Remote sensing technologies and energy applications in refugee camps

Chapter · December 2019

DOI: 10.4324/9781351006941-11

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Challenges to energy interventions for electricity, lighting and cooking

The humanitarian sector lacks data on the success of historical energy interventions and the paucity of data is regularly decried by major actors working on humanitarian energy (for example UNHCR, 2014). Wireless sensors and communication technology offer one potential remedy. Even though energy and cooking issues present in camps have been reported as far back as 1995, it is only since renewable energy technologies have become more established and cost competitive, that solutions and innovations based on these technologies have started to become more widespread (Bellanca, 2014).

In recent years there has been a particular need for data on the use of diesel generators, which are extremely prevalent in the humanitarian sector and often expensive, polluting and inefficiently run (Grafham and Lahn, 2018). It is not recommended that diesel gensets are operated below 50% of their rated load to avoid component damage and reduced efficiencies, but evidence suggests that a lack of understanding on diesel gensets in humanitarian settings means they are often over- or under-loaded in camps, with data on fuel consumption, running hours and servicing not being properly monitored or reported (Grafham and Lahn, 2018). As a result, the cost of generating electricity in UN compounds has been estimated to be very high at around 0.60 $/kWh (WFP, 2017), with an estimated $620 million being spent in 2017 on diesel for electricity generation (and associated maintenance) (Grafham and Lahn, 2018). It is thought that over 450 million could have been saved by implementing affordable alternative technologies and well-established better practices (Grafham and Lahn, 2018). A lack of data on seasonal and diurnal load variations can also make it particularly difficult to provide reliable and cost-effective energy services, which could be easily monitored and reported.

But replacing these diesel generators with alternative renewable energy technologies has not always proved easy and past interventions have had varying degrees of success. Guidelines for the use of portable and modular off-grid solar photovoltaic (PV) systems to provide emergency relief are relatively well-established; however larger micro-grid systems have only just started to be utilised, and research on their operating and implementation in camp setting is limited. The IKEA Foundation's Brighter Lives for Refugees Programme (IKEA Foundation) funded the world's first PV power plant, located in Jordan's Azraq refugee camp, in 2017; and the largest refugee camp PV power plant funded by the German government, followed soon after, located in Jordan's Za'atari refugee camp (Hashem, 2017). Ossenbrink et al. (2018) examined why PV systems have not been adopted more widely in camps. They evaluate PV systems for a range of camp settings highlighting how much lower energy costs would be in comparison to diesel and grid electricity. Following consultation with experts and humanitarian agencies, they attribute the lack of PV systems to be a result of a limited awareness on potential cost and emission savings, suggesting that expertise in the humanitarian sector and in the field need to be improved.

There have been numerous instances of difficulties with using PV technology for street lighting, water pumping and solar lanterns. Lahn and Grafham (2015) review a number of energy projects in refugee camps, identifying that a lack of social and cultural understanding and poor maintenance are often major causes of project failures. Streetlights in Kutupalong refugee camp in Bangladesh were found to be poorly maintained and limited uptake was reported for new solar, energy efficient and gas cookers were highlighted on projects in Burkina Faso, Eritrea and Niger respectively (Lahn and Grafham (2015). The majority of PV-based water pumping solutions in Uganda have been found to reduce costs in comparison to diesel gensets or water trucking (Llario, 2017)[1] and solar-genset hybrids have proven popular for water pumping in many humanitarian settings across Sub-Saharan Africa. However, a lack of water level monitoring and theft of PV panels have been frequent problems. A number of solar-based water pumping stations have also stopped working due to a lack of maintenance. Where systems have been working well, an influx of more people to the area has meant that some systems are now undersized. Aste et al. (2017) investigated a number of hybrid electric systems in use in informal refugee settlements in Lebanon. They identified a lack of local skills to deal with technical issues as they arose. They stressed that monitoring is crucial to deal with unexpected operating conditions when making energy interventions in informal settlements.

Biomass systems have focused on using alternative feedstocks directly for cooking purposes (e.g., pellets or briquettes) or converting a waste feedstock (e.g., food or sewage waste) into a biogas, which can be used for cooking or electricity generation. Biogas units have attracted interest as they have the potential to address multiple issues related to waste and agricultural management, sanitation and energy supply. However, biogas systems trialled in camps have had mixed success. In Haiti, a biogas system comprising of five digesters connected to 60 toilets was built by a nongovernmental organisation (NGO) to provide gas to several community kitchens. The biogas project failed for multiple reasons: technical failures (inadequate gas obtained, lack of water for flushing, pipe damage and gas regulation issues), a lack of accountability for maintenance and socio cultural reasons (community kitchens are not commonly used by Haitians and disputes occurred due to the limited gas supply) (Bellanca, 2014). Many of these technical issues could be monitored with sensors to provide early detection and reporting of gas and water flow problems.

Despite these difficulties, there are nonetheless large potential benefits to unlock. Lehne et al. (2016) assert that efficient cook stoves and solar lanterns could save refugees $303 million a year against their current spending. And thinking beyond products towards delivery models and the entire value chain (e.g., when implementing a new stove, the fuel type, size, cost and collection method needs to be considered to avoid potential problems) could reap even greater benefits (Lahn and Grafham, 2015).

Multi-criteria and multi-objective energy decision making in refugee camps

Research on the use of decision-making techniques for the design and management of energy provisions in refugee camps remains almost completely unexplored. But having better data coming in also means that we can increasingly make better decisions about how energy solutions should be structured in the future. Decision-making models can play a significant role in assisting with camp planning and increasing the success of future energy interventions.

There is now a wide range of energy generation and distribution technology options. However, there are numerous social, technical and economic criteria to consider when trying to deploy and operate sustainable energy services within a refugee camp. Moreover, there are many different conflicting objectives (e.g., minimising capital costs, unit energy costs, network losses and carbon emissions; maximising human development, accessibility and system efficiencies). These objectives can vary for different camps, as do many other constraints and variables (e.g., population size, geographical distribution, available finances and meteorological conditions). To manage these types of decision-making problems, decision support systems based on multi-criteria analyses and multi-objective optimisation methods have become popular tools for renewable energy planning (Pohekar and Ramachandran, 2004).

Many energy project planners need to consider decisions with a whole host of surrounding issues and repercussions. This makes projects complex and difficult to manage. Decision makers will typically use their judgement, experience or intuition to make choices rather than using a holistic and structured approach to evaluate fully decision problems; this can result in poor decisions being made or important aspects of a problem not being sufficiently analysed. Saaty (1980) developed a multi-criteria decision-making method known as the Analytical Hierarchy Process (AHP) to provide decision makers with a systematic method of decomposing a complex problem into several more manageable sub-problems. One major advantage of AHP is its ability to encompass both known and unknown data into the decision rationale; where there are gaps in information, expert opinion and judgement can be used. This flexibility is particularly useful as there are often many uncertainties or subjective data in complex decision problems. Applications of AHP originally demonstrated by Saaty included choosing a school for his son and transportation planning. The AHP is now used all over the world in a vast range of applications including energy planning, marketing, information technology, education and policymaking (Vaidya and Kumar, 2006).

The AHP involves three main processes: 1) identifying the decision goal, selection criteria and alternatives, and organising them into a hierarchy; 2) carrying out pairwise comparisons throughout all levels of the hierarchy and checking for consistency and 3) synthesising all the pairwise comparisons to determine each alternative's overall preference (Saaty, 1988). An example AHP framework for selecting an energy technology for a new refugee camp from a finite number of alternatives is shown in Figure 10.1. In this scenario, it would be invaluable to have data obtained from sensors on prior systems in similar contexts for performance, surplus capacity that goes to waste or activities taking place as monitoring at an individual appliance level.

Despite the benefits of systematic and holistic decision-making models, they have not been utilised for refugee camp energy planning. There are, however, a few examples of such tools being used to address other challenges facing refugee camp sites. Since 2011, hundreds of thousands of refugees have arrived in Turkey from Syria; many remain homeless and new camps need to be built. Çetinkaya et al. (2016) used a multi-criteria approach combined with a Geographical Information System (GIS) to assess new potential camp sites. They used a Fuzzy Analytical Hierarchy Process (AHP) to determine priority weightings for a range of site selection criteria and TOPSIS (The Technique for Order of Preference by Similarity to Ideal Solution) to rank the alternatives sites. A site availability score was determined using GIS and other geographical, infrastructure, risk and social criteria were considered. TOPSIS was used to rank the sites based on an ideal solution formed from a combination of all the sites. Fifteen sites were identified as potentially better locations than the current refugee camps in Turkey; however, as with any decision-making study, the results are highly dependent on the chosen criteria and experts' options. Whilst decision-making tools can be based on expert judgement, their reliability is improved with good quality data.

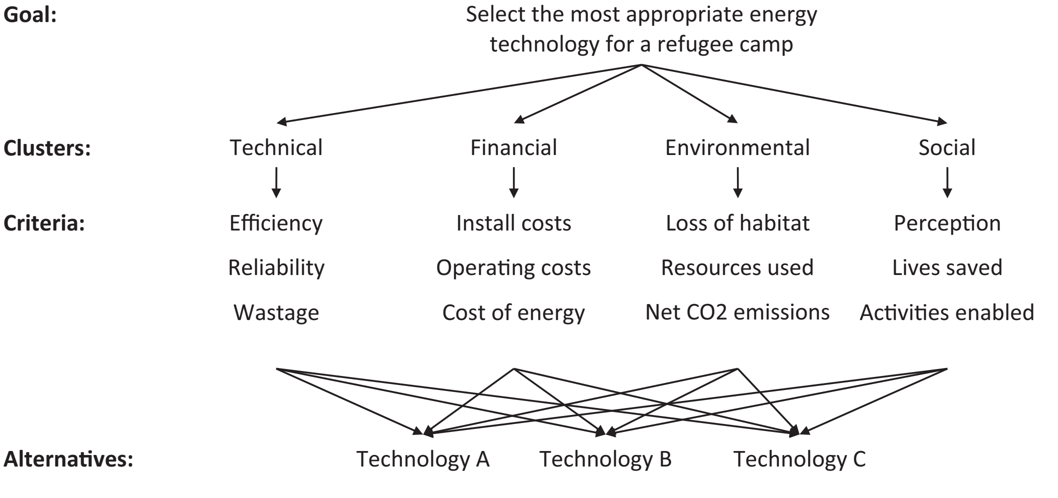

Figure 10.1 Example hierarchy for refugee energy technology selection using AHP

Source: Author's own.

Garfi et al. (2009) used AHP to consider four alternative waste collection strategies for a refugee camp in Saharawi. In addition to technical, financial and social criteria, they took into account environmental impact, human development index and millennium development. Hosseini et al. (2016) used the Integrated Value Model for Sustainable Assessment (MIVES) model (a ranking method which is similar in principal to AHP) for assessing temporary housing units, including water and energy needs. They compared a number of different material and prefabricated components for temporary housing units and suggested that pressed reeds and concrete masonry units were the most sustainable options. Other extensions of AHP have also grown in popularity such as the Analytical Network Process to consider interdependences between criteria (Saaty, 2004) (see Figure 10.2). For example, there is a relation between the cost of a system and technical performance. There are also dependences between social and technical criteria, such as reliability and perception; failure to consider these interdependences can influence the recommendations arising from decision-making studies.

When there is a large number or infinite number of alternatives, multi-criteria decision-making methods can be used to find an optimal solution via an algorithm. For example, optimisation of micro-grids using multi-criteria decision-making techniques is a well-studied area, with researchers investigating both system component and control optimisation. This is due to there being are a large number of different energy generation and storage combinations, which can all be controlled in a variety of different ways. System design decision criteria include capacity of the generating units, type of generating units and financing models. However, there are also many constraints and objectives to consider for system control (e.g., managing peak power demand and equipment loading in order to minimise system inefficiencies and energy costs). Researchers have tackled the problem using numerous optimisation approaches (e.g., linear programming, genetic algorithms

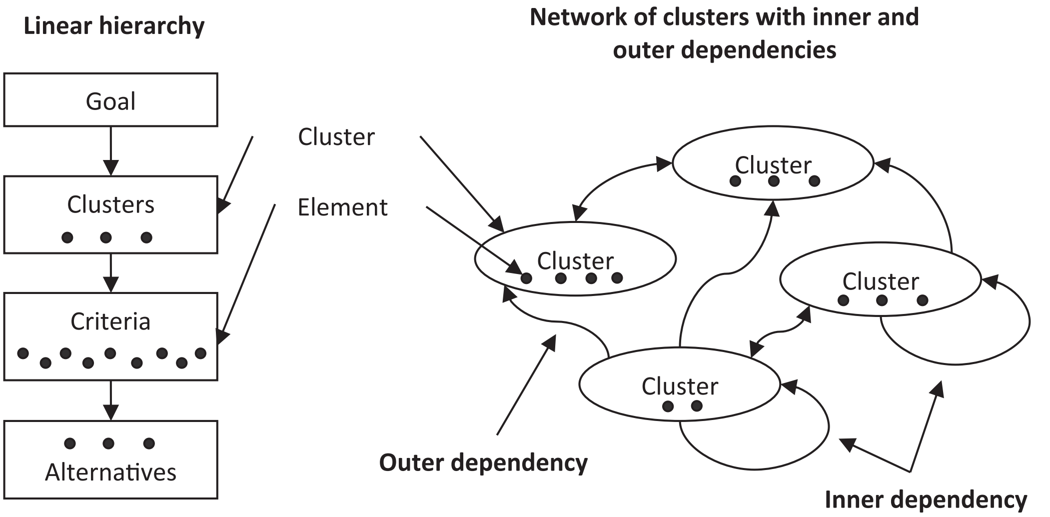

Figure 10.2 Comparison of AHP (left) and ANP (right) frameworks

Source: Author's own.

and particle swarm optimising), considering aspects such as maximising profits and environmental benefits (Tezer et al., 2017; Moghaddam et al., 2012; Sawle et al., 2018; Dawoud et al., 2018). Dufo-López et al. (2016) outlined a micro-grid multi-objective optimisation method for a refugee camp in Tindouf, Algeria. They used a multi-objective evolutionary algorithm for component selection and sizing based on net present cost, human development index and job creation objectives. Using a genetic algorithm, they outline a control strategy for minimising net present cost. A micro-grid solution based on photovoltaic, wind, diesel and battery technologies was outlined, but the authors do not go on to compare their results with the technologies already being used at the case study location, which included diesel generators and PV panels. Therefore, the benefits achieved by the optimisation method remain largely unknown.

Micro-grid control and demand side management strategies

Although most camps do not have access to electricity, there are an increasing number of humanitarian energy interventions, which are prioritising micro-grids. A common approach for micro-grid control is to implement an energy dispatch model, which seeks to minimise instantaneous running costs whilst meeting a total load plus any losses. This is known as an economic dispatch model; however, this approach may not be suitable for refugee camps due to differences in financing arrangements. Demand response programs aim to reduce peak loads by actions being taken by the energy users in response to time varying prices. This would be difficult to implement in a refugee camp, but a simpler request and priority-based approach could be easier for refugees to understand. This would be a form of an incentive-based scheme, designed to incentive users to reduce consumption during peak loads rather than a price-based program, where consumers voluntarily reduce demand based on forward market prices (see Figure 10.3). However, such systems require intelligent interfaces for users to interact with, and engaging with users in this way can be challenging.

To reduce the uncertainty posed by renewable energy inputs into a micro-grid, Aghajani et al. (2017) proposed an incentive-based demand response program

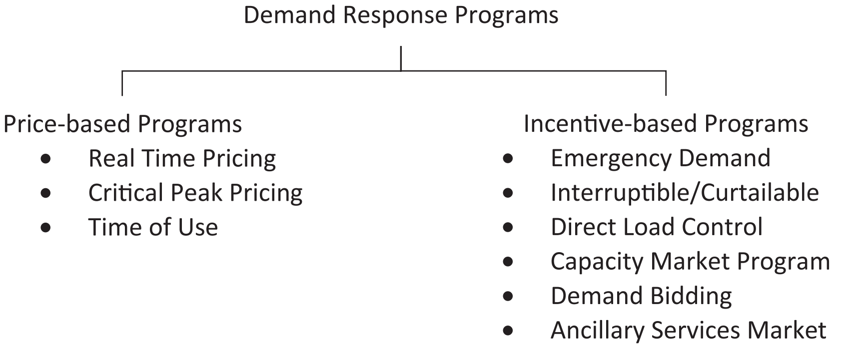

Figure 10.3 Demand response programs can be categorised as price-based or incentive-based, and both involve consumer participation in energy consumption behaviour

Source: Aghajani et al., 2017.

and optimisation method based on probabilistic programming and particle swarm optimisation. The demand response programme objective function was to minimise operational costs and pollution emissions. A number of price package strategies were offered to implement the demand response programme, with lower pricing being offered during low demand periods. Probabilistic programming was used to predict next-day solar and wind generation capabilities. They conclude that if energy users participated in the incentive-based demand response program, costs and emissions could be reduced respectively by 21% and 14%.

Khan et al. (2015) review home energy management systems and demand response program options in various scenarios. They highlight that demand response programs for small residential and commercial areas based on critical peak pricing and load control in the USA have proven very successful. The use of enabling (information communication technology) ICT, sensing and measuring devices is essential to enable smart grid options via a home EMS. A home EMS comprises of a product, which monitors, controls and analyses energy usage within the home, and it functions to reduce energy usage and cost and improve comfort. With the emergence of low-cost and low-power wireless sensors that can be used to control networks and for diagnostics, there is the possibility of them now being used in refugee camp EMS design for the first time to improve automation and intelligence.

The role of sensors for energy planning

Sensors embedded in EMSs are widespread, although a new wave of products and research propose the use of 'per appliance' data to forecast, schedule and control the distribution of energy in renewable based energy delivery systems. Large data sets can now be obtained and stored by energy providers to help them better understand energy usage patterns and emerging behavioural traits. For example, BBOXX, a solar home system provider, is using big data to better understand their systems and predict long-term trends in Kakuma refugee camp (see Chapter 9). Maintenance can be improved by detecting and predicting faults. Payment trends can be evaluated, and operational teams can support their customers more effectively. This information can also be used to inform and devise tools for behaviour change (for example provide user education on effective use of small/limited available energy or help users reduce energy consumption to prevent fuel poverty) or to better plan for/design new energy systems in similar settings. In the context of a refugee camp, quantitative data such as this will help to establish energy patterns and preferences; data that largely remains unknown and is critical to improve energy interventions in camp settings more widely.

Integrating sensors into energy devices, such as streetlights, solar home systems and cook stoves, could enable important information to be gathered that could help to address some of the challenges that have prevented energy interventions in camps from being more successful (Barman et al., 2017; Graham et al., 2014). Where maintenance problems have been encountered, sensors can be used to detect faults and trigger repair services; these sensors can be seen as 'utility meters' that can aid decisions on where assets cease to provide the planned added value or where investment needs to be made due to high failure rates or utilisation. With adequate visualisation and interpretation tools, sensors could warn users of polluting emissions from traditional cookstoves and influence behavioural change (e.g., encouraging the use of an improved cook stove with lower emissions). Table 10.1

Table 10.1 Benefits of sensors and data monitoring of alternative energy options in refugee camps

Technology	*Possible sensors*	*Data to monitor*	*Possible Benefit*
Cook stoves	Thermocouples Emission sensor	Temperature profiles Carbon monoxide and particulate matter emissions	Temperature sensors telling users of efficient cook stoves when they have become too hot and dangerous. Inform households when air quality has become dangerous
Biogas	Flowmeter Thermocouples	Gas yield Digester temperature	Detection of fouling, resulting in the inhibition of microorganisms; improved control of loading rates. Increase in gas yields
Diesel Generator	Bearing sensors	Shaft movement/ vibration and engine conversion efficiencies	Monitor performance/efficiency at low loads Early fault detection and reduced maintenance times and cost. Inform operational change to improve component longevity.
Solar Lanterns	Accelerometer GPS	Movement Location State of charge/ battery health, PV/grid charging rate	To show how lanterns are used by households (e.g., at a standstill in the home during the day or out walking at night, how long are they used, how effectively are they being charged during the day, are they getting wet and damaged during rainy seasons, are they being charged using expensive electricity provided from a diesel genset)
Solar streetlight	Motion and infrared sensors	Mobility and use of space	Better understanding of where and how to operate streetlights in refugee camp settings. Evidence of changes in mobility.
Solar home system	GPS	Operational status Energy availability, usage patterns and preferences.	Theft mitigation/maintenance scheduling Operation change, improved battery life and utilisation efficiencies.
Solar water pump	Ultrasonic sensor	Ground water level Storage water levels	Early water shortage warnings Enable predictive capabilities to improve water management and distribution, thereby mitigating the risk of prolonged periods of water shortages.

Source: Author's own.

summarises some of the alternative sensors to use and data that could be collected on energy intervention in refugee camps and the potential benefits they could enable.

Sensors can be used for improved predictive and automated control (Wu et al., 2010). Imagine streetlamps that can learn patterns of traffic and adapt luminosity and function time, thus enabling energy to be saved and used on other critical services (e.g., health facilities and food refrigeration) and entrepreneurial activities. For water pumping, water levels and quality need to be monitored and, using both forecasted and real-time usage and weather data, water storage and distribution could be managed to avoid long periods of limited water access (Whittle et al., 2013). Similarly, sensor networks are being investigated for improved water irrigation management (Kim et al., 2008). Sensor-based, real-time, decision-making systems in refugee camps will be able to reduce wastage and enable systems to be better balanced. This is critical for camps where fuel, energy and financial resources are limited and evidence-based data on energy usage is unavailable.

One example which brings together these themes is the work undertaken by Coventry University in Rwanda where a smart micro-grid is being deployed to provide power to two nurseries and a sheltered playground. The system is set up to monitor the community's energy needs and patterns of use and show how this changes over time. Another objective of the system is to enable the community to negotiate and share the communal resource. In this instance, an appropriate energy management system (EMS) is needed to control and adjust power flows at an individual appliance level based on priorities and usage quotas. This is particularly needed in a camp setting, where resources are limited and user needs and preferences remain largely unknown, making future system design and control a challenge. Coventry University's work also involves deploying stand alone solar systems and smart streetlights, with a similar focus on characterising energy usage and growth in communal activities. At the time of writing it is too early to say whether the work undertaken in Rwanda will generate data that is truly useful for the sector, but the approach could be instructive for others seeking to contribute to better energy system management of refugee camps.

Conclusion

It is evident that ownership, social acceptance and maintenance are some of the major challenges that need to be addressed to make energy intervention in refugee camps more successful. However, there are a range of tools and technologies which can be utilised to improve the deployment and management of energy interventions in refugee camps.

This chapter has explored the use of multi-criteria, decision-making and optimisation methods, alternative control and distribution strategies and the use of sensors to inform energy system management. Despite the widespread use of multi-criteria decision making for energy planning, it has not yet been taken up for refugee camp energy planning. Refugee camps face multifarious planning problems, which could benefit significantly from holistic systematic decision making, given the wide range of conflicting technical, economic, social and risk criteria and energy technologies solutions that could potentially be used for generation and distribution.

Decision-making tools could play an important role in the future to improve sustainable deployment of energy services in camps. Micro-grid and micro-grid optimisation is another area which has been widely studied, but again it has not been fully explored in the context of refugee camps. Optimal power dispatch and demand side management of hybrid energy solutions remains an exciting area of research for refugee camps as it could significantly reduce energy prices.

Nevertheless, energy usage data still needs to be gathered at camps using sensors, both before and after any intervention, and sensors will play a crucial role in enabling intelligent energy systems to provide cheaper and more reliable services. Sensors will enable systems to be maintained more effectively, reducing downtimes and operating costs, and improve system performance. They will also enable users to use their energy resource more effectively – thereby providing immediate benefits – but they will also capture important data to enable energy technologies to be designed and implemented more effectively to best meet a community's needs in the future.

Note

1 Settlements in Adjumani, Moyo, Yumbe and Arua receiving 90 truck deliveries a month were costing the UNHCR $400,000 per month.

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