PV-based solutions for energy access in refugee camps

J. D. Nixon[*], A. M.Dizqah, Y. Zhoholieva, E. Gaura

Faculty of Engineering, Environment and Computer Science, Coventry University, 1 Gulson Road, Coventry, CV1 2JH, UK
*corresponding author, E-mail: jonathan.nixon@coventry.ac.uk; Tel: 024 7765 3151

Abstract

Refugee camps are meant to be temporary settlements, but many exist for several decades. It has been estimated that only around 11% of people living in refugee camps have access to energy for lighting; a lack of basic energy services has resulted in serious issues regarding safety at night, food preservation and in-door air pollution. Refugees' quality of life could therefore be significantly improved with appropriate energy interventions. Different photovoltaic-based solutions comprising of portable, modular and fixed installations have been tested in camps, but poor maintenance, unclear ownership and a lack of cultural understanding have often caused projects to fail. Moreover, the use of portable and modular systems is relatively well-established in camps, but there is limited research on the implementation and operation of micro-grid systems. There are also large uncertainties with energy purchases in temporary settlements, and design optimisation based on key financial indicators, such as levelised cost of electricity, might not necessarily give the best solution for a refugee camp. In this study, camp sites in Rwanda and Nepal are used as case study locations for designing and comparing alternative PV-based energy interventions for street lighting, water pumping and household electrification. These interventions are defined using primary data collected via surveys carried out at the camp sites and using the Multi-tier Energy Access Tracking Framework. To establish a baseline, conventional system sizing and optimisation based on energy cost is carried out using HOMER Pro®. The differences in possible modular or micro-grid system designs are compared, with alterative system variations being modelled to determine a trade-off between reliability and cost. The financial implications of supply and user preferences' uncertainties are investigated and compared with data gathered on current monthly household income and expenditure. An outcome from the study is several energy intervention strategies that will inform the deployment of pilot plants currently being built in Rwanda and Nepal.

Topic: Photovoltaics technology

Keywords: Micro-grids, solar energy, refugees, optimisation

1. Introduction

In 2014, the number of forcibly displaced people was around 55 million and the average time spent as a refugee was 17 years. By 2016, this had increased to 65.6 million people, with 20 people being forced to leave their homes ever minute [1]. Where electricity is available in camps, it is typically only available for a few hours a day and provided by expensive and inefficient diesel gensets. This is further compounded by poor housing in camps being unfit for habitation and requiring high amounts of energy for heating and/or cooling [2]. As sites are meant to be temporary, they are often hastily put together to respond to a crisis; food, sanitation and shelter are the immediate issues that need to be addressed. Energy infrastructure is, therefore, usually non-existent or poorly implemented. Moreover, there is often a lack of funding for energy interventions, as these are typically long-term investments and considered unsuitable for emergency aid needs

Another major concern in refugee camps is the use of biomass in inefficient cook stoves, which exposes users to indoor air pollutants and cause serious health problems; around 20,000 premature deaths a year are estimated to occur due to indoor air pollution [3]. Fires caused by kerosene lamps and candles are a frequent problem [ibid.]. A lack of fuel for cooking has resulted in many families either missing meals or eating under cooked food. Women and girls often bear the greatest burden of these problems, being intimidated and/or attacked when out collecting firewood or on unlit streets [4]. There are also issues of food preservation in temporary settlements [5].

Energy interventions in camps have taken many forms. Off-grid solar photovoltaic (PV) systems—where there is an abundance of solar energy—can play a pivotal role in addressing poverty reduction by providing energy for critical services, such as food preservation, medical facilities, water pumping, emergency communications, and street and house lighting. Different engineered PV solutions for camps comprise of small and large portable systems for quick deployment, modular components for fixed installations and long-term micro-grids. PV-based micro-grids have been reported to reduce significantly monthly household expenditure on phone charging and lighting [6]. Whilst guidelines for the use of portable and modular systems to provide emergency relief are relatively well established, there is limited research guiding best practice on the implementation and operation of micro-grid systems in refugee camps [7]. Moreover, there are a range of renewable energy technologies that can form hybrid systems that may be more suitable to meet the local needs of refugee camps. The most recent developments in this area are in Jordan’s Za’atari and Azraq refugee camps, where, in 2017, the first large-scale PV systems were implemented.

Despite numerous energy interventions being attempted in camps, a number of projects have been unsuccessful. Lahn and Grafham [3] review a number of example energy projects in refugee camps, highlighting that a lack of social and cultural understanding and poor maintenance are often major causes of project failures. The UNHCR, the United Nations Refugee Agency, outlined a strategy for safe access to fuel and energy given the problems that have arisen. They highlight the paucity of data on energy use in camps and outline the requirement for need assessments, feasibility studies and stakeholder consultations [8]. The UNHCR has also now moved away from distribution models based on handouts (as they have sometimes led to issues such as the reselling of products, tensions with neighbouring communities and implementation of foreign products that are not accepted and utilised) and are now looking at market-based interventions, such as loans or credits.

This study aims to compare the economic feasibility of a range of PV-based solutions for camps and investigate the potential trade-off between supply reliability and cost, as refugees maybe willing to sacrifice accessibility for cheaper alternative energy solutions.

2. Methodology

The paper focuses on comparing solar home system (SHS) and micro-grid solutions based on PV. Two SHS and three micro-grid scenarios are considered for two case study locations: Rwanda and Nepal, incorporating temporary settlement locations for both refugees and internally displaced people. The Global Tracking Framework, outlined by the Energy Sector Management Assistance Program (ESMAP) [9], is used to establish an energy profile for households in a camp setting. Whilst the framework is not specific to refugee camps, it can be used to develop energy profiles for regions where there is no energy supply or existing usage data. For example, the framework defines the amount and duration of energy supplied to meet minimum standards. The framework also outlines targets for cooking, heating and community facilities.

Each scenario is simulated using HOMER Pro, which is a software tool that allows a variety of grid and off-grid renewable energy systems to be modelled using site-specific meteorological and cost data. HOMER runs a number of simulations to determine the ideal combination of systems components and component sizes to minimise the levelised cost of energy (LEC) and overall net present value. The reliability of the systems is investigated in terms of capacity shortage versus unit cost of energy and total system cost. Capacity shortage is defined in HOMER Pro as the total annual shortfall that occurs between required operating capacity and actual operating capacity. Economies of scale are not taken into account so gains in LEC are purely based on micro-grid design and control improvements.

3. Case study locations: Nyabiheke (refugee camp) and Uttargaya (internally displaced people)

Nyabiheke refugee camp is located in Rwanda's Eastern Province. Formed in 2005, the camp contains 15,882 refugees and 2787 households. The camp is located in one of Rwanda's sunniest regions, receiving around 4.8 to 5.5 kWh/m^2 day [10]. Located near the equator, Rwanda's daylight hours are relatively constant being from around 6 a.m. to 6 pm throughout the year. The camp does not have a grid connection and even if it did, household electricity tariffs in Rwanda can be very high—around $0.24/kWh—due to a reliance on oil-fired power plants. This is significantly higher than other countries such as Uganda, Burundi, Kenya, Tanzania were electricity tariffs are around 0.10 to 0.12 $/kWh [11]. The high cost of electricity impedes investment and growth and makes energy supply unaffordable for many. PV/hybrid micro-grids could therefore be more cost-effective and affordable solutions for rural sub-Saharan Africa regions [12].

In Nepal in 2015, a major earthquake left thousands of people homeless. Uttargaya Rural Municipality was one of the most affected areas within the Rasuwa district displacing around 2,000 household who were relocated to lower parts of the district and to the neighboring Nuwakot district. In 2018, around 2380 people still lived in informal settlements in Nuwakot District.

3.1 Energy demand

To achieve a tier 3 level of energy access, as defined in the global tracking energy access framework, a household requires a minimum supply of 1 kWh per day, and energy available for at least 8 hours a day including 3 hours at night. This would be enough to provide power for indoor lighting, a fan and phone charging. Similarly, a tier 3 community institution requires a minimum of 1 kWh per day for 50% of the working hours.

Tier 3 street lighting is defined as a minimum coverage of 50% of a neighbourhood, functioning for at least 50% of night hours. A 40 W LED streetlight is assumed to cover an area of 162 m^2 from a height of 9 m. With a recommended average area per refugee being specified by UNHCR as at least 35 m^2 [13], 0.12 kWh/day/household is required for street lighting.

Water requirement in the camp is defined as a minimum of 20 litres per person per day, with 1 tap being available to serve 80 people (i.e. 100 litres per household assuming 5 people per home) [2]. Water is assumed to be available at a depth 10 m and that a bore hole already exists at the site. Therefore, 0.0056 kWh/day/household is needed to pump water at a differential head of 10 m using a 60% efficient pump and 80% efficient motor. The energy requirements assumed for refugee households are summarised in Table 1 and expected energy demand profiles associated with a single household are shown in Figure 1.

Table 1: Energy requirements for tier 3 household electricity, communal building and street lighting.

Constraints	Capacity	Duration
Household electricity supply	≥ 1 kWh/day	≥ 8 hrs/day inc. 3 hrs/night (18:00-21:00)
Communal building (e.g. school)	≥ 1 kWh/day	≥ 50% of the working hours
Street lighting	≥ 50% coverage; 0.12 kWh/day/household	≥ 50% night hrs/day
Water pumping	≥ 0.0056 kWh/day/household	Deferrable

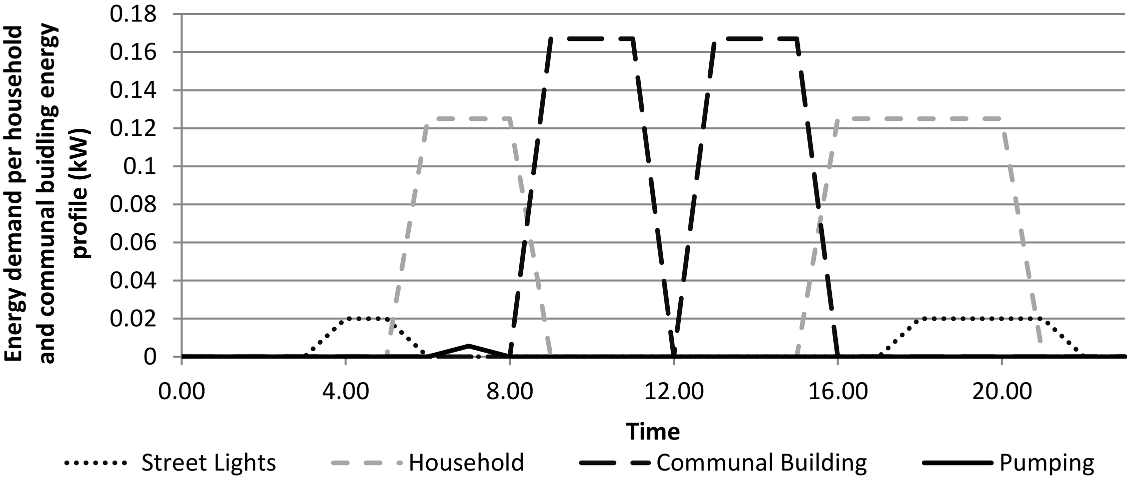

Figure 1: Assumed energy demand profile for household electricity, a single communal building and street lighting and water pumping per household.

3.2 Location costs

The financial assumptions for the two case study locations are shown in Table 1.

Table 1: System economics

Component costs	Rwanda	Nepal
Solar PV panel ($/kW)	600	500
Inverter ($/kW)	600	500
Battery ($/kWh)	190	180

Balance of system (BoS) ($/kW)	500	400
Transmission and distribution [a] ($/km)	5000	5000
Genset ($/kW)	350	250
Cost of diesel fuel ($/l)	1.2	0.8
Nominal discount rate (%)	5	5

[a] Cabling distance for transmission and distribution for 3.125 metres per household.

3.3 PV-based scenarios

In this study, five alternative scenarios are outlined and analysed. Initially, systems are sized to prevent any capacity shortfall throughout the year.

Scenario 1: Solar home system

A solar home system comprising of PV and lead acid batteries to provide tier 3 household electricity only.

Scenario 2: Solar home system + 1 street light

A PV panel and lead acid battery is used to provide tier 3 household electricity and power a single 40 W streetlight for 6 hours.

Scenario 3: Micro-grid supplying 80 homes

A micro-grid comprising of PV and battery and/or a diesel genset to provide 80 homes with tier 3 energy access.

Scenario 4: Micro-grid supplying 80 homes, 40 streetlights, 1 communal building and water pumping

A micro-grid comprising of PV and battery and/or a diesel genset to provide 80 homes with tier 3 energy access, water and tier 3 street lighting. A single tier 3 communal building is also considered. An overview of the system is shown in Figure 2.

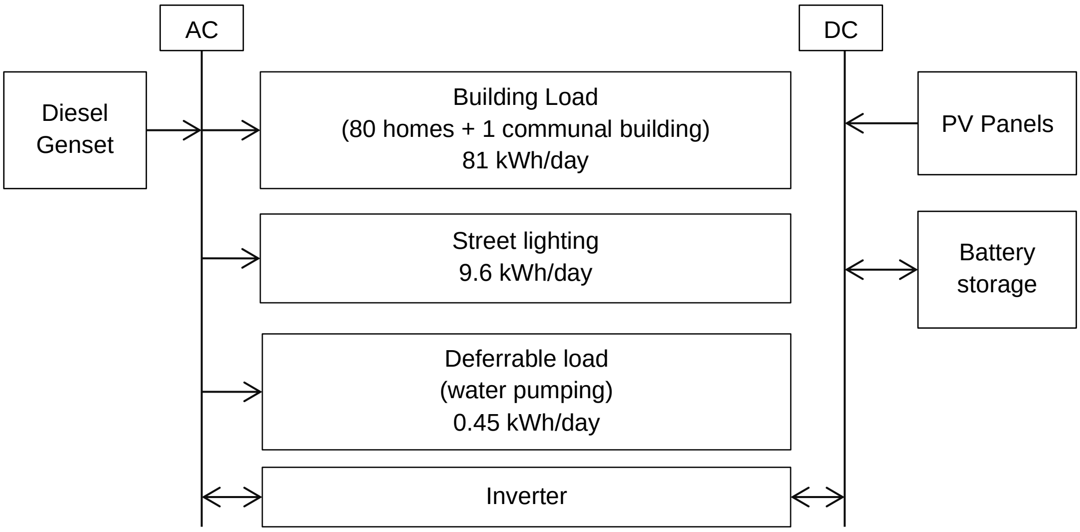

Figure 2: System schematic for scenario 4.

Scenario 5: Micro-grid supplying 2800 homes, 1400 streetlights, 35 communal buildings and water pumping

A micro-grid comprising of PV and battery and/or a diesel genset to provide the entire Nyabiheke refugee camp with tier 3 household electricity and street lighting. An additional 35 communal buildings are also assumed.

4. Results and discussion

The optimised levelised energy costs (LEC) for each scenario and the resulting system designs for Rwanda are shown in Table 2. In comparison to solar home systems (scenarios 1 and 2), which are often used in these types of settings, a micro-grid PV-based system (scenario 3-5) could reduce energy costs by around 20%. For a household using around 1 kWh per day, the monthly energy cost based on these LEC values is approximately $12.5-15. Refugee household incomes in the area are around 50,000 RWF (60 US$) [14], and so this is a significant and challenging amount for a refugee to pay, so alternative cheaper solutions and distribution models are still needed.

Table 2: Results for the five scenarios showing optimised component capacities to achieve a minimised cost of electricity in Rwanda.

Scenario	PV	Genset	LA Battery	Inverter	LEC	Capital cost
	kW	kW	kWh	kW	$/kWh	$
Scenario 1	0.572	na	4	0.146	0.516	1477
Scenario 2	0.896	na	4	0.189	0.489	1859
Scenario 3	35.7	11	138	11	0.413	77150
Scenario 4	40.4	13	154	12.8	0.413	87198
Scenario 5	138	450	249	61.8	0.4	437956

	Production	Consumption	Excess electricity
	kWh/year	kWh/year	kWh/year
Scenario 1	839	365	393
Scenario 2	1313	452	762
Scenario 3	52,281	29,200	19,516
Scenario 4	59,278	33,070	22,030
Scenario 5	1,314,408	1,157,440	142,053

The results show that a significant excess of electricity is wasted due to a lack of load shedding and systems being sized in order to have no capacity shortfall. The sensitivity of the costs in relation to a system designed with a specific capacity shortage are shown in Figure 3a-b for scenarios 1 and 4, highlighting the potential cost savings that can be achieved. For scenario 1, the LEC for Rwanda could be reduced from 0.516 to 0.4 $/kWh. In Nepal, where there is less sunshine, a larger PV system is required, but due to lower component costs, LEC values were found to be lower, ranging from 0.426 to 0.358 $/kWh for different capacity shortages. Figure 3a, shows that a 15% capacity shortage appears to be the ideal design point for a solar home system in Rwanda, achieving the lowest LEC of 0.4 $/kWh; in Nepal, a 10% capacity shortage results in the lowest LEC. An increase in capacity shortage also reduces the total capital cost; however, diminishing financial benefits are observed. For the micro-grid (Figure 3b), a similar capacity shortage of around 15% provides a suitable trade-off between supply reliability and cost. Whilst significant cost savings can be achieved with designed capacity shortage, tier 3 energy access would not be consistently provided throughout the year to camp households. An appropriate energy management system would have to be carefully designed so that critical systems or systems of a high priority were still powered when capacity shortage periods were encountered. Results for a micro-grid system in Nepal are not shown as a diesel genset with a very small PV-battery backup system would be preferable due to the assumed lower cost of diesel fuel (see table 1) providing a LEC of only 0.31 $/kWh.

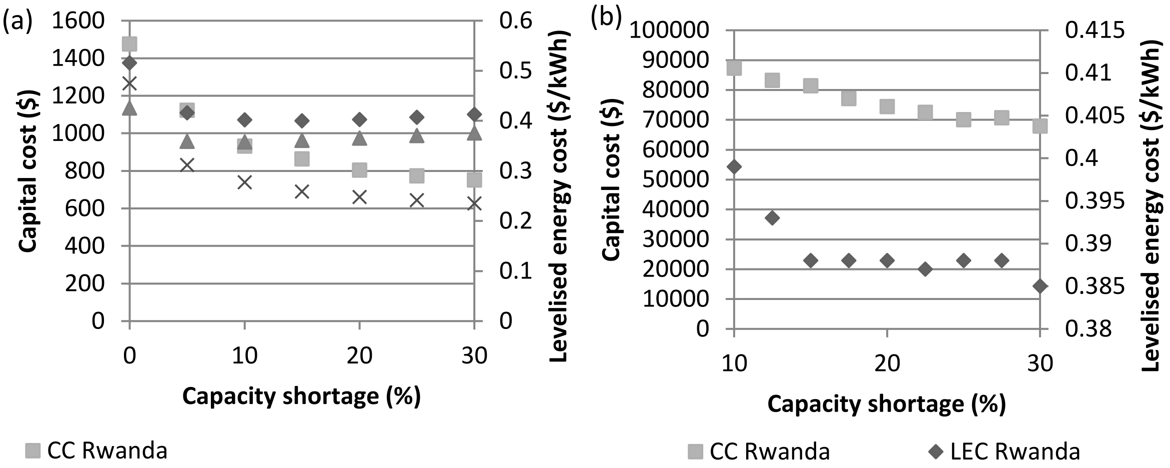

Figure 3a-b: (a) Scenario 1's and (b) scenario 4's costs vs capacity shortage (Pareto front).

Further work needs to include fluctuating diesel fuel prices and time-step and day-to-day variabilities. Inclusion of these variables could further increase LEC values, which are already significantly high in comparison to commercial utility-scale systems where levelised energy costs of around 10 $/kWh are expected [15]. The batteries form the majority of the capital costs (around 70-75% for zero capacity shortage) for both the SHS and micro-grid scenarios, suggesting that this is where research needs to focus to achieve financial and efficiency gains in these types of systems. For example, the battery pack size can be reduced by employing load identifying and shedding algorithms along with intelligent energy management strategies. Economies of scale also need to be considered as this could significantly reduce the capital and operational expenditures.

5. Conclusion

Solar home systems are solutions that can be deployed in temporary settlements for energy generation relatively easily. This study suggests, however, that they cannot provide a tier 3 level of energy access (1 kWh/day with a supply for a minimum of 8 hours including 3 hours at night) consistently and at a competitive price. A PV-based micro-grid for refugee camps in Rwanda could reduce energy costs in comparison to an overreliance on diesel generators; however, diesel gensets appear to be still an important option for Nepal. Whilst the financial costs established are very sensitive to the assumptions that have been made, they do suggest that subsidies and other incentives are still required to increase market uptake of solar home system and PV-based micro-grids in displace population settlements.

Acknowledgements

The authors would like to acknowledge the assistance of Practical Action and financial support from RCUK (EP/P029531/1).

References

[1] UNHCR. Global Trends - Forced Displacement in 2016. 2016.
[2] Alnsour J, Meaton J. Housing conditions in Palestinian refugee camps, Jordan. Cities 2014;36:65-73.
[3] Lahn G, Grafham O. Heat, Light and Power for Refugees, Saving Lives, Reducing Costs. 2015.
[4] Gerrard M, Quick D. Safe Access to Fuel and Energy (SAFE) in Nakivale, Uganda. 2014.
[5] Caniato M, Carliez D, Thulstrup A. Challenges and opportunities of new energy schemes for food security in humanitarian contexts: A selective review. Sustainable Energy Technologies and Assessments 2017;22:208-19.
[6] Cerrada MIF, Thomson A. PV microgrid business models for energy-delivery services in camps for displaced peoples. Journal of Humanitarian Engineering 2017;5.
[7] Franceschi J, Rothkop J, Miller G. Off-grid Solar PV Power for Humanitarian Action: From Emergency Communications to Refugee Camp Micro-grids. Procedia Engineering 2014;78:229-35.
[8] UNHCR. Global Strategy for Safe Access to Fuel and Energy: A UNHCR Strategy 2014-2018. 2014.
[9] Bhatia M, Angelou N. Beyond Connections. 2015.
[10] Safari B, Gasore J. Estimation of Global Solar Radiation in Rwanda Using Empirical Models. Asian Journal of Scientific Research.
[11] Minicom. Ministry of Trade and Industry Government of Rwanda: National Industrial Policy. 2011.
[12] Moner-Girona M, Solano-Peralta M, Lazopoulou M, Ackom EK, Vallve X, Szabó S. Electrification of Sub-Saharan Africa through PV/hybrid mini-grids: Reducing the gap between current business models and on-site experience. Renewable and Sustainable Energy Reviews 2018;91:1148-61.
[13] UNHCR. Camp planning standards.
[14] Alloush M, Taylor JE, Gupta A, Rojas Valdes RI, Gonzalez-Estrada E. Economic Life in Refugee Camps. World Development 2017;95:334-47.
[15] IRENA. Renewable Power Generation Costs in 2017. 2018.