Bake bread while the sun shines: Solar bakery for off-grid rural community development

J. Meyer, S. von Solms

Abstract— In South Africa there are still more than 1.5 million households which are unlikely to be connected to the utility grid in the near future. These rural communities are faced with economic development, social and environmental challenges brought about as result of not being connect to the utility grid. Renewable energy offers environmentally favourable and cost effective solutions which are attractive for rural development of communities not connected to the utility grid. Gwakwani is an off-grid rural village situated in northern Limpopo South Africa. As a result of being off-grid, economic and social development of the village was haltered and become near stagnant. In this paper a renewable solar energy solution is utilised in the Gwakwani rural off-grid community for the powering of a small bakery. A solarised container bakery was developed and installed in the community. The bakery operated by four bakers is capable of producing up to 160 loafs of bread per day. The bakery has become the main supplier of bread to the neighbouring communities and is now the largest source of income and employment in Gwakwani, driving economic development. An overview of the technical implementation, bakery operation as well as the social aspects are presented. Social development was facilitated through the training of community members on the operation of the bakery and the economic business development thereof. Results from the social and economic impact of the off-grid solar bakery are presented and discussed.

***Index Terms*— Solar solutions, Rural development, Bakery, Off-grid, Economic development, Social impact**

1 INTRODUCTION

The 1996 World Food Summit states that "Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [1]. Food security is seen as a Constitutional Right in South Africa and guarantees its citizens the right to have access to sufficient food and water. Strategies employed by the government and the private sector in South Africa aim to enable these food insecure groups to gain access to income and employment opportunities to enhance their power to purchase food and are empowered to eat nutritious and safe food.

According to the Poverty Trends in South Africa: An examination of absolute poverty between 2006 and 2015 report released by Statistics South Africa in 2017, the people most vulnerable to poverty are children (aged 17 or younger), females, Black Africans, people living in rural areas, those residing Limpopo, and persons with little or no education [2].

These rural food insecure populations predominantly have to survive on social grants and although many of these people can be considered as subsistence farmers, a considerable portion of their available income is spent on food [3]. The majority of residents of Gwankani falls within this description, where the majority of the residents live from government unemployment grants.

The University of Johannesburg (UJ) has partnered with the people from the village of Gwakwani in order to implement various strategies to enable the villagers to gain access to income and job opportunities for social and economic development of the community. These strategies, however, are difficult to implement in a rural community such as Gwakwani, as they lack electricity form the utility grid and other municipal services. The use of renewable energy offers environmentally favourable and cost effective solutions for rural development of these communities.

This paper discusses the implementation of a rural solar bakery which provides the Gwakwani community with the largest source of income and employment as well as a safe supply of additional food. The aim of this research is to analyse the social, technological and economic impact on an experimental implementation of a photovoltaic (PV) bakery in a rural, off-grid area for economic enablement. The paper is structured as follows: Section 2 provides a background to the case study and an overview of the Gwakwani community. Section 3 provides an overview of the Bakery implementation, touching on the technological, social and economic aspects relating to the bakery. Section 4 provides a discussion and Section 5 concludes this paper.

2 BACKGROUND

Gwakwani is a small, rural village in the Northern part of the Vhembe district of the Limpopo province in South Africa. The population density of the Gwakwani area can be classified as less than 10 – 25 people per square kilometre [4] with approximately 70 people residing in the village. The village is approximately 17 km from the nearest town and closest petrol filling station. Due to the isolated location of the village, it is deprived of supplied grid electricity, direct mobile cellular connection as well as municipal water supply or sanitation services. The connection of the village to these services were denied in the past as it is financially unviable and outweighs the advantages of connecting this small rural

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community to these services. The villagers mainly survive on subsistence farming whose income is supplemented by government grants of approximately R300 per month. Some households receive contributions from breadwinners who migrate to urban centres.

Electrification by a power utility of the Gwakwani rural area is seen as financially unviable and consequently the University of Johannesburg, based on impact and needs assessments with the community, found that a promising method for sustainable development in the community was through the implementation of renewable energy resources. This is in line with the work of other researchers who engage with rural communities, which indicated that one of the most common uses for solar energy as a source of electricity supply are for homes and buildings which do not have grid-connection [5].

Various solar strategies were implemented in the village, which includes the installation of a photovoltaic borehole pumping schemes, a drip irrigation farm, solar house lighting and cellular phone charging stations. These interventions proved to improve the social and economic stature of the village as a sustainable source of clean water close to the community members' dwellings promoted the cultivation of crops. This increase in subsistence farming made the villagers less dependent on using their social grants for buying basic foods. In some cases, the increased production enabled community members to sell excess produce at the local market.

In a further attempt to improve food security in the village, an off-grid solar bakery was implemented in the village. The technical installation of the bakery was conducted by UJ, where the daily operation and management of the bakery is conducted by the Gwakwani bakery team. The following section provides the technical, social and economic overview of the bakery operation.

3 IMPLEMENTATION OVERVIEW

Due to the lack of grid-tied electricity, the bakery is a total off-grid solution. This solution, although beneficial to the environment, provides certain operational constraints where the bakers are only able to bake bread when the sun shines. Their daily baking strategy is mainly based on the effort to match power demand to power availability and minimise the use of stored electrical energy.

3.1 Off-grid solar power supply

The rural solar bakery is implemented in a 6 meter shipping container equipped with a single deck general purpose bakery oven with a top and bottom heating element, 20 kg capacity dough mixer and dough proofer oven with capacity of 20 bread loafs. The electrical power demand for the bakery equipment is given in Table 1.

Table I. Electrical power demand of the equipment in the rural bakery.

EQUIPMENT	LOAD (KW)
Oven heating element 1 (Top)	4 kW
Oven heating element 2 (Bottom)	4 kW
Proofer	2 kW
Mixer	1 kW
Lights	100 W
Total load (maximum)	12 kW

An off-grid photovoltaic (PV), powered electrical power supply system for the bakery was designed as depicted in the block diagram shown in Fig 1. The design philosophy that was the baking process will only be driven from direct solar supplied energy with energy supplied from the battery bank limited as much as possible. The rationale for this design decision was to reduce the cost of the power solution by limiting the size of the required battery bank as well as the power capacity of the battery inverter to extending the life of the battery bank as long as possible preventing expensive replacement costs. The PV system has an installed maximum capacity of 11 kWp. A Schnieder Electric Conext XW-8000 battery inverter, DC coupled to a 48 V, 400 Ah battery bank was used to create a micro grid supplying 220 V AC. The AC supply is supplemented using two AC coupled Schnieder Electric RL-5000 grid-tie PV inverters. The grid-tie inverters are each supplied from 280 Wp PV panels in a 10S2P string configuration. A Schnieder Electric Conext MPPT 60 150 PV solar charge controller battery charger supplied from 280 Wp PV panels in a 4S1P configuration, was DC coupled to the battery bank to keep the batteries charged.

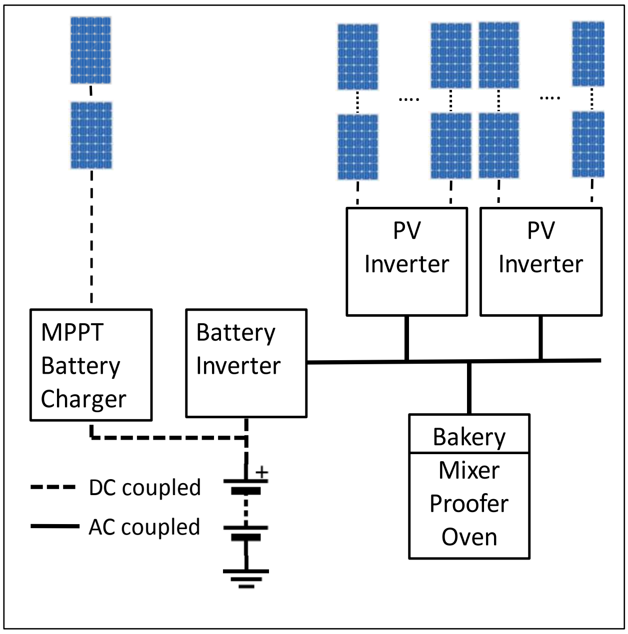

Fig. 1. Block diagram of the solar PV electricity supply for the rural bakery.

The continuous power rating of the inverters in the power supply system for the rural bakery are shown in Table 2.

Table 2. Electrical power supply equipment continuous power rating.

EQUIPMENT	POWER RATING (KW) (CONTINUOUS)
Battery inverter	6 kW

PV inverter 1	5 kW
PV inverter 2	5 kW
Total	16 kW

An important aspect of AC coupled systems which combine battery inverters and grid-tied PV inverters are the ability of power curtailment of the PV grid-tied inverters. For the configuration shown in Fig. 1, when operating, the PV inverter will increase its AC output current allowing power to flow to the grid consisting of the load and the battery inverter in this configuration. Excess current not absorbed by the load is injected onto the AC output of the battery inverter. Consequently, power will flows from the battery inverter's AC output to its DC battery connection, which raises the voltage at the battery terminals and causes the battery bank to be charged. Therefor a means is required to regulate power flow to the battery to prevent overcharging.

In the depicted system curtailment of the PV inverters are effected by the ability of the PV inverters to curtail its output power based on the sensed AC frequency at its terminals. The battery inverter consequently adjusts its AC output frequency based on the battery bank voltage, allowing the control of the battery charging resulting from the excess current generated by the PV inverters.

A typical bread baking cycle consists of the following steps: dough mixing (M), dough proofing (P) and baking (B) as highlighted in Table 3. The oven is heated (H) using one heating element, once before the baking starts. The peak electrical power demand for the equipment used are also given.

Table 3. Steps for a typical bread baking cycle. The peak electrical power demand and time duration of the step is given.

Baking Process Steps	Duration (Minutes)	Peak Power Demand
Oven heating	40 min	4 kW
1. Dough mixing	20 min	1 kW
2. Dough proofing	40 min	2 kW
3. Baking	60 min	8 kW

Following the design principle "bake when the sun shines", the bread baking cycles have to be aligned to the available solar generated electrical power. A number of solar radiation computational models have been reported, which are used to calculate the available solar radiation for the specific geographical location [6, 7]. Up to 5 baking cycles, each producing 20 loaves of bread, can be deployed during a typical summer's day when solar insolation is at a maximum, for the geographic location of the bakery as depicted in Fig 2.

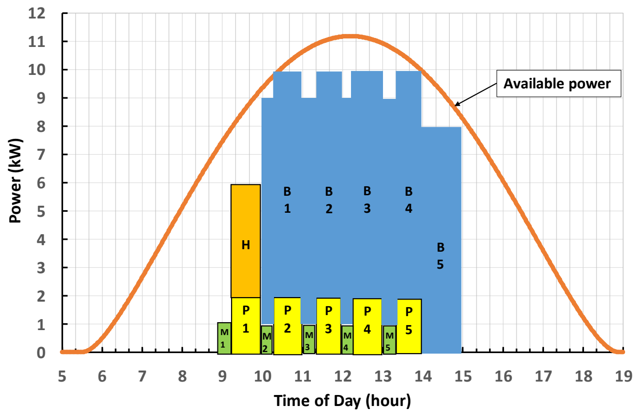

Fig. 2. Bread baking cycles utilising the available solar power during the summer period when maximum solar insolation occurs. Cycle 1 consists of dough mixing (M1), proofing (P1) and baking (B1). Five baking cycles can be deployed within the available solar power.

During winter time when the solar insolation is at a minimum the bread baking cycles are limited to three cycles only, with the additional restriction of using only 1 oven heating element limiting the oven power demand and restricting the use of power from the battery bank. The winter time reduced bread baking cycles aligned with the available solar power is shown in Fig 3. Using only 1 heating element of the oven limits the power demand of the oven to within 4 kW. The baking procedure is adapted to start the baking cycle using the bottom element and alternate switching of the active heating element between the bottom and the top element to allow caramelisation of the dough to form the brown bread crust especially on top of the bread. The total yield of bread loaves decreased to 60 loaves, in winter as result of the reduced solar insolation during the winter period.

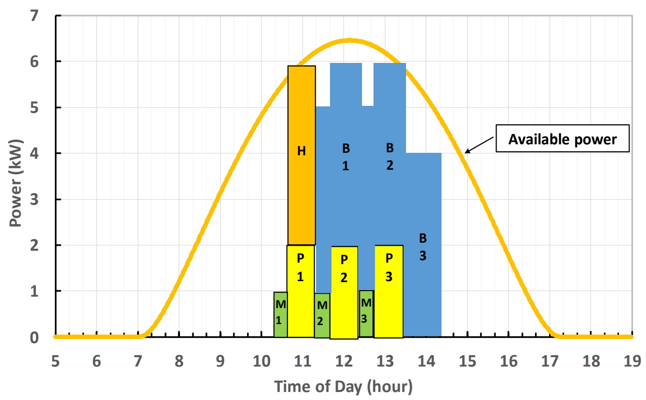

Fig. 3. Bread baking cycles utilising the available solar power during the winter period when minimum solar insolation occurs. Cycle 1 consists of dough mixing (M1), proofing (P1) and baking (B1). Three baking cycles can be deployed within the available solar power.

A section of the shipping container was screened off to create the equipment bay for the installation of the power solution components as shown in Fig 4. Cost was reduced by installing the PV panels without an inclination angle, flat on the zinc roof of a shadeport in front of the bakery.

Fig. 4. Installed PV power solution for an off-grid rural bakery. Battery inverter (A), PV inverter (B), battery bank(C), PV charger (D), PV switching panel (E), AC distribution board (F), system monitor (G).

3.2 Economic

The bakery was registered as a Co-op with a company bank account. All funds are paid into the account on a weekly basis. The bakery is managed by a local manager and treasurer from the village.

On average, the bakery produces 120 – 160 loaves of bread per day. This value will differ depending on the weather as well as the season. The bakery staff bakes a selection of produce, which includes white bread loaves, brown bread loaves, round (hamburger) rolls, long (hot dog) rolls as well as Chelsea buns. The bakery's mark-up is approximately 100% on the products it sells. In general, the majority of baked produce consist of white and brown bread loaves. The prices per unit as well as the cost per unit is summarized in Table 4 below:

Table 4: Price and cost estimates of bakery produce.

PRODUCE	PRICE PER UNIT	COST PER UNIT
White bread loaf	R 8	R 4
Brown bread loaf	R 7	R 3.50
Roll	R 3	R 1. 50
Chelsea bun	R 3.50	R 2. 00

When considering only the selling of white bread, the bakery has a turnover of around R 960 – R 1280 per day (calculated from 120 – 160 loaves x R 8 each). The bakery is operational 6 days a week (Monday to Saturday), equating to approximately R21 120 – R28 160 turnover per month. Based on the costs included in Table 4, the profit made is approximately 50% of the turnover, estimated between R10 560 – R14 080 per month.

The bakery employs 8 people, each working every second day, equating to three days of work per week. Each baker earns a salary of R600 per month, equating to R4 800 of salaries paid per month. The remainder of the funds are used to replenish the stock.

3.3 Social

The bakery lead to the employment of 8 bakers from 8 families in Gwakwani and the neighbouring villages of Matatane and Mbodi. Each baker earns R600 per month, which is double the government unemployment grant of R300 per month.

Skills development were done by the Baking and Food Technology Incubation Centre of South Africa (BICSA). BICSA trained the bakery staff on various skills, including baking, health and safety regulations, financial management, procurement and management of stock as well as Human Resources management. BICSA and UJ assisted the bakery management to register the bakery as a Co-op and opening their bank account.

The bakery not only serves the immediate neighbouring villages of Mbodi and Matatane, but people as far as Tshipise, 60 km away, buys their bread from the bakery. The bakery is in the process of procuring a low power refrigerator for the selling of cold drinks and other products. The bakery management team are looking at possibilities of delivering and selling bread at neighbouring villages as well as at social grant payout points in the Vhembe area.

4 DISCUSSION AND IMPLICATIONS

Argaw, Foster and Ellis state in the report entitled: "Renewable Energy for Water Pumping Applications in Rural Villages" that "renewable energy sources have created considerable opportunities for promoting rural development". They further go on to state that renewable energy sources can "directly improve the quality of life, and help to foster the skills and experience needed to continue economic advancement in rural areas of developing countries" [8].

These statements proved true in the case of Gwakwani village as the rural solar bakery has become a driving force for economic growth and social development in Gwakwani. It has provided the community with the largest source of income and employment, with a monthly turnover of approximately R28 160, creating employment for 8 people directly from the Gwakwani community with various possibilities for expansion.

The development of business skills became clear when the bakery manager expressed their plans for expansion. They planned to procure a refrigerator for the selling of cold products. The bakery management team also plans to expand their business by selling bread at the payout points of government grants. These initiatives are viewed by the research team as positive development of economic and business skills.

In addition to the employment, the development of skills and the exposure of the community to an economic business environment can help foster the economic advancement of this area in the future. The bakery initiated local economy which previously did not exist. It provided a platform for trading of goods and future business expansion. The establishment of the bakery also created business networks with suppliers, a local bank, the larger community and industry. It improved the village's social structures through an increase of people coming to the village bakery. The bakery provides an additional source of fresh, safe food to the community. In the words of the bakery manager, the Gwakwani bakery has become the bread source of choice for the local community in place of the commercial brands.

In the process of bakery establishment and operation, various challenges had to be addressed. The bakery manager was exposed to management and labour relations issues which required careful management and skills development which included the discipline of employed staff and implementation of employment contracts. The bakery staff were exposed to new technology, which included the bakery equipment and electrical power supply infrastructure. The final technology handover was not yet possible as the rate of technical skills transfer did not allow for it yet. Health and Safety Regulatory compliance is currently being developed and stock management requires frequent oversight and mentorship. The lack of sufficient transport networks to the village makes the distribution of bread from the rural bakery as well as obtaining stock a challenge. In an interview, the bakery manager highlighted this challenge.

5 CONCLUSION

This paper discussed the implementation of an off-grid solar bakery in a rural village. This research analysed the social, technological and economic impact on an experimental implementation of a photovoltaic (PV) oven bakery in a rural, off-grid area for economic enablement.

Through a collaborative project with the community, the aim of this bakery was to enable the Gwakwani community to gain access to income and job opportunities to enhance social and economic situation. The successful operation of the bakery proved to have a positive impact on the community as the bakery provides the community with the largest source of income and employment as well as safe food.

Battery lifetime cost could be minimised by the design philosophy of "bake while the sun shines". The baking cycles are based on the weather, thereby ensuring that minimum energy is drawn from the battery bank, therefore mostly utilising energy produced by the solar panels [9].

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