Photovoltaic Microgrid Business Models for Energy Delivery Services in Camps for Displaced People

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ABSTRACT: *Energy services are essential for the protection of basic human rights and dignity. Since 2014, energy issues have been incorporated in the United Nations High Commissioner for Refugees (UNHCR) global protection strategies. Off-grid solar photovoltaic (PV) power solutions can now provide cost-effective clean electricity in camps comprising large populations of internally displaced people and/or refugees. Through microgrid modelling and risk analysis, business models that could provide affordable and appropriate energy to displaced communities are outlined in this paper. The proposed PV microgrid build-own-operate (BOO) business models for camps of displaced populations consider providing for household and institutional demands, and a combination of the two. It is concluded that sustainable energy services can be provided to humanitarian agencies to power their compounds and community services such as health clinics and administrative centres. A fixed tariff of US$1/kWh is viable provided: the local fuel prices are greater than US$0.6/L at the point of use, and the capital costs of a backup or existing diesel generator are already covered. A fixed price tariff mitigates running costs for humanitarian agencies. In addition, by leveraging the institutional energy demands, basic electricity services to up to 500 households for mobile phone charging and lighting could be provided for a monthly tariff of US$1.5 per household, which is favourable compared to the estimated of US$4 monthly cost of kerosene for a typical displaced person's household. The proposed solution will reduce costs and improve the sustainability of humanitarian operations while achieving the UNHCR goals by providing electricity to displaced persons for lighting and communications.*

KEYWORDS: energy-delivery models, humanitarian technology, microgrids, off-grid solar photovoltaic (PV) power

1 INTRODUCTION

At the end of 2014, 59.5 million people were considered forcibly displaced worldwide because of persecution, conflict and/or human rights violations (UNHCR, 2015a). Energy services are essential for the protection of basic human rights and dignity (Grafham et al., 2016). Large numbers of people living in refugee camps or camps for internally displaced people (IDP) lack access to basic electricity services. The absence of electricity access at the household or community level (Gunning, 2014) causes significant distress (Grafham et al., 2016). Since 2014, the United Nations High Commissioner for Refugees' (UNHCR) global strategy for Safe Access to Fuel and Energy (SAFE) has focused on the humanitarian energy response (UNHCR, 2014).

This paper investigates the potential provision of electricity from photovoltaic (PV) microgrids to address the

UNHCR's goals of powering IDP/refugee households. Off-grid solar PV power solutions can now provide cost-effective access to sustainable electricity in IDP/refugee camps (Franceschi et al., 2014). The challenge is in how these technical solutions are delivered to sustain the service (Martinot et al., 2002). Reports on programs that provide free products, such as solar lamps, have found them to be unsustainable in protracted situations (Bellanca, 2014). Although camps have a temporary nature, once established, they function as towns based on the standard economic principles that regulate the exchange of goods and services (Betts et al., 2015). It has been argued that the electricity needs in IDP/refugee camps are best met by a formal energy service rather than by ad-hoc distribution of free products (Bellanca, 2014). Appropriate energy technologies properly delivered offer opportunities for improving conditions and self-reliance of IDP/refugees, and reduce costs and environmental impacts of camp operations (Gunning, 2014).

Short-term funding cycles within humanitarian organisations limit their ability to invest in durable large-scale assets for the provision of sustainable electricity services. There are opportunities for the private sector to deliver sustainable electricity services effectively, through contracts with humanitarian agencies (Franceschi et al., 2014, Zyck and Kent, 2014, Bellanca, 2014, Gunning, 2014, Grafham et al., 2016).

In this paper, PV microgrid build-own-operate (BOO) business models for energy-delivery services in IDP/refugee camps are devised. Financial analysis is conducted using solar insolation levels akin to that of the Middle East and North African (MENA) and Sub-Saharan Africa regions. A PV microgrid BOO business model is a fee-for-service model in which the customer pays regular fixed fees for energy services from a solar energy PV microgrid that is built owned and operated by an energy service company (REN21, 2015). Three possible energy-delivery PV microgrid business models are presented in this paper: the provision of household and institutional demands, and a combination of the two. For each business model, a technical design was devised and validated with Hybrid Optimization of Multiple Electrical Renewables (HOMER) software (Givler and Lilienthal, 2005, HOMER Energy, 2016). A financial structure for the business model is devised followed by a risk analysis, discussion and concluding remarks.

2 METHODOLOGY

The methodology employed as part of this research was the utility-in-a-box approach for rural electrification from a solar powered micro grid (Niraula, 2015). Standardising the technical design is crucial for ease of deployment without the need for major changes or customisation (Niraula, 2015). Standardisation also makes the system simpler, cheaper and faster to install and operate (Buluswar et al., 2014). The identification of potential risks affecting the profitability of the financial model can help standardise the financing structure, contractual terms, and coping mechanisms so that risks are mitigated. To identify the minimum set of common services in IDP/refugee camps around which PV microgrid BOO business models can be standardised the reference utilised as part of this research is a camp sector or a small sized camp, designed for 5,000 inhabitants or 1,000 households (Corsellis and Vitale, 2005, UNHCR, 2015b, Section: Camp planning standards (planned settlements)).

Presented below are three case studies for the application of PV microgrids to improve the energy access for IDP/refugees and camp operators:

- Case Study 1: Supply of energy to IDP/refugees for lighting and mobile phone charging
- Case Study 2: Supply of energy to camp operators to run the camp's essential services, and
- Case Study 3: A combination of Case 1 and 2.

Case Study 1

Without access to basic electric household lighting IDP/refugees rely on kerosene-based lamps that are polluting, dangerous and provide low quality light (Gunning, 2014). Case Study 1 considers the provision of basic electricity services to IDP/refugees at the household level via a PV microgrid BOO business model.

The International Energy Agency (IEA) suggests 300 lumens are required for household lighting. Light emitting diode (LED) globes typically operate at around 100 lumen/W and require 3 W for three to five hours in the evening to provide adequate lighting (Lysen, 2013). Charging a mobile phone typically requires a total of 3 W for four hours. An appropriate basic household service is thus assumed as the provision of 3 W for five hours of lighting in the evening (6 P.M. to 11 P.M.) and 3 W for four hours for mobile phone charging in the afternoon (2 P.M. to 6 P.M.).

Table 1 summarises the total electricity demand for household services modelled in Case Study 1, and for the institutional demand presented in Case Study 2 that follows. The case of providing services to 250, 500, and 1,000 households, assuming an average household size of 5 persons, in a 5,000 person sector or camp, equates to 25%, 50% and 100% of camp occupants respectively (Corsellis and Vitale, 2005, UNHCR, 2015b, Section: Camp planning standards (planned settlements)).

Table 1: Electricity daily demand per household, for Case Study 1, for basic lighting and mobile phone charging (labelled "Household"), and electricity daily demand to power institutional camp facilities, Case Study 2 in a sector (labelled "Institutional")

Case Study 1, Demand per Household				
	Lighting	**Mobile phone charging**		**Total**
Electricity demand	0.015 kWh	0.012 kWh		0.027 kWh
Case Study 2, Institutional Demand				
	Lighting	**Administration**	**Health clinic**	**Total**
Electricity demand	15 kWh	10 kWh	10 kWh	35 kWh

Case Study 2

Electricity is also needed to power institutional facilities such as a health clinic or administration compound. A PV microgrid BOO business model providing electricity to humanitarian agencies to power institutional facilities is considered as a case study for reducing camp operator's fuel expenses and greenhouse gas emissions whilst providing IDP/refugees access to sustainable electricity at the community level.

The minimum provision to institutional facilities is standardised (Corsellis and Vitale, 2005, UNHCR, 2007, UNHCR, 2015b). The electricity demand of these communal facilities in a camp sector (serving 5,000 inhabitants) has been calculated for lighting, administrative, and health centre energy requirements, a detailed analysis of the institutional energy demand can be found in Cerrada (2016). Table 1 summarises the total electricity demand modelled in Case Study 2.

Case Study 3

As camps become established, the institutional demand to power public services could act as an anchor load around which the standard PV microgrid is designed, and additional household loads could be served to consume the excess electricity and to constitute an additional source of income. For this case study providing services to 250, 500 and 1,000 households in a 5,000 person camp sector or camp was considered.

Both Case Studies 1 and 3 rely on the IDP/refugee families having some capacity to pay for the service. Obviously, this capacity depends significantly on the local situation. In this Case Study, the same core system from Case Study 2 design was utilised with additional poles and wires to distribute excess electricity to the camp households.

2.1 Technical Design

System Capacity

The microgrid is designed at the system level. The PV module capacity required $C_{PV,NOM}$ in Watt peak (Wp) can be determined using Equation 1:

$$C_{PV,NOM} = \frac{L_{md}}{(1-f_{dust})\times(1-f_{temp})\times\eta_{INV}\times\eta_{CC}\times\eta_{B}\times PSH}$$

Equation (1)

where:

L_{md} is the daily electricity demand in Watt hours

f_{temp} and f_{dust} are factors accounting for temperature and dust losses

η_{INV}, η_{CC} and η_B are the efficiencies of inverter, charge controller and battery, and

PSH is the peak solar hours

As this work designs standard microgrid systems to operate at any camp within the MENA and Sub-Saharan Africa regions, the minimum PSH for the total region is selected. To determine this value, the average annual values for the region (estimated between 15°W to 45°E longitude, and 7°S to 38°N latitude) are obtained from the NASA Surface Meteorology and Solar Energy database (NASA, 2016).

The required capacity of the battery bank $C_{B,NOM}$ in Ampere hours can be determined using Equation 2.

$$C_{B,NOM} = \frac{L_{md}\times DoA}{V_{B,NOM}\times\eta_{B}\times PD_{MAX}}$$

Equation (2)

where:

DoA denotes days of autonomy

$V_{B,NOM}$ is the battery bank voltage, and

PD_{MAX} is the battery maximum depth of discharge.

The microgrid is designed to use lead-acid batteries, although there is rapid progress in other battery technologies, which could reduce costs in future designs. The $V_{B,NOM}$ is selected following standard recommendations as 24 V for microgrids up to 4 kWp capacity, and 120 V for microgrids larger than 10 kWp capacity (Chaurey and Kandpal, 2010).

Electricity Distribution

For the distribution of electricity to IDP/refugee shelters, an aerial single phase two wire distribution line configuration with aluminium-conductor steel-reinforced (ACSR) is selected, a common practice in microgrid design (Inversin, 2000). The size of the conductor is selected so that the resistance of the conductor (R) in Ohm per kilometre, is sufficient to keep the voltage drop at the end of the line within acceptable limits. The required resistance of the conductor can be calculated by Equation 3.

$$R = \frac{VD}{2 \times L_{MAX} \times I_{MAX}}$$

Equation (3)

where:

VD is the absolute allowed voltage drop

L_{MAX} is the maximum length of the line in kilometres, and

I_{MAX} is the maximum current along the line in Amperes, determined in turn by the maximum peak load and the nominal voltage of the system.

As required, the size of the inverter (in Wp) is also determined by utilising the maximum peak load of the system.

Costing

The total capital cost of the system (capital expenditure CAPEX) is derived from the technical design by summing the costs of components as shown in Equation 4.

$$CAPEX = C_{PV,NOM} \times (C_{oPV} + C_{oBOS}) + CoB \times C_{B,NOM} + CoINV \times C_{INV,N} + CoTL \times L$$

Equation (4)

where:

C_{oPV} represents the capital cost of the PV array in $/Wp

C_{oBOS} the capital cost of the balance of the system (BOS) in $/Wp

CoB the capital cost of the battery in $/Ampere hour

$CoINV$ the cost of the inverter in $/Wp

$C_{INV,N}$ the nominal capacity of the inverter

$CoTL$ the capital cost of the transmission lines in $/km, and

L the length of the transmission line.

Component replacement costs are considered equal to their capital cost. Example costing for Case Study 3, supply of power to 250 households, is presented in Table 2. The component costs are summarised in Table A1. The system sizes and cost calculations are summarised in Table A2.

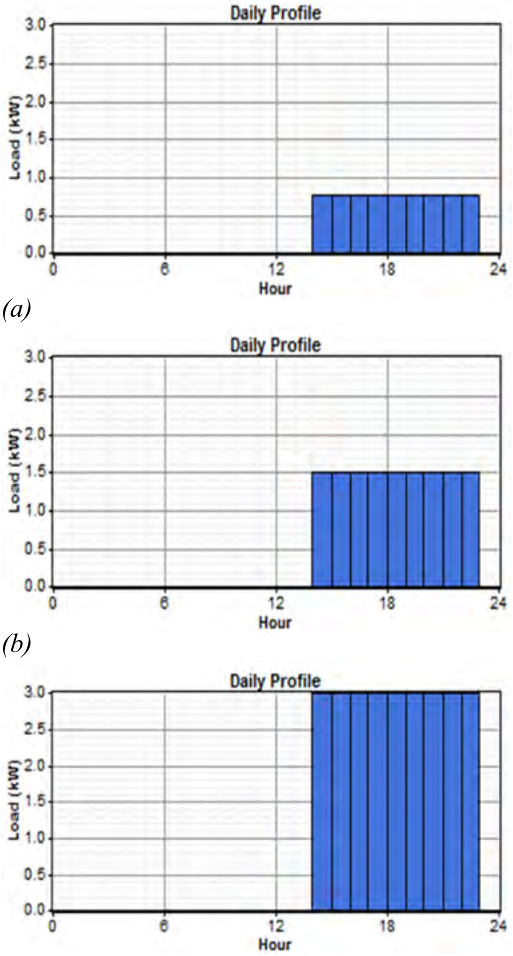
In addition to the above CAPEX, the microgrid will incur some operating expenditure (OPEX). It has been assumed a value of 1% of the initial system cost per year is a reasonable expectation of a PV system operational and maintenance (O&M) cost (Keating et al., 2015). In addition to O&M cost, the OPEX also includes a 3% initial system cost per year to account for insurance against theft, storms and other natural disasters (Niraula, 2015).

Backup Diesel Generation

Backup diesel generators are a necessary part of the energy infrastructure of field operations, notably for programs including health clinics where power cuts can have serious consequences (personal communication R. Onus, 30 May 2016). Therefore, a backup generator is considered for the HOMER software modelling of systems servicing institutional demand (Case Studies 2 and 3). However, it has been assumed that the ownership and operation of the backup diesel generator remains the responsibility of the humanitarian agency. Those costs are therefore not considered in the total system costing or financial structure of the business models.

Table 2: Example CAPEX costing for Case Study 3 supplying power to 1,000 households. Full details of all CAPEX calculations are presented in Table A2.

Parameter	Unit	Unit no.		Unit cost	Total
PV system	$C_{PV,NOM}$ (Wp)	18,000	C_{oPV} ($/Wp)	$0.65	$11,700
PV BOS	$C_{PV,NOM}$ (Wp)	18,000	C_{oBOS} ($/Wp)	$0.40	$7,200
Inverter	$C_{INV,N}$ (n inverters)	1	CoINV ($/Inv)	$1,000	$1,000
Batteries	C (Ah)	8,500	CoB ($/Ah)	$2.50	$21,250
Transmission Line	L (km)	4.185	CoTL ($/km)	$2,754	$3,000
CAPEX					**$44,200**



(a)

(b)

(c)

Figure 1: Daily load profiles modelled in HOMER for a system servicing: (a) 250 households; (b) 500 households; (c) 1,000 households

2.2 Validating the Technical Design with HOMER

The HOMER software was used to validate the technical design. HOMER inputs include size and costs of system equipment, loads, energy resources and feasibility constraints. The system investigated is depicted in Figure A1, with cost and sizing parameters in Table A2.

The total demand considered for the modelling in HOMER is presented in Figure 1 and Figure 2, results from the analysis is presented in Section 1.0. Electrical load profiles are not available, so the data is synthesised by specifying typical daily load profiles for each demand (i.e. lighting, administrative and health clinic) then summing them together with some random variability of 5% day-to-day and time-step-to-time-step. The panels have been modelled as fixed tilt oriented towards south at an angle equal to the latitude of the site +15 degrees, at a tilt of 20 degrees, to have a winter bias and a more constant production throughout the year.

An IDP/refugee camp site (within the region considered for this study) was chosen for the simulation. The Bahn refugee camp was established in Liberia in 2010 and has a planned capacity for a population of 5,000 displaced persons (UNHCR, 2016). The solar resource from the site location (6°53'44.8"N, 11°20'07.8"W) was obtained from the NASA Surface Meteorology and Solar Energy database (NASA, 2016), and is plotted in Figure 3. HOMER employs hourly calculations. Hence, synthetic hourly solar data is generated in HOMER from monthly averaged clearness index. The procedure has been robustly demonstrated to work for a wide range of longitudes and latitudes (Graham and Hollands, 1990).

The simulations with HOMER also enable to set the price of electricity, and to compare the cost-effectiveness of a PV-microgrid with a 5 kW diesel generator that would be used in Case Study 2. The base price for diesel and transport costs can vary considerably amongst camps due to the various fuel taxes and subsidies. In addition, the distance from the fuel storage and processing facilities, typically located close to large urban centres, can vary immensely. Thus, a sensitivity analysis on the price of diesel fuel was also carried out. Prices of $0.4 USD/L to $1.6 USD/L were evaluated.

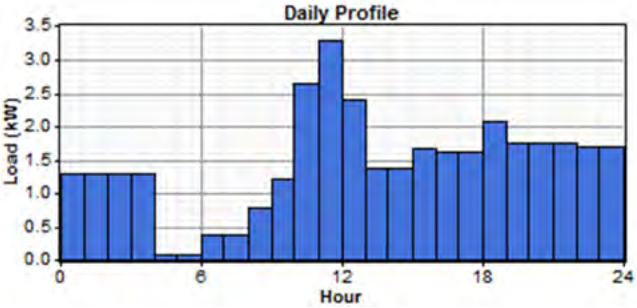


Figure 2: Load profile for institutional camp facilities (agency load) in a sector/small camp for 5,000 IDP/ refugees

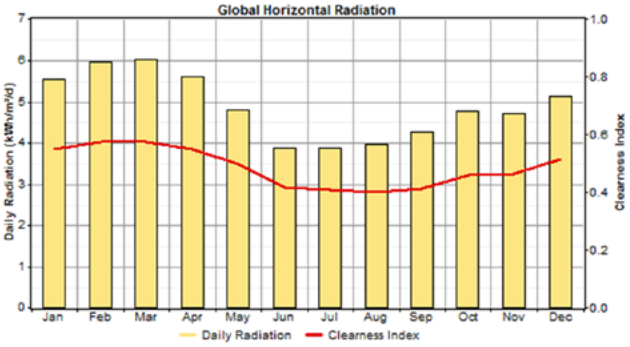


Figure 3: Global horizontal daily radiation throughout the year for Bahn refugee camp location taken from the NASA Surface Meteorology and Solar Energy database (NASA, 2016)

Finally, the reliability constraint defines whether it is acceptable for the system to be down for a small fraction of the year. HOMER models this scenario with the maximum annual capacity shortage constraint. When set to 0% the system must meet all the load all the time, which infers a larger system, and if some non-critical load can be unmet, it might vary between 0.5% and 10% (HOMER, 2014). When the load modelled is a residential load a maximum of 10% annual capacity shortage is considered acceptable (Abdilahi et al., 2014). System sizing with this procedure is commonly used in research and industry (Givler and Lilienthal, 2005, HOMER, 2014, HOMER Energy, 2016), where HOMER system design and the assumptions used are the state-of-the art for techno-economic modelling of off-grid hybrid electricity systems.

2.3 Devising the financing structure

The financial structure and cash flow for each business opportunity were developed. An example is shown in Figure 4, which provides details on the financial assumptions utilised. In the example, a system that provides power for the institutional or anchor load and power to 250 residents is considered. The variables in blue are resultant from the validated system specifications, and the variables in yellow are inputs based on similar works (Niraula, 2015). To evaluate all cases, the system sizes and tariff variables were updated according to Table A1, Table A2, and Table A3.

2.4 Risk assessment

The internal rate of return (IRR) and net present value (NPV) are used in this paper to assess and compare the return on investment and risks of the investment for the devised BOO business models. It is assumed that a business model has a reasonable return on investment if the IRR is greater than or equal to the hurdle rate of 10%, corresponding to the assumed cost of equity (Luecke, 2002). The NPV is used to compare the relative project size. To identify major risks affecting the IRR of the business models, the input parameters of the financing structure are modelled by a triangular distribution.

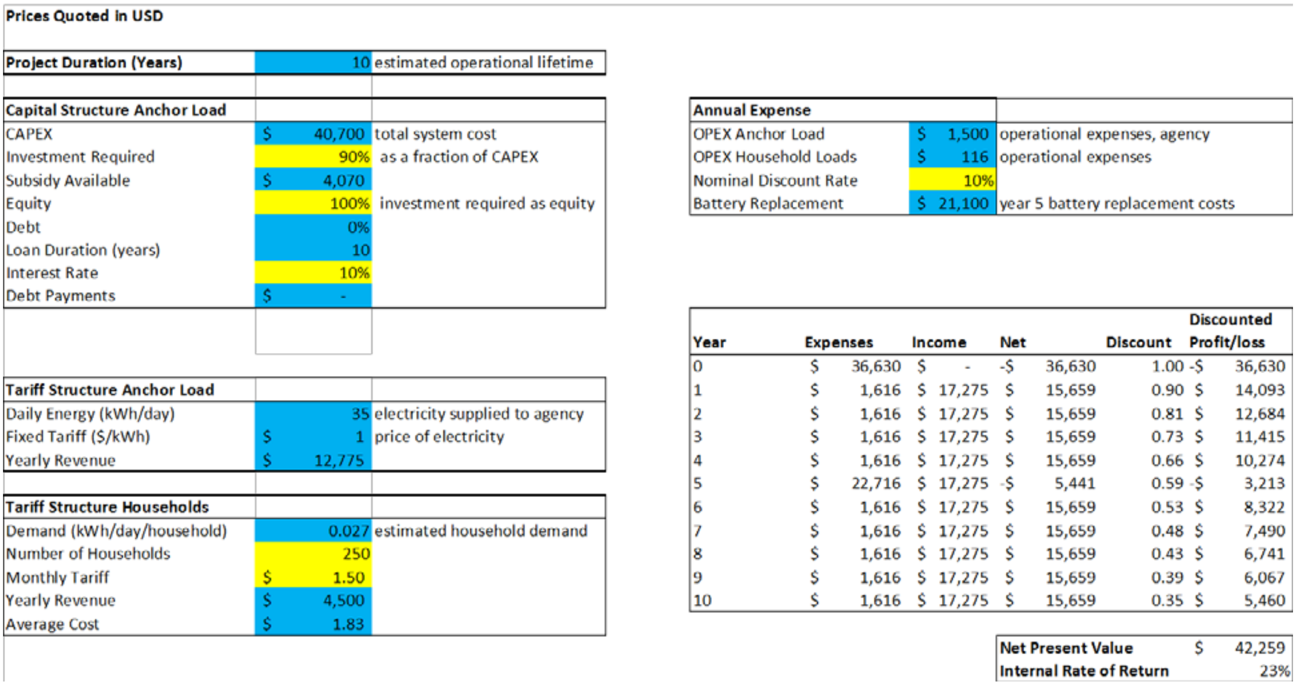
The input risk distributions were defined by a best estimate, and a minimum and maximum, and are summarised in Table A3.

Then a Monte Carlo simulation, using MCSim EXCEL's Add-in (Barreto and Howland, 2010), was used to draw the range of possible IRR values for the different combination of values that such input parameters can take inside their probability distribution. The Monte Carlo simulation was performed for 10,000 runs. Finally, a sensitivity analysis identifies the most important parameters affecting the profitability.

3 RESULTS

3.1 HOMER Modeling of System Designs

The resultant excess electricity, capacity shortage and expected battery life is summarised in Table 3. For Case Study 1 the capacity shortage was well below the recommended levels. For Case Study 2, the system design was sized with HOMER considering a maximum



Prices Quoted in USD

Project Duration (Years)	10	estimated operational lifetime

Capital Structure Anchor Load		
CAPEX	$ 40,700	total system cost
Investment Required	90%	as a fraction of CAPEX
Subsidy Available	$ 4,070	
Equity	100%	investment required as equity
Debt	0%	
Loan Duration (years)	10	
Interest Rate	10%	
Debt Payments	$ -	

Tariff Structure Anchor Load		
Daily Energy (kWh/day)	35	electricity supplied to agency
Fixed Tariff ($/kWh)	$ 1	price of electricity
Yearly Revenue	$ 12,775	

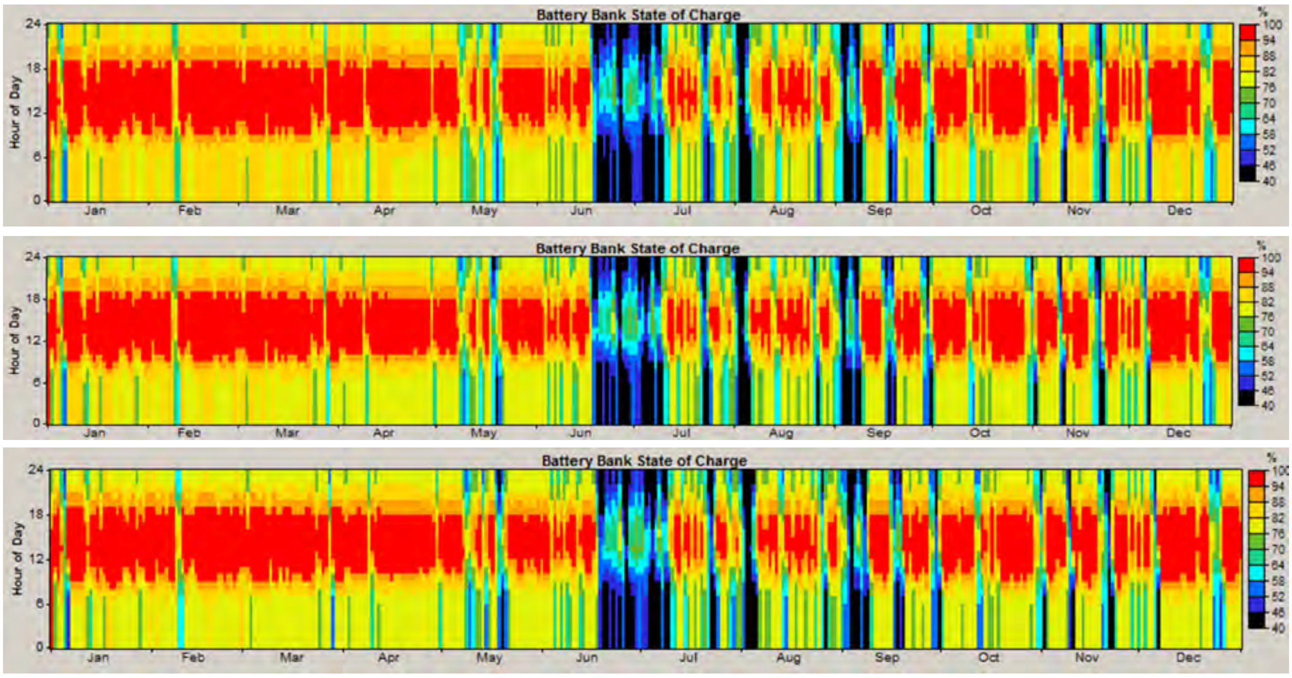
Tariff Structure Households		
Demand (kWh/day/household)	0.027	estimated household demand
Number of Households	250	
Monthly Tariff	$ 1.50	
Yearly Revenue	$ 4,500	
Average Cost	$ 1.83	

Annual Expense		
OPEX Anchor Load	$ 1,500	operational expenses, agency
OPEX Household Loads	$ 116	operational expenses
Nominal Discount Rate	10%	
Battery Replacement	$ 21,100	year 5 battery replacement costs

Year	**Expenses**	**Income**	**Net**	**Discount**	**Discounted Profit/loss**
0	$ 36,630	$ -	-$ 36,630	1.00	-$ 36,630
1	$ 1,616	$ 17,275	$ 15,659	0.90	$ 14,093
2	$ 1,616	$ 17,275	$ 15,659	0.81	$ 12,684
3	$ 1,616	$ 17,275	$ 15,659	0.73	$ 11,415
4	$ 1,616	$ 17,275	$ 15,659	0.66	$ 10,274
5	$ 22,716	$ 17,275	-$ 5,441	0.59	-$ 3,213
6	$ 1,616	$ 17,275	$ 15,659	0.53	$ 8,322
7	$ 1,616	$ 17,275	$ 15,659	0.48	$ 7,490
8	$ 1,616	$ 17,275	$ 15,659	0.43	$ 6,741
9	$ 1,616	$ 17,275	$ 15,659	0.39	$ 6,067
10	$ 1,616	$ 17,275	$ 15,659	0.35	$ 5,460

Net Present Value	$ 42,259
Internal Rate of Return	23%

Figure 4: The financial structure and cash flow for a PV microgrid BOO business model servicing institutional facilities and 250 additional households with basic services of lighting and mobile phone charging

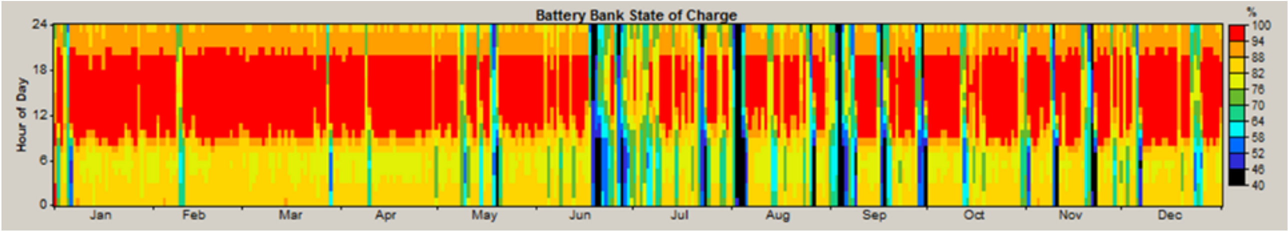


Battery Bank State of Charge

Battery Bank State of Charge

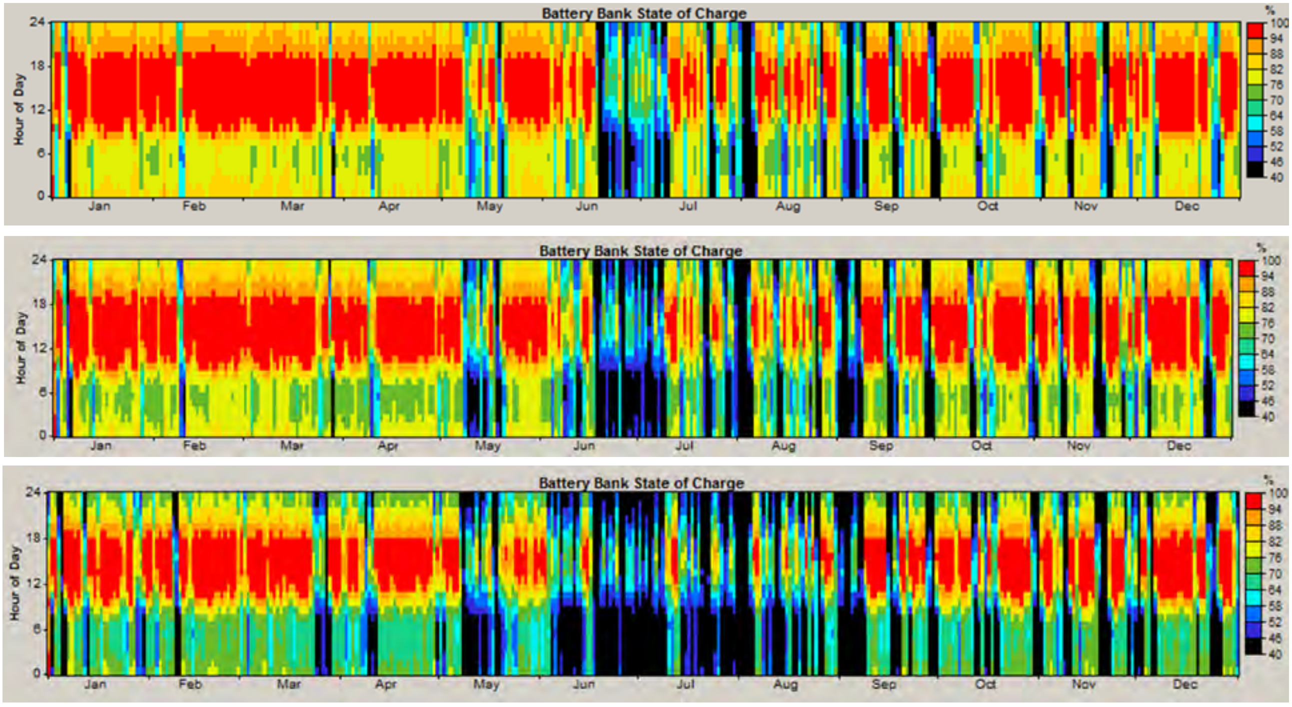
Battery Bank State of Charge

Figure 5: Battery expected state of charge: (top) system serving 250 households; (middle) system serving 500 households; (bottom) system serving 1,000 households



Battery Bank State of Charge

Figure 4: The financial structure and cash flow for a PV microgrid BOO business model servicing institutional facilities and 250 additional households with basic services of lighting and mobile phone charging



Battery Bank State of Charge

Battery Bank State of Charge

Battery Bank State of Charge

Figure 7: Battery expected state of charge of system in Case 2 with additional: (top) 250 household loads; (middle) 500 household loads; (bottom) 1,000 additional household loads

Table 3: Summary of HOMER simulation results presenting the system designs' excess electricity, capacity shortage and battery life

	Number of additional households	**Excess electricity**	**Capacity shortage**	**Battery expected life (years)**
Case Study 1	250	34%	2.3%	5
	500	34%	3 %	5
	1,000	34%	2.1 %	5
Case Study 2	0	40%	2.5%	5
Case Study 3	250	32 %	5%	5
	500	24 %	9%	4
	1,000	13 %	19%	3.5

annual capacity shortage of 0% 2.5% and 5%. A system design with a capacity shortage of 2.5%, was found to be best suited for the application, inferring the existing diesel generator meets the load 2.5% of the time; further analysis is provided in Cerrada (2016). For Case Study 3, the same core system design was found to be suitable, with the addition of poles and wires to distribute the excess electricity. Extending the system to 1,000 users did not meet the capacity shortage requirements; hence a design with a maximum of 500 households was considered.

The systems were simulated and sized for each of the case studies to meet the capacity shortage requirements, the resultant annual hourly simulated battery state of charge graphs of the final designs are presented in Figure 5, Figure 6, and Figure 7. In these Figures, the state of charge per time step is plotted as a colour map, where the days of the year are plotted on the x-axis and the hour of the day is plotted on the y-axis.

The state of charge is higher in the middle of the day due to solar generation. The state of charge goes low predominantly in the wet season. These simulations determine if the system will operate in a manner that shortens the battery life. From these plots, the capacity shortages will occur predominantly in the wet season (June/July).

Another output integrated into the model is the expected battery life, an output of HOMER simulation summarised in Table 3. The battery life is adversely affected if the batteries are kept at a low state of charge for prolonged periods, hence the battery lifetime reduces as the capacity shortage increases.

3.2 Business Modeled Return on Investment, Without Risk

The performance of each case study using the assumed model parameters for financial modelling, listed in Table A3, is plotted in Figure 8.

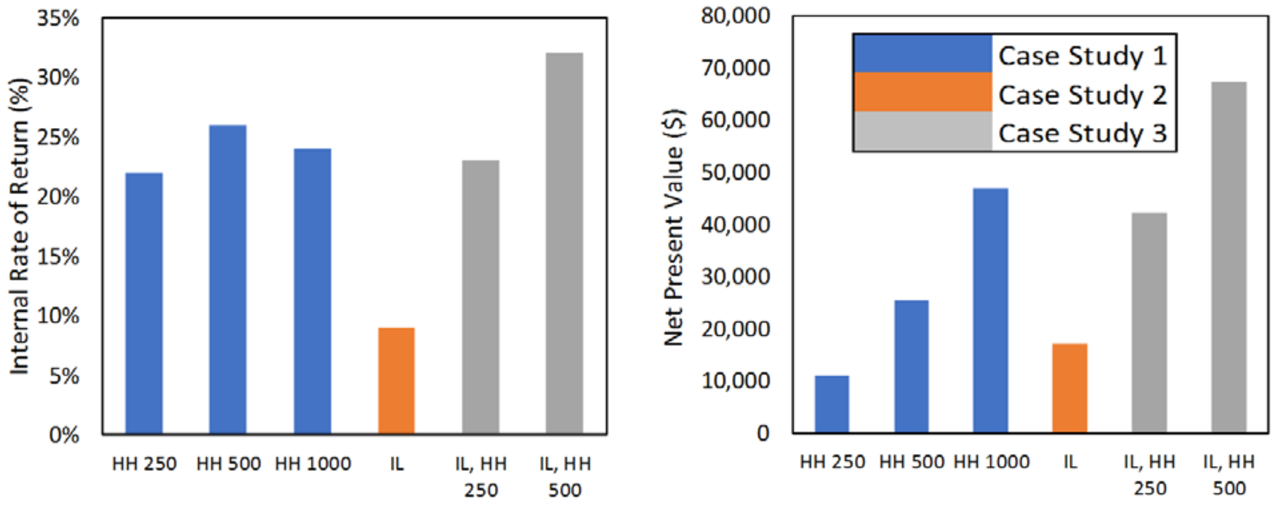


Figure 8: Plot of the IRR (left) and NPV (right) for each case study, including differing household loads. "HH" indicates the number of household loads (i.e. 250, 500 or 1,000) and "IL" indicates if the institutional load was supplied

Case Study 1, the provision of electricity only to households for a monthly tariff of $1.50 USD, presents returns of 22% to 26%. The highest return, of 26%, was for a system designed to supply 500 households.

A BOO business model providing electricity at the community level for a fixed tariff per unit of energy ($1 USD/kWh) charged to the humanitarian agency (Case Study 2), resulted in an IRR of 9%. However, when including additional household loads (Case Study 3) there is the potential to increase the IRR considerably by monetising the excess electricity of the standard technical design.

For Case Study 2, the argument could be made that the excess electricity can be reduced by reducing the number of PV panels, which reduces the initial capital cost. Additional modelling found that by reducing the number of solar panels the rate of return could be increased by 6%. Alternatively, incorporating 500 households would increase the profitability by up to 23%. The NPV of the case studies increases with project size, hence the higher the planned provision of services, the greater the NPV.

3.3 Assessment of Financial Risks

From Section 3, it was found that all case studies were profitable with the model parameters listed in Table A3.

The input parameters to assess risk were varied and histogram plots of normalised IRR frequency and tornado IRR risk plots for each case study were generated (Figure 9). The histograms represent the likely range of returns on investments considering the assumed input parameter ranges in Table A3.

The tornado plots identify the impact of each financial risk. For Case Studies 1 and 3 the supply of a range of households has been considered, from 125 to 500,

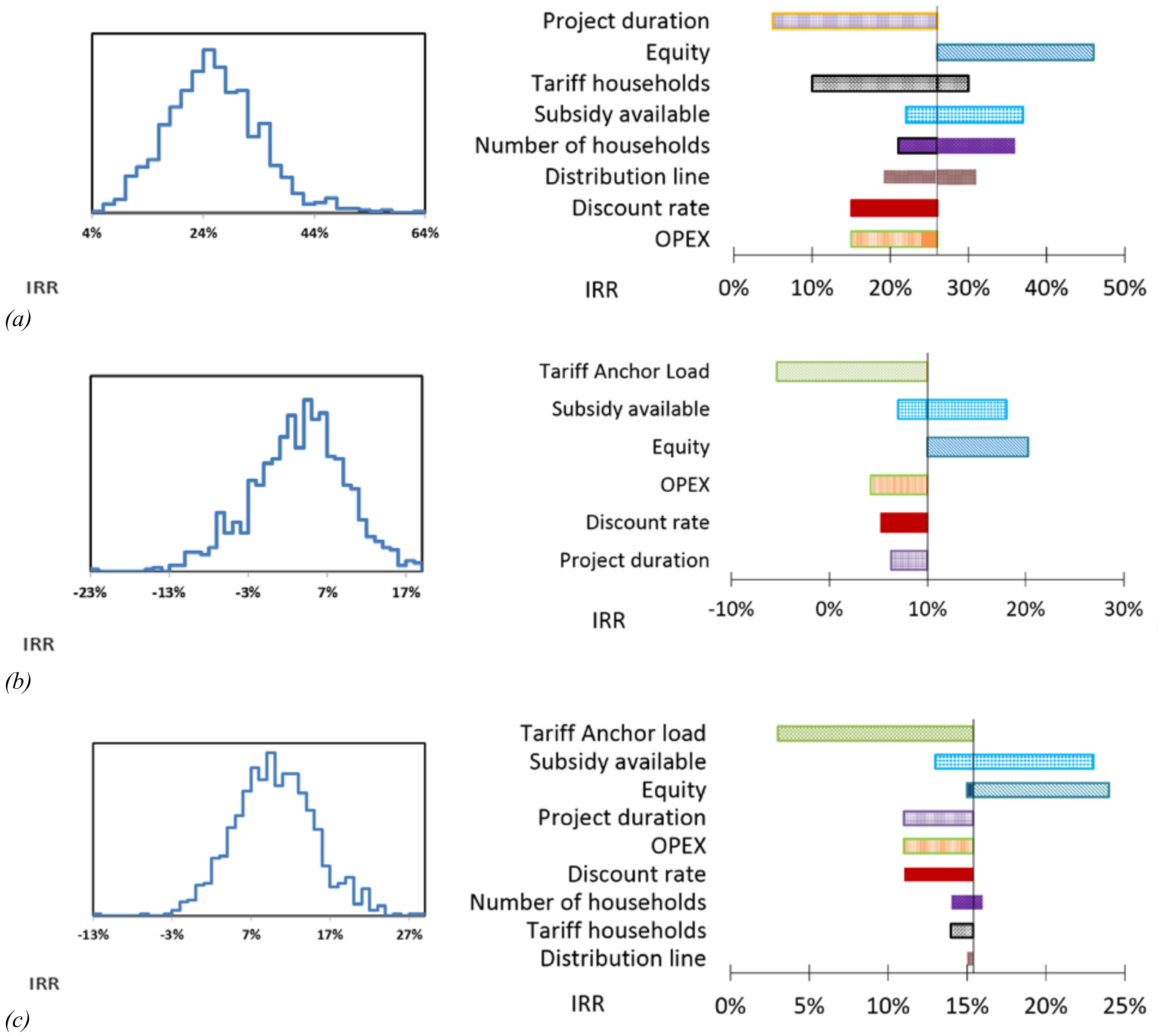


Figure 9: Monte Carlo simulation results and sensitivity analysis results. Histogram plot for the IRR and tornado diagram for: (a) Case Study 1; (b) Case Study 2; and (3) Case Study 3.

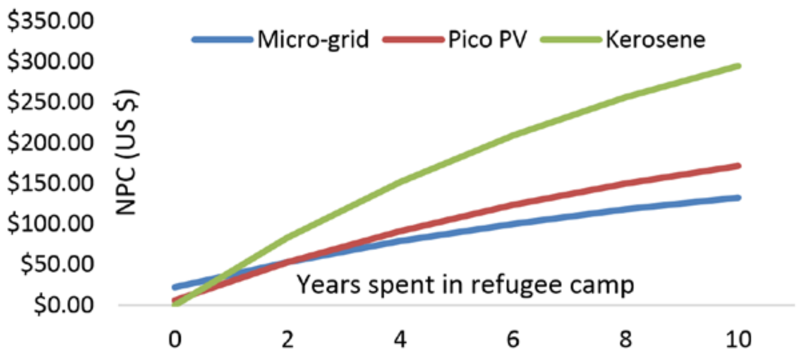


Figure 11: Plot comparing the net present cost of different lighting/ charging technologies to the IDP/ refugee as a function of time. Where the leasing of Pico PV systems is compared to microgrid systems and the use of kerosene. Full details of modelling can be found in in (Cerrada, 2016).

therefore the evaluations of risk are not separated into the sub-categories that were summarised in Figure 8. For Case Study 3, the 1,000 household sub-case was not viable as the capacity shortage was too high. The risk analysis for 1,000 household sub cases are not included as they were for Case Study 1 for brevity, as the risks are essentially comparable throughout.

4 DISCUSSION

Figure 8 and Figure 9 demonstrates that Case Study 1 is profitable and well above the hurdle rate. Case Study 2 is unlikely to be financially viable, however, the addition of household loads through the micro grid (Case Study 3) improves the financial viability and potential attractiveness to an energy services company.

Considering the IRR data, there is no clear differentiation between Case Study 1 and 3 with respect to profitability. However, if the net present value (NPV) of each Case Study is compared, the NPV of Case Study 3 is considerably larger, therefore investments or projects like Case Study 3 may be more attractive to prospective service providers.

The findings on the sources of financial risk are discussed below. For all three case studies, the sensitivity analyses found the IRR increases with cheaper financing or increased subsidy.

Case Study 1 would likely be profitable. The largest financial risks are project duration and the tariff cost for households. The affordability risk in some camps may be mitigated by initiatives like the recently adopted UNHCR "Cash for Work" activities (UNHCR and REACH, 2014). This program provides longer-term positions such as team leaders and team rotating positions for maintenance operations. Further, it is noted that a study of the application of solar lanterns in refugee camps in the Dadaab region of Kenya surveyed the incomes of camp residents. The study found that 50% of people in the camp earned over $36 USD per month, indicating the proposed monthly tariff might be affordable for some families (Fafi Integrated Development Association Kenya, 2013).

Case Study 2 is unlikely to pass the IRR hurdle rate of 10%, the financial risk of project duration could be mitigated by establishing longer term supply contracts between the energy service provider and the camp institutional load. The largest financial risk to this business model is the tariff applied to the institution, the cost of which is in direct competition with the price of diesel generated electricity and hence the price of diesel.

For Case Study 3, the addition of household loads increases the viability of a business model supporting institutional loads, so that roughly half the scenarios modelled pass the hurdle rate. The largest risk for Case Study 3 is the tariff afforded by the institutional load which is linked to the cost of remote diesel power generation. For local diesel prices, lower than 0.6 $USD/L, it is cheaper to provide diesel-generated electricity, than to finance the proposed institutional tariff. Local diesel prices less than 0.6 $USD/L, at point of use, are unlikely.

Through analysis outlined in Cerrada (2016) the costs of lighting technologies for IDP/refugees is compared. In this analysis, the PV microgrid BOO model was compared to the leasing of Pico PV systems, as well as the costs of using kerosene-based lighting. This comparison lead to the conclusion that leasing Pico PV systems is more appropriate for short-term planned camps (less than two years), whereas for longer-term planned camps, a PV microgrid solution outperforms both financially and on the quality of the service (Figure 10).

5 CONCLUSIONS

Offering sustainable energy services to IDP/refugee households is possible as camps are highly concentrated. However, the value propositions of such projects can be improved by providing energy services to institutional loads. By leveraging the institutional loads in a camp sector, up to 500 households (50% of a camp sector population) could be provided with reliable basic household services for lighting and mobile phone charging with low financial risk, where the services would present a cost saving to camp operators, and to the camp residents using micro grid electricity for lighting and phone charging. The research outlined in this paper is a desk study. Model parameters taken from literature or determined via simple analysis.

One risk that was not addressed as part of this desktop study was the risk of households overusing their budgeted 0.027 kWh. Whilst using more energy in the dry season would pose little risk, over use of electricity in the wet season would lead to higher capacity shortages. Tackling the appropriate methods of monitoring usage is a key challenge that has not been addressed in this work. Business overheads were also not considered.

Nevertheless, the findings of this paper demonstrate a clear opportunity for PV microgrids to improve energy access for IDP/refugees, offering essential electricity services that are cost effective and affordable. Importantly, standardising the technical design and the financing structure will reduce cost and improving reliability.

6 ACKNOWLEDGEMENTS

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8 APPENDIX

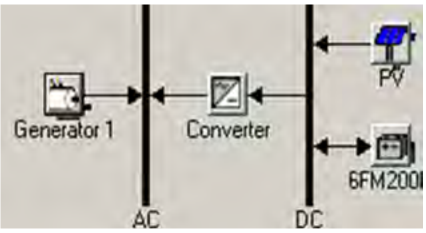

Figure A1: Schematic of equipment considered for the simulation in HOMER software.

Table A1: Costs assumed for the different equipment to consider for the technical design. A full explanation of the sources can be found in Cerrada (2016).

Equipment to consider	Cost	Source
PV modules	$0.65 USD/Wp	(National Rural Electric Cooperative Association, 2016)[1]
Batteries	$2,400 USD/kAh	(Kempener and Borden, 2015)
Inverter	$0.2 USD/Wp	(National Rural Electric Cooperative Association, 2016) [1]
Other BOS components + Installation	$0.4 USD/Wp	(National Rural Electric Cooperative Association, 2016) [1]
Transmission line (size 4 AWG)	$2,305 USD/km	(Deshpande et al., 2015, National Rural Electric Cooperative Association, 2016)
Transmission line (size 1/0 AWG)	$2,754 USD/km	(Deshpande et al., 2015, National Rural Electric Cooperative Association, 2016)

Notes: 1. Conversion from Euro to USD using $1 US = 1.2 €

Table A2: Sized systems and calculated cost for the different case studies and subcases. Full reasoning and expanded case studies can be found in (Cerrada, 2016).

Subcases[1]	**Units**	**Case Study 1**			**Case Study 2**	**Case Study 3**		
			b	**c**		**a**	**b**	**c**
Number of household loads	Units	250	500	1,000	-	250	500	1,000
Days of autonomy	Days		3		6		6	
Component sizes								
PV array size	kWp	3	6	12	18		18	
Battery bank size	kAh	1.7	3.3	6.6	8.8		8.5	
Inverter size	kWp	-			5		5	
Conductor size transmission line	AWG	4, 4, 1/0			-		-	
Component capital costs								
PV array	$	2,000	3,900	7,800	11,700		11,700	
BOS	$	1,200	2,400	4,800	7,200		7,200	
Inverter	$	-	-	-	1,000		1,000	
Battery bank	$	4,800	8,600	16,300	21,100		21,100	
Transmission line	$	3,000	5,800	13,800	-	3000	5,800	11,500
Total CAPEX	**$**	**11,000**	**20,700**	**42,700**	**41,000**	**44,200**	**47,000**	**52,700**
OPEX	**$/year**	**440**	**830**	**1,700**	**1,600**	**1,770**	**1,900**	**2,110**

Notes: 1. The Subcases are denoted by the corresponding slash

Table A 3: Expected range of variability for input parameters based on assumptions for all case studies presented in this paper. Justifications for these can be found in (Cerrada, 2016). In this work, the base case is assumed input, and the minimum and maximum describe the ranges of the triangular distribution.

Input parameters	**Unit**	**Base case**	**Min**	**Max**	**Distribution**
Project Duration	Years	10	3/7(1)	12	Triangular
Subsidy Available Anchor Load	Percentage	10 %	0%	30%	Triangular
Equity Anchor Load	Percentage	100 %	50%	100%	Triangular
Interest Rate	Percentage	10 %	10%	15%	Triangular
OPEX	Percentage	4 %	4%	8%	Triangular
Discount Rate	Percentage	10 %	10%	15%	Triangular
Tariff Anchor Load	USD/kwh	1 $	0.7 $	1 $	Triangular
Tariff Households	USD/month	1.5 $	1 $	1.5 $	Triangular
Number of Households	No.	250	125	500	Triangular
Distribution Line Length per HH	Meter/HH	5	5	10	Triangular

Notes: 1. A larger range, 3 to 12 years was assumed for Case Study 1, as it was considered for shorter-term applications.