Institution: Imperial College London

Unit of Assessment: 9 – Physics

Title of case study: B9-7 Solar minigrids for productive energy use in a refugee camp in Rwanda

Period when the underpinning research was undertaken: 2012 – 31 December 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Jenny Nelson	Professor of Physics	1989 – Present
Philip Sandwell	Research Associate	Oct 2018 - Present
Javier Baranda Alonso	Research Assistant	Oct 2019 – Jul 2020

Period when the claimed impact occurred: 2015 – 31 December 2020

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Our research helped MeshPower install and analyse their first solar minigrid in a refugee camp in Rwanda, powering a health centre serving 60,000 people. Our work will help reduce diesel usage by up to 47% over the system lifetime, save 6,300 kg CO_2 per year, has facilitated electricity access in the new maternity clinic and has increased security via streetlights. MeshPower hired an employee to operate the system and many jobs will be created in the long term via connections for 25 refugee businesses. The project contributes to humanitarian strategies and provides a blueprint for replication by MeshPower in three further camps.

2. Underpinning research (indicative maximum 500 words)

Our research into the greenhouse gas (GHG) mitigation potential of low-carbon energy technologies began in 2010, motivated by the need to quantify the impact of ever-increasing energy generation around the world. Increasing political commitments and decreasing renewables prices resulted in a research focus on Sustainable Development Goal 7 to bring access to clean, affordable and reliable energy to the more than 1.5 billion people who at the time lacked access to electricity. To do this it was necessary to develop an energy system model for community-scale electricity systems.

Early research (2013-15) found that certain components, particularly battery storage, have a significant impact on the performance, cost and environmental impact of the system compared to the choice of photovoltaic (PV) technology. Furthermore, projected renewable technology cost decreases would result in solar-powered systems being cheaper than diesel systems in three to five years (then 2018-20) but would remain more expensive than grid power, making the former competitive where the grid was not available **[1]**.

Developing the model to incorporate emerging trends in energy access (such as supporting improved services, rural businesses, staggered equipment deployment, unreliable grid networks, and institutional loads like health centres) **[2, 3]**, we found that these increased the utilisation of solar energy while decreasing electricity costs. We found that renewables-only or solar-dominated hybrid systems have both the lowest costs and GHGs in the long term, even for systems with the highest reliability requirements.

We made the code for the model (CLOVER) open-source and it has been used to investigate a number of energy-for-development objectives. Academics and students from the College, the University of Rwanda and EPFL have undertaken collaborative research projects with NGO and

commercial partners (MeshPower, BBOXX) to investigate opportunities for improved electricity access for businesses and community needs.

This research was supported by collaborations with minigrid companies. Our ongoing six-year relationship with MeshPower has included co-supervision of three MSc students, collaboration during two PhD studentships, and formal partnerships on two projects **[4]**. These relationships led to co-authorship of a journal article and contributions to two policy briefs **[5]**. We have also engaged with NGOs (Practical Action 2018-20, Energy 4 Impact 2019-20) and international agencies (UNITAR 2020) to inform our research's direction and policy-relevance.

Our research was ideally positioned to address the challenge of minigrid deployment in humanitarian settings, which came to prominence in 2017 following commitments by international agencies. Refugee camps are often located in remote areas of developing countries with diesel generators powering critical camp operations. Global commitments to renewable energy and diesel mitigation are highly compatible with our research, especially whilst also supporting refugee employment opportunities that can often be achieved only by providing electricity access.

These opportunities led to our focus on humanitarian energy, including a knowledge transfer secondment into Practical Action delivering renewable energy in camps in Rwanda and an investigation into hybrid minigrids in camps which found, similarly to previous research, that renewable minigrids can provide cheaper, cleaner electricity and extend the benefits of energy access to displaced populations **[6]**.

3. References to the research (indicative maximum of six references)

[1] Philip Sandwell, Ngai Lam Alvin Chan, Samuel Foster, Divyam Nagpal, Christopher J.M. Emmott, Chiara Candelise, Simon J. Buckle, Ned Ekins-Daukes, Ajay Gambhir, Jenny Nelson (2016) Off-grid solar photovoltaic systems for rural electrification and emissions mitigation in India, Solar Energy Materials and Solar Cells, 156, 147-156, https://doi.org/10.1016/j.solmat.2016.04.030.

[2] Philip Sandwell, Ned Ekins-Daukes, Jenny Nelson, (2017) What are the greatest opportunities for PV to contribute to rural development?, Energy Procedia,130, 139-146, https://doi.org/10.1016/j.egypro.2017.09.416.

[3] Philip Sandwell, Clementine Chambon, Amit Saraogi, Apolline Chabenat, Marek Mazur, Ned Ekins-Daukes, Jenny Nelson (2016) Analysis of energy access and impact of modern energy sources in unelectrified villages in Uttar Pradesh, Energy for Sustainable Development, 35, 67-79, https://doi.org/10.1016/j.esd.2016.09.002.

[4] Resilient Electricity Networks for a productive Grid Architecture (RENGA) (2018-22), EPSRC Grant Number EP/R030235/1.

[5] Christopher J.M. Emmott, Davide Moia, Philip Sandwell, Nicholas Ekins-Daukes, Markus Hösel, Lukas Lukoschek, Charith Amarasinghe, Frederik C. Krebs, Jenny Nelson (2016) In-situ, long-term operational stability of organic photovoltaics for off-grid applications in Africa, Solar Energy Materials and Solar Cells, 149, 284-293, https://doi.org/10.1016/j.solmat.2016.01.036.

[6] Javier Baranda Alonso and Philip Sandwell (2020) Sustainable mini-grid systems in refugee camps: A case study of Rwanda, Grantham Institute, Imperial College London, https://doi.org/10.25561/77296.

4. Details of the impact (indicative maximum 750 words)

Mahama Refugee Camp, the largest in Rwanda, is home to approximately 60,000 refugees fleeing conflict in Burundi. The camp opened in 2015, and later in 2017 gained a health facility. At the time of this opening Seraphine Mukantabana, the minister for disaster management and refugee affairs highlighted the need for electricity to the camp in her statement **[A]**. The UN Refugee Agency (UNHCR) and the Rwandan Government oversee camp administration, with primary

healthcare services provided by Alight, an NGO who serve 56,000 refugees quarterly **[B]**. Previously electricity provision in Mahama was typical of the five other camps in Rwanda: a diesel minigrid operated by Alight supplied a restricted number of users including the health clinic and camp offices. The system had an estimated annual fuel consumption of 6,800 litres, at a cost of approximately $6,000 and with high GHG emissions (13,500 kgCO_2), as well as air and noise pollution throughout the night. Other users were not permitted and refugee businesspeople in the marketplace had little access to modern energy sources.

MeshPower engaged with Alight to install a hybrid solar, diesel and battery system to reduce fuel consumption and were fundraising for and designing a system to meet the needs of the health clinic, the primary source of healthcare in the camp, and potentially extend it to the refugee marketplace **[B, C, D]**. Based on our longstanding relationship, including collaborative impact-focused energy modelling projects since 2015, we identified an opportunity to apply our knowledge of energy system design in humanitarian settings **[1, 2, 3]**, with MeshPower's planned installation, supported by their high-resolution remote monitoring capabilities which we used in previous projects.

MeshPower installed the largest amount of solar and storage capacity based on the funds available but lacked the capability to investigate the operational control strategy of the diesel generators. They also needed to justify to Alight and UNHCR the number of businesses it would be possible to connect to the system without significantly affecting its performance or increasing fuel use and costs. We collaborated to navigate relationships with camp authorities to permit extension of the infrastructure to the marketplace and, post-installation, inform how the operation of the system could improve its performance and provide greater benefits **[C]**.

Our research contributed to the impact of the system by investigating:

1. The electricity load to be met by a) analysing monitored data of the main institutional and health centre loads to predict future usage, and b) by transferring our research from rural businesses to quantify the potential electricity demand of different numbers and types of refugee enterprises which could be connected. Our research also helped MeshPower to *"better understand the growing needs of the health centre, whose recent expansion with maternity facilities and increasing energy demands such as for air conditioning and refrigeration."* **[C]**
2. The predicted performance of the system using CLOVER over several years to a) set a baseline for its performance, b) evaluate its operation and potential benefits under a range of different usage strategies, and c) the impacts of connecting refugee businesses to the system.

Using our findings, MeshPower presented to Alight the cost, fuel and emissions savings of the new hybrid system, including scenarios we proposed for connecting different numbers of refugee businesses to the minigrid **[C]**. MeshPower used *"Imperial's analysis of productive energy use*" to *"support of Alight and UNHRC to connect 25 refugee businesses, once access to the camp is available again, with more businesses connected in further phases in the future. This will increase the opportunities in the camp for refugees to start businesses and hire employees themselves.*" **[C]**. Our research "*has been valuable in supporting the work in Mahama"* and it has "*helped to quantify the benefits of solar energy, identify potential cost savings, and to understand the impacts of providing electricity to businesses in the marketplace*" **[B]**. This is all supporting UNHCR's refugee livelihood objectives.

Comparing the original diesel-only system to the current usage we estimate that fuel costs have decreased by 32% and emissions by 4,300 kg CO_2 per year. This is whilst both increasing the electricity use in the health centre (expanding the services, installing a vaccine fridge, and powering a new maternity centre), providing connections to additional offices, and increasing the security of the camp by providing street lighting and connecting the camp police station. Using our analysis of the optimum diesel generator usage, we expect that MeshPower will be able to get 34% more usage from the solar and battery system, saving a further $900 and 2,000 kg CO_2 annually **[C]**, in the years to come – with 47% lower fuel usage than the original system. As a

direct result of the work in Mahama MeshPower have an agreement with Alight to replicate the system in three further camps in Rwanda, which cumulatively host 43,000 refugees, subject to funding **[C]**.

This project contributes to UNHCR's global goals, encouraging the use of renewable energy for more sustainable operations **[E]**, and the policies of the Government of Rwanda (and many other countries) to support the economic integration of refugees through productive livelihoods **[F]**. In addition, our research is "*directly relevant to the UNHCR Clean Energy Challenge, which aims to provide cleaner and safer energy to displaced people worldwide, and so the work in Mahama Refugee Camp will serve as a valuable example of private sector delivery supported by academic research*" **[E]**. As one of the first systems of its kind in the world, our project has received much attention **[G, H]**. UNITAR, who coordinate global humanitarian energy implementation, invited us to present this project as an example of the value of research applied to energy in humanitarian settings in September 2020 at an event attended by UN agencies, NGOs, academics and the private sector from around the world **[E]**. We are now engaging with UNITAR to explore opportunities to apply this work to their projects in Djibouti **[E]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[A] Article in The New Times (Rwandan daily paper) about the original set-up of the health centre in the camp with details about the services provided, *Burundian refugees at Mahama camp get new health facility*, 28 January 2017 (link), noting final line. (Archived here)

[B] Supporting letter from Alight

[C] Supporting letter from MeshPower

[D] Alight website with details about their work and partnership with MeshPower (link) (Archived here)

[E] Supporting letter from UNITAR

[F] UNHCR Rwanda Country Response Plan January 2020 – December 2021 (link) (Archived here), relevant links to national humanitarian policy below including:

- "Clean and sustainable energy sources will also be encouraged (ex. Solar energy). These will also be encouraged for lighting and to reduce fuel consumption from diesel generators. CRP [Country Response Plan] partners with expertise in energy will also continue to promote the use of sustainable energy for productive use through a market-based approach"
- "This initiative can be linked to UNHCR's partnership with the private sector for the supply of clean energy to refugees and host communities"
- "Training cooperatives members in farming as business and access to finance including the development of inclusive business models for the big cooperative and assist cooperative members in appropriate identification and use of clean energy"

[G] Article and interview in Microgrid Knowledge (trade association website for decentralised electricity systems), Report Examines Sustainable Minigrids for Rwandan Refugee Camps, 9 April 2020 (link) (Archived here)

[H] Article on UNITAR's Global Plan of Action website, Sustainable mini-grids in refugee camps: A case study of Rwanda, 14 April 2020 (link) (Archived here)