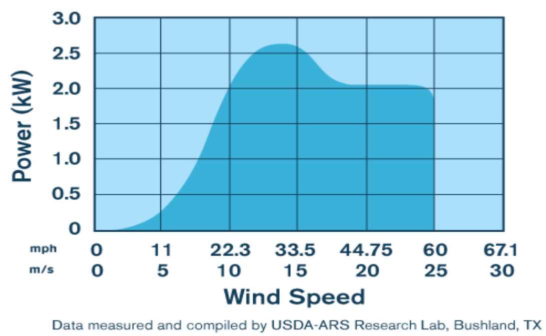
Components- PV, Wind, and Hydro

- PV Array

$$P_{PV} = f_{PV} Y_{PV} \frac{I_T}{I_S}$$

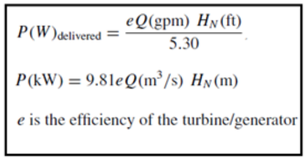


  - f_{PV}: PV de-rating factor
  - Y_{PV}: Rated Capacity [kW]
  - I_T: Global Solar Radiation incidence on the surface of the PV array [kW/m²]
  - I_S: Standard amount of radiation, 1 kW/m².
- Wind Turbine
  - Wind turbine power curve



- Hydro Turbine
  - Power Output Eqn = Turbine efficiency, density of water, gravitational acceleration, net head, flow rate through the turbine

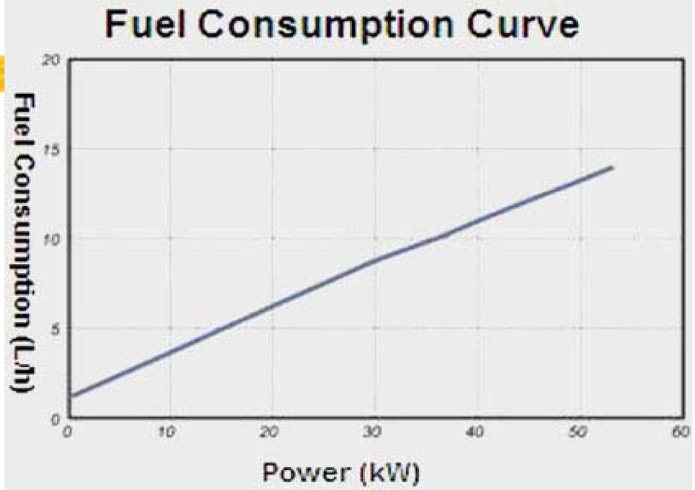
$$P_{hyd} = \eta_{hyd} \rho_{water} g h_{net} \dot{Q}_{turbine}$$

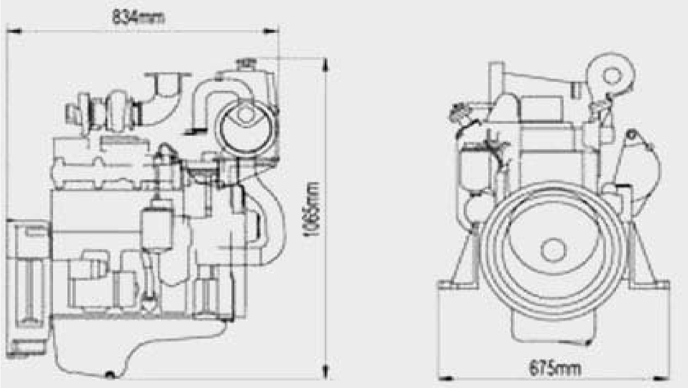


Components - Generator

- Generators
  - Principal properties: max and min electrical power output, expected lifetime, type of fuel, fuel curve
  - **Fuel curve**: quantity of fuel consumed to produce certain amount of electrical power. Straight line is assumed.
  - Fuel Consumption (**F**) [L/h], [m^3/h], or [kg/h]:
    - F_o - fuel curve intercept coefficient [L/h-kW];
    - F_1 - fuel curve slope [L/h-kW];
    - Y_{gen} - rated capacity [kW];
    - P_{gen} - electrical output [kW]

$$F = F_0 Y_{\text{gen}} + F_1 P_{\text{gen}}$$





Components - Generator

- Generator costs: initial capital cost, replacement cost, and annual O&M cost per operating hour (not including fuel cost)
- **Fixed cost:** cost per hour of simply running the generator without producing any electricity

$$c_{\text{gen,fixed}} = c_{\text{om,gen}} + \frac{C_{\text{rep,gen}}}{R_{\text{gen}}} + F_0 Y_{\text{gen}} c_{\text{fuel,eff}}$$

$c_{\text{om,gen}}$ is the O&M cost per hour,
$C_{\text{rep,gen}}$ the replacement cost
R_{gen} the generator lifetime in hours.
F_0 the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt.
Y_{gen} the capacity of the generator (kW).
$c_{\text{fuel,eff}}$ the effective price of fuel in dollars per quantity of fuel.

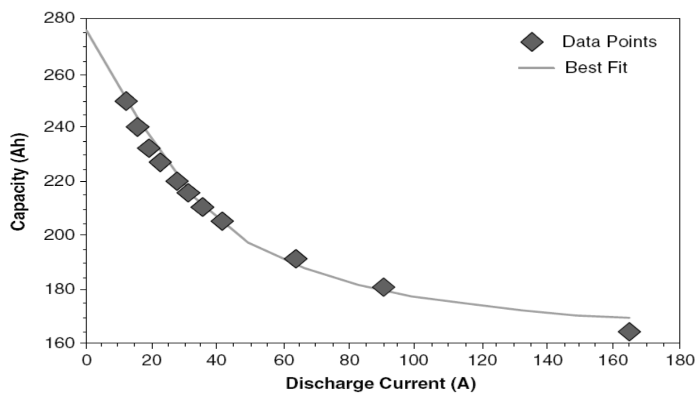
- **Marginal cost**: additional cost per kWh of producing electricity from the generator

$$c_{\text{gen,mar}} = F_1 c_{\text{fuel,eff}}$$

F_1 is the fuel curve slope in quantity of fuel per hour per kilowatthour

Components – Battery Bank

- Battery Bank
  - Principal properties:
    - nominal voltage
    - **capacity curve:** discharge capacity in AH vs. discharge current in A
    - **lifetime curve**: number of discharge-charge cycles vs. cycle depth
    - **minimum state of charge:** State of charge below which must not be discharges to avoid permanent damage
    - **round-trip efficiency**: percentage of energy going in to that can be drawn back out
  - Example capacity curve for a deep-cycle US-250 battery (Left)



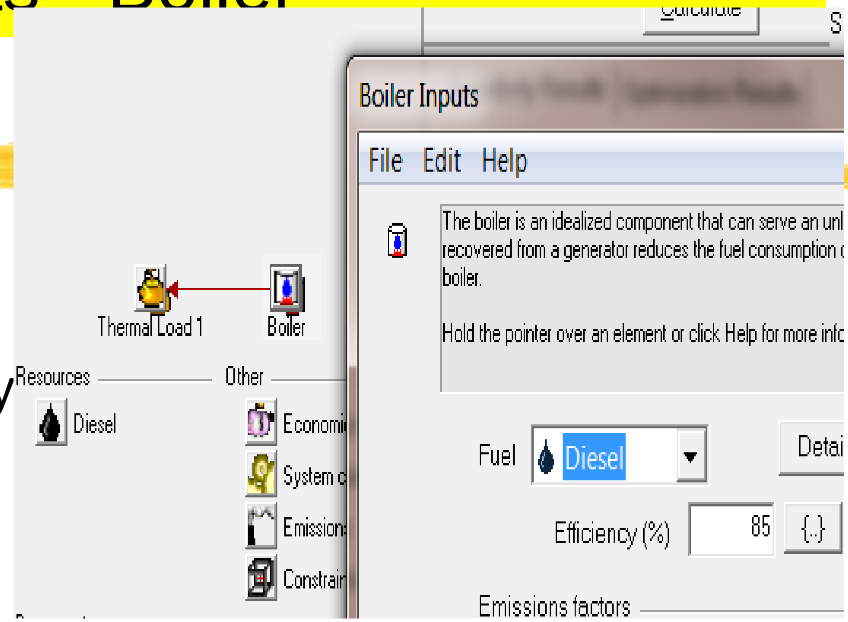
Components - Grid

- Grid and Grid Power Cost
  - Grid power price [$/kWh]: charges for energy purchase from grid
  - Demand rate [$/kW/month]: peak grid demand
  - Sellback rate [$/kWh]: price the utility pays for the power sold to grid
- Net Metering: a billing arrangement whereby the utility charges the customer based on the net grid purchases (purchases minus sales) over the billing period.
  - Purchase > sales: consumer pays the utility an amount equal to the net grid purchases times the grid power cost.
  - sales > purchases: the utility pays the consumer an amount equal to the net grid sales (sales minus purchases) times the sellback rate, which is typically less than the grid power price, and often zero.
- Grid fixed cost: $0
- Grid marginal cost: current grid power price plus any cost resulting from emissions penalties.

Components - Boiler

⌘ Boiler

- Assumed to provide unlimited amount of thermal energy on demand
- Input: type of fuel, boiler efficiency, emission
- Fixed cost: $0
- Marginal cost:



$$c_{\text{boiler,mar}} = \frac{3.6 c_{\text{fuel,eff}}}{\eta_{\text{boiler}} \text{LHV}_{\text{fuel}}}$$

$c_{\text{fuel,eff}}$ is the effective price of the fuel (including the cost of any penalties on emissions) in dollars per kilogram

η_{boiler} is the boiler efficiency

LHV_{fuel} is the lower heating value of the fuel in MJ/kg

Components – Converter

- Converter
  - Inversion and Rectification
  - Size: max amount of power it delivers
  - Synchronization ability: parallel run with grid
  - Efficiency
  - Cost: capital, replacement, o&m, lifetime

Components –Fuel Cell

- Electrolyzer:
  - Size: max electrical input
  - Min load ratio: the minimum power input at which it can operate, expressed as a percentage of its maximum power input.
  - Cost: capital, replacement, o&m, lifetime
- Hydrogen Tank
  - Size: mass of hydrogen it can contain
  - Cost: capital, replacement, o&m, lifetime

System Dispatch

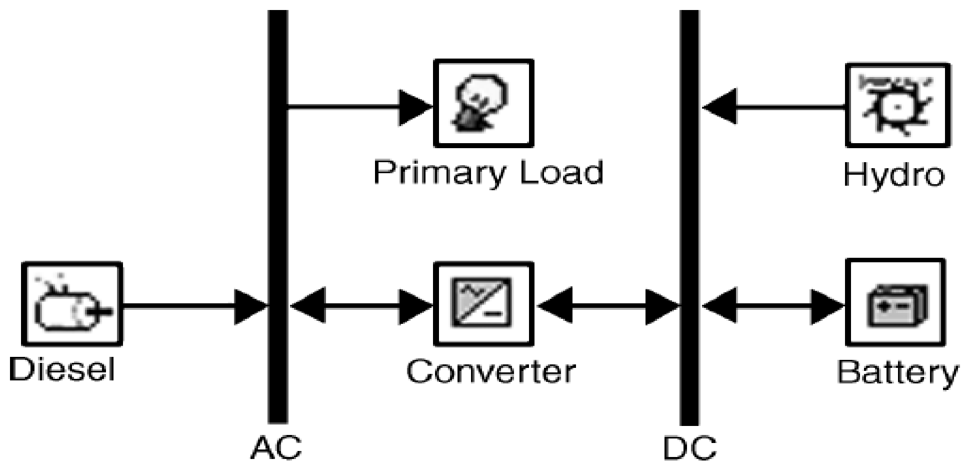
- Dispatachable and non-dispatchable power sources
- Dispatchable source: provides operating capacity in an amount equal to the maximum amount of power it could produce at a moment's notice.
  - **Generator**
    - In operation: dispatchable opr capacity = rated capacity
    - non-operation: dispatchable opr capacity = 0
  - **Grid:** dispatchable opr capacity = max grid demand
  - **Battery:** dispatachable opr capacity = current max discharge power
- Non-dispatchable source
  - Operating capacity (**PV, Wind, or Hydro**) = the amount the source is currently producing (Not the max amount it can produce)
- NOTE: If a system is ever unable to supply the required amount of load plus operating reserve, HOMER records the shortfall as "**capacity shortage**".
  - HOMER calculates the total amount of such shortages over the year and divides **the total annual capacity shortage** by the **total annual electric load**.

Dispatch Strategy for a system with Gen and Battery

- Dispatch Strategy
  - Whether and how the generator should charge the battery bank?
  - HOMER provides 2 simple strategies and lets user model them both to see which is better in any particular situation.
    - **Load-following:** a generator produces only enough power to serve the load, and does not charge the battery bank.
    - **Cycle-Charging:** whenever a generator operates, it runs at its maximum rated capacity and charges the battery bank with the excess
    - It was found that over a wide range of conditions**, the better of these two simple strategies** is virtually as cost-effective as the ideal predictive strategy.
  - "**Set-point state charge**": in the cycle-charging strategy, generator charges until the battery reaches the set-point state of charge.

Control of Dispatchable System Components

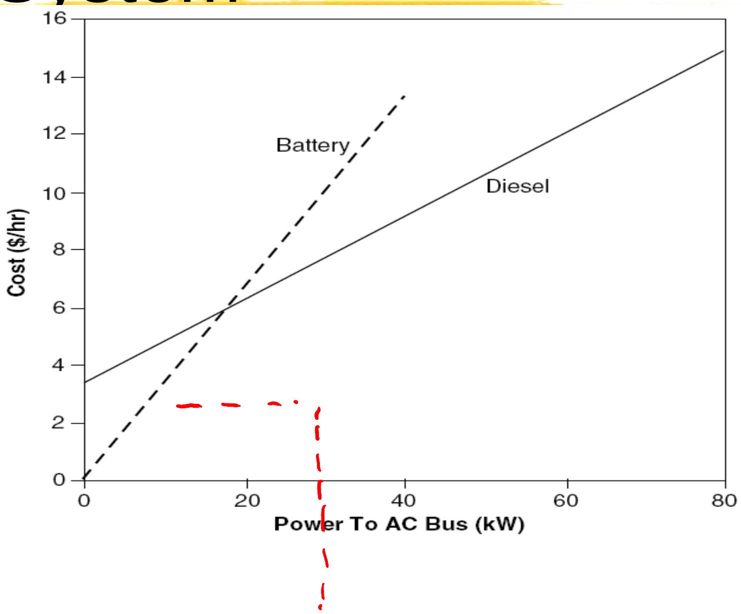
- Fundamental principle: cost minimization – fixed cost and marginal cost
- Example: Hydro-Diesel-Battery System



- Dispatachable sources: diesel generator [80kW] and battery [40kW]
- If net load is negative: excess power **charges battery**
- If net load is positive: **operate diesel** OR **discharge battery**

Dispatch Control Example

⌘Hydro-Diesel-Battery System

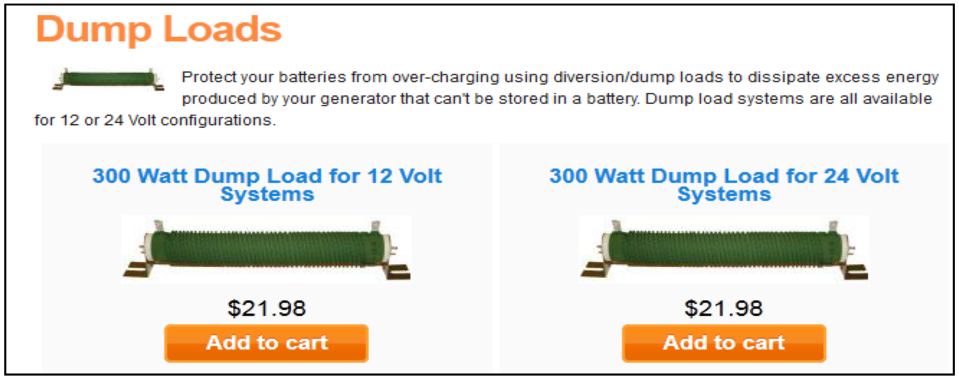


⌘Net load < 20kW: Discharge the battery

⌘Net load > 20kW: Operate the diesel generator

Load Priority

- Decisions on allocating electricity
- Presence of ac and dc buses
- Electricity produced on one bus will serve
  - First, primary load on the same bus
  - Then, primary load on the opposite bus
  - Then, deferrable load on the same bus
  - Then, charge battery bank
  - Then, sells to grid
  - Then, electrolyzer
  - Then, dump load



Economic Modeling

- Conventional sources: low capital and high operating costs
- Renewable sources: high initial capital and low operating costs
- Life-cycle costs= capital + operating costs
- HOMER uses NPC for life-cycle cost
  - NPC is the opposite of NPV (Net present value)
- NPC includes: initial construction, component replacements, maintenance, fuel, cost of buying grid, penalties, and revenues (selling power to grid + salvage value at the end of the project lifetime)

$$S = C_{\text{rep}} \frac{R_{\text{rem}}}{R_{\text{comp}}}$$

S is the salvage value,
C_{rep} the replacement cost of the component,
R_{rem} the remaining life
R_{comp} the lifetime of the component.

Real Cost

- All price escalates at the same rate over the lifetime
- Inflation can be factored out of analysis by using the real (inflation-adjusted) interest rate (rather than nominal interest rate) when discounting the future cash flows to the present
- Real interest rate = nominal interest rate – inflation rate
- Real cost → in terms of constant dollars

NPC and COE

- Total NPC

$$C_{\text{NPC}} = \frac{C_{\text{ann,tot}}}{\text{CRF}(i,\ N)}$$

$C_{\text{ann,tot}}$ is the total annualized cost.
i the annual real interest rate (the discount rate)
N the project lifetime.
$\text{CRF}(\cdot)$ is the capital recovery factor

$$\text{CRF}(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1}$$

- Levelized Cost of Energy (COE): average cost/kWh

$$\text{COE} = \frac{C_{\text{ann,tot}}}{E_{\text{prim}} + E_{\text{def}} + E_{\text{grid,sales}}}$$

$C_{\text{ann,tot}}$ is the total annualized cost.
E_{prim} total amounts of primary load.
E_{def} total amounts of deferrable load.
$E_{\text{grid,sales}}$ is the amount of energy sold to the grid