General Introduction to the training

ECREEE Regional Training of Trainers Workshop:
HOMER software for RE project design

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I. Considerations for an hybrid system in this training (I)

Definition of hybrid system

What is an hybrid system in this training?

For a first comprehensive understanding of an *hybrid energy system*, watch the following public video on renewable energy technology for stand-alone grids.

TO SEE THE VIDEO, CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR

http://player.vimeo.com/video/52066424?title=0&byline=0&portrait=0&badge=0&color=ffffff&autoplay=1

This video has been developed by the SMA Solar Technology AG

Source: SMA SOLAR TECHNOLOGY AG

Definition of Hybrid System for this training

- **Hybrid system**: electricity generation system, based on the integration of various energy sources (such as photovoltaics, wind turbines, small hydro power or diesel generators).

Source: ECREEE

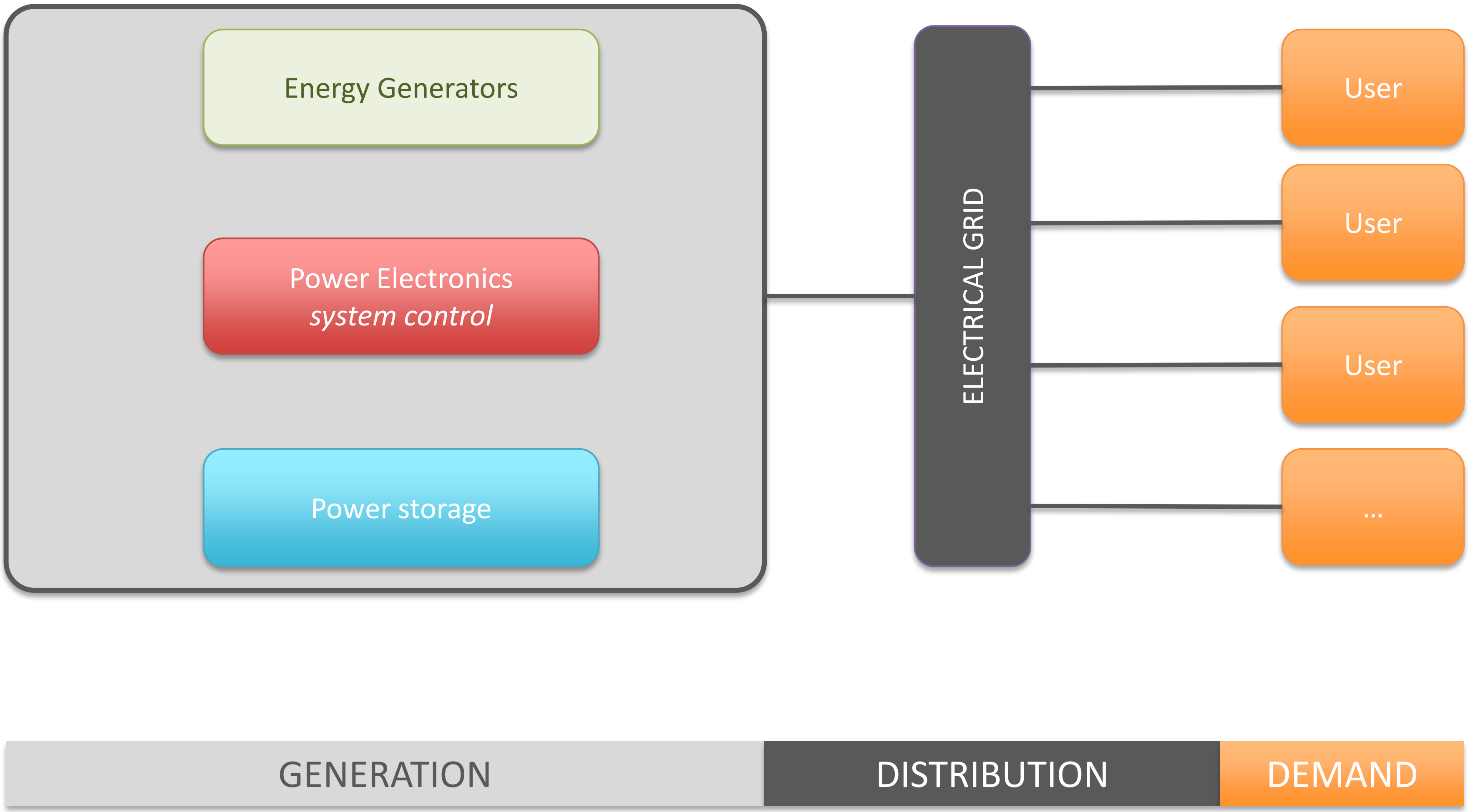
- (…) hybrid configurations can potentially deliver improved performance and better economic values for a given electrification situation.

Source: ESMAP, 2007

II. Considerations for an hybrid system in this training (II)

General architecture of an energy system

General architecture of an energy system (simplified)



III. Considerations for an hybrid system in this training (III)

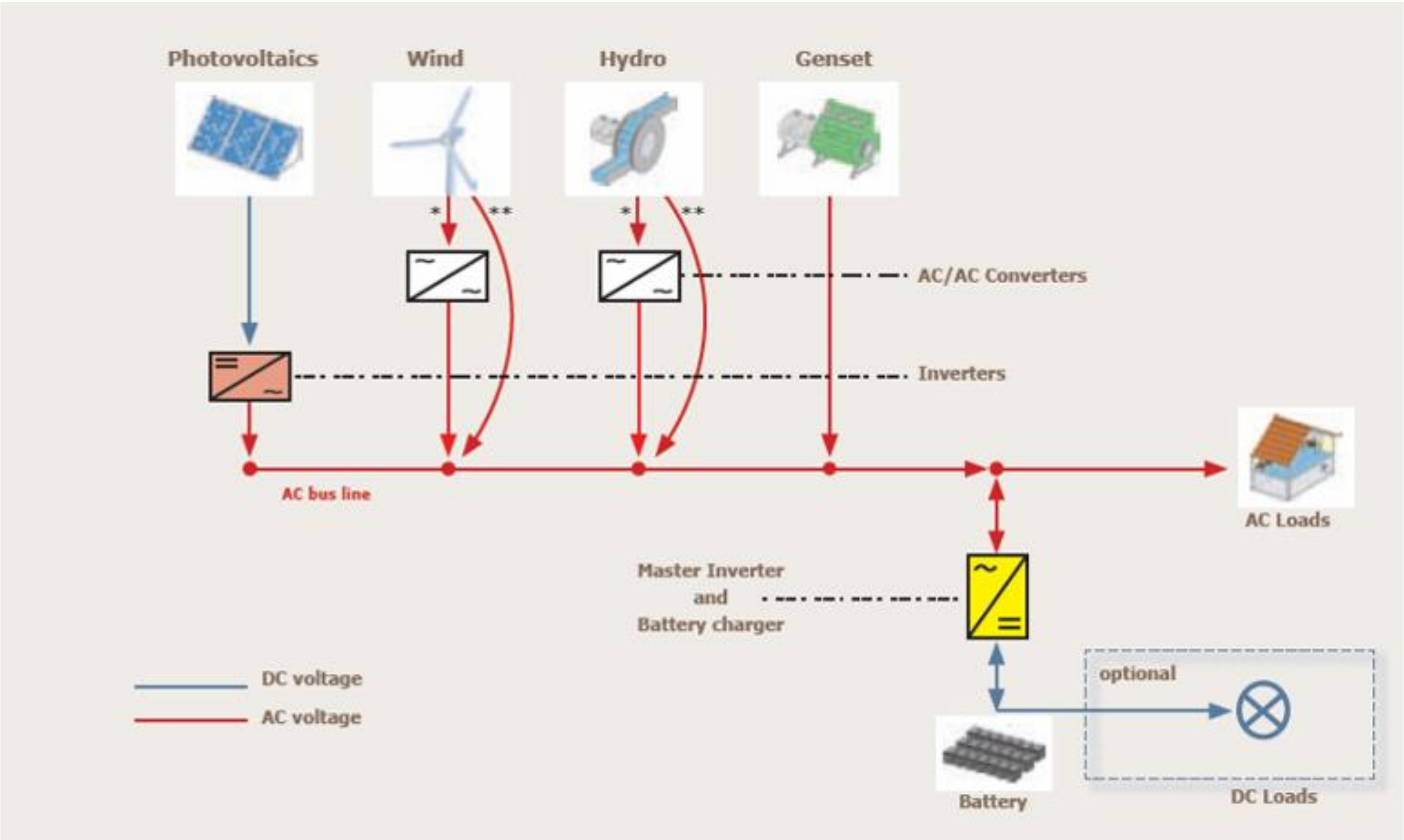
Architectures for hybrid systems

based on the control strategy

Architectures for hybrid systems based on the control strategy

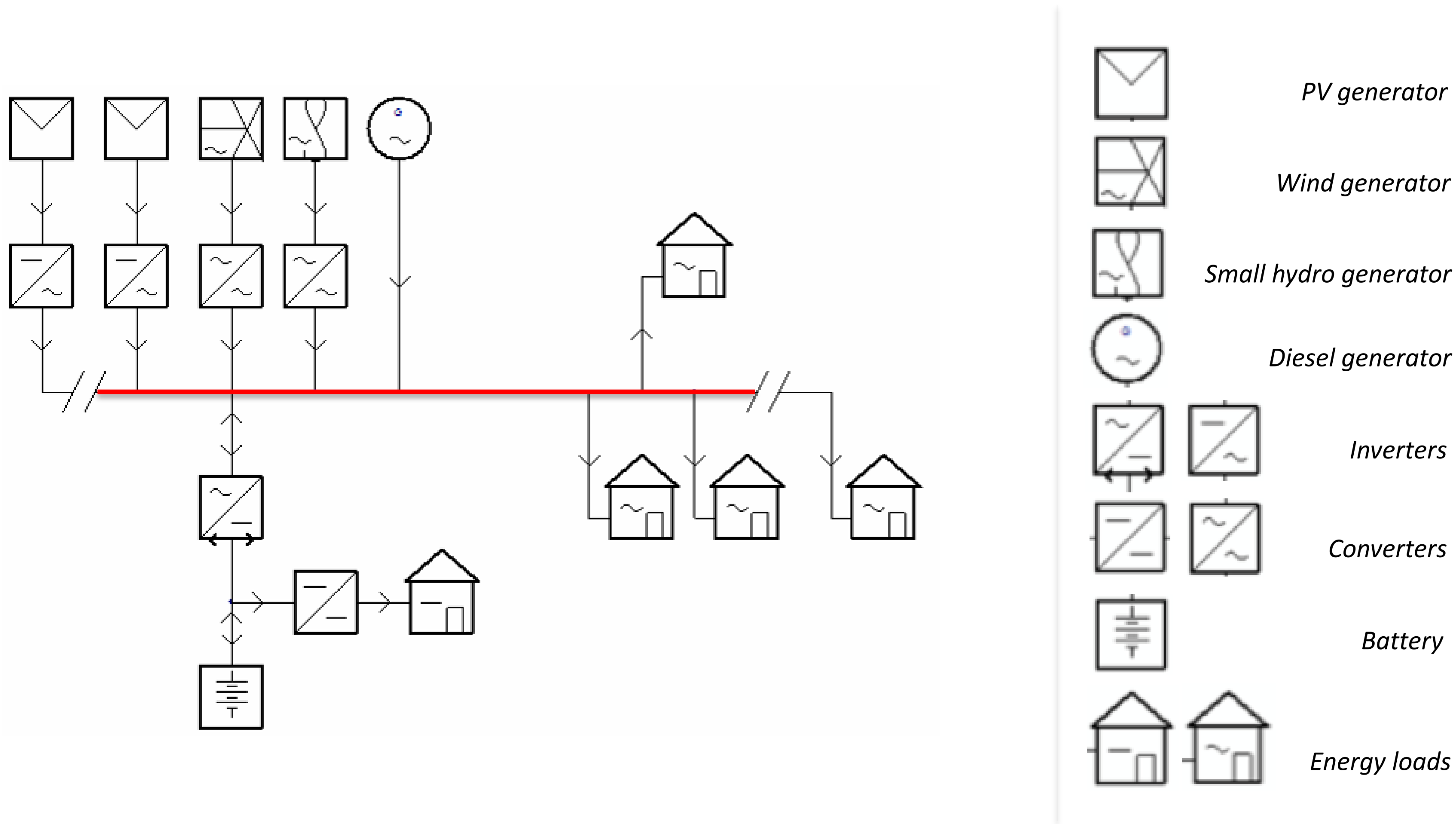
- There are several system architectures for hybrid systems. Based on the power electronics' control strategy, two examples are:
  - Alternate Current bus coupling
  - Direct Current bus coupling
- Other architectures for hybrid systems may have a mixed combination of the two above.
- These architectures have to be taken into consideration when dimensioning and simulating the hybrid system.

SYSTEM ARCHITECTURE:
AC BUS COUPLING



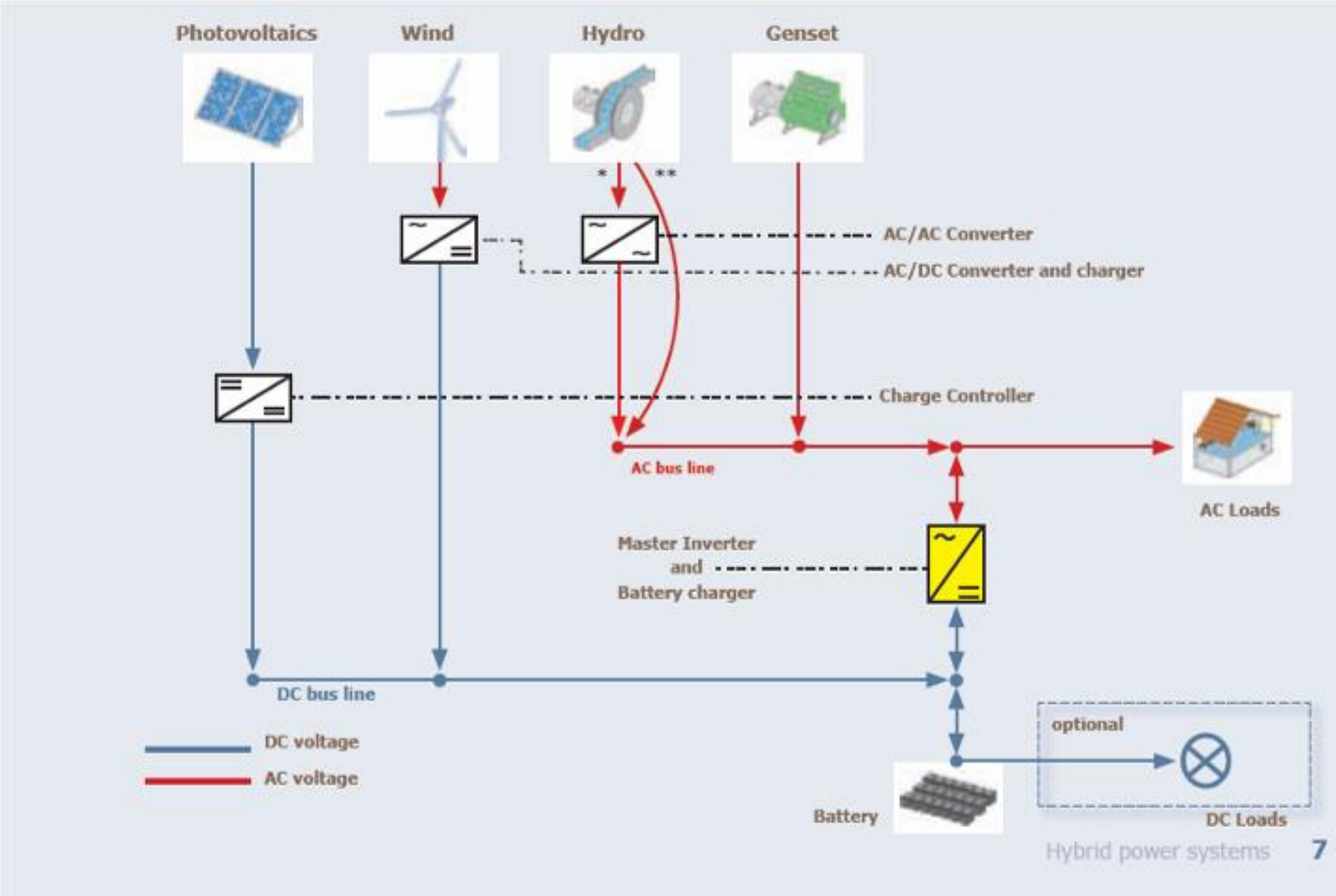
Source: ARE, 2008

AC BUS COUPLING
EXAMPLE OF TECHNICAL SCHEME



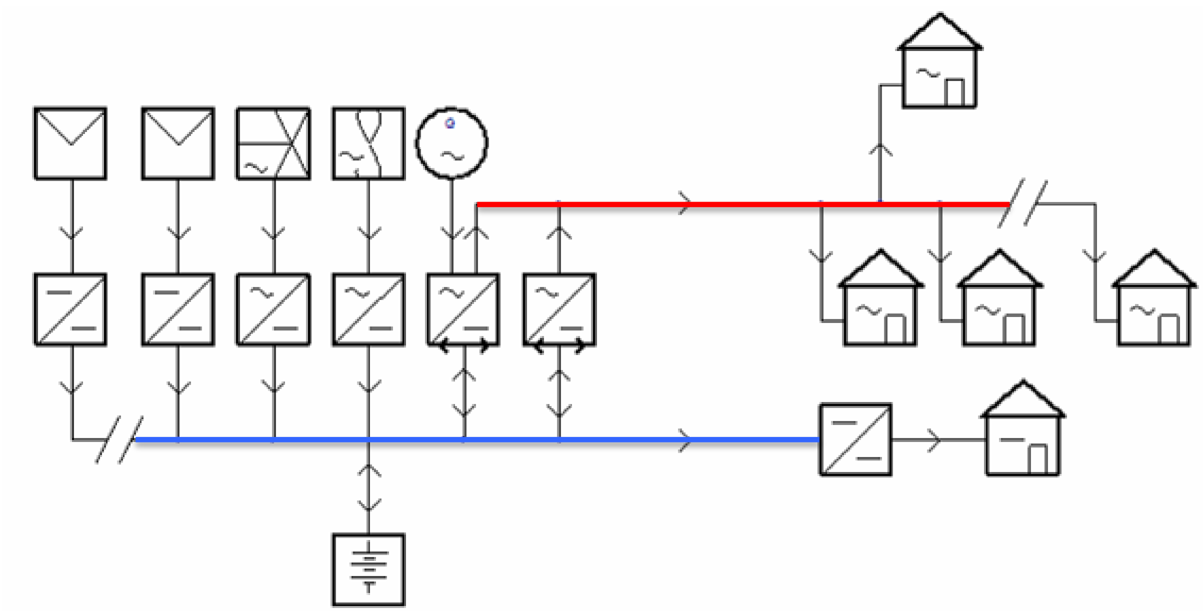
Source: TRAMA TECNOAMBIENTAL

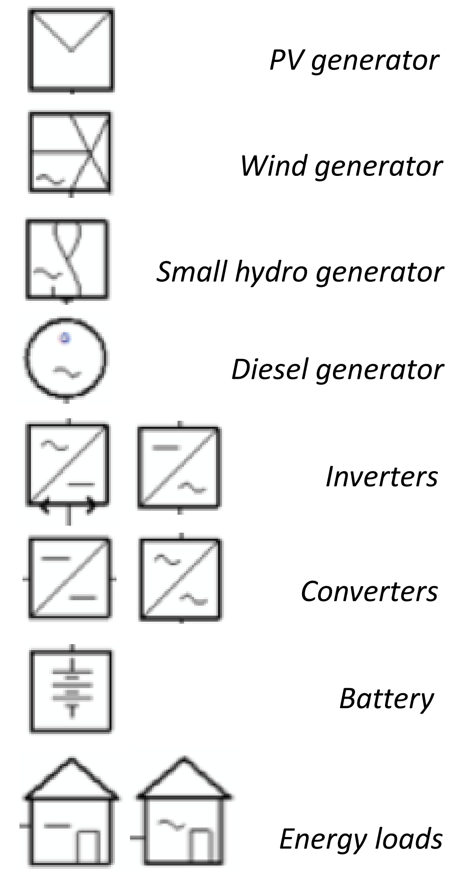
SYSTEM ARCHITECTURE: DC BUS COUPLING



Source: ARE, 2008

DC BUS COUPLING
EXAMPLE OF TECHNICAL SCHEME



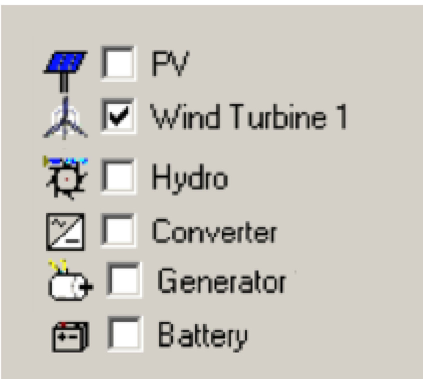


Source: TRAMA TECNOAMBIENTAL

IV. Considerations for an hybrid system in this training (IV)

Hybrid system’s input units

INPUT UNITS



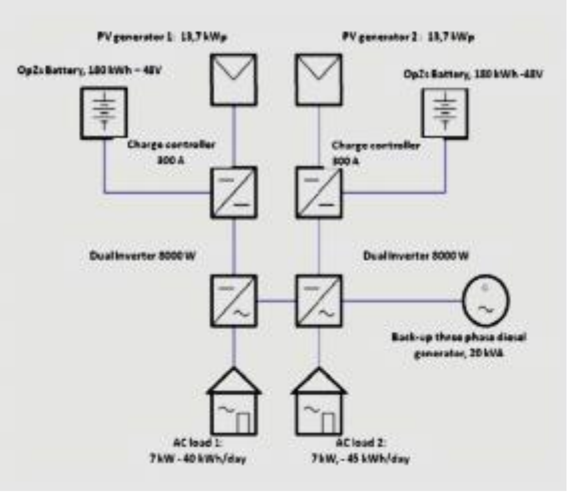
PV generator	*(kW)*	*Kilowatt*
Wind Turbine	*(Quantity)*	*number of units*
Hydro	*(m) meters of head (L/s) liters per second or flow*	
Converter	*(kW)*	*Kilowatt*
Generator	*(kW)*	*Kilowatt*
Battery	*(Quantity)*	*number of units*

Source: HOMER ENERGY, 2011

V. Example of an operational energy system in an isolated village of 600 people

Monte Trigo, Cape Verde, West Africa

Monte Trigo’s energy system



Source: BRIGANTI et al, 2012

Technical notes of the system

- In February 2012, entered into service of Cape Verde's first rural micro grid with 100% renewable energy generation. This project was carried out within the framework of the "Energy Facility" ACP-EU program. Permanent electricity access had been strongly requested by the local stakeholders and community of the village to cover basic energy needs such as lighting, communication, community services and ice production for fish preservation.

- The objective of the project was the electrification of the village of Monte Trigo (600 people) in Santo Antão Island, with a Multiuser Solar micro-Grid (MSG).

- The project was implemented in 2011, and is currently in the post commissioning follow-up period. A key aspect of the project has been to ensure the long-term sustainability of the electricity service. In addition to the description of the plant and the operation and management scheme, this article underlines the importance of the Energy Daily Allowance (EDA) concept from social, technical and economic perspectives. In conclusion the article intends to highlight the validity of both the technical solution and management model.

- *Among other expert methods of calculation, simulation tools were used to analyze the feasibility and the design of the system.*

✔ **For further reading (1): CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR**
http://www.ecowrex.org/document/implementation-pv-rural-micro-grid-island-santo-antao-cape-verde-individual-energy

Source: BRIGANTI et al, 2012

VI. Considerations on energy demand (I)

UNITS

UNITS

• Power	(kW)	*Kilowatt*
• Time	(h)	*hour*
• Energy	(kWh)	*Kilowatt*(per)*hour*

Generation (generator side): is the energy produced by the *power* of an energy generator during a certain period of *time*.

Energy = Power of an energy generator (kW) · Time (period of hours)

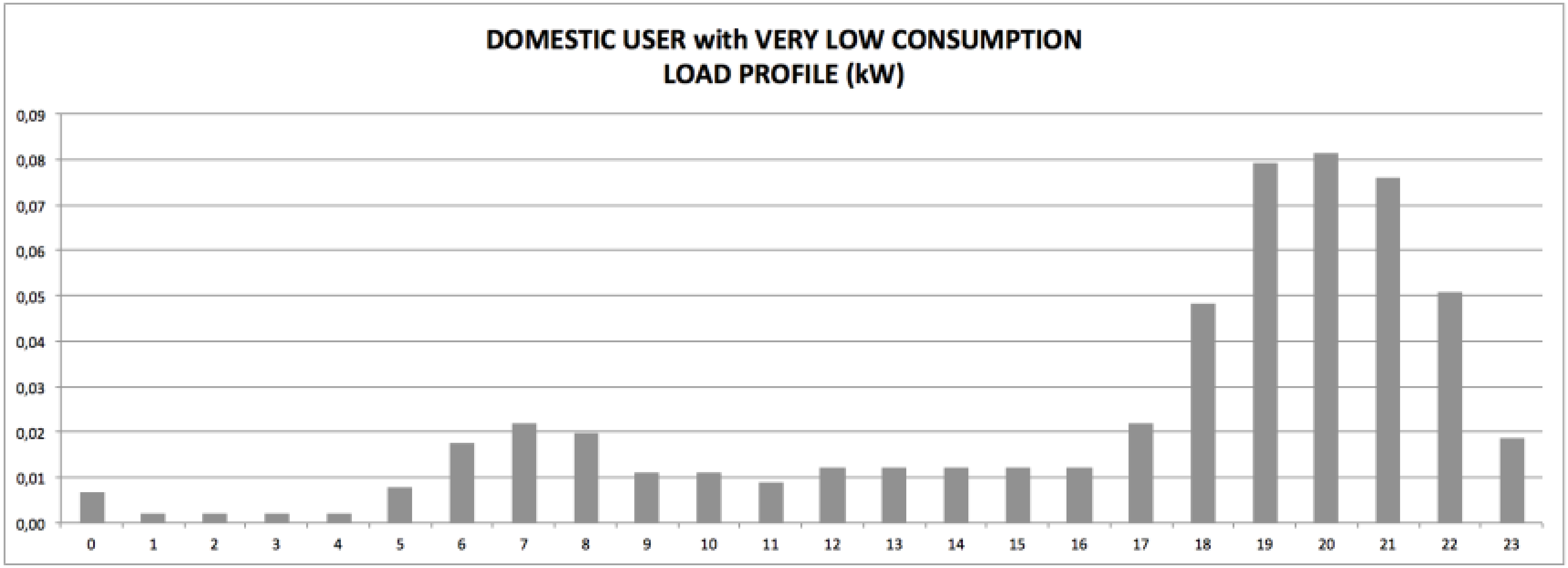
Energy Demand (users side): is the total energy the consumers need, during a certain period of time; and the amount of energy that normally they are charged for (as part of an arbitrary tariff).

Normally, the energy produced by an energy generator has to be higher than the energy demand. This is related to the losses and performance of the system, among other factors, that have to be carefully taken into consideration. <u>The detail is taken out from this training due to the deep level of analysis that it needs.</u>

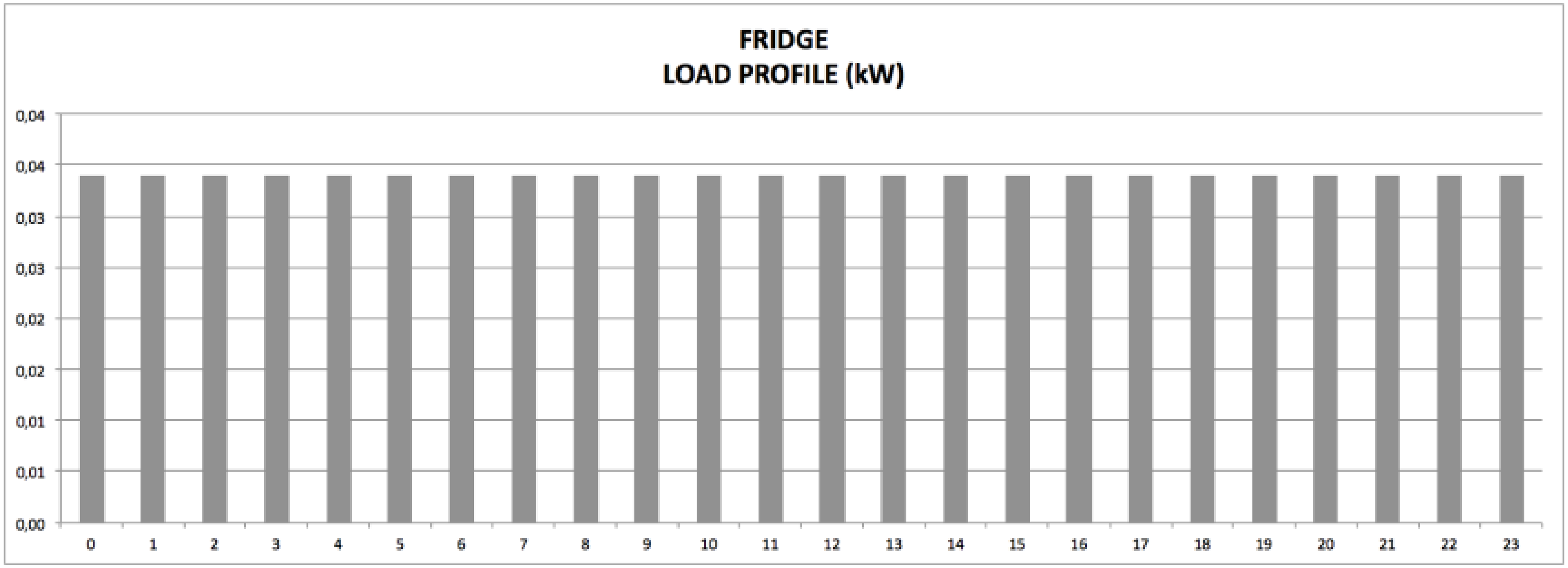
VII. Considerations on energy demand (II)

LOAD PROFILE

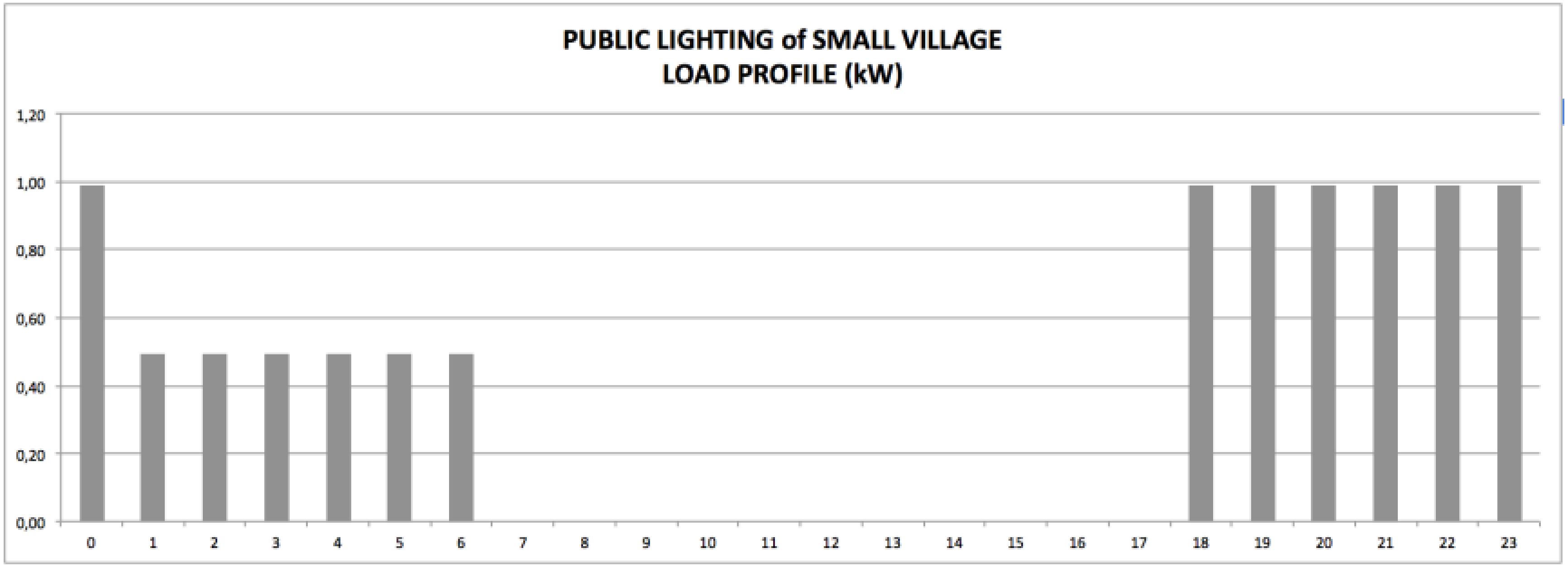
Example of daily load profile (1)



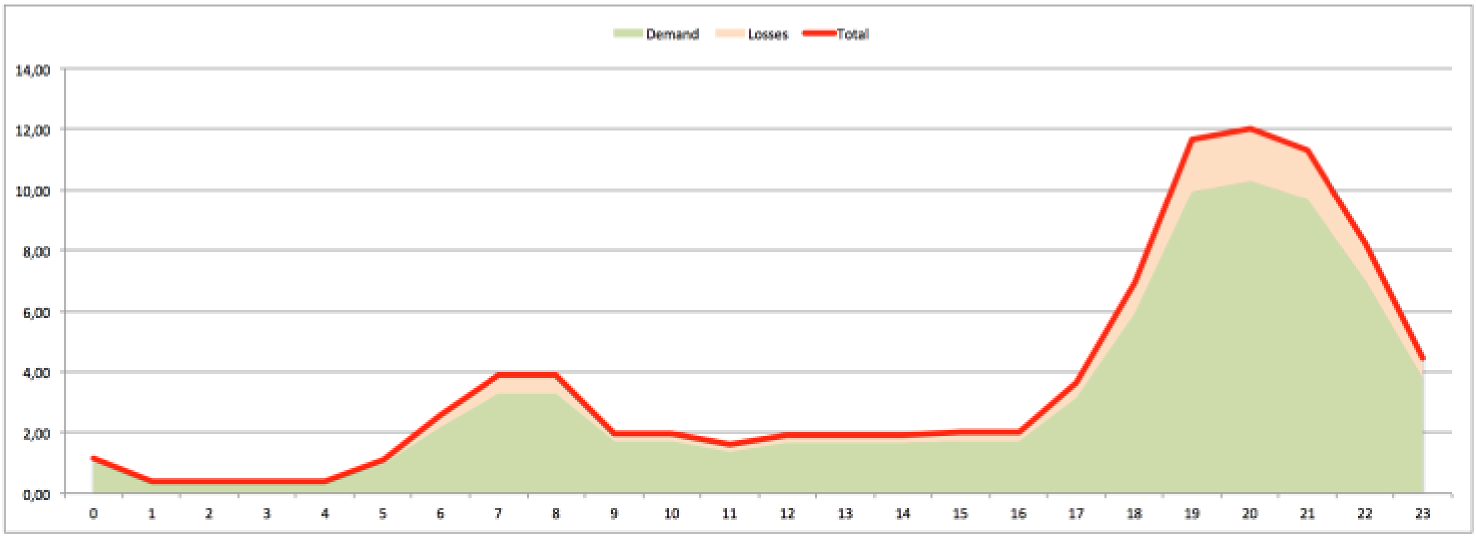
Example of daily load profile (2)



Example of daily load profile (3)



Aggregated daily Load profile



	Time	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Demand	Power (kW)	0,99	0,33	0,33	0,33	0,33	0,93	2,19	3,31	3,31	1,69	1,69	1,36	1,63	1,63	1,63	1,73	1,73	3,12	5,92	9,95	10,28	9,68	7,02	3,81
	Hours (h)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	Energy (kWh)	0,99	0,33	0,33	0,33	0,33	0,93	2,19	3,31	3,31	1,69	1,69	1,36	1,63	1,63	1,63	1,73	1,73	3,12	5,92	9,95	10,28	9,68	7,02	3,81

TOTAL ENERGY PER DAY 74,95 kWh

Losses	Losses (kW)	0,17	0,06	0,06	0,06	0,06	0,16	0,37	0,56	0,56	0,29	0,29	0,23	0,28	0,28	0,28	0,29	0,29	0,53	1,01	1,69	1,75	1,65	1,19	0,65

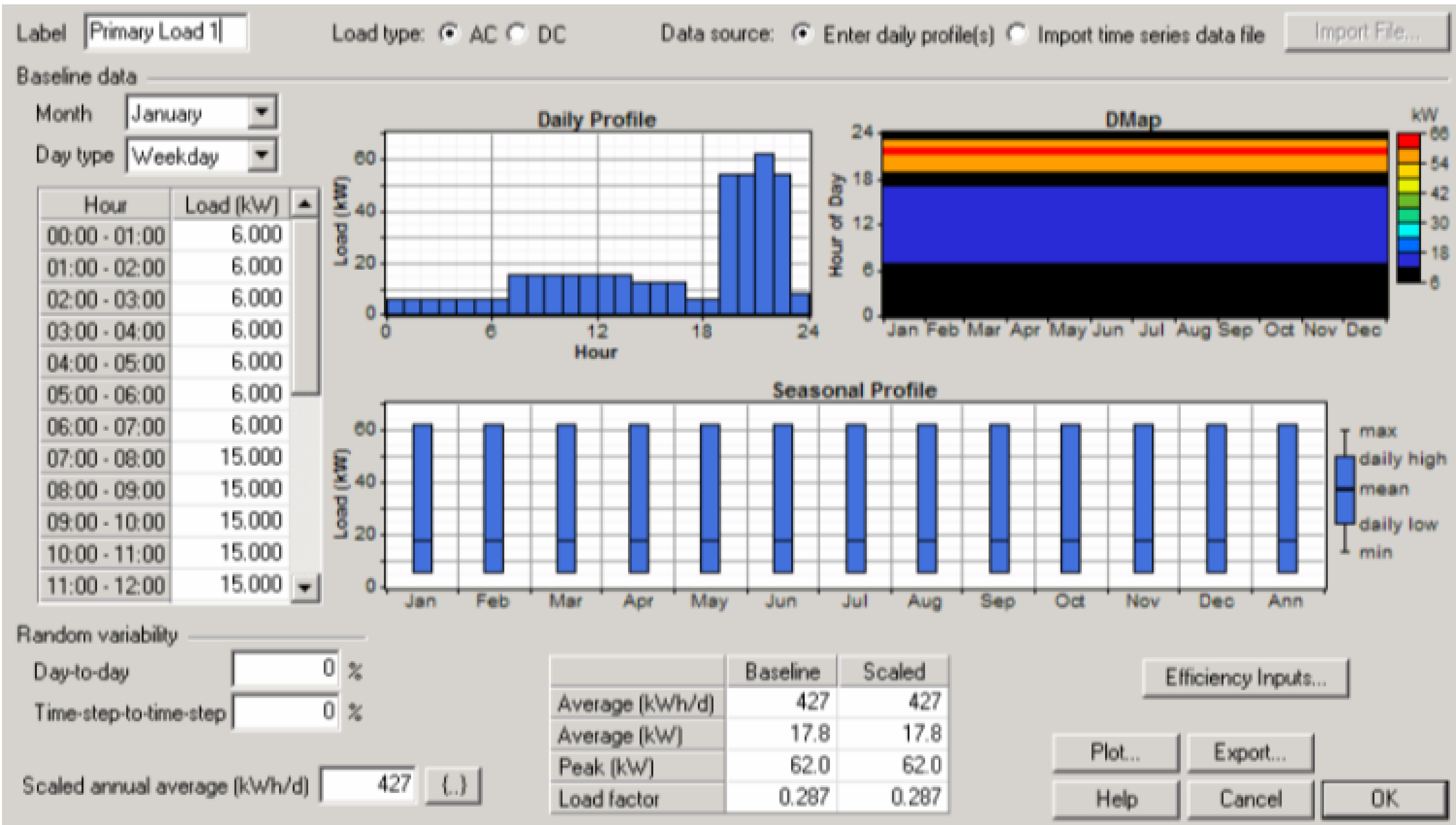
TOTAL ENERGY PER DAY 12,74 kWh

Total	**TOTAL Generation**	1,16	0,39	0,39	0,39	0,39	1,09	2,56	3,87	3,87	1,98	1,98	1,60	1,91	1,91	1,91	2,03	2,03	3,66	6,92	11,65	12,03	11,33	8,21	4,46

TOTAL ENERGY PER DAY 87,69 kWh

Source: ECREEE

Simulation software use (aggregated) Load daily Profile



Source: HOMER ENERGY, 2011

Recommendation on sizing and simulating RE hybrid systems with multiple users

- Users should have *dispenser meters* with Energy Daily Allowance (EDA) management according to the contracted tariff (limitations through smart devices that control the kWh of energy consumed).

- (…) The concept of *energy daily allowance* **introduces certainty in the most uncertain parameter when sizing and simulating RE hybrid micro grids with multiple users**

Source: GRAILLOT et al, 2012

Dispenser meter: a key device for dimensioning hybrid systems

- From a technological stance, it enables components like batteries and inverters to ***operate within their specified range***.
- From a financial point of view it reduces load uncertainty and its associated risk regarding collected revenues.
- From a social point of view, it responds to users' needs more accurately and guides them through the management of energy use and energy budget.

Source: GRAILLOT et al, 2012

VIII. Considerations on costs (I)

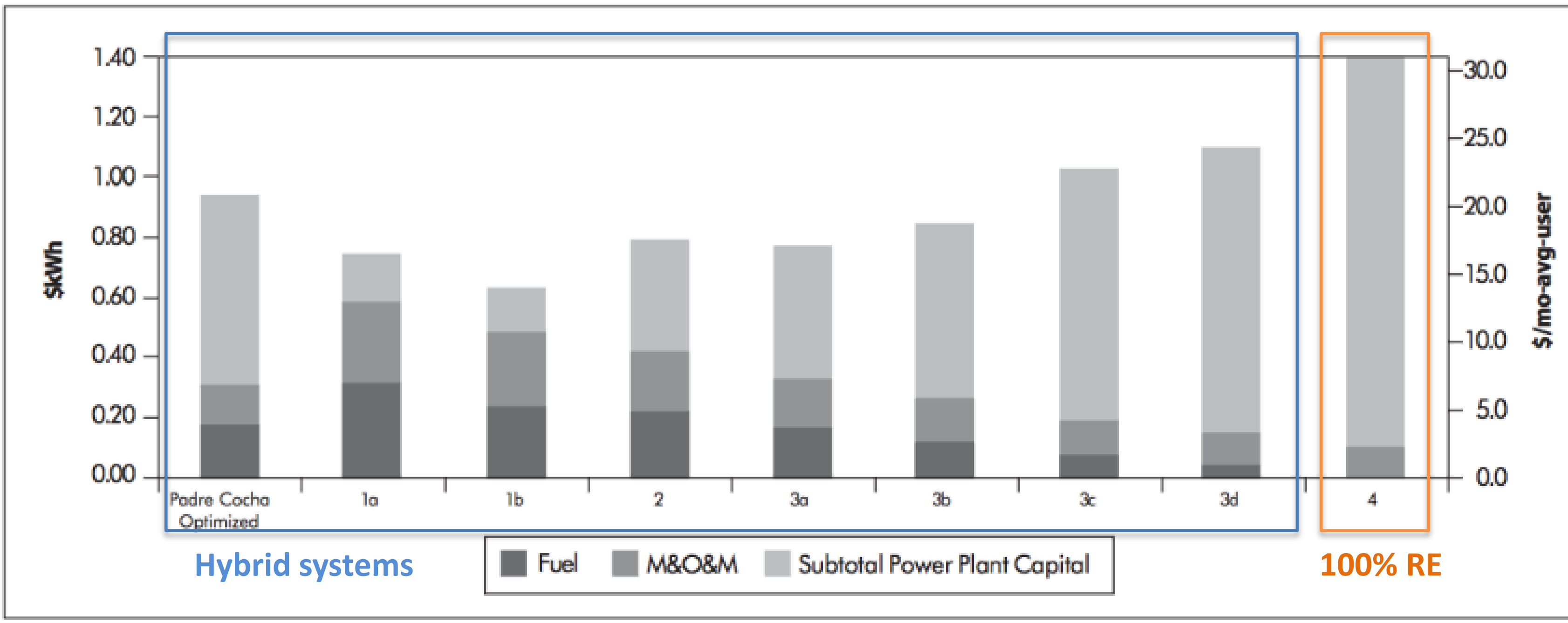
Comparison of costs of hybrid systems

Type of costs related to an hybrid energy system

EXPENSES	INCOMES
Capital Costs	Tariff
Replacement costs	Subsidy
Operation, Maintenance and Management	…
Fuel	
…	

Comparison costs of hybrid solutions

Figure 3.1: Comparison of Cost Breakdown for each Option



Split of levelized costs at 10% of discount rate and fuel at 0.57 &/liter per energy unit and per user service for different case studies

Source: ESMAP, 2007b

Comparison costs of hybrid solutions

		PV Arrays kWp	Genset kW	Batteries kWh	Power Conditioning	
					Rectifier kW	Inverter kW
Padre Cocha RAPS (Optimized)[1]		30	128			40
1.Diesel-only	1a. Alternative One Stand-by Unit		1 x 36 kW	0	0	0
	1b. Alternative Peak and Off-peak		2 x 18 kW	0	0	0
2. Diesel-battery-hybrid			1 x 36 kW	310	20	10
3. Diesel-PV-hybrid	3a. Solar PV 25%	25	36 kW	310	20	10
	3b. Solar PV 50%	50	36 kW	310	20	10
	3c. Solar PV 75%	75	36 kW	524	10	20
	3d. Solar PV 85%	93	36 kW	524	10	20
4. Solar PV 100%		140	0	765	0	25

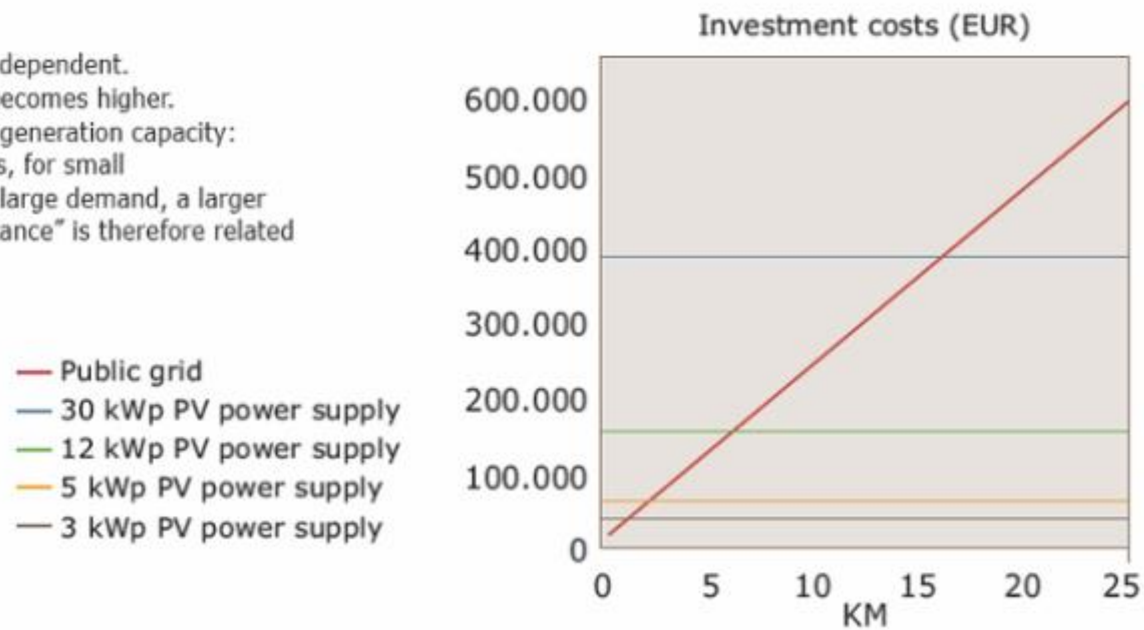
[1] *Actual figures from Padre Cocha but with improvements to significantly reduce distribution losses.*

Source: ESMAP, 2007b

Grid extension costs

Economical comparision: grid extension vs. hybrid systems (investment costs)

Grid extension costs are primarily distance dependent.
If the site is further away, the investment becomes higher.
PV Hybrid costs are related to the required generation capacity:
that depends on the required demand. Thus, for small
demand, a small investment is needed, for large demand, a larger
investment is needed. The break even "distance" is therefore related
to the demand.



- The extension of the grid has to be taken into consideration when dimensioning and simulating an isolated multi user hybrid system.

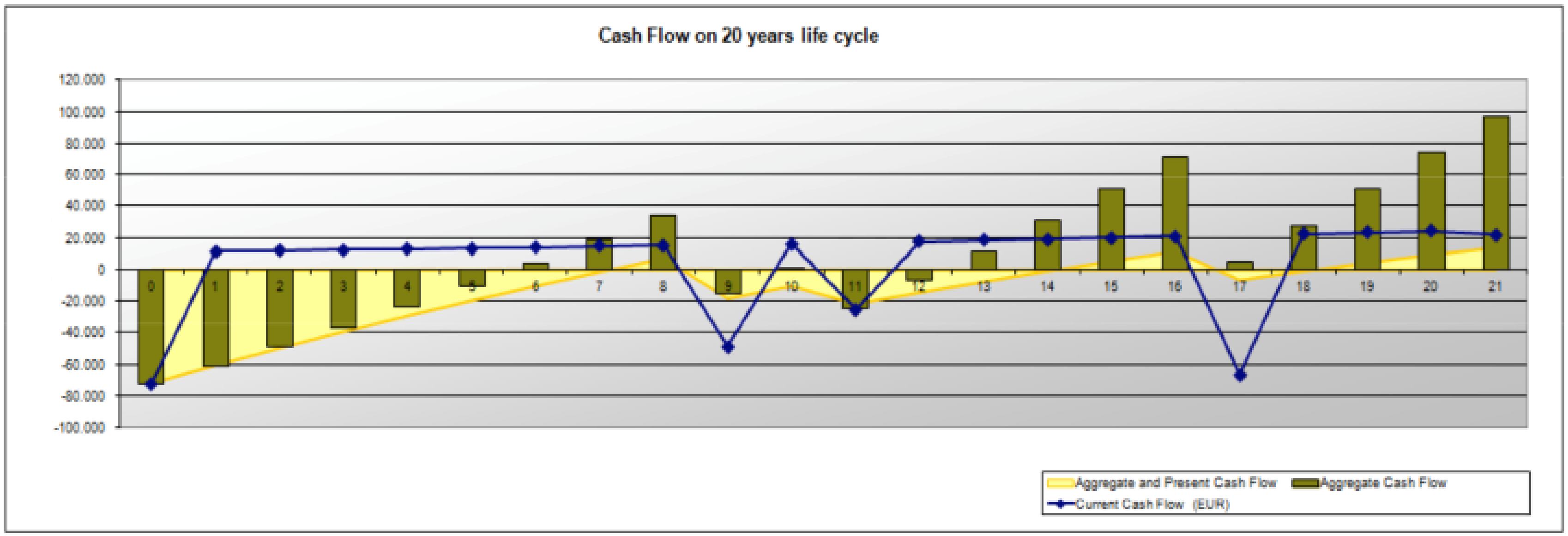
Source: ARE, 2008

IX. Considerations on costs (II)

The Levelized Cost of Energy

Simulation software give the possibility to analyze economics

- Scenario for a life cycle of 20 years, cash flow evolution as a result of aggregated incomes and expenses.



Source: TRAMA TECNOAMBIENTAL

Levelized cost of Energy (LCOE)

- Cash flow evolution of several possible hybrid systems may differ, specially due to the type of technology chosen: replacement costs are not the same for PV solar panels than for Wind generators, different batteries have different replacement costs, and the costs at the beginning of a life cycle are not “economically” the same as the costs at the end of the life cycle due to the evolution of the value of a currency through the years (among other factors).

- We need a reference value to compare different multi year scenarios.

- LCOE is a constant value ($/kWh) used as a reference to compare (through a life cycle period) different technologies and systems that produce energy.

- It is referred to the minimum energy income per kWh, that equals expenses of the implementation and operation of the system with the incomes generated by the system.

- The LCOE is based on the Net Present Value economical methodology in a multi year scenario.

Source: ECREEE

Simple example: one year scenario

How much has to be the energy income ($ per kWh) to pay back the cost of the system in one year?

Cost of the Hybrid System ($) = Energy generated (kWh) · Energy cost ($ / kWh)

So,

Energy cost ($/kWh) = Cost of the system ($) / Energy generated (kWh)

Note.- When performing a rigorous financial analysis of a system we should consider "energy to sell" (the amount of kWh that can be sold to the consumer) rather than energy generated. Energy generated normally is higher than energy consumed. For example, losses can not be sold to someone and get incomes. So the levelized cost of an energy system is better to be related to the energy potentially being sold, rather than simply to the energy generated.

Source: ECREEE

Understanding LCOE in 3 steps (Net Present Value)

one year scenario

1	INCOMES ($)	=	EXPENSES ($)
	Energy generated (kWh) • Energy cost ($/kWh)	=	Costs of the Hybrid System ($)

multi year scenario

2	**NPV (INCOMES)** ($)	=	**NPV (EXPENSES)** ($)
	NPV (Energy generated • Energy cost**)**	=	**NPV (**Costs of the Hybrid System**)**

*the Levelized Cost of Energy is a **constant value** through the life cycle -by definition-*

3	Life Cycle INCOMES ($)	=	Life Cycle EXPENSES ($)
	Energy cost • **NPV (**Energy generated**)**	=	**NPV (**Costs of the Hybrid System**)**

This Energy cost is the LCOE

$$LCOE = \frac{\sum_{1}^{t} \frac{C_t}{(1+d_{nom})^t}}{\sum_{1}^{t} \frac{E_t}{(1+d_{nom})^t}}$$

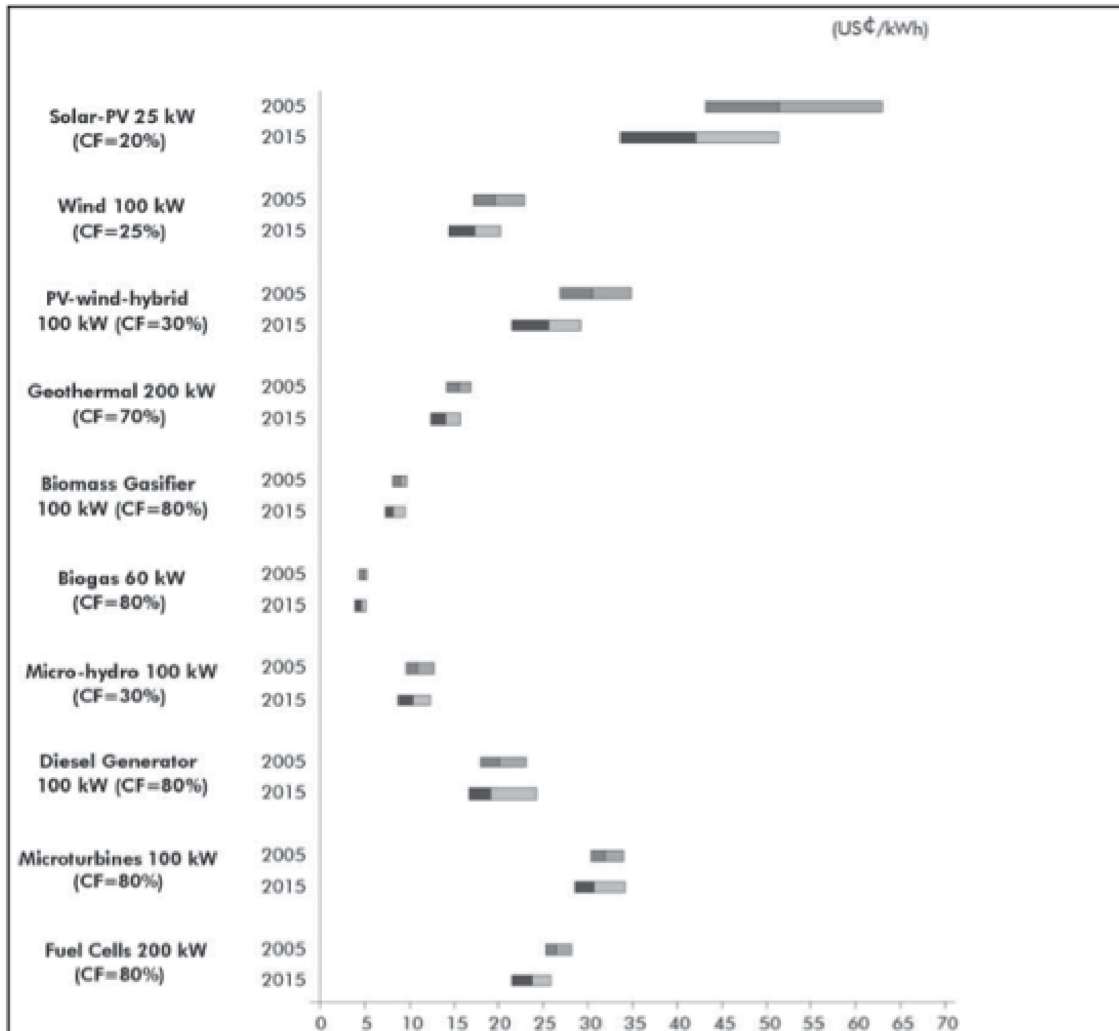
Source: ECREEE

More about LCOE

- Range
  costs

  technology.
- The LCOE
  to
  technologies
  electricity
  with
  flows.

Figure 2: Mini-grid Forecast Generating Costs



Source: ESMAP, 2007

X. About the HOMER software

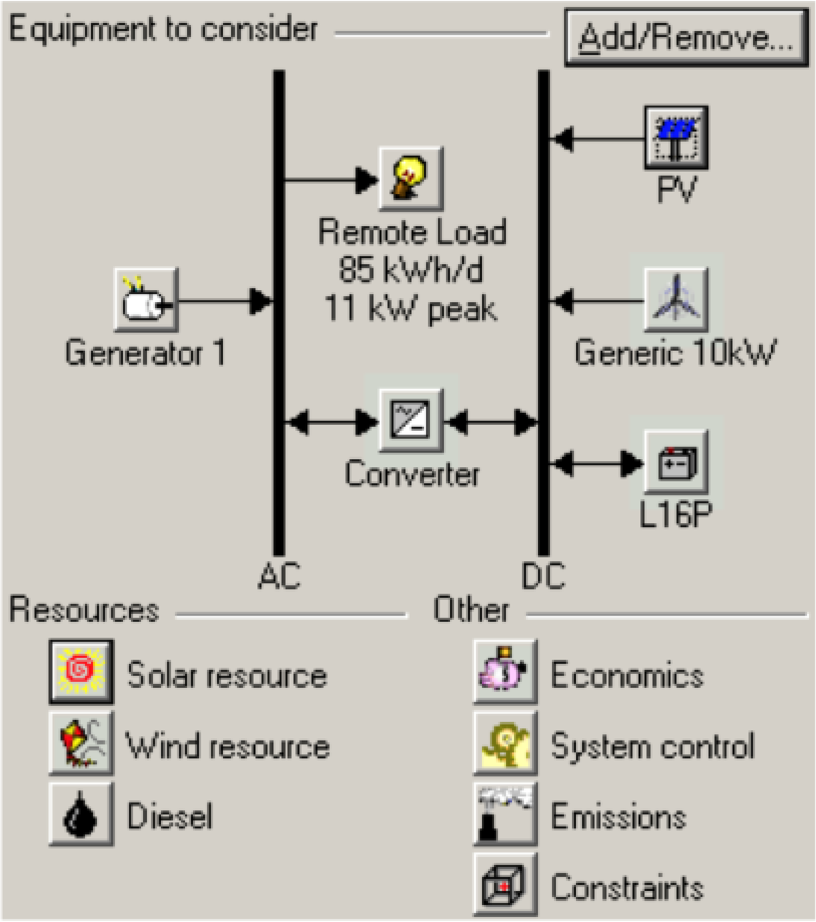
Hybrid **O**ptimization **M**odel for **E**lectric **R**enewables

About the HOMER software

- HOMER is an *energy modeling software.*
- It is powerful tool for designing and analyzing *hybrid power systems*.
- The hybrid power systems contain a mix of conventional generators, combined heat and power, wind turbines, solar photovoltaics, batteries, fuel cells, hydropower, biomass and other inputs.
- It is currently used all over the world by tens of thousands of people.
- ✔ **For further reading (2): CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR** *http://www.ecowrex.org/document/getting-started-guide-homer-legacy-version-268*

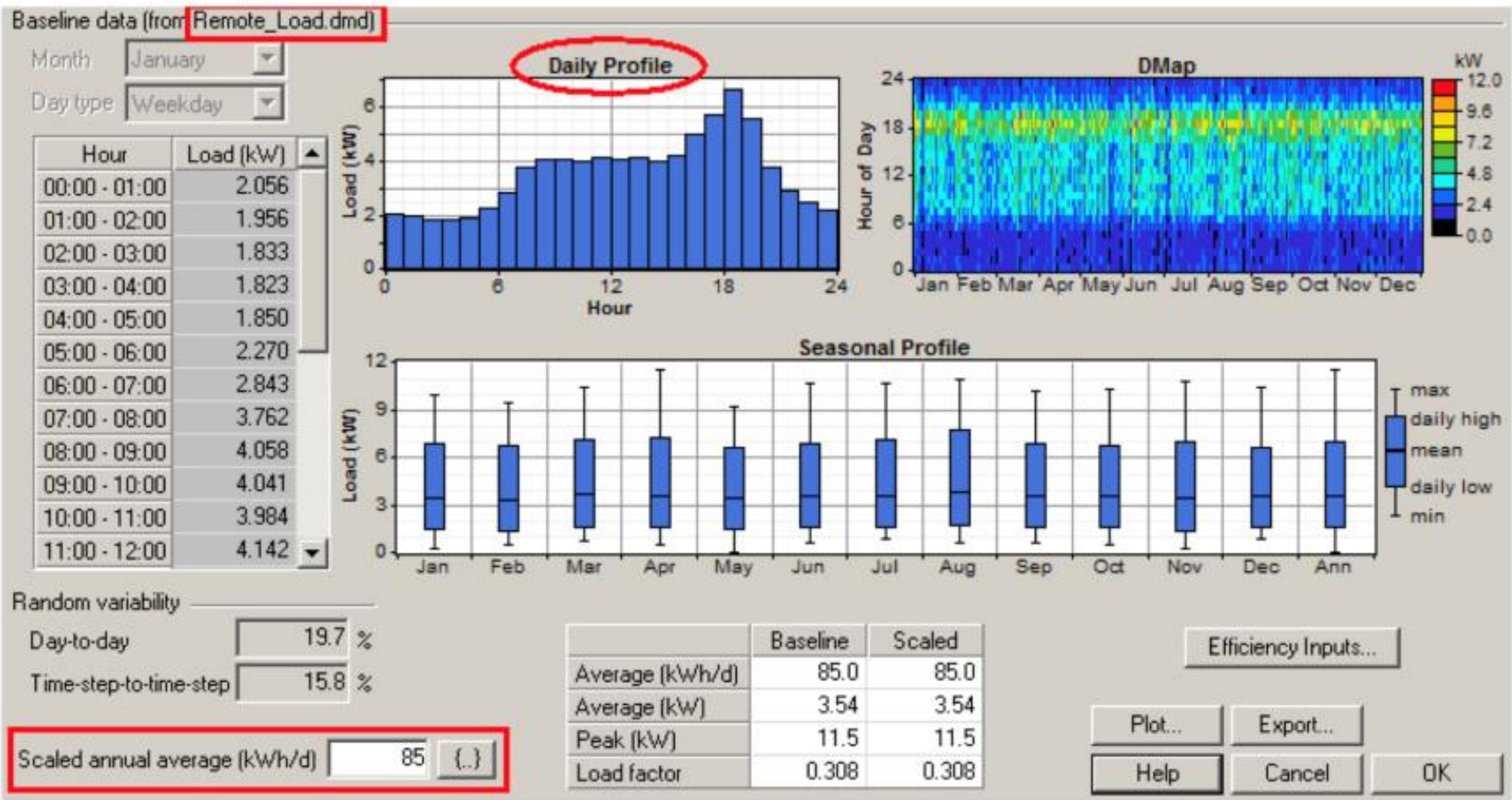
Source: HOMER ENERGY, 2011

Examples of the user interface



Source: HOMER ENERGY, 2011

Examples of the user interface

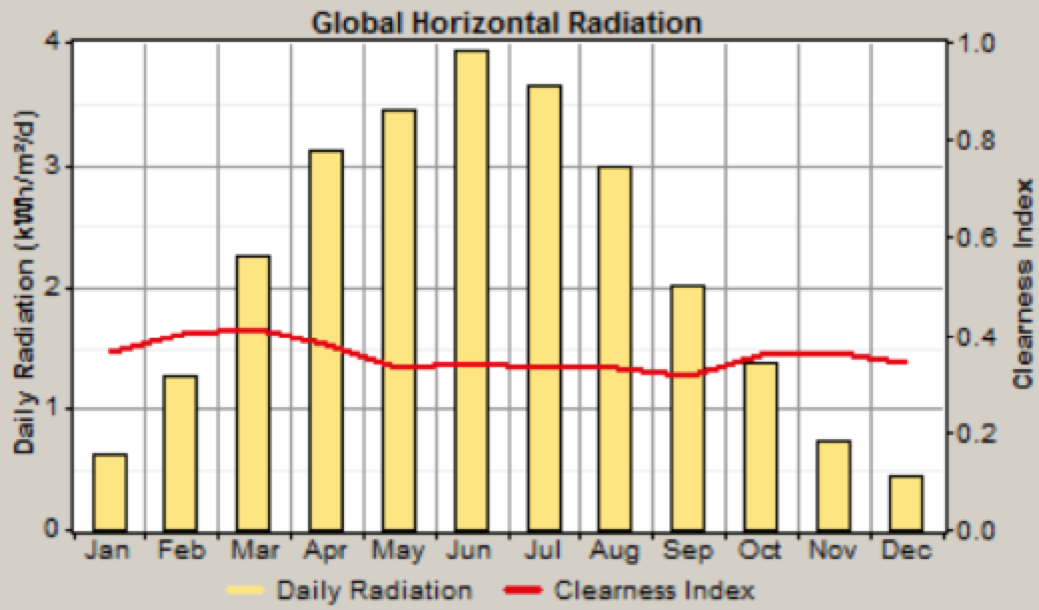


Source: HOMER ENERGY, 2011

Examples of the user interface

Baseline data (from AK Cold Bay.sol)

Month	Clearness Index	Daily Radiation (kWh/m2/d)
January	0.366	0.621
February	0.401	1.251
March	0.414	2.260
April	0.379	3.108
May	0.330	3.446
June	0.343	3.928
July	0.333	3.646
August	0.329	2.973
September	0.315	2.009
October	0.360	1.366
November	0.363	0.728
December	0.341	0.446
Average:	0.349	2.153



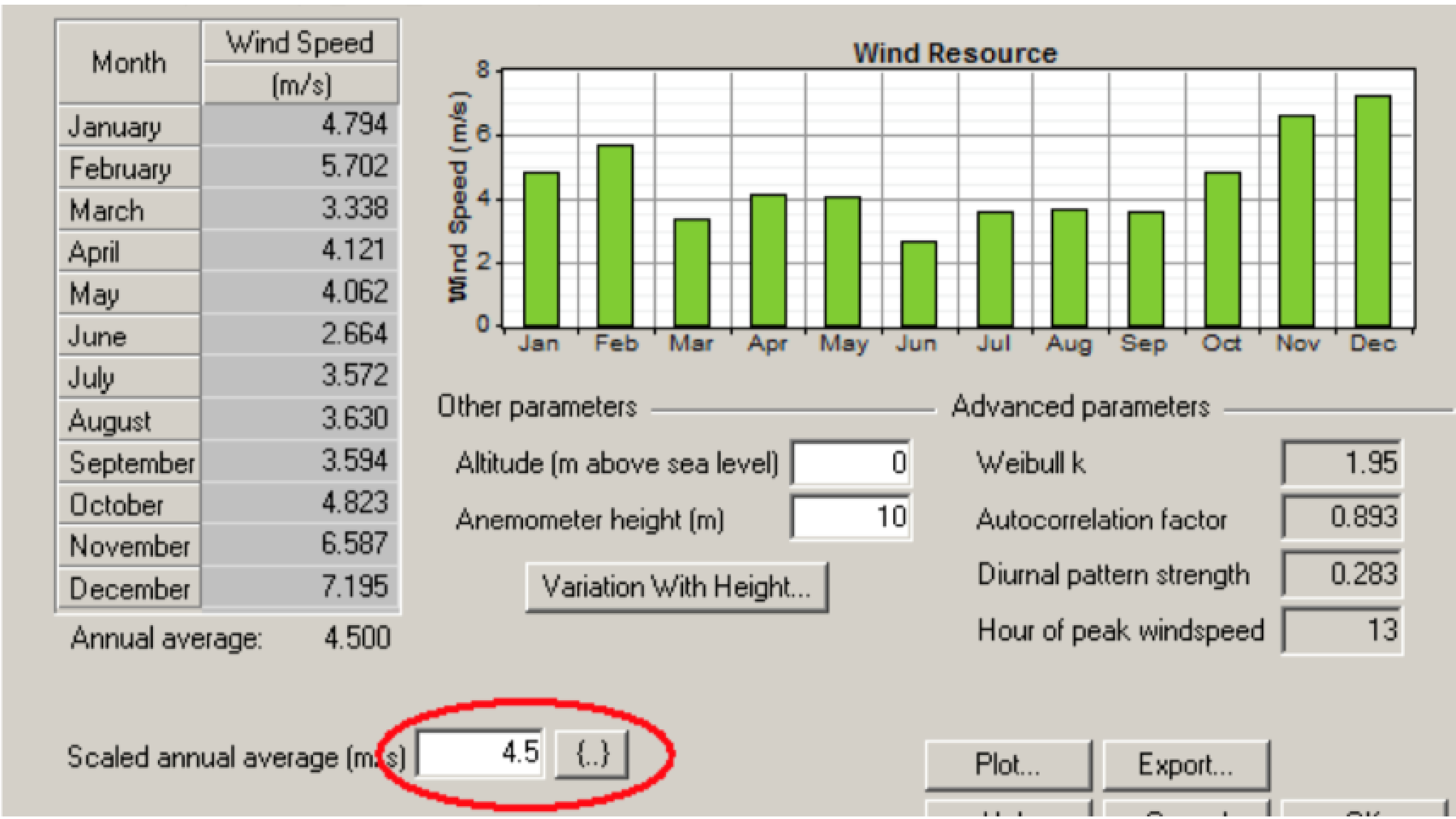
Scaled annual average (kWh/m²/d) 2.15 {..}

Plot... Export...

Help Cancel OK

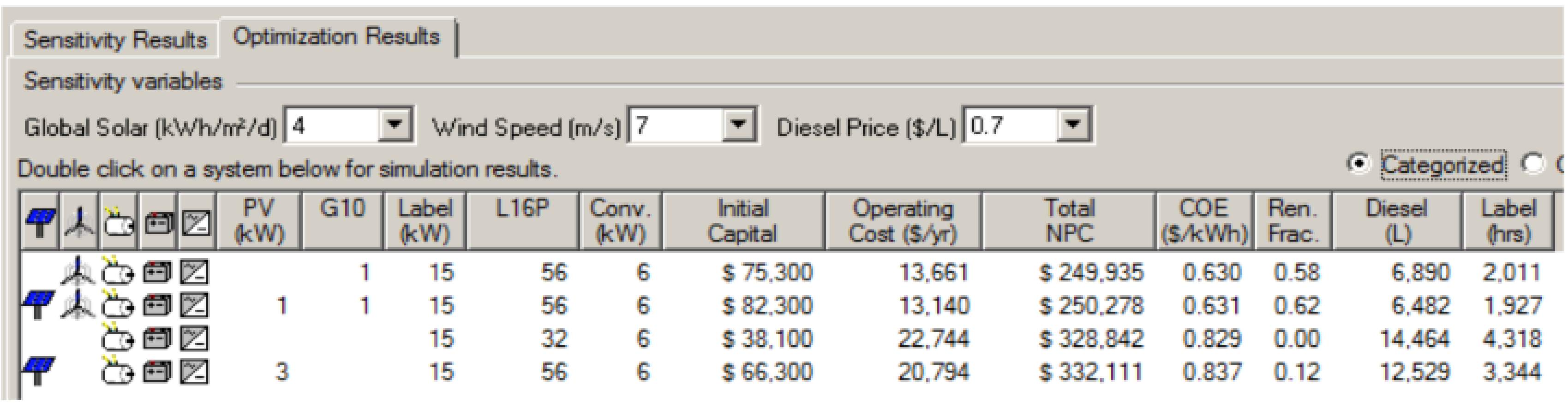
Source: HOMER ENERGY, 2011

Examples of the user interface



Source: HOMER ENERGY, 2011

Examples of the user interface



					PV (kW)	G10	Label (kW)	L16P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Diesel (L)	Label (hrs)
						1	15	56	6	$ 75,300	13,661	$ 249,935	0.630	0.58	6,890	2,011
					1	1	15	56	6	$ 82,300	13,140	$ 250,278	0.631	0.62	6,482	1,927
							15	32	6	$ 38,100	22,744	$ 328,842	0.829	0.00	14,464	4,318
					3		15	56	6	$ 66,300	20,794	$ 332,111	0.837	0.12	12,529	3,344

Source: HOMER ENERGY, 2011

Convenience of an energy simulation tool and when?

- The hybrid systems have a high level of complexity related to the possibility of many combinations and solutions.
- Due to the interaction of several energy resources, many industrial technologies and prices, different energy user profiles, constrains and costs, etc… it is very convenient to use a powerful simulation tool to achieve good compromised solutions and to analyze different scenarios
- Very suitable for analysis and feasibility studies.
- Once the type of solution is targeted, other experienced methodology of calculation and dimensioning may apply.

Source: ECREEE

HOMER compared to other software

HOMER simulates the annual performance of each of the system combination possibilities for a specified set of energy sources and calculates also the system and operating costs over the given period.

The outcome of the simulation is a list of the possible systems in order of the arising costs. A graph depicts the various ranges of the most profitable systems over the given operating period, based on the selected criteria.

Detailed results can be output for each of the individual simulated systems (graphs, tables, scatter plot, print-out).

- ✔ **For further reading (3):** **CLICK ON THE LINK OR COPY AND PASTE THIS LINK INTO YOUR WEB BROWSER ADDRESS BAR** *http://www.ecowrex.org/document/world-wide-overview-design-and-simulation-tools-hybrid-pv-systems*

Source: IEA, 2011

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Simulation models are very useful; one important thing is to set the right questions to them and know how to interpret the given results; always, and in any stage of the project design.

"Computers are useless. They can only give you answers."

Pablo Picasso

Step 1

Getting Started Guide

Step 1: Formulate a question that HOMER can help answer

HOMER can answer a wide range of questions about the design of small power systems. It is useful to have a clear idea of a question that you want HOMER to help answer before you begin working with HOMER. Examples of the kinds of questions that HOMER can answer are:

- Is it cost-effective to add a wind turbine to the diesel generator in my system?
- How much will the cost of diesel fuel need to increase to make photovoltaics cost effective?
- Will my design meet a growing electric demand?
- Is it cost-effective to install a microturbine to produce electricity and heat for my grid-connected facility?

References

- *ARE (2008), Hybrid power systems based on renewable energies: a suitable and cost-competitive solution for rural electrification, Alliance for Rural Electrification, Brussels. http://www.ecowrex.org/document/hybrid-power-systems-based-renewable-energies-suitable-and-cost-competitive-solution-rural*

- *BRIGANTI, M., VALLVÉ, X., ALVES, L., PUJOL, D., CABRAL, J., LOPES, C. (2012), Implementation of a PV rural micro grid in the island of Santo Antao (Cape Verde), 27th European Photovoltaic Solar Energy Conference and Exhibition, Frankfurt. http://www.ecowrex.org/document/implementation-pv-rural-micro-grid-island-santo-antao-cape-verde-individual-energy*

- *ESMAP (2007), ESMAP Technical Paper 121/07 Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies, The World Bank, Washington. http://www.ecowrex.org/document/technical-and-economic-assessment-grid-mini-grid-and-grid-electrification-technologies*

- *ESMAP (2007b), ESMAP Technical Paper 111/07 olar-diesel Hybrid Options for the Peruvian Amazon. Lessons Learned from Padre Cocha, The World Bank, Washington. http://www.ecowrex.org/document/solar-diesel-hybrid-options-peruvian-amazon-lessons-learned-padre-cocha*

- *GRAILLOT, A., BRIGANTI, M., SOLANO-PERALTA, M., VALLVÉ, X., (2012), "Daily Energy Allowance" concept in rural micro grids. 15 years of experience, 6th European PV-Hybrid and Mini-Grid Conference, Chambéry. http://www.ecowrex.org/document/15-years-field-experience-daily-energy-allowance-concept-basis-load-control-and-guide*

- *HOMER Energy (2011), Getting Started Guide for HOMER Legacy (Version 2.68), Homer Energy and National Renewable Energy Laboratory, Colorado. http://www.ecowrex.org/document/getting-started-guide-homer-legacy-version-268*

- *IEA, (2011), Report IEA-PVPS T11- 01:2011 World-wide overview of design and simulation tools for hybrid PV systems. http://www.ecowrex.org/document/world-wide-overview-design-and-simulation-tools-hybrid-pv-systems*

References

- *ECREEE* http://www.ecreee.org
- *ECOWREX* http://www.ecowrex.org
- *HOMER ENERGY* http://www.homenergy.org
- *SMA Solar Technology AG* http://www.sma.de/en.html
- *TRAMA TECNOAMBIENTAL* http://www.tta.com.es

CEREEC ECREEE

ECOWAS Regional Centre for Renewable Energy and Energy Efficiency

Centre Régional pour les Energies Renouvelables et l'Efficacité Energétique de la CEDEAO

Centro Regional para Energias Renováveis e Eficiência Energética da CEDEAO

Merci! Thank you! Muito obrigado!

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