UNIVERSIDADE DE LISBOA
FACULDADE DE CIÊNCIAS
DEPARTAMENTO DE ENGENHARIA GEOGRÁFICA, GEOFÍSICA E ENERGIA

Evaluation of the potential of demand side management strategies in PV system in rural areas

Catarina Filipa Rodrigues Augusto

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Dissertação orientada por:
Professor Doutor Miguel Centeno Brito
Doutoranda Rita Hogan Almeida

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Abstract

According to the latest data, there are still about 1.1 billion people (17% of the global population) lacking access to electricity. Due to unplanned power outages, massive losses and low power quality, further 1 billion people have access only to unreliable electricity networks.

The Renewable Energy (RE) systems depend strongly on energy efficiency since it has a direct impact on the size and capacity of the RE system power and, as a consequence, on investment costs. In developing countries, where energy access is poor and investment costs in RE systems are high, energy losses and potential gains are even more dramatic than in developed economies. Demand Side Management (DSM) could be an answer to this problem. Therefore the goal of this study is to understand if it is possible to improve RE microgrid systems in remote areas with DSM and if its implementation could reduce the need for fossil fuels and improve the performance of batteries in microgrids, two of the most expensive components of the system.

A range of different scenarios were designed, based on the main DSM strategies: conservation, peak clipping, load shifting and valley filling. The study is based on Soroti community, a small town in central-east of Uganda (1.72N, 33.6E), supplied by a PV-diesel microgrid system. The tools used in this study are LoadProGen (for load profile estimation) and HOMER (for DSM scenarios analyses). Model results demonstrate that the combination of all strategies has the better outcomes on the power system components and on the LCOE. They also show that the nominal power capacity of the system has a higher impact on the value of LCOE than the reduction of diesel consumption. With optimized energy demand, the LCOE has an improvement of almost 20%.

These results highlight the importance of the often-neglected DSM strategies for isolated microgrids, which have the potential for promoting access to electricity in many regions of the world with clean renewable energies.

Keywords: Demand Side Management, photovoltaic system, energy access and microgrids

Resumo

Em 2016, as Nações Unidas apresentaram dezassete metas para o desenvolvimento da humanidade, denominadas como *Sustainable Development Goals*, entre as quais se encontra o acesso à energia limpa. Esta meta é um bem essencial para o desenvolvimento da sociedade, permitindo, nomeadamente, a refrigeração de alimentos e medicamentos, o abastecimento público de água, iluminação e ferramentas de comunicação para educação, e equipamentos modernos para assistência médica. No entanto, o acesso à eletricidade é ainda um dos grandes problemas em muitas zonas rurais, nomeadamente em países em desenvolvimento. Atualmente, mais de mil milhões de pessoas não têm acesso a eletricidade e outras tantas têm apenas acesso a sistemas não fiáveis. Para além do acesso, a qualidade da distribuição de energia é também bastante relevante, nomeadamente em países em desenvolvimento em que a carência é maior e o investimento em sistemas de energia renovável é elevado. O sistema de micro-rede com geração renovável e geradores a diesel é visto como uma das soluções mais competitivas para estas localizações. No entanto, este tipo de sistema depende fortemente do dimensionamento e uso eficiente do mesmo, i.e. o uso incorreto ou o excesso de consumidores na rede podem causar problemas e fazer com que o equipamento eletrónico não trabalhe adequadamente. Apesar de os geradores a diesel e as baterias serem dois componentes essenciais à estabilidade da distribuição de energia nestes sistemas, são também dos componentes mais caros. O uso incorreto das baterias faz com que tenham um tempo de vida mais curto e que seja necessário uma substituição antecipada. O diesel é um combustível caro e difícil de adquirir em algumas zonas rurais. Projetos relacionados com este tipo de sistema de energia indicam que a gestão da procura demonstra ser uma potencial solução para estes problemas. A gestão da procura (*Demand Side Management - DSM*) consiste na gestão do consumo energético por parte do consumidor, através de medidas ou mecanismos que tornem o diagrama de carga o mais adequado ao sistema de produção e aos consumidores da rede.

No entanto, a maior parte do trabalho desenvolvido nesta área está relacionado com zonas urbanas ou com o sector industrial, casos de grande densidade populacional e atividade económica, i.e. elevado consumo energético. Muitas das estratégias de *DSM* descritas em parte da literatura não podem ser usadas para este género de sistemas produtores. A gestão da procura em micro-redes pode ser desafiante visto requerer competências nos ramos da engenharia, finanças, gestão, política e educação. Existem três fatores importantes que podem sublinhar a especificidade da *DSM* para micro-redes: o tamanho do sistema produtor, a fonte de energia e os consumidores.

O principal objetivo deste trabalho é compreender qual o potencial da gestão da procura na otimização de sistemas de micro-rede com geração fotovoltaica e diesel em zonas rurais. Em detalhe pretende-se determinar se a aplicação de estratégias de *DSM* reduz a necessidade de recorrer à utilização de diesel e/ou se o tempo de vida das baterias aumenta. Além disso, este estudo tem também o intuito de determinar o potencial de *DSM* para reduzir o custo da energia para os consumidores e os impactos sociais destas estratégias. A capacidade do sistema produtor renovável (painéis e baterias) versus o consumo diesel foi outro dos pontos estudados.

Para responder às questões propostas, foram desenhados diversos cenários de gestão de energia numa micro-rede híbrida com geração fotovoltaica e diesel. Os cenários baseiam-se numa pequena comunidade em Soroti, Uganda (1.72N, 33.6E), com cerca de 1000 habitantes ligados a uma micro-rede constituída por painéis solares fotovoltaicos com um total de 204 kW, um gerador diesel de 10 kW e um banco de baterias de 792 kWh. LoadProGen e HOMER são as

duas ferramentas usadas neste trabalho para o desenho e análise dos perfis de carga. A ferramenta LoadProGen permite desenhar o diagrama de carga de um sistema elétrico com base nos dispositivos elétricos utilizados pelos consumidores. O modelo HOMER é usado para otimizar o desenho de sistemas energéticos.

Os cenários analisados foram construídos com base nas estratégias clássicas de *DSM*: conservação*, peak clipping, load shifthing e valley filling*.

A conservação é a redução de consumo energético diário através da substituição de equipamento eletrónico com maior gasto energético por outro mais eficiente ou através da mudança de comportamento relativamente ao consumo energético por parte do consumidor. Um dos exemplos desta estratégia é a substituição das lâmpadas convencionais por lâmpadas LED. Neste caso, sendo os frigoríficos o equipamento eletrónico com maior gasto energético, para uso desta estratégia os frigoríficos usados nas atividades comerciais (quiosques, mercado, farmácia entre outros) foram substituídos por outros com maior eficiência energética. Os resultados mostram que esta estratégia não foi bem sucedida, devido ao excesso de capacidade de geração já existente. Com esta estratégia o custo de energia é maior do que sem aplicação da estratégia. Se fosse para aplicação num sistema em projeto mas não implementado, o seu impacto seria positivo, reduzindo a capacidade PV a instalar e portanto reduzindo o custo de energia para o consumidor.

Peak clipping é a redução do consumo energético durante o pico de consumo diário. Um exemplo é a restrição do uso de alguns eletrodomésticos durante o período de maior consumo e limite de consumo energético durante o mesmo intervalo. Neste estudo, esta estratégia inclui três cenários, *peak clipping* a 60 kW, 50 kW e 40 kW, sendo o pico médio de 67 kW. Os cenários *peak* 50 kW e *peak* 40 kW são os que apresentam melhores resultados em termos de poupança energética.

Load shifting baseia-se no deslocamento de consumo energético de intervalos com maior procura para intervalos de menor procura, denominados de vales. Neste caso os consumidores não têm de deixar de usar alguns dos seus equipamentos elétricos nem têm de diminuir o consumo, apenas terão de mudar os seus horários de consumo para intervalos menos sobrecarregados. A análise desta estratégia foi dividida em dois cenários, cada um com dois sub-cenários. O primeiro cenário baseia-se na alteração dos horários de funcionamento das pequenas e grandes empresas, os maiores consumidores do sistema, para horas de menor consumo elétrico. O segundo cenário baseia-se no deslocamento do consumo dos frigoríficos, o eletrodoméstico que consume mais, para horas de menor consumo tendo em conta que o frigorífico tem uma autonomia de 12h, sem ter de estar ligado à corrente. Neste caso foram testados dois cenários, o uso de frigoríficos apenas durante o dia ou durante a noite. Dos quatro cenários referidos nesta estratégia o primeiro é o que apresenta maior poupança energética relativamente ao custo inicial.

Ao contrário das estratégias anteriores, v*alley filling* tem como objetivo aumentar o consumo energético mas apenas durante os períodos de menor consumo, de forma a equilibrar o perfil de carga e melhorar o uso da energia de um ponto de vista económico. Um exemplo desta estratégia é a utilização do excesso de energia produzida para a aplicação em outras atividades que aumentem a economia da comunidade. Esta estratégia foi dividida em dois cenários e cada cenário foi posteriormente divido em outros dois. O primeiro cenário consiste na adição de um sistema de irrigação para plantações de citrinos, usando o excesso de produção dos painéis solares para o sistema de bombagem. Os sub-cenários associados diferem no tamanho do campo de cultivo, 20 e 25 hectares. O segundo cenário consiste na adição de uma fábrica de sumos com

horas de trabalho durante as 11:00 e as 16:00 horas. Os sub-cenários associados diferem no tamanho da fábrica, em termos de consumo energético, 10 kW e 15 kW. Dos quatro cenários referidos nesta estratégia o último é o cenário com melhores resultados em termos de custo de energia.

De cada estratégia foi selecionado o melhor cenário com base no custo da energia (*LCOE*). O resultado obtido da junção dos melhores cenários de cada estratégia num só foi de 18% de decréscimo no custo energético. Caso a capacidade do sistema produtor fosse redimensionada o resultado seria 20%. Os resultados sublinham uma vez mais a importância da gestão da procura em micro-redes isoladas e o potencial destas estratégias na eficiência deste tipo de sistemas.

Palavras-Chave: gestão da procura, sistemas fotovoltaicos, acesso à energia e micro-redes

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List of Acronyms

AMI	Advance Metering Infrastructure
AMSCC	Advance Metering Systems with Centralized Communication
BS	Best Strategy
CFL	Compact Fluorescent Light
DOD	Depth of Discharge
DR	Demand Response
DSM	Demand Side Management
EC	Energy Conservation
EE	Energy Efficiency
EMC	Electricity Management Committee
INR	Indian Rupee
LCOE	Levelised Cost of Energy
LED	Light Emitting Diode
LS	Load Shifting
PPM	Prepaid Meters
PV	Photovoltaic
RE	Renewable Energy
SOC	State Of Charge
TDH	Total Dynamic Head
VF	Valley Filling

1. Introduction

Electricity is a key element for the well-being and growth of society. In 2016, the United Nations set seventeen Sustainable Development Goals for the humanity development, being access to affordable clean energy one of the goals (goal 7) [1]. Modern energy allows, among other things, access to refrigerators for food preservation and medicines, pumping systems for drinking water, lights and communication tools for education, and modern equipment for health care. According to the latest data, there are still about 1.1 billion people (17% of the global population) lacking access to electricity [2]. Due to unplanned power outages, massive losses and low power quality [3], further 1 billion people have access only to unreliable electricity networks [4]. So even for those that the rate of access to electricity is improving, the quality of supply is still an issue.

Microgrids, systems that range from 10 kW to 10 MW, seem to offer a more economical solution for un-electrified locations comparing to grid extension [5]. In addition, renewable energy (RE) microgrids with diesel generators as a backup have been shown to be a competitive solution to promote electricity access to remote large communities in rural areas [6]. However, despite the enormous advantages of microgrids, there are also some constrains that affect their performance and therefore the energy' supply. Limited power generation, restricted energy storage and fuel cost are some of these restrictions. Limited power generation can cause brownouts, due to peak demands, making appliances stop working properly [7]. Batteries make systems more stable by storing the energy for peak consumption when there is insufficient production from renewable sources, although if not regulated can be exhausted. Diesel generators fulfil the renewable sources supply gaps and high demands. Nevertheless, these components have high costs, batteries represent a significant part of the cost of electricity over the lifetime of the microgrid, due to replacement costs, and diesel is an increasingly expensive fuel, thus both increase the cost of electricity. Batteries and diesel also have high environmental footprint. Proper energy management should maximize the lifetime of the batteries and, whenever possible, reduce the needs of diesel fuel. This may be achieved by reducing load or spreading load over time, ensuring that electricity is equitably shared among the microgrid users. This type of energy management is entitled Demand Side Management (DSM).

Most of the work seen in this area is related to urban areas or the industry sector in developed countries, cases where there is a large density of population, economic activity and, therefore, large electricity consumption. The following studies present some measures implemented at national level. Long-term political commitment, environmental action plans, policy measures and energy regulatory tax are some of the DSM programs adopted in the called leading countries (i.e. Europe, Japan, USA), as pointed out by [8]. The same paper gives us also a review of the current state of DSM initiatives in some Latin American countries (Brazil, Mexico, Costa Rica). In [9], the author makes a brief review of the DSM techniques put into practice in the UK electricity system: night-time heating with load switching, direct load control, time-of-use pricing, load limiters, commercial/industrial programs, frequency regulation, demand bidding and smart metering and appliances. Some of the measures and techniques mentioned in these papers, and the vast literature on DSM cannot be applied in the same way for rural areas and others simply do not fit the profile of remote electric systems. DSM in microgrids may be challenging, since it requires competence in the fields of engineering, finance, management, policy, and community education [6].

There are three important factors that underline the specificity of DSM for microgrids: the size of the generation system, the energy source and the end-users. Regarding the size of the electric system, in remote locations, the demand for electricity is typically very small due to the fact that the economic activity and population density are lower. The energy source can be renewable, and therefore variable and unpredictable. Thirdly, end-users of microgrids in isolated areas are usually low income and without prior experience as energy consumers, thus hindering the application of DSM strategies.

Realistic design of power systems is important for the reliability of the supply and the energy cost. Some studies show that load estimation has relevant impact on the power system components sizes (PV array and battery) and on the cost of systems [10]. Besides, in cases where people never had access to energy it is difficult to quantify the number of electrical equipment, making more difficult to have a realistic load. Therefore, using DSM to change the reference load profile can also affect the reliability and cost of the system.

The goal of this study is to analyse the potential of DSM strategies in renewable microgrid systems in isolated areas. In order to understand the difference from the usual DSM approach and its potential in isolated small power systems. This study also aims to reflect on the effect of these strategies in the community activities. The research questions addressed are:

- What is the technical and economic potential of DSM in rural areas?
- Could the implementation of DSM reduce the need of fossil fuels and improve the performance of batteries, in microgrids?
- What are the social impacts of these strategies?

Contributing to answer these questions allows new insights into the functioning of the potential of DSM in remote locations. In addition, it will be possible to determine the DSM strategies that can contribute to solving the limitations of microgrid systems in these areas.

In Chapter 2, DSM is explained in detail and a literature review of DSM concepts is presented, including demand response, energy efficiency and energy conservation. This chapter also presents an overview of 13 case studies of several DSM strategies, including measures and technologies special designed for this kind of systems.

In Chapter 3, the methodology of this study is described. The methodology includes the introduction of the case study, the description of the two main tools used, HOMER and LoadProGen, and their limitations for this study. The limitations associated with data and the lack of information about the community is also presented in this chapter.

In Chapter 4, the results of the different scenarios designed are presented and discussed and in Chapter 5, the conclusions are drawn and future work is recommended.

Part of this work was presented at the 6th International Conference on Clean Electrical Power (ICCEP) and published in IEEE (DOI: 10.1109/ICCEP.2017.8004840).

2. Literature review

To understand the diversity of DSM strategies, a brief description of demand side management and the related concepts, demand response, energy efficiency and energy conservation, is presented. Furthermore, the available studies on DSM strategies in rural areas are reviewed in order to allow a discussion on the DSM potential in microgrids.

2.1. Demand side management

Demand Side Management (DSM), also known as energy demand management, consists on the implementation of strategies and procedures to improve the efficiency of an energy system from the side of consumption. It can control, influence and usually reduce energy consumption, allowing an efficient perspective on the projection of RE systems or an efficient use of the systems already installed. These strategies can bring significant cost benefits to energy end-users and a reduction in carbon emissions. Measures to reduce energy consumption are not necessarily expensive, and may even be free of charge, hence often easy to implement in developing areas [11]. Depending how the demand management is carried out, according to [8], DSM has three main concepts: demand response, energy efficiency and energy conservation.

Demand Response (DR) consists of changing the customer's usage of electricity, transferring their load during periods of high demand to off-peak periods, by implementing strategies of dynamic pricing: by changing the price of electricity over time (at off-peak time it is less expensive) or by incentive payments, price signals induce customers to reduce energy demand during a specific time of the day. DR measures are usually related to metering technologies that inform end-users about their energy consumption. Advance Metering Infrastructure (AMI) is an example of this kind technology [8].

Energy Efficiency (EE) lies on the reduction of the energy demand due to the use of more energy efficient appliances/equipment or due to the elimination of systems' energy losses, not affecting consumer's activities. Replace old electric equipment, like refrigerators, for more energy efficient ones, or replace incandescent bulbs by CFLs bulbs, are examples of energy efficiency measures [8].

Energy Conservation (EC) refers to the reduction of energy demand due to the change of behaviour of the consumer and not in the change of the electrical equipment. In this case, the consumers are encouraged to reduce the energy use in return for saving money. Examples are using less air conditioner in summer or using more clothes thus reducing heating needs in winter [8].

EE and EC are more long-term strategies that do not answer only to instantly demand peaks as DR. These three concepts act in different ways (electricity market and price signals, technological solutions and consumers' behaviour) and, if implemented together, the end-user will profit even more of their potential [8].

DSM is executed by strategies that can be based on measures or/and technologies. There are different classifications of DSM strategies, but this study follows those proposed by [12], namely peak clipping, load shifting, conservation and valley filling.

Peak clipping strategy, also known as peak shaving, consists of the reduction of energy consumption during the peak period, time of high-energy demand (Figure 1a)). An example of this strategy is the restriction of high-power appliances during the peak period. In Rukubji village (Bhutan, India) [13] case, with the help of a "smart" current limiter, consumers are just able to use high-power appliances, as rice cookers, when sufficient power is available, i.e., at peak time the use of electricity is restricted.

Load shifting strategy reduces the energy consumption of the daily peak period without having to limit the use of appliances. The load is transferred to lower demand periods without having to reduce the daily energy demand (Figure 1b)). However, the consumers are obliged to change their activities. In Ban Phang Praratchatan village (Thailand) [12], the refrigerator is deeply cooled down during the day, in order to store thermal energy for the night, therefore the use of the refrigerator is shifted from night to day-time.

Conservation strategy (Figure 1c)) as the purpose of reducing the entire daily load, by using efficient appliances and electric equipment or even by educating consumers to have more concern for the use of energy. The exchange of incandescent light bulbs for CLF light bulbs is one of the most known examples of conservation. The *Solar2World* (S2W) program encourages energy efficiency consulting to their project developers (S2W partners). In Bamako village (Mali), standard lights were replaced by energy saving light bulbs, inefficient refrigerators were replaced by A++ ones and computers were replaced by laptops. With these changes the energy demand decreased 70%, the systems cost was reduced in 60% and the costs for S2W partner decreased 55% [14].

Valley filling strategy (Figure 1d)) aims built-up energy demand during off-peak periods to smooth out the load and improve the economic efficiency of utilities. In [15], to support a desalination unit and the domestic load, all the excess of energy is used to charge de batteries in the off-peak periods, to cover the moments where there is a high demand of electricity and not enough supply from the diesel generator or any production from the PV system.

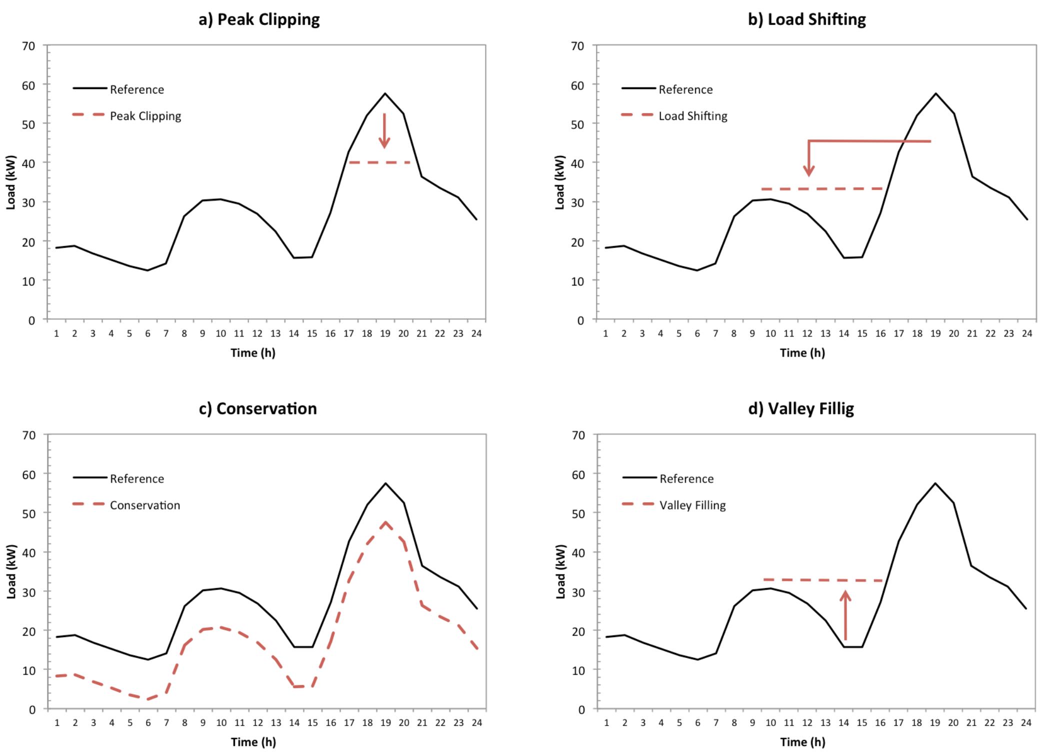

Figure 1: Illustrative DSM strategies for a microgrid with a strong photovoltaic component.

These strategies can be implemented with some of the DSM measures and technologies mentioned in the following sub-chapters.

2.1.1. DSM measures

The author of the *Review of Strategies and Technologies for Demand-Side Management on Isolated Mini-Grids* [7] lists five examples of encouraging load management without resorting to DSM technologies: efficient appliances and lights, commercial load scheduling, restricting residential use and community involvement, prices incentives and tariffs structure, and community involvement and consumer education. Table 1 presents a brief description of these strategies, as well as their application and potential.

Table 1: Examples of DSM measures, adapted from [7]

DSM Measure	Application	Potential
Efficient appliances and lights	Use of efficient light and appliances, for reducing peak demand and incite energy conservation.	At the start of project: Long-term cost savings for customers and reduction in the initial generation capacity. Existing project: can help accommodating load growth without investing in additional generation capacity.
Commercial load scheduling	Limitation of the "business hours" of non-essential loads to periods of low total demand or times with excessive generation. May be achieved by encouraging the community (time-of-use pricing) or enforced by mini-grid operator ("smart" current limiter technology).	Minimizes the commercial impact on the residential peak load. Protects commercial equipment and processes from damage due to low voltages. Can substantially lower operating costs on hybrid systems
Restricting residential use	Restriction of the use of certain types of residential appliances. The system is primarily designed for a small group of appliances; no additional appliances may be used.	Reduces brownouts. Village agreements without technical or community enforcement are usually ineffective (combination with other DSM measures, such as current limiters might improve the strategy).
Price incentives and Tariff Structure	Capacity-based tariff: the customer is charged per maximum power they are allowed to use. Consumption-based tariff: the customer is charged per energy used, encouraging energy conservation.	Capacity-based tariffs: can make billing easier; are appropriate for power-limited mini-grids (such as micro-hydro). Consumption-based tariffs: encourage energy conservation; are appropriated for energy-limited mini-grids (such as solar and wind)
Community involvement, consumer education	Education of community members regarding performance and limitations of their mini-grid systems.	Village committees can improve the management of mini-grids

2.1.2. DSM technologies

DSM technologies are usually more expensive solutions than DSM measures, since they require the purchase of equipment. They can be classified in six types [7]. Some are specially made for DSM, while others, like prepaid meters aid load management as an auxiliary function. These technologies are: Current limiters, *Gridshare* (a 'smart' current limiter), Distributed Intelligent load Controllers, Conventional meters, Prepaid meters (PPM) and Advanced metering systems with centralized communication (AMSCC). In Table 2 a summary description of these different technologies and their applicability for remote microgrid systems are presented.

Table 2: Examples of DSM technologies that have the aim of supporting load management on microgrids, [7].

Technology	How it works	Applicability in renewable remote electrification systems
Current limiters	The device imposes an upper limit on the current in order to protect the circuit generating or transmitting the current from harmful effects due to a short-circuit or similar problem in the load.	The most simple and economical technology. On mini-grids with variable generation (solar/wind), it is recommended to combine the installation of this device with energy metering devices.
GridShare **('Smart' current limiter)**	The device uses LED lights to alert residents of voltage drops on the grid and use a circuit-driven relay to regulate the use of large appliances before severe brownouts occur. Prevention of brownouts (occurrence of severe brownouts decreased by over 90%); No static current limiting restrictions;	Allow consumers to use high-power appliances (e.g. rice cookers and water boilers), when abundant power is available and restricts electricity use when power is limited. Technology still in the pilot phase on a micro-hydro grid system.
Distributed Intelligent Load Controllers	Designed to monitor the frequency of the electrical system to determine the availability of electricity and to cut off power to large and dispensable loads when resource is limited.	Ability to have a reliable electric supply while still being able to use high-power appliances. Can be used as a combination with current limiters.
Conventional meters	This device measures the kilowatt-hours of electric energy used by the consumer. Metering does not actively limit power or energy consumption.	It is important to add a monitoring and billing schemes based on energy consumption for systems with inconsistent generation and limited storage, especially for solar and wind microgrids. Consumers that do not fully understand how their use of electricity can affect their bills can receive bills that are beyond their means to pay.
Prepaid meters	Metering system with prepayment. The customer is required to make an advance payment before	Higher initial investment than

	electricity can be used. When the paid credit is achieved the supply of electricity is cut off. Payment can be done by mobile phone and in small local vendors.	conventional meters. Prepaid meters do not necessarily restrict peak power use, although some have this option. Current limiter or "smart" DSM should be added on microgrids for energy conservation and restrict power demand. This method is not new for some consumers due to their experience with prepaid systems for mobile phones.
Advanced metering systems with centralized communication (AMSCC)	Advanced mini-grid control system with a variant of prepaid metering and a supervisory control system.	These kinds of devices are specially designed for solar or wind diesel hybrid mini-grids. However most of them could be adapted to micro-hydro systems,

2.2. State of the art

DSM strategies in developed areas work differently from strategies in isolated microgrid systems in developing areas. It is important to understand how these strategies operate, how they should be implemented and how the community reacts to them. This topic presents a background study on demand side management strategies for renewable microgrid systems for isolated locations in developing countries. The thirteen identified projects are reviewed and analysed with the goal of answering these questions and properly design the scenarios for the forthcoming study.

The projects were evaluated on five factors, to understand the performance and potential of DSM for remote renewable electric systems: financial benefits, technical limitations, efficiency, impact and fairness. The financial benefits factor is related to the profit that the customers will have with DSM. The technical limitations factor is related to the technical performance (hardware and software) of these strategies on the microgrid. The efficiency factor consists of the effectiveness of the measure or/and technology used, i.e., if it works and if it is simple for customers to handle it. The impact factor is about the changes seen on the microgrid performance and on consumers affected by the measures used. Finally, the fairness factor evaluates if the service provided to consumers takes into account the wealth of consumers, considering the total system: cost, electricity payment structure, energy efficiency policies and energy distribution among consumers.

From the thirteen projects, twelve of them include at least one DSM measure and six of them a DSM technology. Figure 2 and Figure 3 show the distribution of the measures and technologies presented in the collected studies. Regarding the DSM measures (Figure 2) the consumer education and involvement (consumers training, education and involvement in the operation of the electric system) is the most common in the projects. Most of project planners mention the importance of teaching how the system works, what they have to do for their better use and the future changes that must be done, as summarised in Table 3.

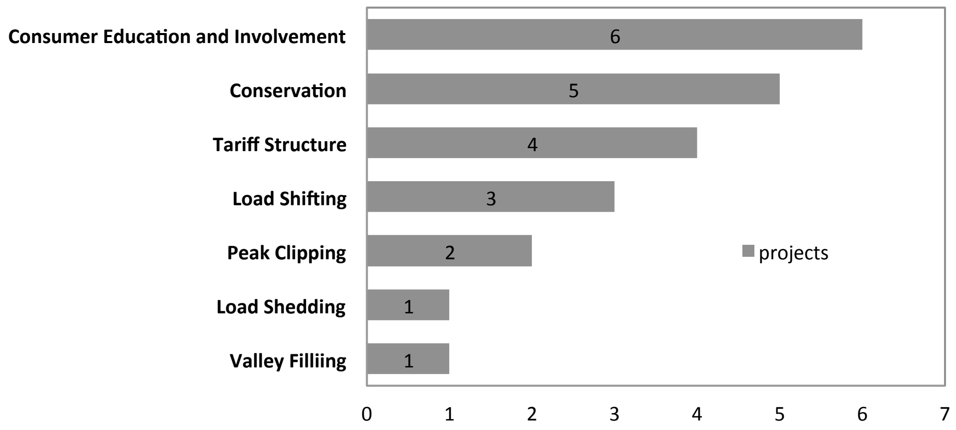

Figure 2: DSM measures on the 13 projects reviewed

Half of the DSM technologies case studies include the use of prepaid meters, the less expensive DSM technology between this three (Figure 3).

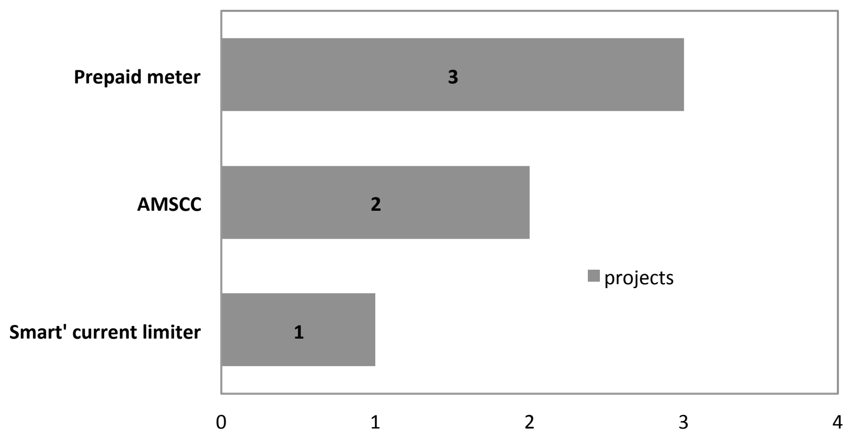

Figure 3: DSM Technologies distribution on the 13 projects reviewed

Table 3 presents a summary of the collected projects, including information on the location, the documents analysed and the different measures/technologies used to achieve DSM.

Table 3: Summary of the information of thirteen projects studied in this document.

Project[a]	Source	DSM Strategy / Technology	Observations
Thailand (Ban Phang Praratchatan) PV system (26 x 75kWp), battery storage (220Ah) and diesel generator (5kW)	Thesis from University of Kassel, Germany [12]	**Peak clipping**: The refrigerator is turned off at night; the refrigerator operates only during the day. **Load shifting**: The refrigerator is deeply cooled down during the day, to store thermal energy for the night.	Daily peak demand is 150 W lower (reduction of 8.41%). Benefits for the battery (SOC and DOD). Longer lifetime, which means reduction of the energy specific cost of the system, less 2%. No significant improvements on the diesel generator operation. (No changes on the daily energy demand). Village of 22 households
Nigeria (Ibadan) PV System (200kWp), battery storage (200 batteries) and diesel generator (40kW)	Article from University of Lagos, Nigeria [11]	**Conservation strategy**: use of CFL bulbs instead of conventional lamps, putting off redundant light fitting during the day, discouraging the use of electric cooker and encouraging the use of fans instead of Air Conditioners.	Power system designed with HOMER Total daily consumption had a decrease of 56.8%. No diesel consumption needed after DSM. Rural community in Ibadan with around 54 houses
Sultanate of Oman (Yanqul) PV system (5kWp), battery storage and diesel generator (20kW)	Article from Centre for RE and Sustainable Technologies and Curtin University Technology, Australia [15]	**Valley filling**: excess of energy used to charge the battery; Peak clipping: the deficit is covered by the battery, i.e. the peak demands are covered with the storage energy;	The solar data used to design this power system is from Masirah Island (Oman). By using DSM the system components can be reduced in size and therefore reducing the capital cost of the system. The efficient use of PV reduces the DG need. Six house remote community and reverse osmosis desalination unit (water supply)
Bhutan (Rukubji) Micro-hydro system (40kW)	Article from Humboldt State University, USA and Bhutan Power Corporation and Department of Energy [13] [16]	***GridShare* (a 'smart' current limiter)**: The system provides information to the users about the status of the grid, like restrict use or not, with LED lights (green light means the consumer can use the appliance and red light means that its use is restricted) and an enforcement mechanism to limit load when grid is overburdened. This program as the	The *GridShare* is a pilot project. Feasible for power-limited microgrids. Prior to *GridShare*: the village had energy meters with tariffs (did not encourage conservation or load-shifting), village wide-restrictions (space heaters and immersion water heaters) and conservation measures (promotion

[a] In some cases the specific characteristics of each project, like the PV system capacity, are not presented due to lack of information in the original documents.

		support of an education program focused on load shifting.	of CFL bulbs). After *GridShare*: Over 92% less days with severe brownouts. A village of around 90 households
Burundi PV system, battery storage and diesel generator	Article from Delft University of Technology [17]	**Battery management with load shedding strategies**: Load shedding works on the basis of priority of load groups. The best one is load shedding by scheduling: the SoC of the battery is compared to every sampling period with the energy required, in order to find a balance between the energy required and the energy available. This strategy has the goal of compensate the energy shortage by shedding the groups with lowest priority as is maximum.	Load classification by priority. No diesel consumption needed. To keep the system working well, it is necessary to add smart meters to the system. This strategy can accommodate load changes. A village of 670 households
Mali (Bamako) PV system and battery storage	Solar2World program [14]	**Conservation**: use of energy efficient appliances (light bulbs, laptop and fridge)	Reduction of 76% of energy consumed. The costs were brought down by 14,900€.
India (Durbuk) PV system (4 x 25kWp) and battery storage (1000Ah)	Greenpeace India Society report, October 2011 [18]	**Conservation**: restriction of electric heaters and mandatory use of CFL bulbs; **Training people**; **Tariffs**: domestic and school government offices have a flat tariff; the clinic has a tariff based on average usage.	Because CFL bulbs are mandatory and expensive, employers steal them from the clinic. Flat fees (no meters), covers 2 CFL bulbs per house.
India (Udmaroo) **Micro-hydro system (32kVA)**	Greenpeace India Society report, October 2011 [18]	**Conservation and tariffs**: domestic ([b]Rs. 90/month fee for the use of 5 CFLs bulbs) and non-domestic (income generating activities and special occasions), arranged by the electricity management committee (EMC); **Load shifting**: domestic load just at night; **Consumer education and involvement:** volunteer EMC.	Excess consumption is not policed due to high power availability; Pro-poor policy: free electricity; Diesel fuel financial savings. There is a fine of [b]Rs. 500 for late payment.
Cabo Verde (Santo Antão) **PV system (27.3kWp), battery storage (370kWh) and diesel generator (20kVA)**	CIRCUTOR Magazine article 2012 [19] and Mini Grid Policy ToolKit website [20]	***Circutor Electricity Dispenser***: Energy Daily Allowance (EDA) concept with tariff collection, energy available to each user to an agreed maximum. The meter (electricity dispenser) includes a signal that encourages or refrains the user to consume energy. Users training and energy efficiency strategies are used.	The limit of energy is flexible, depending on the plant's condition (more sun, more energy); Tariff is based on fixed monthly rates related with EDA and taking in account the population payment capacity.
India	Book p.90-p.94 published by Ministry of New and	***Gram* power system**: includes smart prepaid meters that charge consumers by hour, encouraging the use of energy	This system offers up to 84% energy savings (decrease of energy from 2.4

[b] The conversion of Indian Rupees to Euros is 1 INR = 0.01335 EUR [37]

(Rajasthan) PV system	Renewable Energy 2012 [21]	efficient appliances and conservation. The bulk energy credit of power generated locally is sold wirelessly to a trained local entrepreneur that sells the power to consumers at a retail prince by the prepaid system. The system contains theft detection, load limit, load scheduling, variable pricing and remote monitoring. The community is trained by the Gram power on the use and maintenance of the smart microgrid.	kWh/day to 0.4 kWh/day). A recharge of [b]Rs. 50 buys 200 hours of CFL lighting or 50 hours of a fan use.
India (Sagardeep Island) PV system (25kWp) and battery storage (800Ah)	Article from Chavan College of Engineering and Visvesvaraya National Institute of Technology, India [22]	**Prepaid energy meter**: By inserting the prepaid Solaris energy card the energy meter is activated. The meter alerts the consumer when 75% of the prepaid amount has been used. The price of each prepaid card is between Rs. 1500-2000[b]	The use of metering reduces abuse by consumers. This control makes more electricity available for other consumers.
Tanzania (Matipwili) PV system and battery storage	Devergy website [23]	**Prepaid metering system**: Consumers send an SMS message with a credit code to the payment system. Customers can charge their mobile phones at home and recharge small batteries. The system was designed to require no user maintenance and is remotely monitored for faults (demand is monitored 24/7). In case of more energy needed the technical support is automatically informed.	Matipwili is Devergy's first pilot project. The power system consists on solar towers distributed along the community (a panel and a battery) connected between each other. The power capacity is planned at the minimum needs, so when demand increases the grid is extended with the necessary solar towers. A small fee at the time of connection is charged to each user. Around 150 houses in Matipwili, more than 90 using Devergy (2012).
Haiti (Les Anglais) PV system (93kWp), battery storage (400kWh) and diesel generator	EarthSpark International and SparkMeter (EarthSpark's spin-off metering company) websites [24], [25]	***SparkMeter* (prepaid meter)**: prepayment and real-time monitoring and control (allows theft detection and reaction). Energy-based tariffs. Community work on clean energy.	The device model gives operators flexibility to choose and create a unique billing structure to suit their application.

In the several studies described above, twenty-two measures (Figure 2) and six technologies (Figure 3) are mentioned. Some of the case studies feature more than one strategy. The combination of conservation, load shifting and consumer education and involvement in the Udmaroo (India) [18] is an example of this situation where there is a combination of energy savings with scheduling energy consumption arrangement and the need to explain the community how to work with this strategies.

The measures and technologies are: peak clipping, load shifting, conservation, valley filling, 'smart' current limiter, consumer education and involvement, load shedding, tariff structure, AMSCC technology and prepaid meters devices.

Regarding the financial benefit, peak clipping strategy and *Circutor Electricity Dispenser* (AMSCC technology) have a significant impact on the battery performance. In addition, this device also has a positive effect on the inverter performance [19]. The battery and inverter are two expensive components, so the extension of the lifetime of these components reduces the energy specific cost and makes unnecessary to invest in replacement for a longer period. Conservation strategy and tariffs structure also have a positive effect by reducing the use of energy, reducing the needs of diesel fuel (in certain conditions even reduced to zero [11]). Valley filling and conservation strategies limit the need for microgrid power generation increases. The same happen with load shedding strategies, which reduce or eliminate the need for diesel consumption and have the ability to accommodate eventual growth in demand. The prepaid meters and the Gram power system (AMSCC technology) have the lowest impact, their benefits are: control of the electricity spending and flexibility on the payments plans, in this second case, consumers can choose their own plans depending on their electricity needs, and, in both cases, consumers do not have to pay for what they do not use. Regarding the low-cost device *GridShare*, its cost is justified only if the brownouts are significant. In terms of investment, peak clipping strategy and *Circutor Electricity Dispenser* seem to be the best options. However, in terms of electricity payment, prepaid meters and Gram power system seem to be the best services.

The information on technical limitations is scarce. The *Gridshare* [13], [16] technology is particularly suited for microgrids systems that operate continuously, such as micro hydro and some diesel generators. Its use is limited by the local renewable energy resource. However, the device is programmable [16], so the control software could be redesigned to meet the needs of different types of microgrid systems.

Concerning the efficiency factor, all the measures seem to work from the results presented in the documents. However, there are still some issues on the performance of the DSM strategies based on users behaviour. For example, the *Gridshare* device apparently raises some confusion from the side of the end-users on how the system works. The support for education and involvement of the consumers is one of the most important measures, even more when DSM technologies are used due to its complexity. The existence of a solid market with energy-efficient appliances is also an important part of this factor evaluation that is often overlooked in these studies.

The results on the impact factor demonstrated that in general, the DSM strategies have a significant impact on the environment and economic sectors. The reduction in energy consumption or the energy savings due to the applied strategies can cause a reduction in diesel and storage needs. Therefore, the carbon dioxide emissions decrease and the life cycle of batteries increase, making the systems more efficient, clean and affordable. Furthermore, projects that include technologies and tariff services have relevant impact on the service stability and performance. The devices implemented can alleviate brownouts caused by peak power, making the electrical service more reliable.

The fairness factor results indicate that in terms of payment prepaid meters and AMSCC technologies seem to be the best option. PPM and Gram Power users only pay for what they consume, instead of paying a fixed tariff for the electrical service. In the Circutor Electric Dispenser, the limit of energy available to each user depends on plant's condition, still, tariffs are established within the consumer's payment capacity and it is used to pay part of the investment cost. Moreover, on this kind of technologies due to the scheduling and load limit method, the grid can supply electricity to more consumers, allowing project revenue to increase. Tariff structure, based on a flat rate, is an example of an unfair payment since no distinctions are made between users' consumption. Even when excessive demand is not an issue, due to high power availability, flat tariffs should not be acceptable, such as in [18] where there is a monthly fixed tariff for the domestic consumption. Equipment restriction without a good support on the local appliance market is also not the best solution. The mandatory use of specific electrical appliances, in this case, CFLs light bulbs [13], [18] can be unfair to consumers without the right support and management at the local appliance market or without the existence of one[c]. Regarding the energy distribution, in [17]the load is distributed by priority, giving consume priority to the most critical loads and the lowest priority for those that consume less, making the system fairly managed. Apart from all the cases mention above, the total cost invested, in the system and in DSM strategies, is the most important factor and the source for most of the problems. The improper planning of the entire electrical system and the indifference to the implementation of some of these measures at the time of microgrid design, make projects less fair to end-users.

For a DSM strategy to succeed it is important to make a complete background study on the community where it will be implemented. Studies like these should include a set of information on the local energy resources, on the income of the consumer's activities, on the appliances used on the costumer's houses and local businesses if possible, and on the appliance market and policies of the country. With this information, it is possible to know which technologies can be implemented and to assess which measures work best for the users, how can the load be managed and how much can customers pay for electricity and energy efficiency appliances. However, in cases where there is no electricity the approach has to be different.

Most of the reviewed documentation has clear description of the different projects but does not include detailed assessment of its impacts and therefore it is difficult to critically evaluate the projects' performance regarding DSM strategies. Nevertheless, it was still possible to understand that some improvements must be done.

The fact that most of DSM strategies should be implemented before the sizing of the power system is one of the lessons learnt with this review. The reduction in the consumption of energy, a result of these measures, reduces the diesel needs and may delay the renovation of system's components the lifetime of batteries and inverters (the most expensive parts of the system) is extended, postponing the upgrade of the power system. Therefore, DSM should be taken into account when the power systems are being planned and not just after their implementation, as shown in [10], [12],[26].

Regarding the fairness factor, probably the most critical factor for these projects, this seems to be the most negatively affected. Measures such as tariffs services and energy efficiency policies that were implemented in some of the projects do not improve the electric service and well-being of the consumers. In the tariff service case, the flatness of service payment make customers pay for

[c] For example in one of the cases [18], people stole light bulbs from their workplace to use on their houses, because they could not pay for the CFLs bulbs.

energy that they did not use. And in the case of energy polices, an example of this policies is the mandatory employment of CFL light bulbs (that can be expensive for some customers) and the restriction of some electric equipment (that can reduce the income activity or the well-being of the customers).

Concerning the tariffs problem, this one can be solved by the implementation of the metering systems technologies that make payments more flexible and more fair for customers, with end-users paying for the energy they actually use. With some advanced technologies it is possible to collect detailed data on the individual energy consumption, like how much energy it is still available until the limit that the costumer prepay to use, allowing more energy savings and alleviating brownouts caused by peak power demand, making the systems more efficient and reliable.

Regarding the energy efficiency policies' issues, in particular the mandatory use of energy efficient equipment, there is no clear solution. Most of the projects that use/change the non-efficient equipment for more efficient ones, the equipment were provided by the project organization or by some public sector entity at the time. However, this approach is clearly not a sustainable option since when the equipment achieves its lifetime and needs replacement some customers will not be able to afford and/or to be willing to pay for the more expensive choice, even if in a long-term period this is the optimum choice. It is important to note that the availability of low cost energy efficient equipment in many low-income communities is often a problem precisely due to affordability issues.

At last, the fact that DSM measures in most of the cases are neglected at the time of the power system design is another fairness weakness, making the total cost of the systems more expensive than they could be.

In addition, the implementation of these measures cannot succeed and it is not fair without strong support education to customers, since they are who will have direct contact with the equipment and devices and they are the ones that are paying for the electric service.

In general it is possible to see there are still a lot of improvements to be done and issues that must be solved. This field of energy management on remote electrification projects is still a new area of research and work and most of these locations seem not to be ready in terms of energy efficiency policies and appliance markets, besides that the economic factor has a heavy weight on delaying the deployment of this kind of projects. It is not possible to define which measure is the best one as each project is an isolated and particular that requires careful characterization. The most important conclusion of this study is that DSM has a strong potential for renewable microgrid systems, making components more efficient and electrical service more reliable and therefore energy management should not be neglected by all the identities included in these kinds of projects.

3. Methodology

The four DSM strategies mentioned in Chapter 1 are used to evaluate the DSM potential for a hybrid microgrid system with PV and diesel generator: conservation, peak clipping, load shifting and valley filling. Using the daily electricity load profile as reference, different scenarios were designed for each of these strategies. The procedure is divided in 3 steps: first, the background study of the community (population, business and social activities) and its electricity demand; then, the design of the different scenarios based on the strategies and electricity use; and finally, these scenarios are analysed in terms of battery bank operation, diesel needs and energy cost.

The following sub-chapters describe the community under study, the tools used for the study, LoadProGen and HOMER, and how the input data was collected and processed.

3.1. Case study – Soroti

This study is based on Soroti municipal, the main town of Soroti District in central-east of Uganda (1.72N, 33.6E) with a total population of 49,685 (2014 national census) [27].

The district has one of the highest poverty densities in the east of Uganda, around 53%. The agriculture is one of the most important activities in this area, due to the proximity of Lake Kyoga (Figure 4). Soroti has a citrus production potential, supported by the government [28].

Regarding Uganda's population, the higher religious affiliations are Catholic, Protestant and Islam [29]. Uganda’s temperature ranges between 25-31ºC and has an average of 6.05 hours of sun [28]. In 2014, 20.4% of the population had access to electricity in Uganda [30].

Regarding the power system, the microgrid’ users are assumed to be around 800-1000 people divided by 100 households, with a total average daily load of 663.385 kWh/day. In order to analyse their consumption patterns, the users have been modelled by considering 17 user classes: 6 classes of households based on increasing income levels and 11 classes of business activities and local services (big and small enterprises, kiosks, market place, school, pharmacy, club, barber, mobile money, tailor and streets lights) (detailed information can be find on Appendix - Table 6) [31].

Figure 4: Soroti district location in Uganda [28]

3.2. LoadProGen

LoadProGen (Load Profile Generator) is a mathematical algorithm in Matlab, created by the UNESCO chair Group in Energy for Sustainable Development of Politecnico di Milano. It can estimate daily load profiles of un-electrified communities in rural areas. The algorithm is based on a stochastic bottom-up approach, i.e., with a given set of input data, the computation of a number of load profiles is initially built from each single user class to the aggregation of all the user classes in one final load profile [32]. The LoadProGen_1.0 is the used version in this study.

The appliances input file is divided into different user classes' types. Each user class contains a detailed description of every appliance: nominal power rate, number of users and appliances in the class, degrees of uncertainty, functioning time and windows. This structure allows the tool user to change the demand in the system, as an example by changing the appliances functioning windows to study different demand options.

In this study, the LoadProGen was used to produce the daily load profile (reference load) and to redesign it DSM strategies. The tool was used to determine the loads of the load shifting and conservation scenarios; for the former considering different usage times for individual appliances and, for the latter, by changing the reference appliances for more energy efficient ones. The peak clipping was modelled by modifying the reference load data, restricting the maximum power that could be requested from the system. Valley filling scenarios were also modelled by modifying the reference load, by adding alternative productive uses of electricity - as an illustrative example, a solar water pump for irrigation is studied. The appliance input data (Table 6) was collected from previous studies about Soroti. This data is based on local questionnaires and surveys, which can influence the design of the loads profile [10].

LoadProGen features the possibility to add uncertainty in the input data, by the parameters *Rft* and *Rfw*. The *Rft* parameter refers to the random variation of the functioning time of the chosen appliance and the *Rfw* parameter to the random variation of a functioning window of the appliance. The maximum suggested degree of uncertainty is 30% for both parameters. To maximize the uncertainty of the demand, the maximum degree was used.

The LoadProGen version 1.0 used for this work has some limitations regarding the functioning windows for the fridge's demand profile. The functioning windows structure is the same for all appliances; however fridges have a particular mode of operation since it is 'ON' all day, but only consumes electricity by cycles and when its door is open for a significant period of time or when it is open too often. The variability degree for the probability of opening the fridges door during the day, which depends on the type of use (residential or commercial), is not taken in account when the load profile is created.

3.3. HOMER

HOMER (Hybrid Optimization of Multiple Electric Renewables) software by *HOMER Energy*, developed at the *National Renewable Energy Laboratory,* optimizes the designing of microgrid systems. This software is made of three tools, which combine the work of engineering and economics: simulation, optimization and sensitivity analysis. In simulation, all possible combinations initially decided by the user are tested, to achieve a viable power system. In optimization, as the second step, all the options are filtered and classified according to the user criterions, such as fuel consumption. The last step, sensitivity analysis, is an optional step used to test the impact of variables that cannot be controlled by the user, such as fuel cost, and see what changes in the optimal system.

DSM strategies impact was evaluated with HOMER through battery bank features (storage depletion, expected lifetime and replacement cost), diesel fuel consumption and energy cost (LCOE). Storage depletion is the difference between the initial battery state of charge (SOC) and final battery SOC (at the end of the year). The Levelised Cost of Energy (LCOE) is the average cost per kWh of useful electrical energy produced by the system (Equation 3.3.1).

$$LCOE = \frac{Annualized\ cost\ of\ producing\ electricity[€]}{Total\ electric\ load\ served\ \left[\frac{kWh}{yr}\right]}$$ Equation 3.3.1

Regarding the HOMER inputs, only electric load and deferrable load are used. The electric load is the primary load of the system, the load (calculated using LoadProGen) that the system must meet to avoid unmet load. The deferrable load is a secondary electrical load that must be met within some period, but before charging the batteries. The load following strategy was used, so HOMER serves the deferrable load only when the system is producing excess of electricity or when the storage tank is depleted. The input to calculate the deferrable load demand, i.e. for water needs, was collected from an irrigation study about Uganda agriculture projects and solar water pumps sizing studies [33][34][35].The irrigation system capacity input (pump power and storage capacity) is based on the hours of sunshine (6.05 hour, HOMER estimation based on the solar resource input with Soroti geographical location (1.72N/33.6E)).

The PV system capacity (PV array, battery bank and inverter capacities) is also based on a previous study about Soroti [32]. However, in this study, a diesel generator was added to the microgrid since most microgrid systems have one as a supply and in order to understand the impact of DSM on diesel generators. To maintain approximately the same power capacity, the PV array capacity was reduced accordingly.

All DSM scenarios were tested in the following conditions (with exception of the valley filling add15 kW scenario):

- Unmet Load: <= 5%
- Maximum annual capacity storage: <= 1%

Maximum annual capacity shortage is the maximum capacity missing to supply the electrical demand. A system is feasible when the capacity shortage fraction (fcs) is less than the maximum annual capacity shortage:

$$Cap.Shortage\ fraction\ (fcs) = \frac{Total\ capacity\ shortage\left[\frac{kWh}{yr}\right]}{Energy\ demand\left[\frac{kWh}{yr}\right]}$$ Equation 3.3.2

The deferrable load inputs are: peak load, storage capacity, average load per month and minimum load ratio. To calculate these inputs for the deferrable load some equations from [35] are used. In this study the minimum load ratio was considered to be 0. The data of water need (Table 11) for the crop irrigation used in this study is from a previous study on Soroti irrigation systems [33]. The water tank is assumed to have 3 days of autonomy, following the recommendation of [35].

The peak load consists on the maximum power that can serve the deferrable load. In water pumping systems is the rated power of the pump (Equation 3.3.3).

$$Peak\ load\ [kW] = \frac{\frac{TDH[m]\times g\left[\frac{m}{s^2}\right]\times\rho_{water}\left[\frac{kg}{m^3}\right]\times Q\left[\frac{m^3}{h}\right]}{3.6\times10^6}}{\eta}$$ Equation 3.3.3

- *TDH* – total dynamic head is the total vertical distance that the water runs to the tank plus losses of pipes friction, the value is assumed to be 40 m, according with [33] and [35].
- g – acceleration due to gravity, the value is 9.8 $\mathrm{m/s^2}$
- ρ_{water} – water density, the value is 1000 $\mathrm{kg/m^3}$
- Q - flow of the water in m^3/h
- η – efficiency of the pump, the value is assumed to be 0.6

Storage capacity consists on the total amount of water that can be stored in the water tanks, expressed in the quantity of energy needed to fill the tanks (Equation 3.3.4).

$$Storage\ Capacity\ [kWh] = Peak\ Load[kW]\times t_{fill\ tank}[h]$$ Equation 3.3.4

- $t_{fill\ tank}$ – The amount of time that it takes to fill the water tank

Average load per month, in kWh/day, represents de amount of power needed for water to leave the storage tank to irrigate the crop plantation and keep the level in the tank constant.

$$Edemand\ [kWh/day] = \frac{TDH[m]\times g[\frac{m}{s^2}]\times \rho_{water}[\frac{kg}{m^3}]\times V_d[\frac{m^3}{day}]}{3.6\times 10^6} \quad \text{Equation 3.3.5}$$

- TDH – total dynamic head is the total vertical distance that the water runs to the tank plus losses of pipes friction, the value is assumed to be 40 m, according with [33] and [35].
- g – acceleration due to gravity, the value is 9.8 $\mathrm{m/s^2}$
- ρ_{water} – water density, the value is 1000 $\mathrm{kg/m^3}$
- V_d – Volume of water required per day, according with the plantation area irrigated

4. Results and discussion

This chapter is divided into six sections. Each one presents and discusses the results of the different DSM scenarios, by comparing the impact of the strategies on the diesel needs, battery bank operation, energy cost and on the socio-economic values. The scenarios were also tested regarding the impact of the power system capacity versus the impact of diesel needs in the energy cost.

4.1. Reference scenario

The reference scenario is used to study the electricity demand in the community. The average daily load and the power peak, calculated by HOMER, are: 664.44 kWh/day and 67.37 kW, respectively. The 20 enterprises are the main consumers, 35% of the average daily load (Figure 5). Most appliances are already energy efficient, with exception of the fridges (Table 6). The fridges are the appliances with higher consume of electricity, 26% of the average daily load.

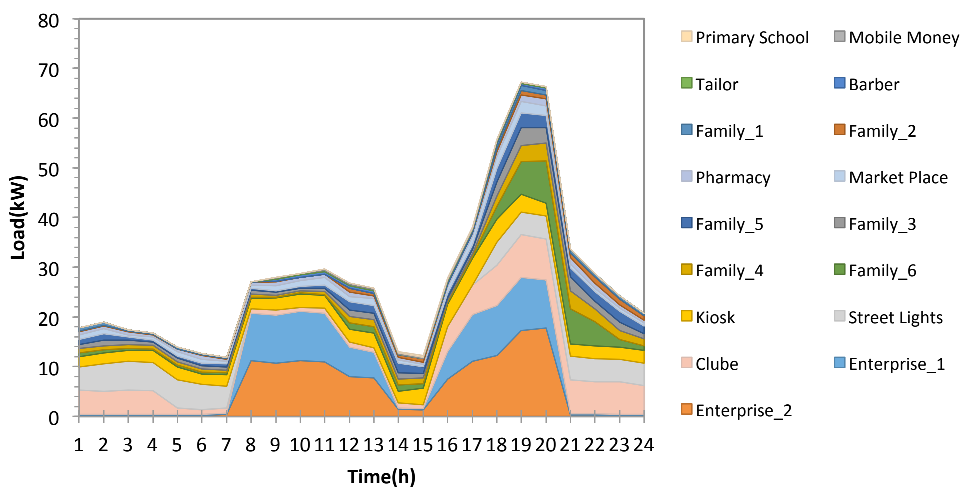

Figure 5: Distribution of energy consume by Soroti user classes, demand profiles created with LoadProGen

This study assumes a hypothetical PV microgrid system to supply the community. The main components of the system are: a PV array, a battery bank, a diesel generator and an inverter. The size of each component was based on previous studies about Soroti with an added diesel generator. The PV array is considered to have 204 kW. The battery bank has 330 batteries with a total of 792 kWh. The diesel generator has 10 kW. For a power peak of 67.37 kW, the inverter efficiency is assumed to be 90% hence the size of the inverter is 75 kW [32]. The systems components are described in more detail in Appendix section: HOMER input data.

Figure 6 presents the average daily supply of electricity. The day-time demand is usually supplied by the PV array and the night-time is usually supplied by the energy stored in the battery bank, when possible. Being a hybrid system the generator is used when neither the PV array nor the battery is sufficient to supply the demand. Regarding the figure below, the diesel generator is always present, during the night-time, due to the fact that this is an average supply demonstration.

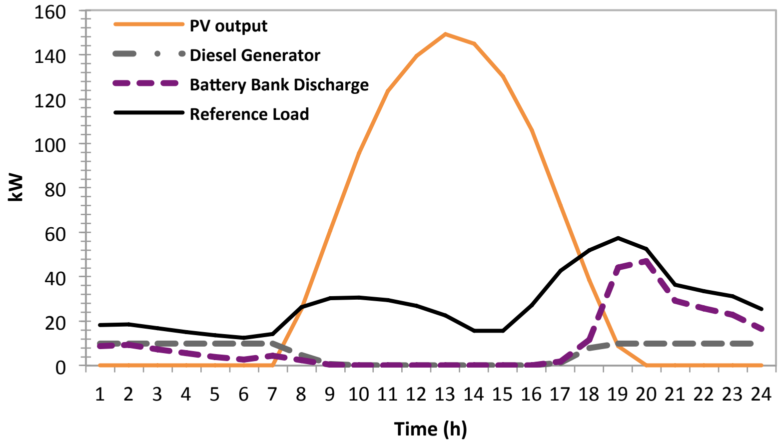

Figure 6: Soroti daily average power supply distribution, generated in HOMER software

HOMER results indicate that, in this reference scenario, the battery bank expected life is 3 years, the storage depletion is 225 kWh/year and the annual diesel consumption is 17748 L/year. The levelised cost of energy is 0.378 €/kWh.

Based on the information given by the reference load and user classes appliances schedule, 14 scenarios were designed. The conservation strategy scenario is based on the exchange of non-energy efficiency appliances to more efficient ones. In this case, the current commercial fridges were changed for more efficient ones. The peak clipping strategy was divided in 3 scenarios based on the annual demand peak power during the peak period (5:00 p.m. - 9:00 p.m.). The load shifting strategy was divided in two cases, each one with two scenarios: load shifting of user classes with higher demand (small and big enterprises) and load shifting of the appliance with higher demand (fridges). The valley filling strategy was also divided in two cases, each one with two scenarios: solar water pumping for irrigation and addition of productive load, in this case a juice factory. In the end, for each strategy a scenario was chosen based on technical and economic results of the impact of DSM and combined in one scenario, the optimum DSM scenario. Peak clipping scenarios 50 kW and 40 kW were both used in separated, for the design of the optimum DSM scenario. The 14 scenarios were also optimized for PV and battery bank capacity to understand the DSM effect on the power system capacity and sizing. Table 4 includes a summary of all DSM scenarios.

Table 4: Summary of DSM scenarios

Strategy	Scenarios	
Conservation	Exchange of the current commercial fridges for more energy-efficiency ones	
Peak Clipping	**Peak 60 kW-** Peak clipping at 60 kW during the peak period (5:00 p.m. to 9:00 p.m.)	
	Peak 50 kW- Peak clipping at 50 kW during the peak period (5:00 p.m. to 9:00 p.m.)	
	Peak 40 kW- Peak clipping at 40 kW during the peak period (5:00 p.m. to 9:00 p.m.)	
Load Shifting	Load Shifting 1: load shifting of the main user classes' demand (small and big enterprises)	**LS 1.1:** all the enterprises work from 7:00 a.m. to 6:00 p.m. (no lunch break)
		LS 1.2: all the enterprises work from 6:00 a.m. to 12:00 p.m. and from 1:00 p.m. to 6:00 p.m. (with 1h of lunch break)
	Load Shifting 2: load shifting of the main appliance demand (Fridges)	**LS 2.1:** Fridges off during the night (working period: 6:00 a.m. to 6:00 p.m.)
		LS 2.2: Fridges off during the day (working period: 6:00 p.m. to 6:00 a.m.).
Valley Filling	Valley filling 1: the addition of a solar pump for an irrigation system	**VF 1.1:** Irrigation system for a citrus plantation of 20 hectares
		VF 1.2: Irrigation system for a citrus plantation of 25 hectares
	Valley filling 2: the addition of a juice factory, working from 11:00 a.m. to 4:00 p.m.	**VF 2.1:** Addition of juice factory with 10kW of demand
		VF 2.2: Addition of a juice factory with 15kW of demand
Optimum Strategy	Sum of the best scenarios of all DSM strategies (conservation, peak clipping, load shifting and valley filling)	**BS 1.1:** Conservation+ Peak 40kW + LS1.1+Valley add 15kW
		BS 1.2: Conservation+ Peak 50kW + LS1.1+ Valley add15kW
	Sum of the best strategies (without conservation strategy)	**BS 2.1:** Peak 40kW + LS1.1+ Valley add 15kW
		BS 2.2: Peak 50kW + LS1.1+ Valley add 15kW

4.2. Conservation strategy

Most of the appliances used have a low power rate. As an example, lights have a 3 W power rate (Table 6). Most of them can thus be considered energy-efficient appliances. The fridges are an exception. In this case, commercial fridges have 300-500W. According to *ENERGY STAR* equipment, commercial refrigerators and freezers can be in average 40% more energy efficient than standard models [36]. So considering that actual commercial refrigeration system is equipped with standard models, the power rate of commercial fridges (kiosk, market place, club and pharmacy) was reduced to 60% of the original data. Figure 7 illustrates the impact of this energy efficiency measure on the reference load. The new average daily load is 610.66 kWh/day and the annual power peak is 61 kW.

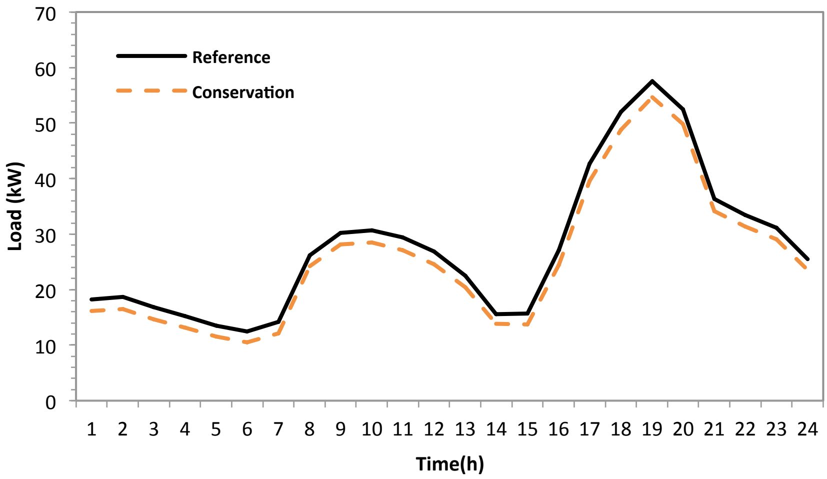

Figure 7: Impact of conservation strategy on load profile, produced with LoadProGen

As shown in Figure 8, the improvements on the battery bank seem to be higher than diesel consumption improvements. However, batteries improvements are still small.

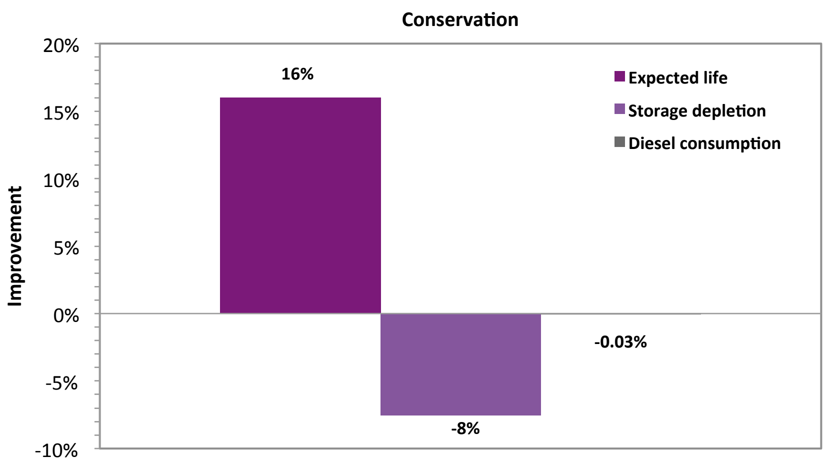

Figure 8: Impact of conservation strategy on battery bank and diesel consumption

Regarding LCOE improvements (Figure 9) this conservation strategy has an unexpected result. It increases the LCOE when comparing to the reference power system, as more energy is being wasted due to oversizing system. By changing the capacity of the PV array and the battery bank (180kW$_{PV}$ and 250 batteries) the LCOE decreases 3%. It is thus clear that the implementation of this strategy would only have positive results if applied before the design of the power system.

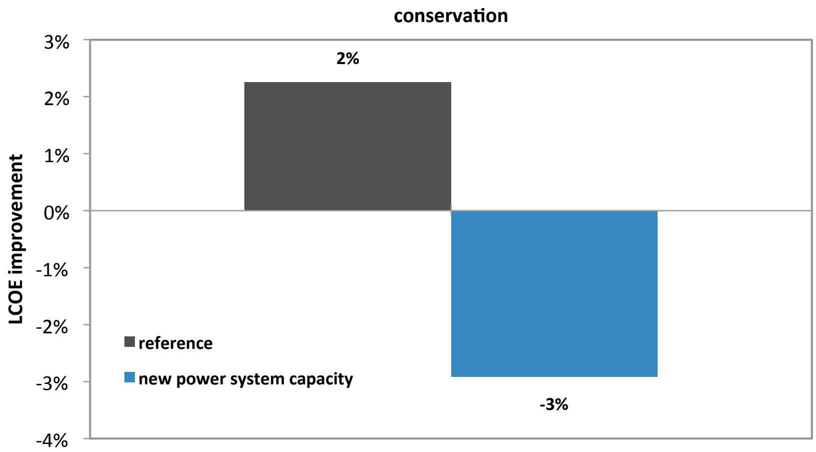

Figure 9: Comparison between LCOE with reference power system capacity and new power system capacity

The conservation strategy can have a relevant impact on the load profile. By reducing the consumption of energy used by the appliances more energy is available for the end-users without the need to increase the power system. Although, in this scenario, the consumer's energy use did not increase, therefore there is an excess of energy produced that is not being used. For this reason, the LCOE is higher than the reference scenario. Over time the use of energy in the community will probably increase and the LCOE should decrease. A relevant conclusion from this scenario is that excess energy is more expensive for microgrid' users than having unmet load. Since the cost of the system components is included on the annualized cost of producing electricity (Equation 3.3.1), the end-users are paying for energy that they do not use (the higher the size of the system, the higher the investment cost). Regarding the social impact of this strategy, the replacement of old commercial fridges for new ones is expensive. Furthermore, the appliances markets in these areas usually do not have this kind of equipment nor the spare parts for replacements.

4.3. Peak clipping strategy

The daily average power peak is around 57 kW, as illustrated in Figure 10. However, the annual power peak of the microgrid is 67.37 kW in September. The maximum power allowed in the system was gradually restricted at: 60 kW, 50 kW and 40 kW.

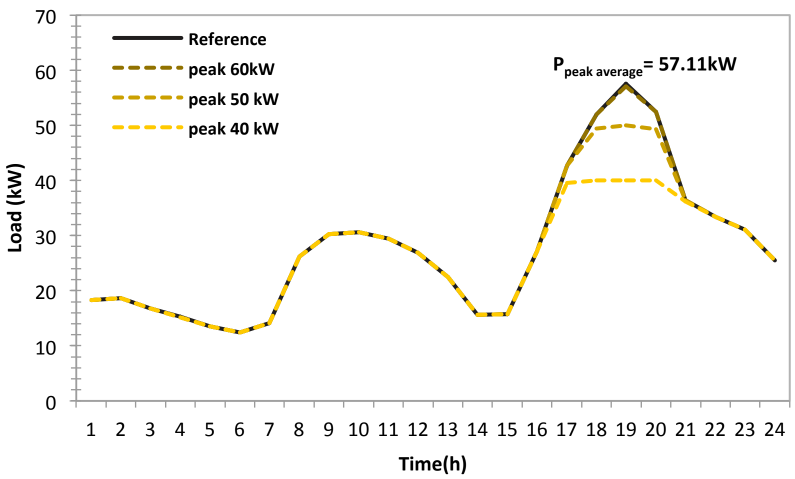

Figure 10: Peak clipping strategy scenarios illustration of the daily average demand

The three scenarios were analysed regarding the battery bank operation, diesel consumption and LCOE improvements. As shown in Figure 11, the clipping during the peak period can have a positive effect on the battery bank, the storage depletion decrease in all scenarios. In the peak 40 kW scenario, the expected lifetime of the batteries increases 33%, one more year than for the reference scenario.

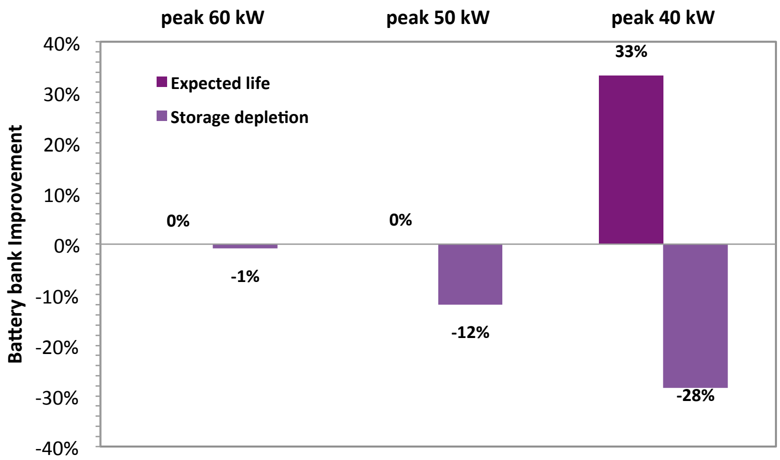

Figure 11: Impact of peak clipping scenarios on the battery bank

The impact of each scenario has similar results on the fuel needs, as shown in Figure 12. Less storage energy is used and therefore the need of diesel decreases. The peak 40 kW scenario also shows the best results regarding the diesel consumption, with less 2.31% of fuel needs. Comparing battery bank and diesel fuel results, this harsher strategy has the highest impact on the batteries operation.

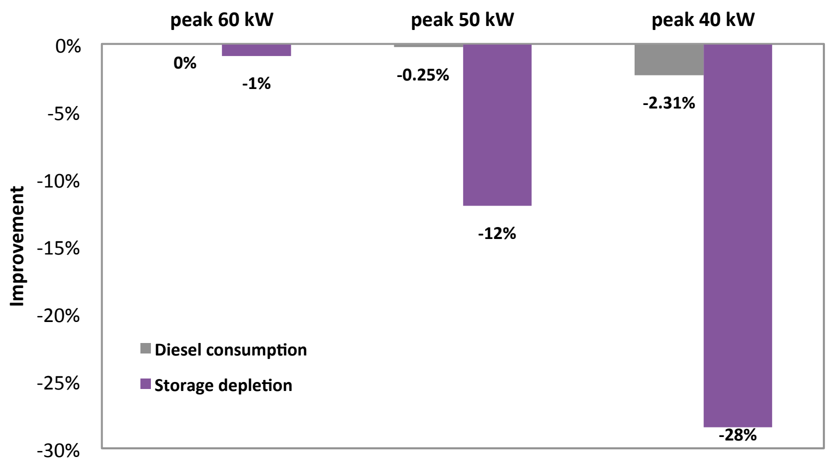

Figure 12: Comparison of peak clipping scenarios impacts on the diesel consumption with battery operation

Figure 13 illustrates the improvements on the LCOE with the implementation of peak clipping both on the reference power system as well as an optimally re-designed system. The new sizes of PV-Battery components are: peak 60 kW scenario- 200 kW_{PV} and 300 batteries; peak 50 kW scenario- 204 kW_{PV} and 260 batteries; peak 40 kW scenario- 190 kW_{PV} and 230 batteries.

Regarding the reference power system, the first scenario shows no improvement on the LCOE. The peak 60 kW scenario has an insignificant impact on the battery and diesel components, which is reflected on no variation on the LCOE. The remaining scenarios present better results for both components. However, the LCOE improvement is still small: maximum LCOE improvement with this strategy is only 0.53%. For an optimized system, reducing the PV-Battery capacity and maintaining the diesel generator capacity leads to improvements of the LCOE that can reach 6.3%.

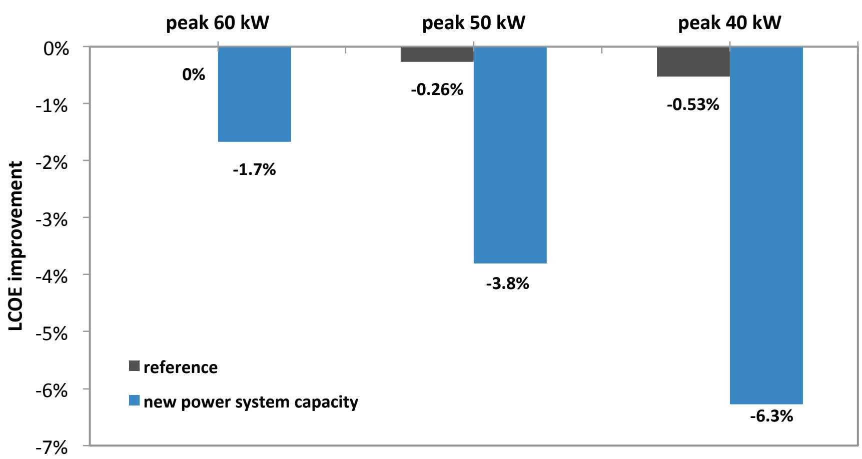

Figure 13: Comparison between LCOE with reference power system capacity and new power system capacity

Peak clipping strategy can have a high impact in social-economic activities. By limiting demand, the use of some electric appliances is being restricted during this time. The average maximum energy reduction with these scenarios is approximately 68 kWh. This can affect some of the business sector (enterprises, clubs and kiosks) and the families demand during this period. There are measures and technologies that control the demand and can mitigate its social-economic impact, such as the GridShare appliance discussed earlier.

4.4. Load shifting strategy

Load shifting strategy is divided in two scenarios:

- Scenario 1- load shifting of the main user classes' demand and
- Scenario 2- load shifting of the main appliance demand.

For each scenario two sub-scenarios were considered, depending on the schedule of the shifted load.

Regarding scenario 1, the goal is to smooth out the power peak period (5:00 p.m. – 9:00 p.m.) by shifting two hours of Enterprise 1 and 2 load to off-peak period, as shown in Figure 14. These classes have the highest energy consumption in Soroti. In total, there are 15 small enterprises and 5 big enterprises, working from 7:00 a.m. – 1:00 p.m. and 3:00 p.m. – 8:00 p.m. The sub-scenarios are:

- LS 1.1- all the enterprises work from 7:00 a.m. – 6:00 p.m. (no lunch break) and
- LS 1.2- all the enterprises work from 6:00 a.m. - 12:00 p.m. and from 1:00 p.m. - 6:00 p.m. (with 1h of lunch break).

To avoid reducing productivity, the new working schedule continues to cover an hour of the peak period.

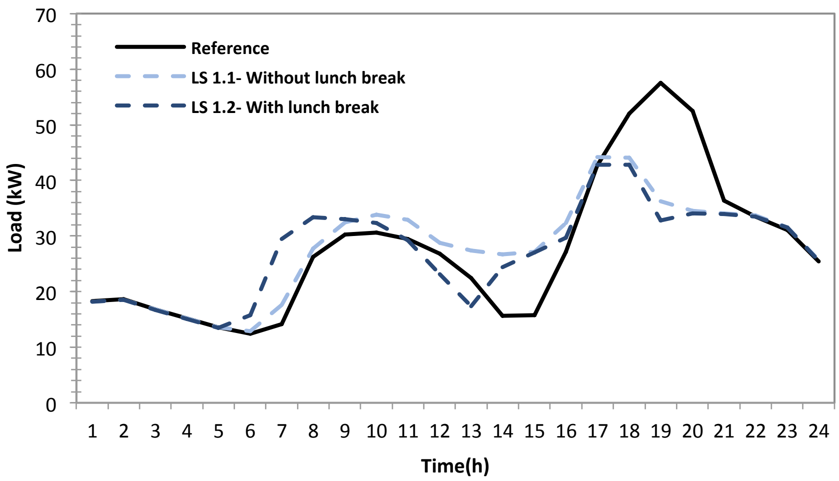

Figure 14: Load shifting strategy scenarios 1.1 and 1.2

Figure 15 illustrates the impact of these two sub-scenarios on the battery bank. Regarding the use of the battery, the LS 1.1 scenario shows better results, with more 15% increase on batteries expected life than LS 1.2 scenario. The battery use decreases since end-users are mostly using PV array production.

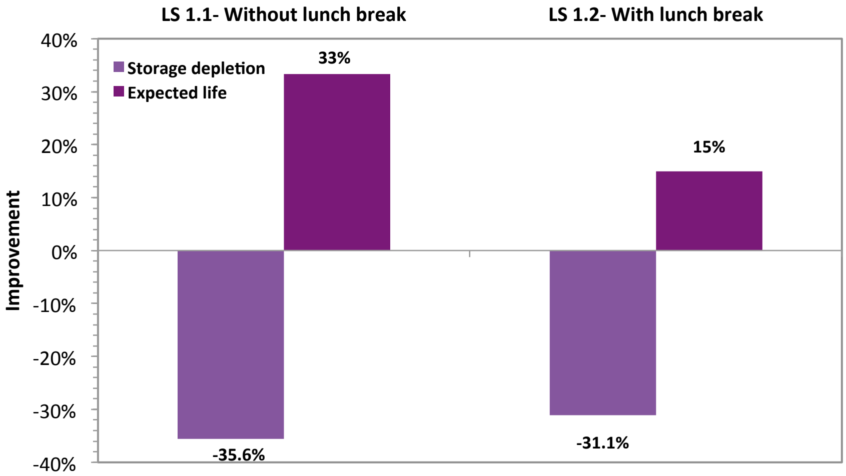

Figure 15: Impact of load shifting strategy scenarios 1.1 and 1.2 on the battery bank operation

Regarding the impact of these sub-scenarios on the diesel consumption, LS 1.1 scenario continues to have a higher performance. However, the improvement on diesel consumption is not as significant as the storage depletion improvement. The LS 1.2 scenario has a small increase of diesel needs, possibly due to the lack of PV supply at 6:00 am.

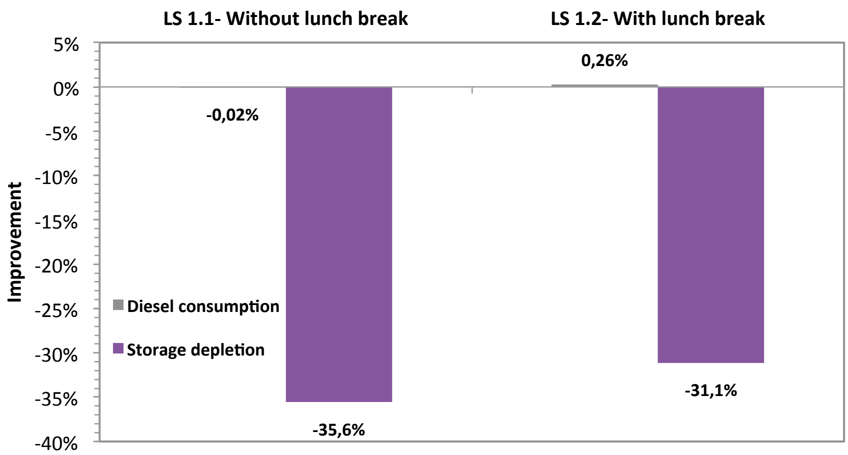

Figure 16: Comparison of load shifting scenarios 1.1 and 1.2 impacts on the diesel consumption with battery operation

The load shifting strategy scenario 2 is divided into:

- LS 2.1- Fridges off during the night (working period: 6:00 a.m. - 6:00 p.m.)
- LS 2.2- Fridges off during the day (working period: 6:00 p.m. - 6:00 a.m.).

Figure 17 illustrates these two scenarios. The fridges' reference cycle is a 24h period with 5h or 8h working hours, depending on the user class type. In load shifting scenarios the work period is reduced to 12h and the working hours are 2.5h or 4h, depending on the user class type.

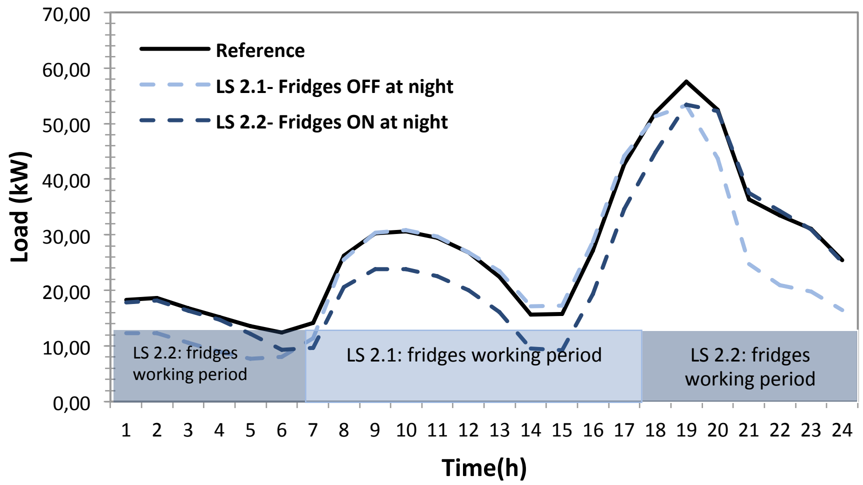

Figure 17: Load shifting strategy scenario 2.1 and 2.2 illustration

Scenario LS 2.1 shows that by turning off the fridges during the night, batteries expected life can have improvement of 67%, this means more 2 years on batteries life than for the reference case. LS 2.2 scenario has an insignificant improvement on these two features, because the demand is mostly reduced during PV production time. The need of energy storage practically does not change from the reference case. Figure 17 details these results.

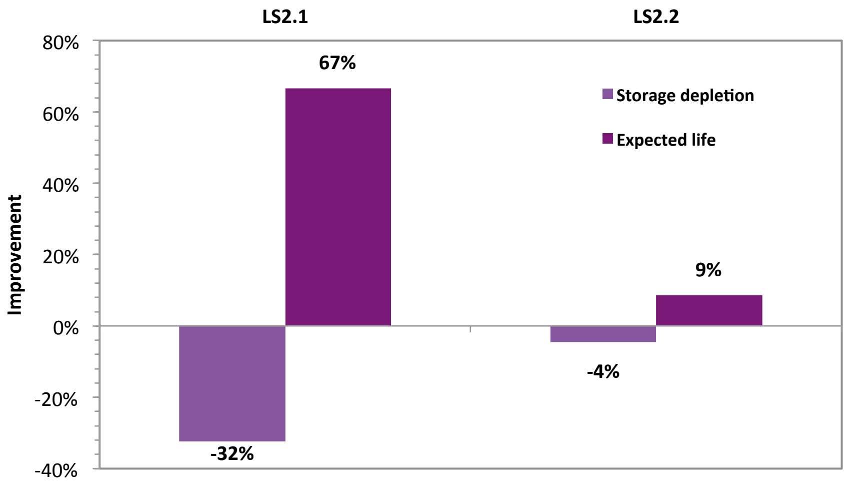

Figure 18: Impact of load shifting strategy scenarios 2.1 and 2.2 on battery bank operation

When the fridges' demand during the day is eliminated, the energy stored in the batteries can increase, reducing the diesel consumption (Figure 18). The 1% difference between these two scenarios is due to the fact that there is more energy available on the batteries in the LS 2.2 scenario than in the LS 2.1 scenario (Figure 18).

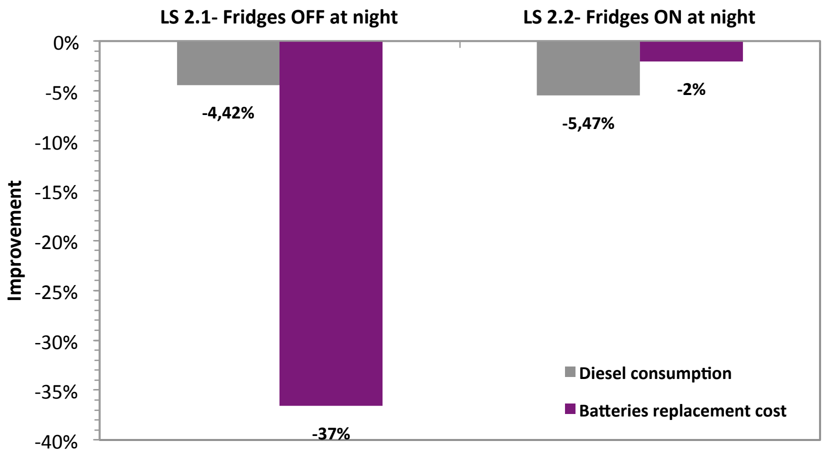

Figure 19: Comparison of load shifting scenarios 2.1 and 2.2 impacts on the diesel consumption with batteries replacement cost

Figure 20 illustrates the improvements on the LCOE with the implementation of load shifting strategies. The LS 2.2 scenario shows no improvement on the LCOE. The remaining scenarios present better results, although with little improvements. The new sizes of PV-Battery components are: LS 1.1 scenario- 180 kW_{PV} and 270 batteries; LS 1.2 scenario- 204 kW_{PV} and 290 batteries; LS 2.1 scenario- 140 kW_{PV} and 260 batteries; LS 2.2 scenario- 170 kW_{PV} and 250 batteries.

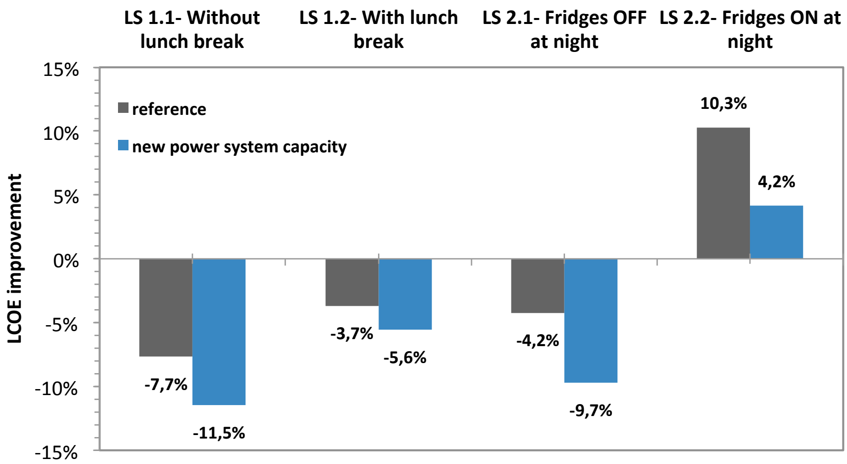

Figure 20: Comparison of LCOE between reference power system capacity and new power system capacity

The LS 1.1 scenario is the best scenario for load shifting strategy, with 8% LCOE improvement. This strategy has high impact on end-users due to the design of a restrict schedule for energy consumption. Changing working hours (LS 1. scenarios) have a definitive effect on the life of a community. Changing fridges' demand would require hardware investment and would be challenging to accept, as it would require change of habits regarding their use.

Again, the simulation results underline the importance of considering this type of DSM strategy during the design phase since the positive impacts are much more significant for an optimized system.

4.5. Valley filling strategy

The addition of productive load during the PV production is an approach for decreasing the waste of energy produced that cannot be stored. Valley filling strategy was studied in two scenarios:

- Scenario 1- the addition of a solar pump for an irrigation system
- Scenario 2- the addition of a juice factory, working from 11:00 a.m. to 4:00 p.m.

Each scenario includes two sub-scenarios, depending on the size of the plantation (20 or 25 hectares) and on the size of the factory (constant power of 10 or 15 kW).

Regarding scenario 1, Figure 21 illustrates the impact of adding deferrable load to the reference load. In this case, an irrigation system is added to the community to take advantage of excess energy produced by the PV system. The irrigation system works seasonally, (as it can be seen in Table 11) in a perfect match with the PV production, i.e. the irrigation is only required in the months with higher solar irradiance.

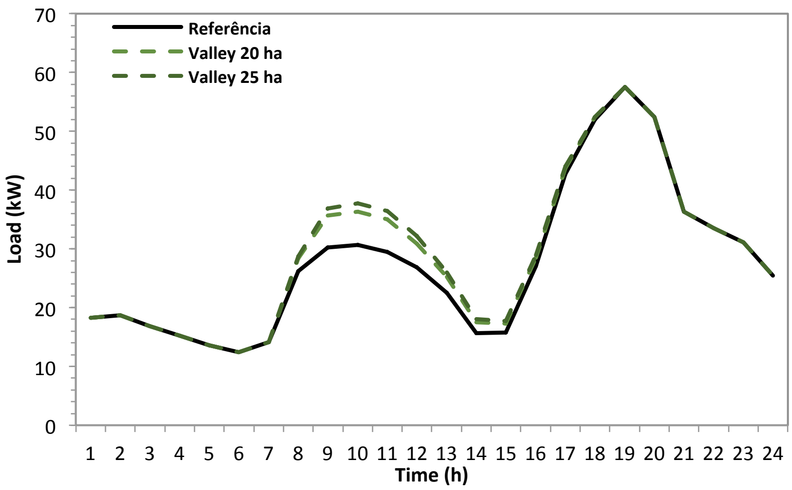

Figure 21: Impact of Valley filling scenario 1.1 and 1.2 in the daily load profile

Concerning scenario 2, Figure 22 illustrates the effect of adding a juice factory to the community demand, with working hours from 11:00 a.m. to 4:00 p.m. By adding this productive load during the excess PV production time, the energy wasted will decrease and therefore the LCOE will decrease.

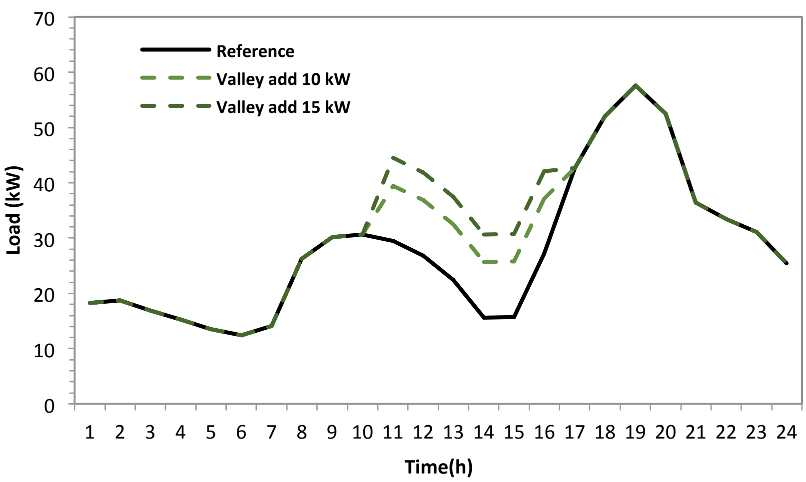

Figure 22: Impact of Valley filling scenario 2.1 and 2.2 in the daily load profile

Since the storage depletion of the battery bank is not affected in this case, the impacts of this DSM strategy were only assessed regarding the diesel consumption and the expected battery life, as shown in Figure 23.

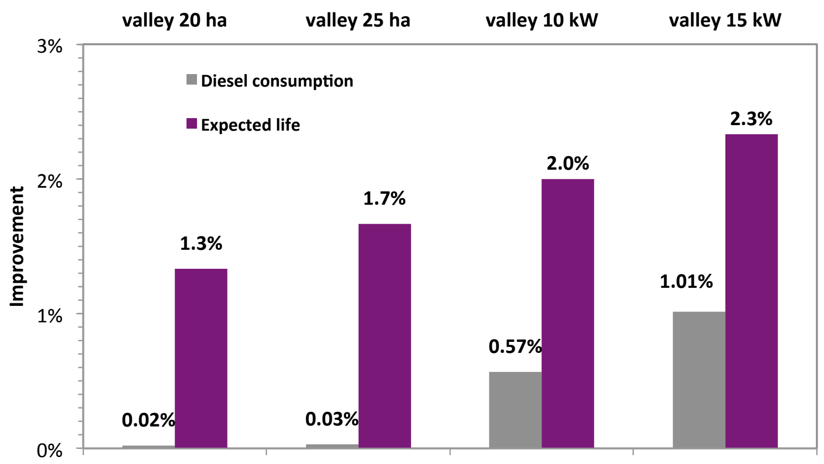

Figure 23: Impact of Valley Filling scenarios on battery bank and diesel consumption

Comparing scenario 1 and 2, the latter shows the best results in terms of diesel and storage operation. The increase of energy consumption during PV peak decreases the needs of using storage and diesel. Less energy is stored in the batteries since it is being use for a productive activity.

This conclusion is confirmed with the LCOE analysis, represented in Figure 24. The scenario valley filling 2.2 is the best scenario of the valley filling strategy with 12% LCOE improvement.

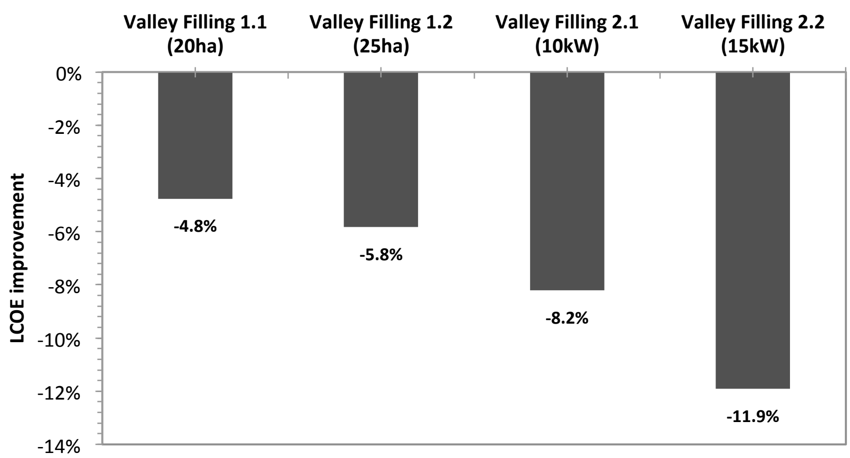

Figure 24: LCOE improvement with valley filling scenario

This strategy does not seem to have negative impacts on the social activities of the community. In fact, the addition of these productive uses of excess solar energy would certainly have a positive effect on the economy of Soroti, with job and wealth creation.

4.6. Optimum strategy

The optimum DSM strategy is the combination of the best scenarios for each individual strategy. The best scenario in each strategy were, respectively: peak 50 kW and 40 kW, load shifting 1.1 – shifting of working hours without lunch break, valley filling 2.2 – juice factory with 15 kW of demand. Despite the limited impact of the conservation scenario in this study, this strategy was also added to one of the optimum strategy scenarios to understand the combination of all strategies (conservation, peak clipping, load shifting and valley filling). Figure 25 illustrates the impact of these strategies combination in the load demand profile. Scenario 1 refers to 40kW peak clipping while scenario 2 is for 50kW peak clipping.

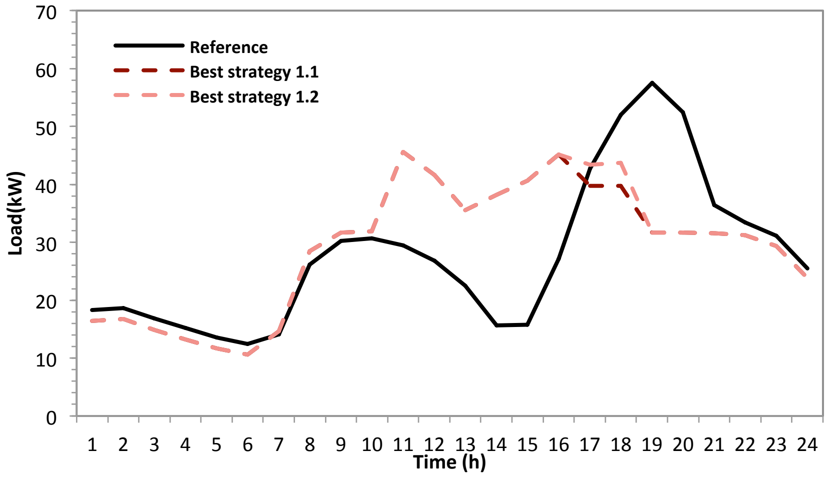

Figure 25: Impact of the best scenarios of each strategy in the load demand profile

The combination of all the four strategies shows the best results (see Figure 25). For the 40kW peak clipping, the improvement on the battery bank's expected lifetime would be 36% and around 3% on the diesel consumption. These are relevant results on the technical performance of the power system.

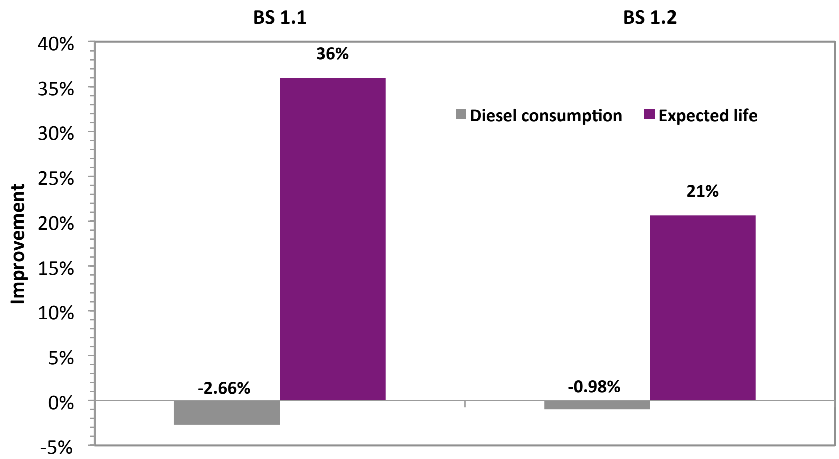

Figure 26: Impact of the four DSM strategies on the battery back and the diesel consumption.

Due to the results of the conservation strategy, the study of the LCOE improvement with best scenarios of each strategy was conducted with and without the conservation strategy. The new sizes for the PV-Battery components are:

- BS 1.1 (with conservation strategy and peak 40kW) scenario- 190kW$_{PV}$ and 230 batteries;
- BS 1.2 (with conservation strategy and peak 50kW) scenario- 200kW$_{PV}$ and 260 batteries;
- BS 2.1 (without conservation strategy and peak 40kW) scenario- 200kW$_{PV}$ and 285 batteries;
- BS 2.2 (without conservation strategy and peak 50kW) scenario- 204kW$_{PV}$ and 290 batteries.

Figure 27 illustrates the four options of best combinations of DSM scenarios. The scenarios without the application of the conservation strategy seem to be the best option, since the LCOE continues to be lower with is strategy. The other two scenarios have similar results in terms of LCOE improvement, around 18-20% depending on the power system capacity. The final decision would be on the social impacts these strategies can have on the community.

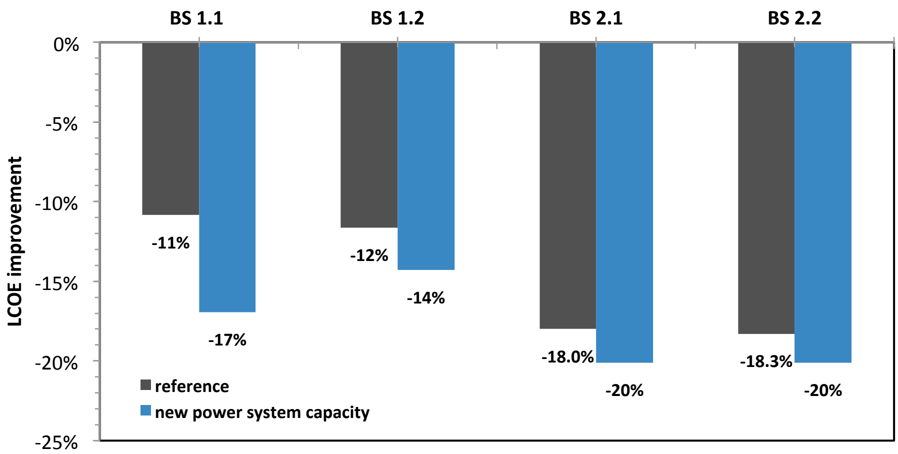

Figure 27: LCOE Improvements for the best strategy scenarios and for best strategy scenarios without conservation strategy

Regarding the technical and economic potential the best strategy scenarios are the best option. However, the social impacts are much heavier, since this strategy leads to the accumulation of all the previous impacts. The implementation of all DSM strategies would have to have a much more careful background study on the community to diminish the negative impacts.

4.7. Scenarios' summary

Table 5 summarizes the results of all DSM scenarios under study. It is possible to see the technical and economic improvements for each strategy. Results show that the impact of these strategies on the batteries lifetime seem to be higher than on diesel use, maintaining the need of diesel. Regarding the generation system size, the changes of the size of the PV array and battery bank have a positive effect in all scenarios. Hence, the DSM should also be conducted during the design of systems.

Table 5: Summary of DSM scenarios' results

Scenario		Battery lifetime improvement (%)	Diesel use improvement (%)	LCOE improvement (%)		New system	
				Reference	New	PV array (kW)	#Battery
Conservation		+16	-0.03	+2.0	-3.0	180	250
Peak clipping	60 kW	0	0	0	-1.7	200	300
	50 kW	0	-0.3	-0.3	-3.8	204	260
	40 kW	+33	-2.3	-0.5	-6.3	190	190
Load shifting	LS 1.1	+33	0	-7.7	-11.5	180	270
	LS 1.2	+15	+0.3	-3.7	-5.6	204	290
	LS 2.1	+67	-4.0	-4.2	-9.7	140	260
	LS 2.2	+9.0	-5.0	+10.3	+4.2	170	250
Valley filling	VF 1.1	+1.3	0	-4.8	--	--	--
	VF 1.2	+1.7	0	-5.8	--	--	--
	VF 2.1	+2.0	0.6	-8.2	--	--	--
	VF 2.2	+2.3	1.0	-11.9	--	--	--
Optimum strategy	BS 1.1	+36	-2.66	-11	-17	190	230
	BS 1.2	+21	-0.98	-12	-14	200	260
	BS 2.1	+25	-0.25	-18	-20	200	285
	BS 2.2	+23	+1.04	-18.3	-20	204	290

5. Conclusions and future work

5.1. Conclusions

The aim of this work is the study of the potential of DSM on isolated RE microgrid systems. The foregoing discussion includes different simulation examples of DSM strategies (peak clipping, load shifting, conservation, and valley filling) applied to Soroti, a small town in Uganda. Before that, a description of the main characteristics of DSM and a background study on DSM projects in microgrids is also presented.

In what concerns the background study on DSM projects, it is possible to conclude that, in general, there are still a lot of improvements to be done and issues that must be solved. This field of energy management on remote electrification projects is a new area of research and most of rural areas seem not to be ready in terms of energy efficiency policies and appliance markets. Furthermore, the economic factor has a heavy weight on delaying the deployment of this kind of projects.

Regarding the proposed research' questions, the different scenarios indicate that DSM strategies in microgrid systems can have a high economic potential for the end-users. This reduction is mainly achieved by the reduction of the nominal power capacity of the system and, to a less extent, by the lower usage of the diesel generator. The value of LCOE is lower when the DSM measures have the potential of reducing the net present cost (life cycle cost). The technical potential is mainly verified by the increase of battery lifetime in some of the simulations under study.

As for fossil fuels and batteries, the battery bank management has a higher impact on the LCOE than the diesel consumption. Since DSM measures decreases the needed capacity of the power generation system, the study of these measures should be done before the power generation system design.

Another important conclusion of this study is that these approaches have meaningful socio-economic impacts that have to be taken into account. Also, its local implementation faces important challenges, requiring local support and education, perhaps coupled with customised financial incentives, for example tariffs. In this case, it was not possible to understand precisely the social impacts of these scenarios in the daily activities. However, it is also possible to conclude that a quality background study of the end-users activities and needs is crucial for the design of the DSM strategies.

The combination of all strategies shows better improvements on the power system components and on the LCOE. Although, the conservation strategy in this case, where the growth of energy over time is not been taken into account, increases the value of the LCOE, due to the existing oversized capacity of the power system. The best LCOE achieved, has an improvement of approximately 20%. The scenario with this value is the optimum scenario, without the conservation strategy and with the redesign of the PV array and battery bank capacities.

Still, these results highlight the importance of the often-neglected DSM strategies for isolated microgrids, which has the potential to facilitate the access to electricity in many regions of the world with RE. It is important to recall that, nowadays, around one billion people in the world have access to an unreliable electricity network and another billion have no electricity at all.

Besides, the results also show that the planning and design of RE microgrid systems still needs improvements and that DSM has a strong potential for these systems, since DSM can increase the efficiency of different components of the system and the reliability of the electrical service. Therefore energy management should not be neglected by any of the identities included in these kind projects.

5.2. Future work

The results presented in this work were applied to a small town in Uganda. Although, the input data were based on simulations, the RE microgrid system is not the one presented in the town, and the DSM strategies were not applied in the field. Thus, a DSM strategy in a real RE microgrid system should be performed in order to verify the real impact of energy management in the community and the potential of application of the strategy. An in-field measuring campaign of at least one year should be done to validate both the feasibility and reliability of the proposed DSM strategy. If this strategy is applied to a previously installed microgrid, it is interesting to have access to the energy consumption and microgrid production before the application of the DSM. If this data is not available, at least a door-to-door inquiry to a representative part of the energy consumer should be conducted, as well as an interview to the energy producer(s).

Regarding the size of the systems under study, this work is about microgrid systems, which means, medium power systems. Accordingly, the study of DSM potential on small power systems may also be considered.

6. References

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7. Appendix

7.1. LoadProGen Appliances Input data

Table 6: Appliances Input data in Soroti community

Class Type	N_{us}	App name	P[W]	N_{app}	h_{funct}	$W_{f,1}$ h_{start}	$W_{f,1}$ h_{stop}	$W_{f,2}$ h_{start}	$W_{f,2}$ h_{stop}	$W_{f,3}$ h_{start}	$W_{f,3}$ h_{stop}	Tot_w
Family_1	50	Lights (normal)	3	4	6	0	2	17	24	-	-	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Security Light	5	1	12	0	7	17	24	-	-	14
Family_2	15	Lights (normal)	3	4	6	0	2	17	24	-	-	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Radio	5	1	4	6	9	17	24	-	-	14
		AC-TV (small)	100	1	5	11	15	17	24	-	-	10
		Security Light	5	1	12	0	7	17	24	-	-	11
Family_3	15	Lights (normal)	3	8	6	0	2	17	24	-	-	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Radio	5	1	4	6	9	17	24	-	-	10
		Security Light	5	2	12	0	7	17	24	-	-	14
		AC-TV (small)	100	1	5	11	15	17	24	-	-	11
		Fridge (small)	250	1	5	0	24	-	-	-	-	24
Family_4	10	Lights (normal)	3	12	6	0	2	17	24			9
		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	1	4	6	9	17	24	-	-	10
		Security Light	5	4	12	0	7	17	24	-	-	14
		AC-TV (small)	100	1	5	11	15	17	24	-	-	11
		Standing Fan	55	1	6	8	24	-	-	-	-	16
		Decoder	15	1	5	11	15	17	24	-	-	11
		Fridge (small)	250	1	5	0	24	-	-	-	-	24
		Internet Router	20	1	6	0	24	-	-	-	-	24
		Laptop (small)	55	1	6	0	2	11	15	17	24	13
Family_5	5	Lights (normal)	3	16	6	0	2	17	24			9
		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	2	4	6	9	17	24	-	-	10
		Security Light	5	6	12	0	7	17	24	-	-	14
		AC-TV (big)	200	1	6	11	15	17	24	-	-	11
		Standing Fan	55	2	6	8	24	-	-	-	-	16
		Decoder	15	1	6	11	15	17	24	-	-	11
		Fridge (big)	400	1	5	0	24	-	-	-	-	24
		Internet Router	20	1	8	0	24	-	-	-	-	24
		Laptop (big)	80	2	8	0	2	11	15	17	24	13
Family_6	5	Lights (normal)	3	16	6	0	2	17	24			9

		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	2	4	6	9	17	24			10
		Security Light	5	6	12	0	7	17	24			14
		AC-TV (big)	200	1	6	11	15	17	24			11
		Standing Fan	55	2	6	8	24	-	-			16
		Decoder	15	1	6	11	15	17	24			11
		Fridge (big)	400	1	5	0	24	-	-			24
		Internet Router	20	1	8	0	24	-	-			24
		Laptop (big)	80	2	8	0	2	11	15	17	24	13
		Hair Dryer	1000	1	0.5	17	24	-	-	-	-	7
		Printer	50	1	0.5	17	24	-	-	-	-	7
		Stereo	100	1	3	17	24	-	-	-	-	7
		Water Heater	660	1	2	0	2	18	24	-	-	8
Enterprise_1	15	Fluorescent Tube (small)	36	10	6	7	11	16	20	-	-	8
		Phone Charger	5	4	3	7	13	15	20	-	-	11
		Security Light	5	4	12	0	7	17	24	-	-	14
		Internet Router	20	1	10	7	20	-	-	-	-	13
		Laptop (big)	80	1	8	7	13	15	20	-	-	11
		Laptop (small)	55	5	8	7	13	15	20	-	-	11
		Printer	50	2	2	7	13	15	20	-	-	11
		Standing Fan	55	2	8	7	13	15	20	-	-	11
Enterprise_2	5	Fluorescent Tube (big)	47	20	6	7	11	16	20	-	-	8
		Phone Charger	5	15	3	7	13	15	20	-	-	11
		Security Light	5	10	12	0	7	17	24	-	-	14
		Internet Router	20	1	10	7	20	-	-	-	-	13
		Laptop (big)	80	5	8	7	13	15	20	-	-	11
		Laptop (small)	55	10	8	7	13	15	20	-	-	11
		Printer	50	3	2	7	13	15	20	-	-	11
		Standing Fan	55	5	8	7	13	15	20	-	-	11
		Water dispenser	550	1	3	7	13	15	20	-	-	11
		Photocopier	750	1	1	7	13	15	20	-	-	11
		Ceiling Fan	75	5	8	7	13	15	20	-	-	11
		PC	400	1	10	7	20	-	-	-	-	13
Mobile Money	5	Lights (normal)	3	2	3	8	11	16	20	-	-	7
		Phone Charger	5	3	3	8	18	-	-	-	-	10
		Standing Fan	55	1	6	10	18	-	-	-	-	8
Kiosk	10	Lights (normal)	3	2	3	8	11	16	20	-	-	7
		Phone Charger	5	1	3	8	18	-	-	-	-	10
		Standing Fan	55	1	6	10	18	-	-	-	-	8
		Fridge (small)	180	1	8	0	24	-	-	-	-	24
		Fridge (big)	300	1	8	0	24	-	-	-	-	24
Barber	2	Lights (normal)	3	5	8	8	13	15	20	-	-	10

		12V shaver	10	5	6	8	13	15	20	-	-	10
		Ceiling Fan	75	3	8	8	13	15	20	-	-	10
		UV sterylizer	50	1	2	8	13	15	20	-	-	10
Tailor	3	Lights (brighter)	5	3	8	8	13	15	20	-	-	10
		Sewing machine	50	1	3	8	13	15	20	-	-	10
		Ceiling Fan	75	1	8	8	13	15	20	-	-	10
Market Place	1	Lights (normal)	3	25	3	8	11	16	20	-	-	7
		Security Light	5	25	12	0	7	17	24	-	-	14
		Fridge (small)	180	3	8	0	24	-	-	-	-	24
		Fridge (big)	300	3	8	0	24	-	-	-	-	24
		Standing Fan	55	10	8	8	13	15	20	-	-	10
		Radio	5	10	4	10	13	15	18	-	-	6
Club	3	Fluorescent Tube (small)	36	10	8	0	4	17	24	-	-	11
		Fluorescent Tube (big)	47	5	8	0	4	17	24	-	-	11
		Security Light	5	5	12	0	7	17	24	-	-	14
		Phone charger	5	10	8	15	24	-	-	-	-	9
		AC-TV (small)	130	2	9	0	4	15	24	-	-	13
		AC-TV (big)	200	1	9	0	4	15	24	-	-	13
		PC	400	1	9	0	4	15	24	-	-	13
		Laptop (big)	80	10	6	15	24	-	-	-	-	9
		Printer	50	1	1	15	20	-	-	-	-	5
		PicoProjector	18	1	4	0	2	20	24	-	-	6
		Amplyfier	6	1	4	0	2	20	24	-	-	6
		Ceiling Fan	75	3	8	0	4	15	24	-	-	13
		Music System	178	1	8	0	4	15	24	-	-	13
		Internet Router	20	1	9	0	4	15	24	-	-	13
		Fridge (small)	180	2	8	0	24	-	-	-	-	24
		Fridge (big)	300	1	8	0	24	-	-	-	-	24
Street lights	1	Lights (Street)	50	100	12	0	7	17	24	-	-	14
		Led strips	8	100	12	0	7	17	24	-	-	14
Primary School	1	Fluorescent Tube (small)	36	10	4	8	17	-	-	-	-	9
		Phone Charger	5	7	3	8	17	-	-	-	-	9
		Security Light	5	4	12	0	7	17	24	-	-	14
Pharmacy	1	Lights (normal)	3	10	3	8	11	16	20	-	-	7
		Security Light	5	4	12	0	7	17	24	-	-	14
		Fridge (small)	180	3	8	0	24	-	-	-	-	24
		Fridge (big)	300	2	8	0	24	-	-	-	-	24
		Standing Fan	55	3	8	8	13	15	20	-	-	10

7.2. HOMER input data

Table 7: PV array input data for HOMER Software in Soroti community

PV array - Monocrystalline			
Size (kW)	**Capital (€/kW)**	**O&M (€/kW.year)**	**Lifetime (year)**
204	1000	17.29	25
De-rating factor (%)	**Ground ref (%)**	**Angle (º)**	**Slope (º)**
90	20	0	15

Table 8: Diesel Generator input data for HOMER Software in Soroti community

Diesel Generator			
Size (kW)	**Capital (€/kW)**	**Replacement (€/kW)**	**O&M (€/kW.hr)**
10	546	455	0.068
Lifetime (hour)	**Fuel Cost (€/L)**	**Diesel LHV (MJ/kg)**	**Diesel Specific Volume (kg/m^3)**
15000	0.81	44.39	825

Table 9: Battery bank input data for HOMER software for Soroti community

Sealed Lead Acid Battery Bank 12V-200Ah (1 battery=2.4 kWh)			
Size (kWh)	**Capital (€/kW)**	**O&M (€/battery.year)**	**Lifetime Throughput (kWh)**
792	140	37.13	917
Strings	**Number of Batteries**	**Initial State of Charge (%)**	**Minimum State of Charge (%)**
1	330	100	40

Table 10: Converter input data for HOMER software for Soroti community

Converter		
Size (kW)	**Capital (€/kW)**	**O&M (€/kW.year)**
75	500	5
Inverter		
Lifetime (year)	**Efficiency (%)**	
10	90	
Rectifier		
Relative Capacity (%)	**Efficiency (%)**	
100	85	

Table 11: Deferrable load input for a 20 and 25 hectares citrus plantation

Month	Water need (mm/day)	Energy $_{demand}$ (kWh/day)	
		Plantation Area= 20 ha	Plantation Area= 25 ha
Jan	2.8	60.98	76.22
Feb	2.4	52.27	65.33
Mar	1.8	39.20	49.00
Apr	0	0	0
May	0	0	0
Jun	0	0	0
Jul	0	0	0
Ago	0	0	0
Sep	0	0	0
Oct	0	0	0
Nov	1.2	26.13	32.67
Dec	2.5	54.44	68.06