

# The challenge of making reliable carbon abatement estimates: the case of diesel microgrids

## Annexes

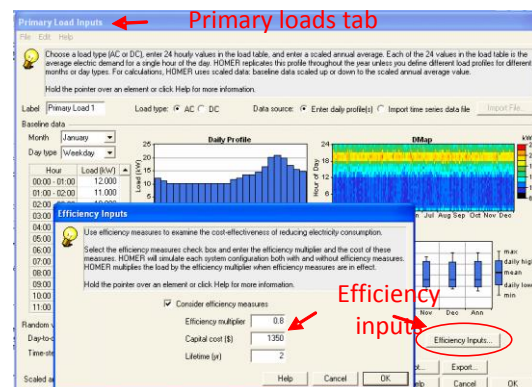
### Annex 1: Efficiency values in a HOMER simulation

The figure below shows the details of the calculation used to estimate the demand impact from replacing each of three incandescent light bulbs in 150 houses. Compact fluorescent light (CFL) bulbs typically deliver the same luminance using only 25% of the electricity of incandescent bulbs<sup>1</sup>. We assume that each of the three 60 W bulbs in the 150 households is replaced with a CFL, resulting in a reduced daily load of 251 kWh, down from 312 kWh, a 19% decrease in daily average consumption, which is equivalent to an 81% efficiency multiplier. Based on field experience, we assume a three dollar cost for purchase and installation of each bulb, resulting in a total implementation cost of \$1350. The bulbs are assumed to be used for 3 hours per day. We assume a conservative lifetime of 2 years (2190 hours) due to voltage fluctuations in the microgrid, and imported bulbs manufactured to weak quality standards.

The values highlighted in grey will be entered into the *Efficiency inputs* tab, found on the *Primary load* tab. The *Primary load* tab appears when clicking on the *Primary load* button in the *Equipment to consider* section on the main graphical user interface of the HOMER model.

**Figure A-1: Calculations and inputs for lighting efficiency in a HOMER simulation. The three values that are highlighted in grey in the table are the efficiency inputs into the model.**

Number of light bulbs (3 per house)	450
Incandescent load (kWh/day)	81
CFL load (kWh/day)	20
Daily grid load with incandescents (kWh)	312
Daily grid load with CFLs (kWh)	251
Reduction of load (%)	0.19
HOMER efficiency multiplier	0.81
Cost per bulb (\$) (capital + installation)	\$3.00
Total upfront cost (\$)	\$1 350
Lifetime of bulbs (years)	2
Lifetime hours	2 190



<sup>1</sup> Gadgil, A.J. & G. De Martino Jannuzzi (1991). Conservation potential of compact fluorescent lamps in India and Brazil. *Energy Policy* 19(5): 449–463.

## Annex 2: Description of parameters used in simulations

- Diesel fuel price: 1.06 \$/liter. This fuel price is based on the average retail diesel price for 2008 (derived from data from the Nicaragua Institute of Energy<sup>2</sup>). The diesel prices in rural areas in 2009 remained at or above this price.
- Annual discount rate: 8.0%. The discount rate accounts for market interest rate minus inflation (i.e. the real interest rate). In 2003, 14% was an average cost of capital in Nicaragua, and the rates of interest between 2003 and 2009 were not dissimilar<sup>3</sup>. However, due to the fact that many of these systems for rural electrification are subsidized by the government or supported by international lending institutions such as the World Bank and the Inter-American Development Bank, they would most likely have access to capital at interest rates lower than the typical market rates in the country, which is why 8.0% was chosen.
- Lower heating value (LHV) of diesel fuel: 9.84 kWh/liter. This is the default value from the micro-optimization model, HOMER<sup>4</sup>. (The LHV is the net heat value of a fuel, assuming that all water is in the vapor stage following combustion (i.e. the latent heat of vaporization is not recovered), which is the case for diesel plants that do not use any heat recovery processes. Note that the marginal cost of generation is equal to diesel fuel price / (9.84 kWh/liter x diesel efficiency).
- kg CO<sub>2</sub> / liter of diesel: 2.668 : This is the value recommended by the US Environmental Protection Agency (EPA) calculated in accordance with IPCC guidelines<sup>5</sup>. Turbine and tower lifetime: 15 years (based on manufacturer specifications).
- 10 kW turbine: \$27 600. The performance of several wind turbines was modeled using HOMER in class 1/class 2 wind sites. Abundant Renewable Energy's ARE 442 was found to have lower overall lifetime costs than other turbines, even though it required additional hardware costs to make it compatible with both a battery bank and the microgrid. The wind turbine's power curve has been verified by the US National Renewable Laboratory (NREL)<sup>6</sup>. In 2010, Abundant Renewable Energy was purchased by a new company, Xzeres. The authors assume that the Xzeres 442 is the same as the ARE 442<sup>7</sup>. Turbine tower (25 meters): \$5,000 (this price was based on local fabrication) O&M (maintaining the turbine and batteries): \$500/year. (Present value: \$4 922.)
- Inverter: \$16 157. (This is more expensive, almost double that of utilizing a typical cost of 0.75 \$/W for an inverter. This is because the ARE442 needs to utilize a specific grid-tie inverter (SMA Wind Boy), and then another inverter (SMA Sunny Island) in order to maintain a grid voltage and interface with the battery bank. Even with the additional cost, the ARE 442 produced lower modeled lifetime costs due to greater efficiencies at low wind speeds, in comparison to other wind turbines available in North America.
- Installation, wiring, and shipping: \$2 800.
- Estimation of \$1 300 for crating and shipping from the US. \$1 500 for land/water transport to a remote community.

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<sup>2</sup> <http://www.ine.gob.ni>

<sup>3</sup> see lending rates at the national bank: <http://www.bcn.gob.ni/>

<sup>4</sup> <http://www.homerenergy.com>

<sup>5</sup> <http://www.epa.gov/otaq/climate/420f05001.htm>

<sup>6</sup> [http://www.nrel.gov/wind/smallwind/abundant\\_renewable\\_energy.html](http://www.nrel.gov/wind/smallwind/abundant_renewable_energy.html)

<sup>7</sup> <http://www.xzeres.com/products/xzeres442/>

## Annex 3: HOMER simulation results

The following tables show the simulation results and additional calculations used to compute the abatement costs. In Table A-1a, the two measures followed by a single asterisk are calculated with respect to the diesel baseline. In Table A-1b, the measure, followed by a double asterisk, is calculated with respect to the integration of CFL lighting.

**Table A-1a. HOMER simulation results and additional calculations**

	Baseline	Integration of CFL lighting*			Integration of wind generation*		
	Diesel	Lighting	Diesel	Lighting + Diesel	Wind	Diesel	Wind + Diesel
Annualized cost (\$/yr)	\$53 984	\$ 758	\$47 065	\$47 823	\$5 991	\$47 353	\$53 344
Annual energy (kWh/yr)	113 880	-22 776	91 104	91 104	21 537	92 363	113 880
Annualized energy cost (\$/kWh)	\$0.47	\$0.03	\$0.52	\$0.52	\$0.28	\$0.51	\$0.47
Ave diesel efficiency	0.28			0.26			0.26
Emissions (t CO <sub>2</sub> /yr)	111			93.5			94.4
Relative Cost or Savings (\$/yr)	\$0			-\$6,161			-\$640
Carbon abatement vs baseline (tCO <sub>2</sub> /yr)	0			17			16.4
Abatement Cost vs baseline (\$/tCO <sub>2</sub> )	\$0			-\$358			-\$39

**Table A-1b. HOMER simulation results and additional calculations**

	Integration of light then wind**		
	Wind	Diesel	Lighting + Wind + Diesel
Annualized cost (\$/yr)	\$5 991	\$40 021	\$46 769
Annual energy (kWh/yr)	21 256	69 848	91 104
Annualized energy cost (\$/kWh)	\$0.28	\$0.57	\$0.51
Ave diesel efficiency			0.24
Emissions (t CO <sub>2</sub> /yr)			77
Relative Cost or Savings (\$/yr)			-\$1 054
Carbon abatement vs CFL integration (tCO <sub>2</sub> /yr)			16.8
Abatement Cost vs CFL integration (\$/tCO <sub>2</sub> )			-\$63

Annexes of : Christian E. Casillas and Daniel M. Kammen, « The challenge of making reliable carbon abatement estimates: the case of diesel microgrids », S.A.P.I.EN.S [On line], URL : <http://sapiens.revues.org/1228>

## Annex 4. Example of abatement calculations from various perspectives

The tables below provide an example of the values used in the abatement calculations from perspective of society, the utility, and the customers, for the efficient lighting intervention. The society perspective includes the investment costs, without accounting for financial flows passing to the various stakeholders (customers and the utility). In general, the abatement costs to society could include externalities, such as environmental damages. The abatement costs seen by the utility include the society costs (in this particular case, but certainly not cases when negative externalities are included), plus the revenue that comes from customers paying for electricity consumption. The abatement costs seen by the customers are estimated as the negative of the electricity charge revenue accrued by the utility. In this particular case, it is assumed that the utility pays for the installation of the efficient lights. The annual abatement cost is calculated as:

$$\text{Annual abatement cost (\$/tCO}_2\text{)} = \frac{(\text{Annualized cost of intervention}) - (\text{Annualized cost of reference case})}{\text{CO}_2 \text{ abated}}$$

Revenue is approximated as a flat rate of 0.15 \$/kWh and 0.40 \$/kWh, multiplied by the kWh production. The relative annualized costs are the net annualized costs from the electricity system that has integrated efficient lighting, subtracted by the net annualized costs of the diesel baseline.

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**Table A-2. Abatement cost calculations from perspective of society, utility, and consumer for the efficient lighting intervention, using an electricity rate of 0.15 \$/kWh. Positive values are costs, and negative values are revenue or savings.**

<b>Baseline</b>		<b>Diesel and lighting</b>	
<b>Costs to society</b>	<b>Diesel system</b>	<b>Costs to society</b>	<b>Diesel system</b>
Capital (\$/yr)	\$1 402	Capital (\$/yr)	\$1 402
Replacement (\$/yr)	\$3 029	Replacement (\$/yr)	\$3 029
O&M (\$/yr)	\$5 256	O&M (\$/yr)	\$5 256
Fuel (\$/yr)	\$44 576	Fuel (\$/yr)	\$37 652
Salvage (\$/yr)	-\$ 274	Salvage (\$/yr)	-\$ 274
Total (\$/yr)	\$53 989	Lighting (\$/yr)	\$ 758
		Total (\$/yr)	\$47 823
<b>Costs to Utility</b>	<b>Diesel system</b>	<b>Costs to Utility</b>	<b>Diesel system</b>
Capital (\$/yr)	\$1 402	Capital (\$/yr)	\$1 402
Replacement (\$/yr)	\$3 029	Replacement (\$/yr)	\$3 029
O&M (\$/yr)	\$5 256	O&M (\$/yr)	\$5 256
Fuel (\$/yr)	\$44 576	Fuel (\$/yr)	\$37 652
Salvage (\$/yr)	-\$ 274	Salvage (\$/yr)	-\$ 274
Revenue (\$/yr)	-\$17 082	Lighting (\$/yr)	\$ 758
Total (\$/yr)	\$36 907	Revenue (\$/yr)	-\$13 666
		Total (\$/yr)	\$34 157
<b>Costs to customers</b>		<b>Costs to customers</b>	
Total (\$/yr)	\$17 082	Total (\$/yr)	\$13 666
<b>Values for revenue estimation</b>		<b>Values for revenue estimation</b>	
kWh/yr	113 880	kWh/yr	91 104
electricity rate (\$/kWh)	\$ 0.15	electricity rate (\$/kWh)	\$ 0.15
		<b>Society</b>	<b>Utility</b>
<b>CO2 abated (tCO2/yr)</b>		17	17
<b>Relative costs (\$/yr)</b>		-\$6 166	-\$2 750
<b>Abatement cost (\$/tCO2)</b>		-\$ 358	-\$ 160
			<b>Customers</b>
			17
			-\$3 416
			-\$ 199

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**Table A-4. Abatement cost calculations from perspective of society, utility, and consumer for the implantation of efficient lighting intervention, using an electricity rate of 0.40 \$/kWh. Positive values are costs and negative values are revenue or savings.**

<b>Baseline</b>		<b>Diesel and lighting</b>	
<b>Costs to society</b>	<b>Diesel system</b>	<b>Costs to society</b>	<b>Diesel system</b>
Capital (\$/yr)	\$1 402	Capital (\$/yr)	\$1 402
Replacement (\$/yr)	\$3 029	Replacement (\$/yr)	\$3 029
O&M (\$/yr)	\$5 256	O&M (\$/yr)	\$5 256
Fuel (\$/yr)	\$44 576	Fuel (\$/yr)	\$37 652
Salvage (\$/yr)	-\$ 274	Salvage (\$/yr)	-\$ 274
Total (\$/yr)	\$53 989	Lighting (\$/yr)	\$ 758
		Total (\$/yr)	\$47 823
<b>Costs to Utility</b>	<b>Diesel system</b>	<b>Costs to Utility</b>	<b>Diesel system</b>
Capital (\$/yr)	\$1 402	Capital (\$/yr)	\$1 402
Replacement (\$/yr)	\$3 029	Replacement (\$/yr)	\$3 029
O&M (\$/yr)	\$5 256	O&M (\$/yr)	\$5 256
Fuel (\$/yr)	\$44 576	Fuel (\$/yr)	\$37 652
Salvage (\$/yr)	-\$ 274	Salvage (\$/yr)	-\$ 274
Revenue (\$/yr)	-\$45 552	Lighting (\$/yr)	\$ 758
Total (\$/yr)	\$8 437	Revenue (\$/yr)	-\$36 442
		Total (\$/yr)	\$11 381
<b>Costs to customers</b>		<b>Costs to customers</b>	
Total (\$/yr)	\$45 552	Total (\$/yr)	\$36 442
<b>Values for revenue estimation</b>		<b>Values for revenue estimation</b>	
kWh/yr	113 880	kWh/yr	91 104
electricity rate (\$/kWh)	\$0.40	electricity rate (\$/kWh)	\$0.40
		<b>Society</b>	<b>Utility</b>
		<b>Customers</b>	
<b>CO2 abated (tCO2/yr)</b>		17	17
<b>Relative costs (\$/yr)</b>		-\$6 166	\$2 944
<b>Abatement cost (\$/tCO2)</b>		-\$ 358	\$ 171
			-\$ 530